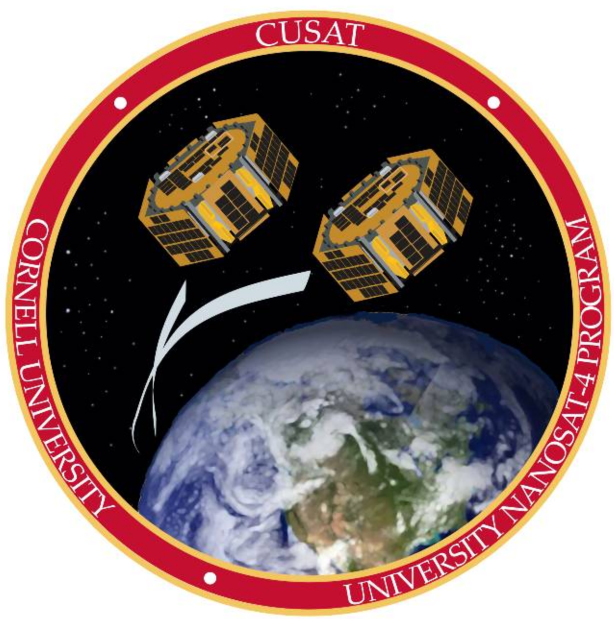
Cornell University
Space Systems Design Studio
CUSat Satellite Project

Cornell University

University Nanosat-4 Program

CUSat Formal Orbital Debris Assessment Report (ODAR)

In accordance with NPR 8715.6A, this report is presented as compliance with the required reporting format per NASA-STD-8719.14, APPENDIX A.



DAS Software Used In This Analysis: DAS v2.02

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Cornell University
Space Systems Design Studio
CUSat Satellite Project

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Signature Page

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PREP (Preparer) Author of technical data initiator of an engineering action. Responsible for obtaining review.
REA (Responsible Engineering Authority) Any qualified individual that reviews and approves technical data.
FAB (Fabricator/Assembler) responsible for fabricating or assembling the part in question.
IT (Integration and Test) responsible for planning, executing, and documenting integration and test of payload
SY (Systems Engineer) defining system requirements and for ensuring the overall satisfaction of these requirements
QA (Quality Assurance) responsible for ensuring that parts are manufactured according to engineering specification
CM (Configuration Manager) Ensures accuracy of as-built documentation and for tracking the history of parts.
PM (Program Manager) is Responsible for resource management and for overall program success
PI (Principle Investigator) Primary individuals invested in the program

Document Revisions

Revision	Description	Date	Approval
A	**Initial Release** Authored by Daniel LaChapelle	2/09/2013	
B	**Changed Signatures** Authored by Arjun Biddanda	3/17/2013	

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1. Introduction

1.1. Overview

This document contains the formal ODAR (Orbital Debris Assessment Report) for the CUSat Nanosatellite Project. This report confirms that there is an extremely low possibility of CUSat generating any orbital debris or being impacted by any orbital debris during its lifetime.

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the CUSat satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

1.2. Scope

This document was written to communicate with the FCC the required information about CUSat the possibility of generating or being affected by orbital debris.

2. Self-assessment and OSMA assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14
A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA STD-8719.14. In the final ODAR document, this assessment will reflect any inputs received from OSMA as well.

3. Assessment Report Format
ODAR Technical Sections Format Requirements:
This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the CUSat satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

4. Mission Desecription
The CUSat space segment is comprised of one satellite that will be launched away from the mission's primary payload using a PSC (Planetary Systems Corp.) Lightband. CUSat's mission is to demonstrate the viability of Carrier-Phase Differential GPS. This will be done in orbit by establishing contact with the GPS satellites and verifying the results on the ground. The satellite will use a centimeter-level accurate Carrier-phase Differential GPS (CDGPS) to navigate and use its cameras to gather target-satellite imagery.

Launch Vehicle and Launch Site: Space Exploration Technologies Falcon 9, Vandenberg AFB, California
Proposed Launch Date: May 2013
Mission Duration: Until de-orbit
Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:
CUSat will be launched away from the primary payload using a PSC (Planetary Systems Corp) "Lightband".

The CUSat orbit is defined as follows:

Apogee: 1500.0 km
Perigee: 325.0 km
Inclination: 80.0 degrees.

CUSat has PPTs (Pulsed Plasma Thrusters) for attitude adjustment; however, these are not powerful enough to actively change CUSat's orbit. CUSat will lose altitude, then slow down due to atmospheric friction and disintegrate on atmospheric reentry approximately 10 years after deployment.

