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Orbital Debris Assessment for the RadSat-u Mission per NASA-STD 8719.14A

Signature Page

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ELVL-2018-0045483

Reply to Attn of: VA-H1

December 11, 2018

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 RadSat-u CubeSat

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. International Space Station Reference Trajectory, delivered May 2017
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. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
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. HQ OSMA Email:6U CubeSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the RadSat-u CubeSat, which will be deployed from the International Space Station. 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.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	December 2018

The following table summarizes the compliance status of the RadSat-u CubeSat to be deployed from the International Space Station. RadSat-u 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 2.46 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 release for RadSat-u

Section 1: Program Management and Mission Overview

RadSat-u is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

RadSat-u: Dr. Brock LaMeres, Main POC, Montana State University

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	December 18th, 2017
Delivery to Nanoracks	August 1st, 2019
Launch	October 1st, 2019

Figure 1: Program Milestone Schedule

RadSat-u will be launched as a payload on the the NG-12 resupply mission to the International Space Station. RadSat-u will be deployed from the International Space Station using the NanoRacks CubeSat Deployer(NRCSD) launcher. The current launch date is no earlier than October 1st, 2019.

RadSat-u weighs approximately 2.9 kg.

Section 2: Spacecraft Description

Table 2: outlines the generic attributes of the spacecraft.

Table 2: RadSat-u Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
RadSat-u	1	3U (326 x 98 x 98)	2.9

The following pages describe the RadSat-u CubeSat.

RadSat-u– Montana State University – 1U

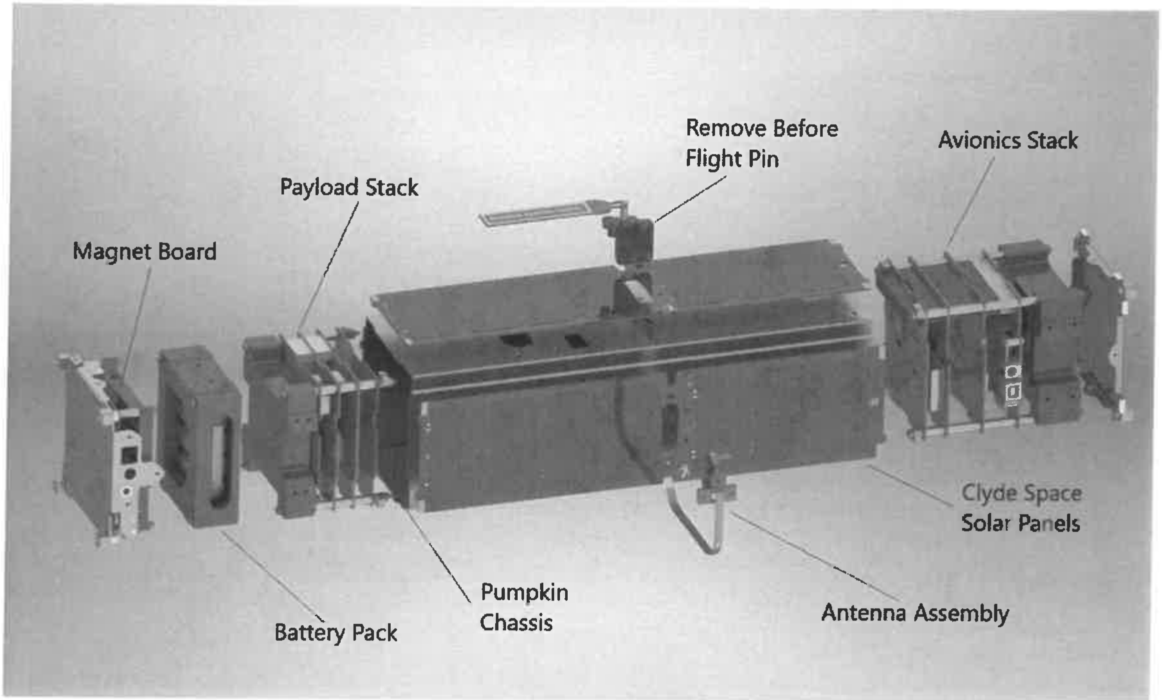

Figure 2: RadSat-u exploded view

Overview

RadSat-u will demonstrate a radiation tolerant computer technology in Low Earth Orbit. The technology is based on commercial off the shelf (COTS), Field Programmable Gate Arrays. RadSat-u deploys a novel single event effect (SEE) mitigation strategy based on spatial avoidance of faults using an array of redundant processors with selective activation and background repair through partial reconfiguration, in addition to an error correction code scheme for memory protection.

