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Orbital Debris Assessment for The INCA 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: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the INCA Mission

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 May 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. ODPO Guidance Email: 6U CubeSat Battery Concerns, J.C. Liou to Eric Haddox, 18 May 2021
K. Debris Assessment Software User's Guide, NASA/TP-2020-5002380, May 2020

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the INCA CubeSat launching on the VCLS Demo-2 A mission. 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	May 2021

Section 1: Program Management and Mission Overview

INCA 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:

Dr. Steven Stochaj, Principal Investigator, New Mexico State University

The following table summarizes the compliance status of INCA mission to be flown on the VCLS Demo 2 A mission. INCA 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 ~5.83 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

INCA will be launched as a payload on the Astra Rocket launch vehicle executing the VCLS Demo-2 A mission. The current launch date is projected to be NET December 15, 2021.

INCA has total mass of about 4.1 kg.

Section 2: Spacecraft Description

INCA is flying as part of the ELaNa 41 mission complement. Table 2 outlines its generic attributes.

Table 2: INCA Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm)	CubeSat Masses (kg)
INCA	1	343.2 x 122.7 x 118.8	4.08

The following pages describe the INCA CubeSat.

INCA – New Mexico State University – 3U

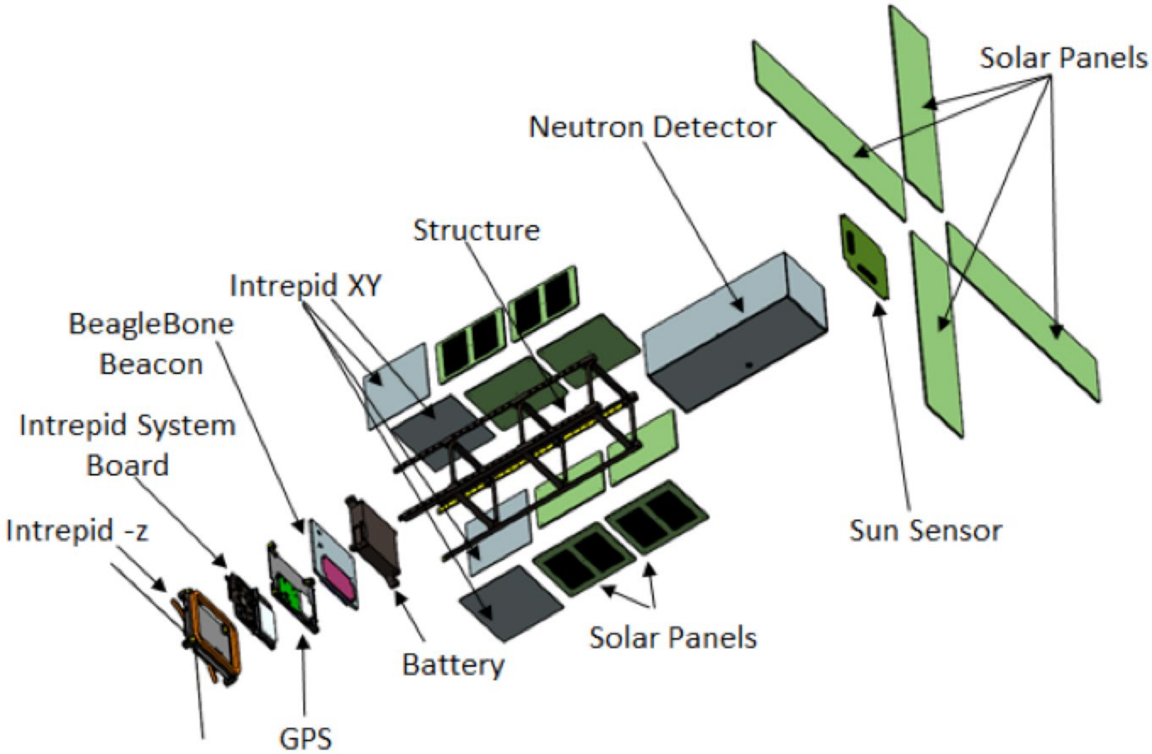

Figure 1: INCA Expanded view

Overview

The Ionospheric Neutron Content Analyzer (INCA) is a 3U CubeSat being built by students at New Mexico State University carries a scintillator, a silicon photomultiplier-based neutron detector being built by NASA's Goddard Spaceflight Center. The INCA mission will, for the first time, study the latitude and time dependencies of the neutron spectrum in low Earth orbit (LEO). These measurements will be accomplished using a new directional spectrometer, which is being developed in conjunction with NASA-Goddard and the University of New Hampshire. INCA will focus on albedo neutrons. However, the instrumentation will also be sensitive to solar neutrons.

CONOPS

