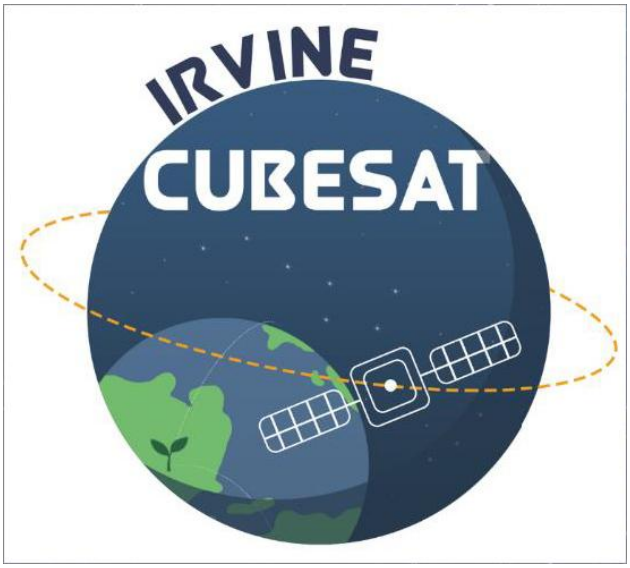
Rev 5
4/13/2017

Orbital Debris Assessment for the IRVINE01 CubeSat per NASA-STD 8719.14A



Signature Page

Brent Freeze, Technical lead, IRVINE01 CubeSat

Archana Jain, Propulsion team leader, Irvine High School

Jennifer Blackie, Communications team leader, Woodbridge High School

Justin Foley, Ground station manager, Cal Poly San Luis Obispo

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. 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
D. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
E. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
F. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
G. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, July 2014

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	Compliant	
4.6-1(a)	Compliant	Worst case lifetime 4.89 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 under IRVINE01 mission

ODAR Table of Contents

ODAR Section 1: Program Management and Mission Overview

Project Manager: Tinh Tran

Foreign Government or Space Agency Participation: The Ecuadorian Space Agency (EXA) will provide many of the necessary parts for the CubeSat, including the batteries and the solar panels. India will control the launch vehicle, which will be launched from Sriharikota, India.

Schedule of Upcoming Mission Milestones:

Mission kickoff date: March 1, 2016
Design review date: April 29, 2016
Delivery date: May 1, 2017
Tentative Launch Date: July 1, 2017

Mission Overview:

IRVINE01 will be dispensed from a PPOD 3U CubeSat dispenser into an estimated orbit of 500 km Apogee and 500 km Perigee with an inclination of 97 degrees. The mission is expected to remain in orbit for a maximum of up to 4.89 years. During this time, our payload will take pictures of celestial objects, such as the Moon and Venus, as well as collect other data using our sun sensors, GPS, and other necessary equipment.

ODAR Summary:

No debris released in normal operations; no credible scenario for breakups; the collision probability with other objects is compliant with NASA standards; and the estimated nominal decay lifetime due to atmospheric drag is under 25 years following operations.

Launch Vehicle and Launch Site:

PSLV, Sriharikota, India

Proposed Launch Date:

July 1, 2017

Mission Duration:

Normal mission operations will take place until contact is lost, or some other mission detrimental factor causes a failure of essential systems. The natural decay time of the CubeSat is under 4.89 years.

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

The launch vehicle will be dispensing various payloads into a nearly circular 500 km sun-synchronous orbit.

