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Orbital Debris Assessment for The CubeSats on the CRS OA-10/ELaNa-24 Mission per NASA-STD 8719.14A

Signature Page

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ELVL-2018-XXXX Rev A

Reply to Attn of: VA-H1

June 28, 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 ELaNa-24 Mission

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 ELaNa-24 auxiliary mission launching on the CRS OA-10 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.

RECORD OF REVISIONS		
REV	DESCRIPTION	DATE
0	Original submission	June 2018

The following table summarizes the compliance status of the ELaNa-24 payload mission to be flown on the OA-10 vehicle. The CubeSat comprising the ELaNa-24 mission are 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 4.5 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 release under ELaNa-21 mission

Section 1: Program Management and Mission Overview

The ELaNa-24 mission 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:

WeissSat: Kevin Simmons, Principal Investigator, The Weiss School

Program Milestone Schedule	
Task	Date
CubeSat Selection	October 1, 2017
Mission Readiness Review	TBD
Dispenser Integration	August 1st, 2018
Delivery to VAFB	September 1st, 2018
Launch	October 1st, 2018

Figure 1: Program Milestone Schedule

The ELaNa-24 CubeSat complement will be launched as a payload on the SpaceX Falcon 9 launch vehicle executing the SSO-A Mission. The ELaNa-24 mission will deploy pico-satellites (or CubeSats) from the Falcon 9 vehicle. Each CubeSat is identified in Table 2: ELaNa-24 CubeSats. The ELaNa-24 manifest includes the WeissSat CubeSat. The current launch date is projected to be October 1st, 2018.

The CubeSat on this mission is a 10 cm cube to 32 cm x 10 cm x 10 cm, with a mass of about 1.3

Section 2: Spacecraft Description

There is 1 CubeSat flying on the ELaNa-24 Mission. Table 2: ELaNa-24 CubeSats outlines their generic attributes.

Table 2: ELaNa-24 CubeSats

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
WeissSat	1	100 x 100 x 100	1.4

The following pages describe the CubeSat flying on the ELaNa-24 mission.

WeissSat– The Weiss School – 1U

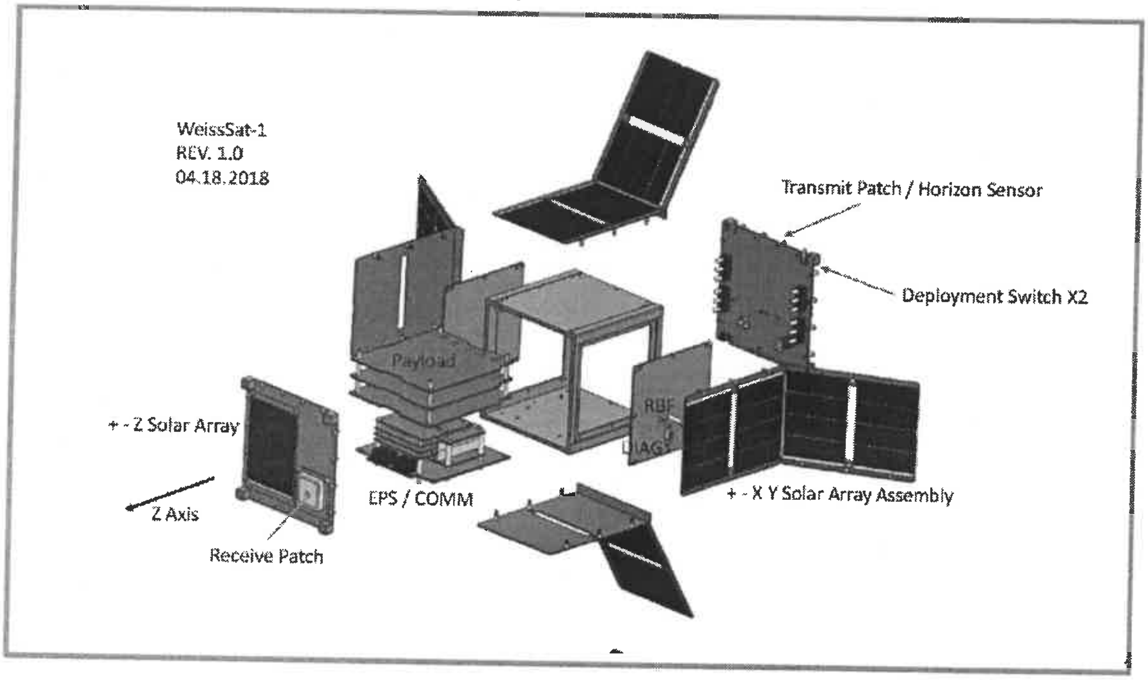

Figure 4: WeissSat Expanded View

Overview

WeissSat-1 will validate the use of a novel lab-on-a-chip payload to evaluate the viability of extremophile bacteria in LEO. Data will be transmitted to the GlobalStar network