Upon deployment from the launch vehicle, INCA will enter a 45 minute sleep period. Once the sleep period is complete, it will deploy its antenna and solar panels. After deployment, the vehicle will begin science operations, and begin the de-tumbling sequence. Once the vehicle is de-tumbled, it will be spin stabilized about the Z-Axis, with the +Z axis pointed towards the sun.

Materials

The primary CubeSat structure is made of Aluminum 7075. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCS and solar cells.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of 4 common lithium ion batteries (BatterySpace Model H896474, 5000 mAh capacity) with built-in circuitry to protect against overcharging, over-discharging, overdrain, and short circuits. The UL listing for these batteries is BBCV2.MH45087, and these batteries have been tested to UL 1642 testing protocol.

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 INCA 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 INCA.

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 INCA battery cells are UL certified under listing BBCV2.MH45087, using UL 1642 testing standards for lithium batteries, which addresses various concerns, including overcharge/overdischarge, temperature cycling, shock, vibration, low pressure, overheating, and other concerns

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 approximately 5.83 years maximum, INCA 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.

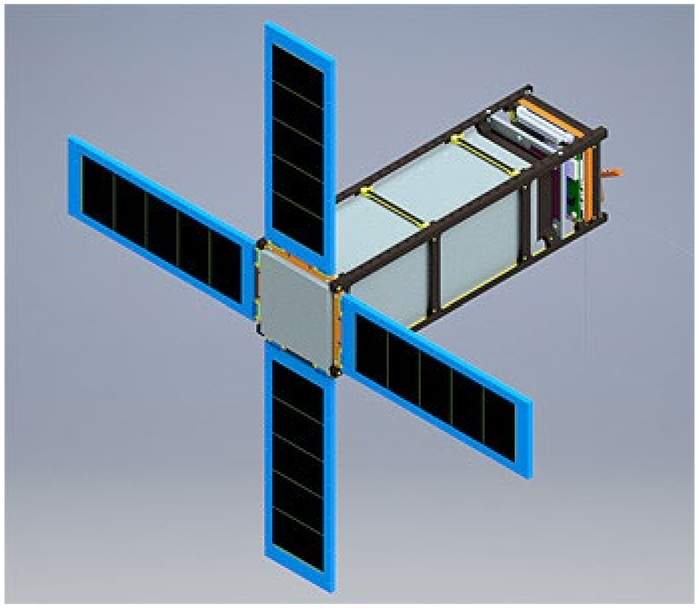

Figure 2: INCA as-deployed view

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

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 is stowed in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the CubeSat from view. Thus, the mean CSA for the stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital life time.

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

INCA's expected orbit at deployment is 500 km circular at a 41° inclination. With an area to mass ratio of .00654 m^2/kg, DAS yields ~5.83 years for orbit lifetime for its as-ejected state, which in turn is used to obtain the collision probability. INCA was 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		INCA
	Mass (kg)	4.08
As-ejected	Mean C/S Area (m^2)	0.0267
	Area-to Mass (m^2/kg)	0.00654
	Orbital Lifetime (yrs)	**5.83**
	Probability of collision	**1.5×10^{-7}**
Operational	Mean C/S Area (m^2)	0.147
	Area-to Mass (m^2/kg)	0.0360
	Orbital Lifetime (yrs)	**1.91**
	Probability of collision	**2.85×10^{-7}**

Solar Flux Table Dated 3/30/21

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of INCA 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 INCA to be compliant. Requirement 4.5-2 is not applicable to this mission.