Figure 1: CUSat Full View

Interaction or potential physical interference with other operational Spacecraft:

The orbit of CUSat is expected to be slightly elliptical with an altitude between 325 and 1500 kilometers above sea level. According to Union of Concerned Scientists' Satellite Database updated in April 2012, there are 493 satellites which are in this orbital range. However, only 3 satellites have an eccentricity and semi-major axis within 10% of the expected orbit of CUSat. These satellites have an inclination that is 11 degrees smaller at 69 degrees, compared to CUSat's 80 degrees. Considering CUSat's launch is currently planned in May 2013, the satellites orbiting lower than this range will not be a concern since their orbits will decay, putting them in an even lower orbit. The satellites with a 'similar' orbit to CUSat are MaSat 1, PW-Sat, and Xa Tcobeo. The risk of colliding with these satellites is very low due to the size of CUSat. The CUSat satellite includes a propulsion system. This propulsion system will allow CUSat to make small orbital changes over an extended period of time. The evolution of the orbit is expected to decay until it re-enters the Earth's atmosphere.

5. ODAR Section 1: Program Management and Mission Overview

Principal Investigator: Dr. James Lloyd
Program Manager: Paul Jackson
Senior Management: Sarah Brotman, Garrick Lau, Andre Heil, Shiva Rajagopal

Schedule of Mission Design and Development:

Mission Readiness Review:	5 March 2013
Expected Launch Date:	5 September 2103

6. ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:
CUSat is a hexagonal nanosatellite with a diameter of 45.72 cm and a height of 25.654 cm. CUSat's mass is 23.156 kg. The CUSat satellite carries three GPS receivers to test centimeter-accuracy CDGPS (Carrier-Phase Differential GPS). In addition, CUSat will have two cameras.

Total satellite mass at launch, including all propellants and fluids: 23.156 kg

Dry mass of satellite at launch, excluding solid rocket motor propellants: 23.156 kg

Description of all propulsions (cold gas, mono-propellant, bi-propellant, electric, nuclear): Micro-Pulsed Plasma Thrusters (PPTs) that utilize vaporized Teflon for attitude/position adjustment.

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.
Not applicable as there will be no fluids or gasses on board.

Fluids in Pressurized Batteries: None. CUSat uses unpressurized standard COTS Nickel-Cadmium batteries.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:
The attitude controller utilizes the IMI reaction wheels on each spacecraft, which consist of three wheels oriented in the X, Y, and Z-axes as defined by the CUSat Mechanical Interface Control Document. These wheels are each capable of provide a torque of ±.635 mN·m in each direction, and can spin up to a rate of 1000 RPM. As a result of separation from the launch vehicle, the spacecraft nutates about its minor axis,

which over time will become unstable. Utilizing the attitude controller feedback algorithm, a command is sent through MOMS to the reaction wheels to spin up to the commanded rate over the course of several orbits to correct the nutation about the minor axis (the Z-axis). The reaction wheels will reduce or eliminate the rotation about the X and Y axes to zero or nearly zero. Due to power limitations, this operation cannot occur continuously in order to damp out the nutation, so it will occur over the course of several orbits.

In addition to nutation control, the attitude controller can command the wheels to set a desired spin rate of the spacecraft following launch vehicle separation. The desired rotation is 6 degrees per second. Without the use of the reaction wheels, the spacecraft could go into a tumble, making further attitude control, data transmission, and CDGPS measurements difficult or impossible. In order to execute the algorithm, the position controller function takes in data about the current attitude or position of the spacecraft from MOMS (given by KFATT and CDGPS) and returns to MOMS the IMI wheel torques to command the hardware.

The position controller uses four sets of PPTs, each with two nozzles for a total of 8 PPTs. The spacecraft is capable of firing two PPTs at a time. Each PPT can provide an impulse of 60 μN·s, and firings can occur approximately 4 seconds apart. Due to the small magnitude of each individual firing, many firings over the course of an orbit (power permitting) are required in order to achieve the desired result. Designed into the architecture of the position controller algorithm is a function to prevent over-firing the thrusters when the required position change reaches a certain magnitude, which essentially prevents "chattering" of the spacecraft.

Description of any range safety or other pyrotechnic devices: None.

Description of the electrical generation and storage system: The power will be generated using solar panels and 10 individual Nickel-Cadmium batteries. The batteries that will be used are Sanyo Batteries (CADNICA) Nickel-Cadmium Batteries. The batteries' combined mass is 0.154 kg.

Identification or any other sources of stored energy not noted above: None.

Identification of any radioactive materials on board: None.