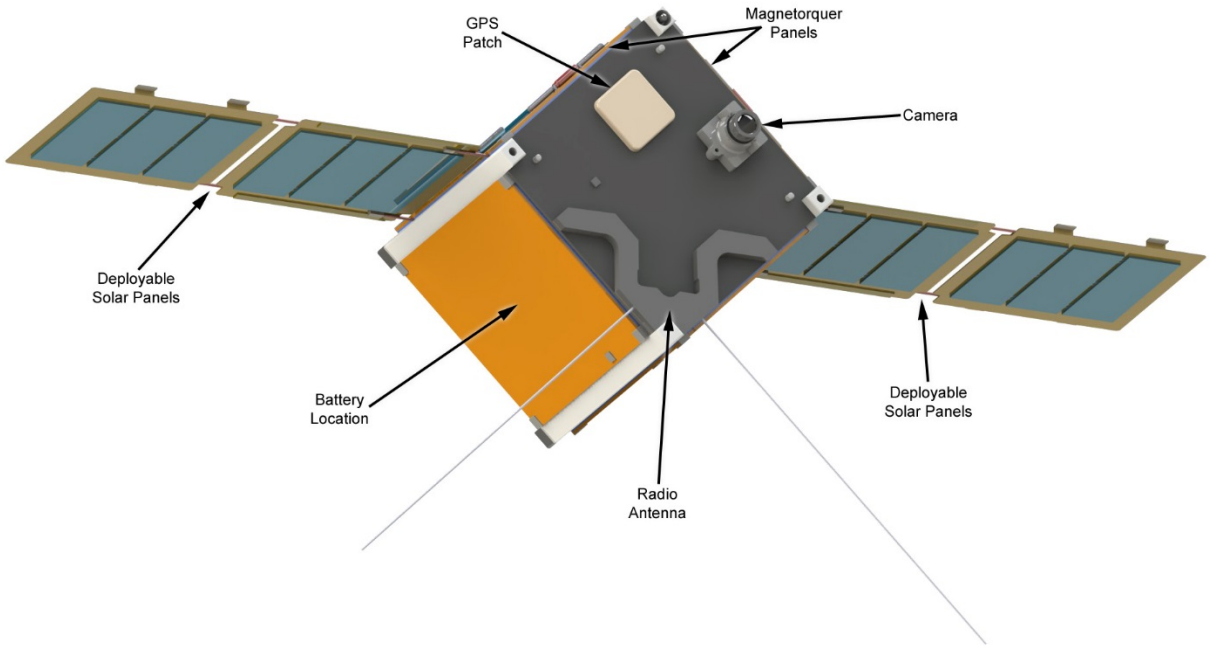
IRVINE01 will decay from an orbit defined as follows:

Perigee: 500 km

Apogee: 500 km

Orbital Inclination: 97 degrees

ODAR Section 2: Spacecraft Description



Mission description: Irvine01's main mission is to take pictures of the moon and planets send them to the ground station, where they will be used for educational purposes. The primary instrument is a 3 MP camera. In addition, magnetorquers will be used for attitude control, and solar panels will be used for power.

Physical description of the spacecraft: IRVINE01 conforms to the 1U CubeSat specification, with a launch mass of 0.983 kg. Basic physical dimensions are 100mm x 100mm x 106mm, with two solar panels with 170mm x 85mm x 2mm extended dimensions. The IRVINE01 solar panel structure is comprised of two 100mm x 100mm plates that are extended. The solar arrays are spring-loaded and burn-wire deployed. Power storage is provided by Lithium-Ion cells. The batteries will be recharged by solar cells mounted on the body of the satellite and on the two deployable solar panels. IRVINE01 attitude is approximately determined using the magnetic field vector, measured by onboard magnetometers. The IRVINE01's attitude will be controlled by a 3-axis magnetorquer controller.

Total satellite mass at launch, including all propellants and fluids: 0.983 kg.

Dry mass of satellites at launch, excluding solid rocket motor propellants: 0.983 kg

Description of all propulsion systems (cold gas, monopropellant, bipropellant, electric, nuclear): None, but there is a zero-propellant mass-model of an electric thruster attached to balance the mass distribution of the spacecraft for the magnetorquers.

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Fluids in Pressurized Batteries: None

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material: There are no intentional releases.

Rationale/necessity for release of each object: N/A.

Time of release of each object, relative to launch time: N/A.

Release velocity of each object with respect to spacecraft: N/A.

Expected orbital parameters (apogee, perigee, and inclination) of each object after release: N/A.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.0.1)
4.3-1, Mission Related Debris Passing Through LEO: NOT APPLICABLE
4.3-2, Mission Related Debris Passing Near GEO: NOT APPLICABLE

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosion

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the IRVINE01 mission.

The probability of battery explosion is very low, and, due to the very small mass of the satellite and its short orbital lifetime, 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)).

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum possible lifetime of 4.89 years the IRVINE01 CubeSat is compliant.

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

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0.1, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

Requirement 4.5-1: Limiting debris generated by collisions with large objects when operating in Earth orbit:
For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Large Object Impact and Debris Generation Probability: (DAS 2.0.2)
IRVINE01; Collision Probability: 0.00000; COMPLIANT.

The above analysis results are a product of the DAS 2.0.2 software. We then assume hard spheres of diameter 1 m for IRVINE01

Requirement 4.5-2: **Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:**
For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post-mission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability:
IRVINE01; Collision Probability: 0.00000 COMPLIANT.

Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering:
No post-mission disposal procedures are necessary, since the satellite's orbit will naturally decay within 4.89 years.

ODAR Section 6: Assessment of Spacecraft Post-mission Disposal Plans and Procedure

6.1: Description of Spacecraft Disposal Option Selected:

IRVINE01 will de-orbit naturally by atmospheric re-entry within 4.89 years. All components will burn up during re-entry.

6.2: Plan for Any Spacecraft Maneuvers Required to Accomplish Post-Mission Disposal:

No maneuvers are required.