CONOPS

Upon deployment from the payload dispenser, WeissSat will power up and start its count down timers. After 30 minutes, the antennas will be deployed, and hourly health and safety transmissions will begin thereafter. Lyophilized bacteria will then by hydrated and maintained at 20° C for 48 hours. The heaters will then be turned off and the bacteria will be allowed to freeze with the light/dark orbital cycles. Then, a fraction of the bacteria will be stained. 15 minutes later, a fraction of the cells will be illuminated by a 488 nm diode. The resulting fluorescence will be measured via photodetectors, and that data will be relayed to the bus processor. The remaining bacteria will be similarly analyzed at L+3, L+3.5, L+4, L+6, and L+10 days. Once completed, the spacecraft will be monitored until orbit decay occurs.

Materials

The CubeSat structure is made of anodized aluminum. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The high speed radio uses a ceramic patch antenna.

Hazards

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

Batteries

The electrical power storage system consists of two 3.7V, 2200mAh Tenergy 925050 polymer lithium ion batteries with Tenergy Model 32089 battery circuit protection module providing over-charge/current protection and over-discharge circuitry. The lithium batteries carry the UL listing number 30156-0.

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 ELaNa-24 CubeSat mission 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 ELaNa-24 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.

The 6U CubeSat in this complement satisfy Requirements 4.4-1 and 4.4-2 if their batteries at equipped with protection circuitry, and they meet International Space Station (ISS) safety requirements for secondary payloads. Additionally, these CubeSats are being deployed from a low altitude (ISS orbits at approximately 400 km), meaning any accidental explosions during mission operations or post-mission will have negligible long-term effects to the space environment.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 4.5 years maximum, the ELaNa-24 CubeSats are 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.

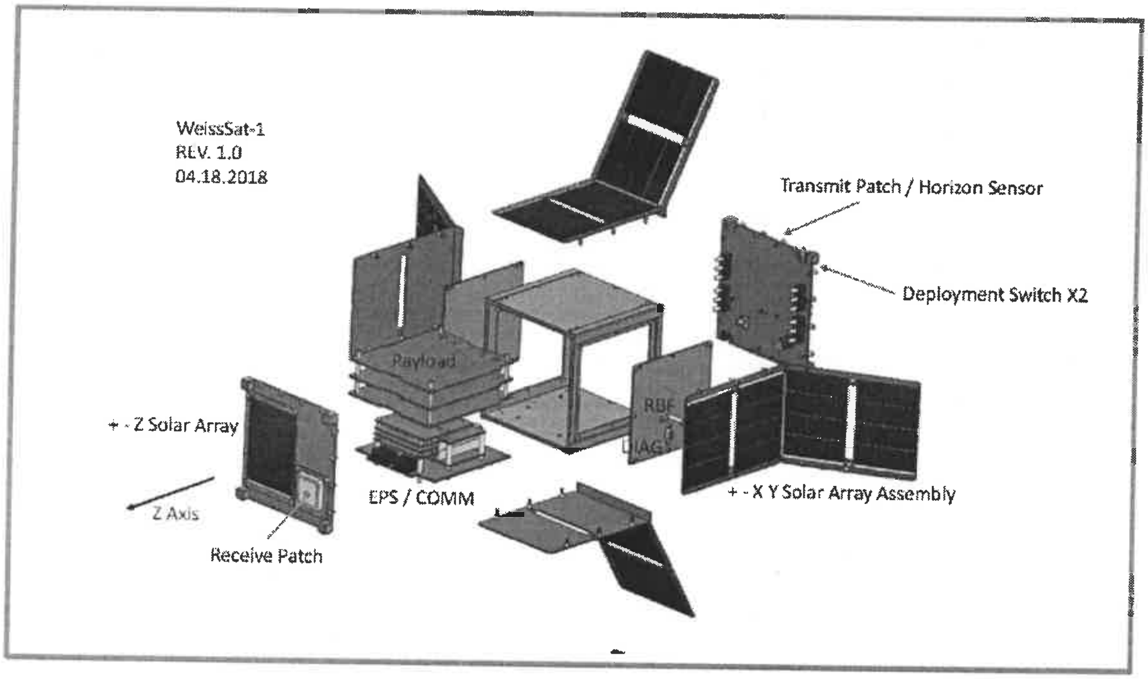

Figure 10: Expanded View (with solar panels deployed)

