ELVL-2023-0046604
July 18, 2023

Orbital Debris Assessment for The Big Red Sat-1 CubeSat per NASA-STD 8719.14C

Signature Page

Jimmy Smith, Analyst, NASA KSC VA-H1

Norman Phelps

Norman Phelps, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

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

ELVL-2023-0046604
August 11, 2023

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 Big Red Sat-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-8719.14C, 5 November 2021
C. International Space Station Reference Trajectory, delivered 07/18/2023
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; November 2012
G. *Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements*, AFSCM 91-710 V3, 15 May 2019.
H. NASA HQ Office of Safety and Mission Assurance (OSMA) Policy Memo/Email to 8719.14: *CubeSat Battery Non-Passivation*, Suzanne Aleman to Justin Treptow, 10, March 2014
I. NASA Orbital Debris Program Office (ODPO) Guidance Email: *Fasteners and Screws*, John Opiela to Yusef Johnson, 12 February 2020
J. *Debris Assessment Software User's Guide*: *Version 3.2*, NASA/TP-2019-220300

This report shows compliance with the orbital debris requirements listed in Reference A for the Big Red Sat-1 CubeSat launching on the SpX-30 Commercial Resupply Mission (CRS) to the International Space Station (ISS). It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of Appendix A.1.6 in Reference 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	August 2023

Section 1: Program Management and Mission Overview

Big Red Sat-1 is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Jeanie Hall. Responsible program/project manager and senior scientific and management personnel are as follows:

Joel Murch-Shafer (PM) – University of Nebraska

The following table summarizes the compliance status of Big Red Sat-1, which will be flown on the SpX-30 mission to the International Space Station. The current launch date is planned for 03/04/2024. DAS version 3.2.5 was used to generate the data provided in this document. The CubeSat 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(s) incapable of debris-producing failure
4.4-2	Compliant	
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	No postmission disposal maneuvers
4.6-1 a-c	Compliant	Maximum lifetime: 0.698 years
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: CubeSat Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Mass (kg)
Big Red Sat-1	1	100 x 100 x 110	1.33

The following pages describe the CubeSat.

Big Red Sat-1 – University of Nebraska – 1U

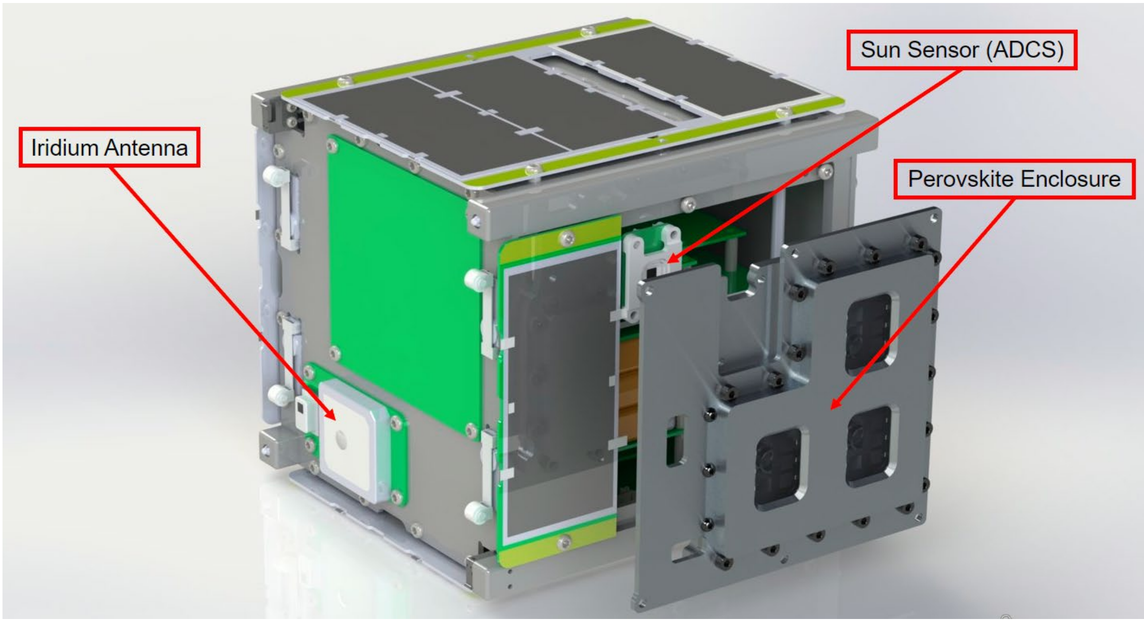

Figure 1: CubeSat Expanded View

Overview

Big Red Sat-1 will be testing experimental perovskite solar cells in orbit to provide a comparison of high TRL space grade solar cells to perovskites. Big Red Sat-1 is a 1U CubeSat with a design mass of 1330g.