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

Identification of any object (>1mm) expected to be released from the spacecraft at 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 v2.02)
4.3-1, Mission Related Debris Passing Through LEO: COMPLIANT

4.3-2, Mission Related Debris Passing Near GEO: COMPLIANT

8. ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potentential for Explosions

Potential causes of spacecraft breakup during deployment and mission operations:
There is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion:
In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating. The battery safety systems discussed in the FMEA describe the combined faults that must occur for any of the seven (7) independent, mutually exclusive failure modes to occur.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:
There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:
The ten (10) Nickel-Cadmium battery cells will be passivated.
Rationale for all items which are required to be passivated, but cannot be due to their design:
The satellite will break up on re-entry at the end of the mission; however, once the objectives of the mission have been completed, the batteries will be drained by elements like the GPS.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:
For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).
Compliance Statement:
Required Probability: 0.001.
Expected Probability: 0.000.

Supporting Rationale and FMEA details:
Battery Explosion:
Effect: All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.
Probability: Very Low. It is believed to be less than 0.1% given that multiple independent faults must occur for each failure mode to cause the ultimate effect (explosion). Additionally, the batteries will be drained of charge after the mission objectives have been completed, which is not likely to take longer than one month.

Failure Mode 1: Internal short circuit

Mitigation 1: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system-rate limited charge and discharge to prove that no internal short circuit sensitivity exists.
Combined faults required for realized failure: Environmental testing **AND** functional charge/discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.
Mitigation 2: Close monitoring of temperatures combined with the ability to shut down overheating components ensures that internal thermal rise will be limited.
Combined faults required for realized failure: Spacecraft thermal design must be incorrect, **AND** external current detection and protection must fail for this failure mode to occur.

Failure Mode 3: Overcharging and excessive discharge rate.
Mitigation 3: This failure mode is negated by a) qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of other such mechanical failures by proto-qualification and acceptance environmental tests (shock, vibration, thermal cycling, and thermal-vacuum tests).
Combined faults required for realized failure: An external load must fail/short-circuit **AND** external over-current detection must all occur to enable this failure mode.

Failure Mode 4: Inoperable vents.
Mitigation 4: Battery vents are not inhibited by the battery holder design or the spacecraft.
Combined effects required for realized failure: The manufacturer fails to install proper venting.

Failure Mode 5: Crushing.
Mitigation 5: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.
Combined faults required for realized failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.
Mitigation 6: These modes are negated by a) battery holder/case design that separates the batteries from conductive elements, and b) operation in a vacuum such that no moisture can affect insulators.
Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators **AND** dislocation of battery packs **AND** failure of battery terminal insulators **AND** failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 7: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.
Combined faults required for realized failure: Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon:
Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.

Compliance Statement:
Once the CUSat mission is complete, mission operators will put CUSat in the End of Life mode. This mode involves re-flashing the power microcontroller (MCU) to prevent it from shutting down the satellite when the batteries have five percent of maximum charge left. During normal mission operations, this feature allows the satellite to hibernate while it orbits the Earth enabling CUSat to charge the batteries and prevent them from completely draining. The MCUs located on CUSat's Power Board can be re-flashed in flight as the design allows new MCU code to be transmitted over CUSat Backplane's serial bus. This new Power MCU code would power down the flight computer, PPTs, and IMI reaction wheels while turning on passive elements such as the GPS receivers to drain the batteries. This would allow the satellites to drain the remaining battery charge in preparation for end of life. The PPTs onboard provide low thrust, and it is not feasible to use them to drastically change the orbit in a short period of time. In addition, CUSat will only be in orbit for 10 years based on the DAS analysis shown in this report, and it is planned to operate until deorbiting. Therefore, no postmission passivation will be performed, as the satellite will break up on re-entry at the end of the mission. Therefore, the CUSat battery will meet the above requirement.

Requirement 4.4-3. Limiting the long term risk to other space systems from planned breakups:

Compliance Statement:
This requirement is not applicable. There are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups.

Compliance Statement:
This requirement is not applicable. There are no planned breakups.

9. 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 v2.02, 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: 0.00001; COMPLIANT.

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 is sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).
Small Object Impact and Debris Generation Probability: 0.000131; COMPLIANT

10. ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. The PPTs onboard provide low thrust, and it is not feasible to use them to drastically change the orbit in a short period of time.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal: None.

6.3 Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:

Spacecraft Mass: 24.67 kg
Cross-sectional Area: 0.20 m^2 (Calculated by DAS v2.02 for the configuration in Figure 1).
Area to mass ratio: 0.008107 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v2.0 and NASA-STD-8719.14 section 4.6):

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 the three methods: (Requirement 56557)

a. Atmospheric reentry 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 but no more than 30 years after launch; or
   - 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 with 10 years after completion of mission.

Analysis: The CUSat satellite reenty is COMPLIANT with Method "a." CUSat will re-enter approximately 10 years after launch with an orbit history shown in Figure 2 (analysis assumes an approximate random tumbling behavior).