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

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 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 WeissSat (1.4 kg) orbit at deployment is 575 km circular orbital altitude, with an inclination of 98 degrees. With an area to mass ratio of 0.0648 m^2/kg, DAS yields 4.2

years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. The CubeSat on ELaNa-24 were 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	WeissSat
	Mass (kg)	7.9
Stowed	Mean C/S Area (m^2)	0.06
	Area-to Mass (m^2/kg)	0.0443
	Orbital Lifetime (yrs)	**4.5**
	Probability of collision (10^X)	**0.00000**
Deployed **	Mean C/S Area (m^2)	0.0875
	Area-to Mass (m^2/kg)	0.0648
	Orbital Lifetime (yrs)	**4.2**
	Probability of collision (10^X)	**0.00000**

Solar Flux Table Dated 3/29/2018

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of any ELaNa-24 spacecraft collision 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.

The CubeSat manifested on this mission have 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 ELaNa-24 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The ELaNa-24 spacecraft 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 the worst-case (smallest Area-to-Mass) post-mission disposal among the CubeSats finds WeissSat in its stowed 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

$$\frac{0.06\ m^2}{1.36\ kg} = 0.044\frac{m^2}{kg}$$

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

<u>DAS 2.1.1 Orbital Lifetime Calculations:</u>
DAS inputs are: 575 km maximum apogee 575 km maximum perigee altitudes with an inclination of 98° at deployment no earlier than April 2018. An area to mass ratio of ~0.044 m^2/kg for the WeissSat CubeSat was used. DAS 2.1.1 yields a 4.523 years orbit lifetime for WeissSat in its stowed state.

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 to be flown on ELaNa-24 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.

Table 4: ELaNa-21 High Melting Temperature Material Analysis

CubeSat	Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
WeissSat	Sep Switches	Stainless Steel	.002	76.6	0
WeissSat	Damping	MU Metal	.265	0.0	8

The majority of stainless steel components demise upon reentry and all CubeSats comply 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
WeissSat	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 all of the ELaNa-24 CubeSats have a 1:0 probability as none of their components have more than 15J of energy.

The CubeSat launching under the ELaNa-24 mission are shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

ELaNa-24 CubeSat will not be deploying any tethers.

ELaNa-24 CubeSat 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/

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Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
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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. ELaNa-24 Component List by CubeSat: WeissSat

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	External Structure	1	Aluminum 6061	Box	550	17	100	100	No	-	Demise
2	Patch Antenna	2	Ceramic	Square	12	100	25	4.5	No	-	Demise
3	Solar Panels	8	Fiberglass	Panel	30	6.7	80	2	Yes	-	Demise
4	Sep Switches	2	Steel / Gold	Square	2	80	6.5	10.25	No	2550°	Demise
5	PIN Diode Detector	1	Fiberglass / Copper / Gold	Square	5	80	15	7.5	No	-	Demise
6	Spring Plungers	2	Steel / Stainless Steel	Round	2	80	3.5	17	No	-	Demise
7	Batteries	2	Aluminum / Plastic /Lithium	Square	85	40	50	12	No	-	Demise
8	FP / EPS Board	1	Fiberglass / Copper	Square	96	54	75	8	No	-	Demise
9	Comm. Board	1	Fiberglass / Copper	Square	33	54	40	31	No	-	Demise
10	Payload	1	Fiberglass / Copper	Square	175	100	82	90.17	No	-	Demise
11	Fasteners / Spacers	50	Stainless Steel / Aluminum	Various	50	.006	12.7	-	No	-	Demise
12	Cabling	-	Copper Alloy	-	50	18.4	-	-	No	-	Demise
13	Damping	5	MU Metal	Flat Plate	265	86	75	75	No	2650°	0 km