6.3: Calculation of Area-to-Mass Ratio After Post-Mission Disposal, if the Controlled Re-entry Option is Not Selected:

Spacecraft Mass: 0.983 kg
Cross-Sectional Area: 141 cm^2

6.4: Assessment of Spacecraft Compliance with Requirements 4.6-1 Through 4.6-5 (per DAS v. 2.0.1 and NASA-STD-8719.14 Section):

Requirement 4.6-1: Disposal for Space Structures Passing Through LEO:

A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods (Requirement 56557):

a. *Atmospheric Re-Entry Option:*
    - *Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission by no more than 30 years after launch.*
    - *Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.*
b. *Storage Orbit Option:*
    - *Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.*
c. *Direct Retrieval:*
    - *Retrieve the space structure and remove it from orbit within 10 years after completion of mission.*

Analysis: The IRVINE01 satellite re-entry is COMPLIANT using method "I".

Requirement 4.6-2: Disposal for Space Structures Near GEO:
Analysis: Not Applicable.

Requirement 4.6-3: Disposal for Space Structures Between LEO and GEO:
Analysis: Not Applicable.

Requirement 4.6-4: Reliability of Post-Mission Disposal Operations:

Analysis: The maximum drag configuration is the aerodynamically stable state, meaning that even under massive subsystem failure we would eventually assume this orientation.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

> ***Requirement 4.7-1***: Limit the risk of human casualty:
> *The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules*:
> *a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).*
>
> **Summary Analysis Results**: DAS v2.0.1 reports that IRVINE01 is compliant with the requirement. There will be no risk of human casualty during reentry because it will completely burn up in the atmosphere.

```
04 12 2017; 18:10:59PM DAS Application Started
04 12 2017; 18:12:28PM Processing Requirement 4.3-1:     Return Status :
Not Run

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-1 ===============
04 12 2017; 18:12:29PM Processing Requirement 4.3-2: Return Status :
Passed

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-2 ===============
04 12 2017; 18:12:31PM Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
04 12 2017; 18:12:33PM Processing Requirement 4.5-1:     Return Status :
Passed

==============
Run Data
==============
```

```
**INPUT**

      Space Structure Name = IRVINE01
      Space Structure Type = Payload
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.014300 (m^2/kg)
      Start Year = 2017.580000 (yr)
      Initial Mass = 0.983000 (kg)
      Final Mass = 0.983000 (kg)
      Duration = 5.000000 (yr)
      Station-Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
04 12 2017; 18:12:34PM Requirement 4.5-2:  Compliant
04 12 2017; 18:12:35PM Processing Requirement 4.6   Return Status :
Passed

==============
Project Data
==============

**INPUT**

      Space Structure Name = IRVINE01
      Space Structure Type = Payload
```

```
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.014300 (m^2/kg)
      Start Year = 2017.580000 (yr)
      Initial Mass = 0.983000 (kg)
      Final Mass = 0.983000 (kg)
      Duration = 5.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 500.000000 (km)
      Suggested Apogee Altitude = 500.000000 (km)
      Returned Error Message = Reentry during mission (no PMD req.).

      Released Year = 2022 (yr)
      Requirement = 61
      Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
04 12 2017; 18:12:40PM *********Processing Requirement 4.7-1
      Return Status :  Passed

***********INPUT****
 Item Number = 1

name = IRVINE01
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 0.983000
Thermal Mass = 0.983000
```

```
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = IRVINE01
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.983000
Thermal Mass = 0.983000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

**************OUTPUT****
Item Number = 1

name = IRVINE01
Demise Altitude = 77.998676
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = IRVINE01
Demise Altitude = 67.285324
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************

=============== End of Requirement 4.7-1 ===============
04 12 2017; 18:12:42PM Processing Requirement 4.8-1:     Return Status :
Passed

==============
Project Data
==============

**INPUT**
      Tether Diameter = 0
      Tether Length = 1.000000
      Tether Mass = 1.000000
      EM Tether = No
      Launch Year = 2017.580000
      Deployed Year = 3.000000
      Retraction Year = 3000.000000
```

```
      Perigee of Highest Mass = 500.000000
      Apogee of Highest Mass = 500.000000
      RAAN = -1.000000
      Inclination = 97.000000
      Argument of Perigee = -1.000000
      Mass of Highest Altitude End Mass = 0.983000
      Mass of Lowest Altitude End Mass = 0.983000
      Cross Sectional Area of Highest Altitude End Mass = 0.010000

**OUTPUT**
      sever = 0.000000
```

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because IRVINE01 does not use controlled reentry.

4.7-1, b) **NOT APPLICABLE.** For controlled re-entry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign land masses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

4.7-1, c) **NOT APPLICABLE.** For controlled re-entries, the product of the probability of failure of the re-entry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled re-entry shall not exceed 0.0001 (1:10,000) (Requirement 56628))

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the IRVINE01 mission.