CONOPS

Big Red Sat-1 will first transmit at T+60 minutes from dispenser deployment. It will then operate in cycles from the light and dark side of orbit taking passive JV curves on the light side and active JV curves of perovskite and GaAs solar cells. The minimum success criteria are 3 months of operation where Big Red Sat-1 will take nearly constant JV curves; however, support will be provided to take more intermittent JV curves of cells up to 18 months or communication is lost. All transmissions are based off of battery level and an internal time.

Materials

The spacecraft structure is made primarily of Aluminum 6061-T6 with stainless steel standoffs and fasteners. It contains standard COTS components, custom PCBs and custom perovskite solar panels.

Hazards

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

Batteries

The battery module is arranged in a 2S4P configuration and the battery contains NSL140743 Lithium-Polymer cells, which carry the UL-listing number BBCV2.MH50009.

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.

As no releases are planned on the CubeSat mission, Requirements 4.3-1a, 4.3-1b, and 4.3-2 are not applicable.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

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 meet Requirement 4.4-2 via 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." (Reference 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.
There are no plans for designed spacecraft breakups, explosions, or intentional collisions for the CubeSat.

Assessment of the power system and hazards in Section 2 shows that the CubeSat is compliant with Requirement 4.4-1.

Assessment shows that with a maximum lifetime of 0.698 years, the CubeSat is compliant with Requirement 4.4-2.

As no breakups are planned on the CubeSat mission, Requirements 4.4-3 and 4.4-4 are not applicable.

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

The 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.

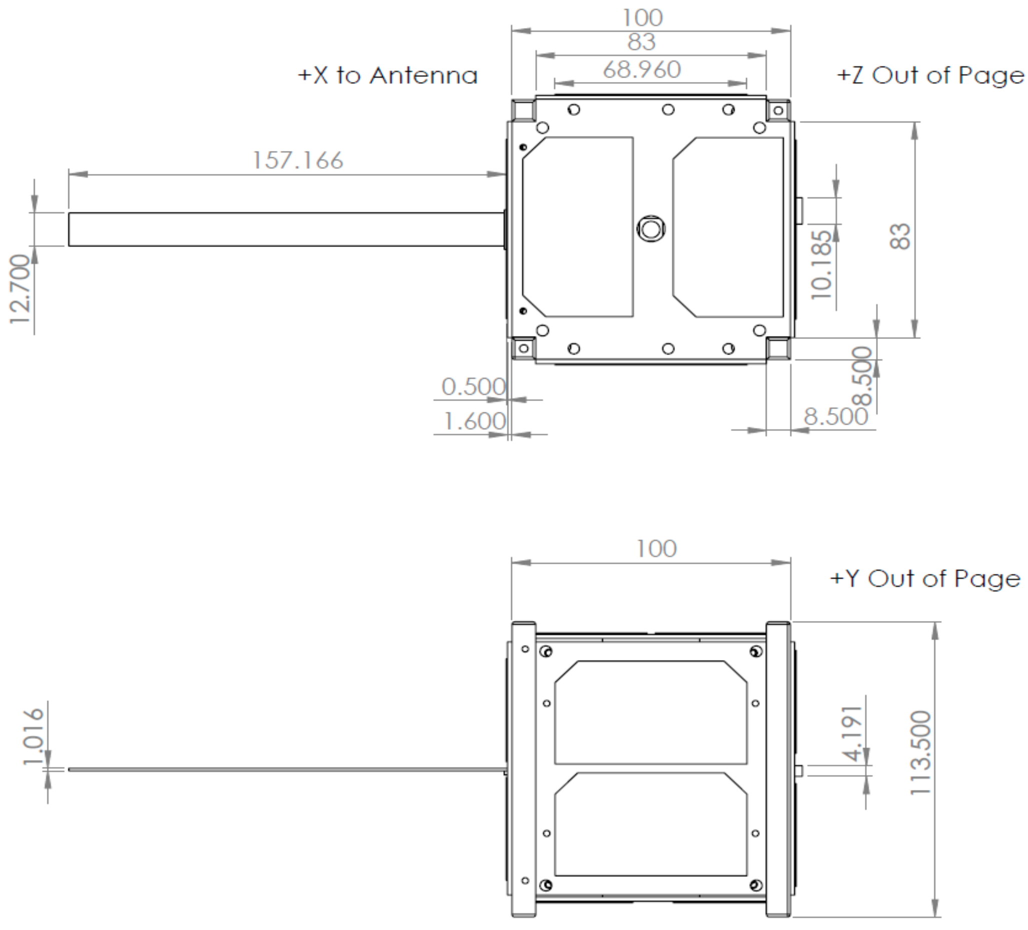

Figure 2: CubeSat Deployed View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

Equation 2: Mean Cross Sectional Area for Complex Objects

The CubeSat evaluated for this ODAR is ejected 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 as-ejected CubeSat was calculated using Equation 1. This configuration renders the longest orbital lifetimes for all CubeSats.

Big Red Sat-1 has no deployables, so the As-Ejected state is used for all analyses.