CONOPS

Upon deployment from the ISS-based NanoRacks CubeSat Deployer, RadSat-u will power up and start a timer system. At 45 minutes RadSat-g will turn on and the flight computer will engage the antenna deployment sequence. The system will then begin UHF beacon transmissions at a 120 second cadence. For the first week of operation the ground station operators will attempt communications to perform checkouts of the spacecraft. Approximately 7 days from launch, data from the computer technology will begin to be downloaded and will continue for approximately 1 year.

Materials

The RadSat-u structural components are made of the following aluminum alloys: 5052-H32, 7075-T6, and 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The UHF/UHF antennas are made of spring steel.

Hazards

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

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 MH48285.

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 for RadSat-u, 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 on the RadSat-u mission.

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 CubeSats 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 prevents 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 CubeSat lifetime of 2.46 years maximum, RadSat-u 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.

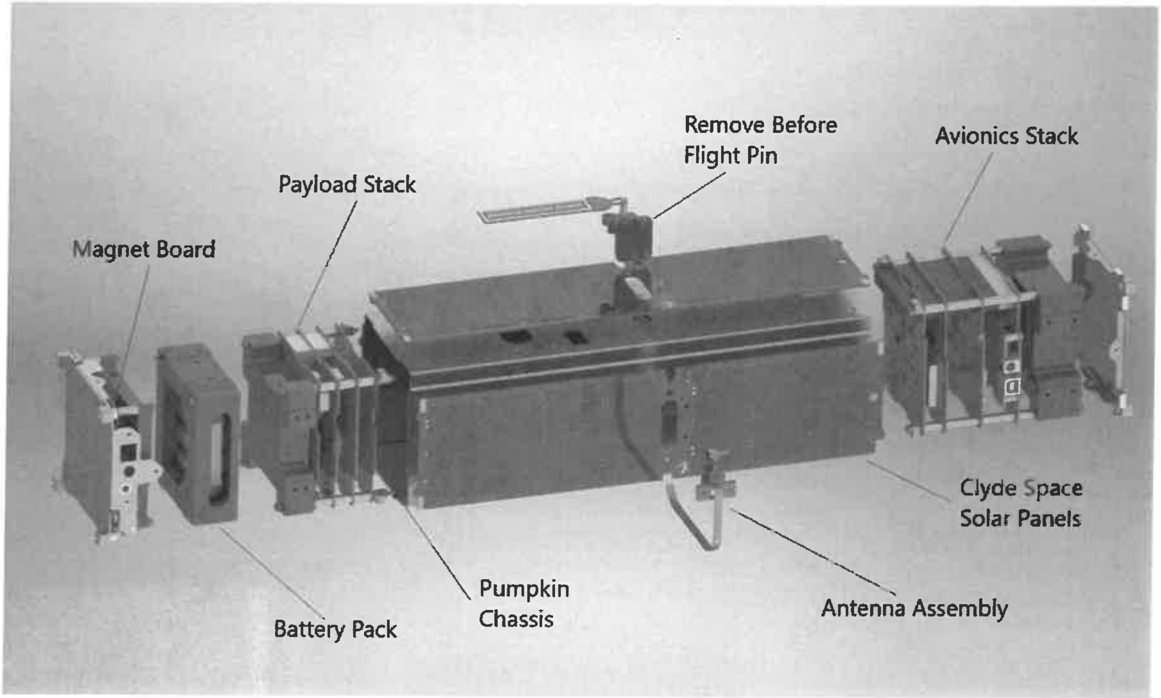

Figure 4: RadSat-u Expanded View

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

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 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 CubeSat.

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

The RadSat-u (2.86 kg) orbit at deployment will approximately 423 x 407 nm at a 51.6° inclination. With an area to mass ratio of 0.0089 m^2/kg, DAS yields 2.46 years for orbit lifetime, which in turn is used to obtain the collision probability. RadSat-u is calculated to have a probability of collision of 0.0. Table 3 below provides complete results.

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

	CubeSat	RadSat-u
	Mass (kg)	2.86
Stowed	Mean C/S Area (m^2)	0.02557
	Area-to Mass (m^2/kg)	0.00895
	Orbital Lifetime (yrs)	**2.464**
	Probability of collision (10^X)	**0.0000**

* Deployed antenna area is negligible with respect to orbital lifetime calculations

Solar Flux Table Dated 9/26/2018

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of RadSat-u 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.