INCA has no capability or plans for end-of-mission disposal, therefore Requirement 4.5-2 is not applicable. INCA will passively reenter and therefore this ODAR also serves as the EOMP (End of Mission Plan)

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

INCA 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 shows finds INCA 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

$$\frac{0.0267\ m^2}{4.08\ kg} = 0.00654\frac{m^2}{kg}$$

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

<u>DAS Orbital Lifetime Calculations:</u>
DAS inputs are: 500 km circular orbit with an inclination of 41° at deployment no earlier than December 2021. An area to mass ratio of 0.00654 m^2/kg for the INCA CubeSat was used. DAS yields a 5.83 years orbit lifetime for INCA in its as-ejected state and 1.91 years orbit lifetime in its operational state with an area to mass ratio of 0.036 m^2/kg.

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 INCA was performed. The assessment used DAS V3.1.2, 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 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 they 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.

INCA does not have any high temperature components that required DAS re-entry analysis. Screws and other similar components are not input into DAS as per guidance from the Orbital Debris Project Office, as per Reference I.

INCA complies with the less than 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

Table 4: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
INCA	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. Although INCA has no pieces that survive to the ground, DAS has an output notation limit of 100,000,000, hence the result displayed in Table 4.

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

Section 8: Assessment for Tether Missions

INCA will not be deploying any tethers.

INCA satisfies 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 launch service 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/Mr. Cheney
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. INCA 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	INCA 3U+	-	-	-	4080	118.8	343.2	122.7	-	-	Demise
2	Structure	1	Aluminum 7075	Thin bars	154	100	341.8	100	No	-	Demise
3	Deployable Solar Panels	4	PCB	Flat Plate	157.6	82	332	3	No	-	Demise
4	Fixed Solar Panels	4	PCB	Flat Plate	160	82	250	3	No	-	Demise
5	Neutron Detector Case	1	Aluminum 6061	Box with open side	855	88	223	86	No	-	Demise
6	Neutron Detector Lid	1	Aluminum 6061	Flat Plate	26	88	223	3	No	-	Demise
7	Scintillators Crystals	2	P-Terfinal	Cylindars	1932	51		42	No	-	Demise
8	Scintillators Holders	2	Aluminum	Box	490	72	72	76	No	-	Demise
9	Veto Boards	4	EJ-212	Flat Plate	940	69	219	3	No	-	Demise
10	Battery Pack	1	Aluminum 6061 and Lithium	Box	247	64.5	75	8.9	No	-	Demise
11	Beagle Bone	1	PCB	Flat plate	40	86	53	~10	No	-	Demise
12	Link Star Radio	1	PCB	Flat plate	48.19	29.11	53.34	86.36	No	-	Demise
13	Intrepid XY	4	PCB	Flat plate	128	103	83	~5	No	-	Demise
14	Novatel OEM-615 GPS	1	PCB	Flat plate	22	71	46	12	No	-	Demise
15	Intrepid Systems Board	1	PCB	Flat plate	104	94	83	~2	No	-	Demise
16	Intrepid -Z	1	PCB	Flat plate	96	91	91	~5	No	-	Demise
17	Sun Sensor	1	PCB	Flat plate	Unknown	100	100	6	No	-	Demise
18	Miscellaneous Nuts and Screws	Unknown	Steel	Cylinder	-	Various	Various	Various	Yes	2500°	Demise
19	Miscellaneous Wiring	Unknown	Copper alloy	-	-	-	-	-	No	-	Demise