The CubeSat's expected orbit at deployment from the ISS has a 424.1-km apogee and a 408.4-km perigee at a 51.6° inclination for the current launch date (see Section 1). To cover phasing and variations in ISS orbit over time, 424.1 km for both perigee and apogee altitudes are input into DAS along with the current launch date to result in the maximum orbital lifetime for each area-to-mass ratio.
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

$$\frac{0.016\,m^2}{1.33\,kg} = 0.012\frac{m^2}{kg}$$

DAS yields the orbit lifetime(s) and corresponding probability(ies) of collision for the CubeSat configuration(s) in Table 3.

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	
	Mass [kg]	1.33
As-Ejected	**Mean C/S Area [m²]**	0.016
	Area-to Mass [m²/kg]	0.012
	Orbital Lifetime [yr]	**0.698**
	Probability of Collision	**1.09E-08**

Solar Flux Table Dated June 2023

The probability of the CubeSat colliding with debris or meteoroids greater than 10 cm in diameter is less than 1.09E-08 for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Assessment of spacecraft compliance with Requirements 4.5-1 shows the CubeSat to be compliant.

As the CubeSat will be disposed of passively and has no postmission disposal maneuvers, Requirement 4.5-2 is not applicable.

Section 6: Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

The CubeSat will naturally reenter from orbit within 25 years after end of the mission, complying with Requirement 4.6-1.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal will be achieved via passive atmospheric reentry.

The as-ejected area-to-mass ratio with the DAS inputs in Section 5 finds the maximum orbital lifetime for the launch date for post-mission disposal; see the as-ejected configuration's orbital lifetime in Table 3.

Assessment of the CubeSat mission shows it to be compliant with Requirement 4.6-1.

As the CubeSat mission's orbit will not exceed a LEO, Requirements 4.6-2 and 4.6-3 are not applicable.

As the CubeSat mission will be disposed of passively and has no postmission disposal maneuvers, Requirement 4.6-4 is not applicable.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on the CubeSat 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: High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Big Red Sat-1	Aluminum T6-6061	1.33	78.0	0.00
GPS Antenna	Ceramic	0.020	0.0	1.46
Iridium Antenna	Ceramic	0.020	0.0	3.54
Sun Sensor	Ceramic	0.008	0.0	0.03

All high melting point components demise upon reentry or impact with less than 15 Joules and the CubeSat 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

Status	Risk of Human Casualty
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; however, none of the CubeSat's components survive reentry to impact the ground.

Assessment of the CubeSat mission shows it to be compliant with Requirement 4.7-1.

Section 8: Assessment for Special Classes of Space Missions

As the CubeSat mission will not be deploying any tethers or is in any of the special classes of space missions, Requirement 4.8-1 is not applicable.

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 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. CubeSat 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	Big Red Sat - 1U	1	Aluminum	Cube	1300	100	100	110	N	N/A	N/A
2	1U Chassis	1	Aluminum	Cube	230	100	100	110	N	N/A	N/A
3	Aluminum Perovskite Enclosure Top	1	Aluminum	Face with Flange	33.65	72.72	67.7	7	N	N/A	N/A
4	Aluminum Perovskite Enclosure Bottom	1	Aluminum	Face with Flange	35.04	72.72	67.7	6.26	N	N/A	N/A
5	Gasket	1	Rubber	Ring	3.55	82.27	85.89	5.38	N	N/A	N/A
6	M2xScrew	20	Black-Oxide Alloy Steel	Cylinder	5.6	9.94	3.69	3.7	N	N/A	N/A
7	M2 Steel Nut	20	Black-Oxide Alloy Steel	Cylinder	2.2	1.49	4.33	4.3	N	N/A	N/A
8	Connector	6	Plastic, Metal	Rectangular Prisms	3.6	30	7	10	N	N/A	N/A
9	Perovskite Solar Panel	3	Perovskite MAPbl3	Square	5.1	25	25	1.1	N	N/A	N/A
10	EPS	1	LiPo, FR4	Cube	222.92	80	80	40	N	N/A	N/A
11	PCB	2	FR4	Face	320	80	80	5	N	N/A	N/A
12	GPS Antenna	1	FR4, Ceramic	Cylinder	20	50	50	6	Y	3595	1.46
13	Irridium Antenna	1	FR4, Ceramic	Cylinder	20	25	45	5.6	Y	3595	3.54
14	Variuos Screws	60	18-8 Steel	Cylinder	30	10	8	4	N	N/A	N/A
15	FSS100 Sun Sensor	1	FR4, Ceramic, Plastic	Rectangular Prism	8	23	16	5	Y	3595	0.03
16	Inhibit Switches	4	Plastic, Steel	Rectangular Prism	8	20	6.5	11	N	N/A	N/A
17	Masterbond Polymer Epoxy	4	Epoxy	Rectangular Prisms	10	20	2	2	N	N/A	N/A