RadSat-u has no capability nor have plans for end-of-mission disposal, therefore requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows RadSat-u to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

RadSat-u 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 is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for RadSat-u, the area-to-mass is calculated for it is as follows:

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

Equation 3: Area to Mass

$$\frac{0.02557\ m^2}{2.857\ kg} = 0.00895\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.1.1 Orbital Lifetime Calculations:

DAS inputs are: 423.4 km maximum apogee 409.6 km maximum perigee altitudes with an inclination of 51.6° at deployment no earlier than October 2019. An area to mass ratio of ~0.0089 m^2/kg for the RadSat-u CubeSat was used. DAS 2.1.1 yields a 2.46 years orbit lifetime for RadSat-u.

This meets requirement 4.6-1. For the complete list of CubeSat 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 of RadSat-u was performed. The assessment used DAS 2.1.1, 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 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.

DAS 2.1.1 show all of RadSat-u's components demise upon reentry and complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follow

Table 4: Requirement 4.7-1 Compliance for RadSat-u

Name	Status	Risk of Human Casualty
RadSat-u	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty > 1:10,000

RadSat-u is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

RadSat-u will not be deploying any tethers.

RadSat-u CubeSats satisfy Section 8's requirement 4.8-1.

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-C/Mrs. Nufer
VA-G2/Mr. Treptow
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. RadSat-u 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	CubeSat	1		Box	2857.36	98.5	98.5	326.5	No	-	Demise
2	Structure, Chassis	1	Aluminum 6061	Box	402	97.6	97.6	326.5	No	-	Demise
3	Structure, Top	1	Aluminum 6061	Box	52	97.6	97.6	17.75	No	-	Demise
4	Structure, Bottom & Foot Switches	1	Aluminum 6061	Box	64	97.6	97.6	44.45	No	-	Demise
5	Power, Battery Pack	1	Lithium	Cylinders	190	72.8	66	18.2	No	-	Demise
6	Power, Battery Bracket (Upper)	1	Aluminum 6065	Box	148.8	97.6	83	13	No	-	Demise
7	Power, Battery Bracket (Lower)	1	Aluminum 6065	Box	180.97	97.6	83	18	No	-	Demise
8	Power, Solar Panels	24	Silicon	Plate	27	69.11	39.7	0.2	No	-	Demise
9	Payload, PWR	1	FR4 Fiberglass	Box	37	96	90.15	1.5	No	-	Demise
10	Payload, FPGA	1	FR4 Fiberglass	Box	51	96	90.15	1.5	No	-	Demise
11	Payload, DATA	1	FR4 Fiberglass	Box	33	96	90.15	1.5	No	-	Demise
12	Avionics, Radio	1	FR4 Fiberglass	Box	68.9	96	90.15	1.5	No	-	Demise
13	Avionics, C&DH	1	FR4 Fiberglass	Box	115	96	90.15	1.5	No	-	Demise
14	Avionics, EPS	1	FR4 Fiberglass	Box	56	96	90.15	1.5	No	-	Demise
15	Avionics, Antenna Unit	1	Copper/ Spring Steel/ Aluminum 6065	Box	92	22.82	205.5	30.5	No	-	Demise
16	Structure, Magnet Housing	1	6065 Aluminum	Box	30	25.4	25.4	14	No	-	Demise
17	Structure, Standoffs	24	2011 Aluminum	Cylinder	39	6	18	6	No	-	Demise
18	Power, Cabling	1	Copper	Cylinder	75	1.5	-	1.5	No	-	Demise
19	Structure, 3M Threaded Rods	4	Aluminum 6061	Cylinder	33.1	3	87	3	No	-	Demise
20	28mm Internal Weight	1	7075 Aluminum	Box	536.97	97.45	92	28	No	-	Demise
21	20mm Internal Weight	1	7075 Aluminum	Box	362.82	97.45	92	20	No	-	Demise

22	Internal Weight (Magnet Board)	1	7075 Aluminum	Box	193.77	88.81	86	10	No	-	Demise
23	Anniversary Name Plates	9	2024 Aluminum Plating	Plate	52	63.5	63.5	0.5	No	-	Demise
24	Remove Before Flight Assembly	1	7075 Aluminum	Box	14.75	30.75	32.6	20.97	No	-	Demise
25	Plasma Shields	2	Ultem 1010	Box	2.28	18.3	18.3	11.8	No	-	Demise