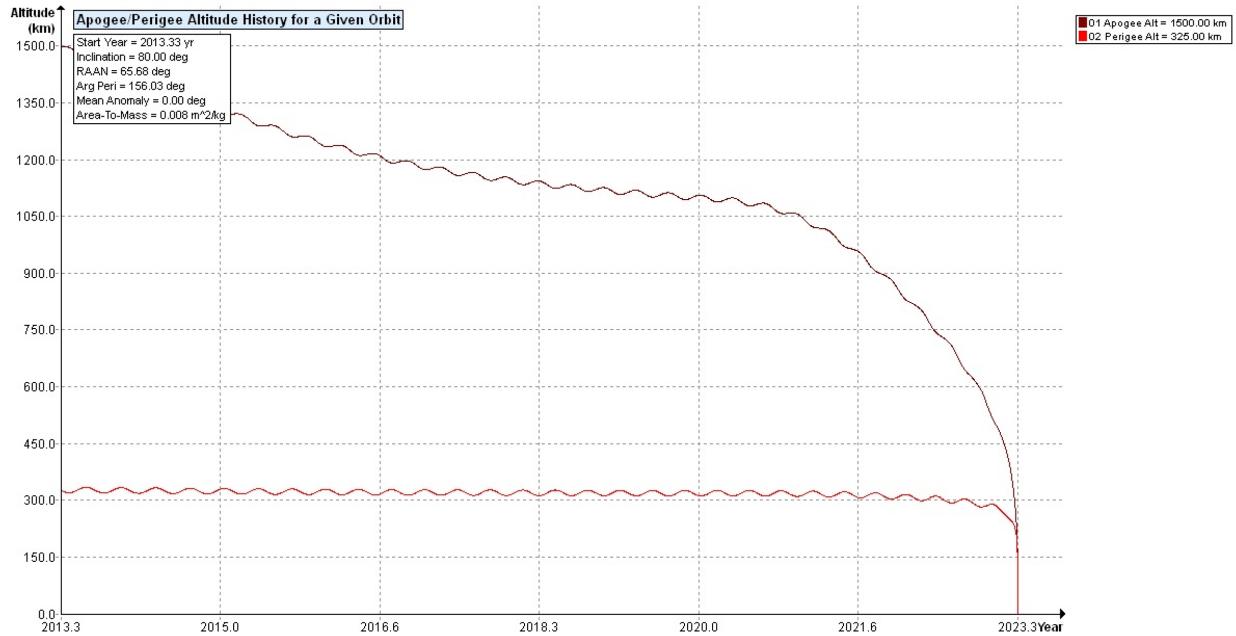

Figure 2: CUSat Orbit History

Requirement 4.6-2. Disposal for space stuctures near GEO.
Analysis: Not applicable. CUSat orbit is in LEO.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.
Analysis: Not applicable. CUSat orbit is in LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations.
Analysis: CUSat de-orbiting does not rely on de-orbiting devices. Release from its launch vehicle with a Planetary Systems Corp (PSC) Lightband will result in de-orbiting in approximately 10 years with no disposal or de-orbiting actions required.

11. 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 casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Summary Analysis Results: DAS v2.02 reports that CUSat is compliant with the requirement. It predicts that no components reach the ground. In addition, the Risk of Human Casualty was calculated to be 1:0. This is an erroneous value since no piece of CUSat will reach the ground to cause any human risk. As seen in the analysis outputs below, the impact kinetic energies are 0.000000 Joules and impact casualty areas are all 0.000000 square meters. Also, there are no titanium components that will be used on CUSat, which is also a reason why no components reach the ground.

```
02 09 2013; 14:01:04PM  Processing Requirement 4.3-1: Return Status :  Not
Run

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

=============== End of Requirement 4.3-1 ===============
02 09 2013; 14:01:06PM  Processing Requirement 4.3-2: Return Status : Passed

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No Project Data Available
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=============== End of Requirement 4.3-2 ===============
02 09 2013; 14:01:08PM  Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
02 09 2013; 14:01:16PM  Processing Requirement 4.5-1: Return Status :  Passed

==============
Run Data
==============

**INPUT**

      Space Structure Name = CUSat Nanosatellite
      Space Structure Type = Payload
      Perigee Altitude = 325.000000 (km)
      Apogee Altitude = 1500.000000 (km)
      Inclination = 80.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.008107 (m^2/kg)
      Start Year = 2013.000000 (yr)
      Initial Mass = 24.670000 (kg)
      Final Mass = 24.670000 (kg)
      Duration = 0.500000 (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 = 0.000006
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

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

=============== End of Requirement 4.5-1 ===============
```

```
02 09 2013; 14:03:02PM  Requirement 4.5-2:  Compliant

==================================================
Spacecraft = CUSat Nanosatellite
Critical Surface = MCU
==================================================

**INPUT**

      Apogee Altitude = 1500.000000 (km)
      Perigee Altitude = 325.000000 (km)
      Orbital Inclination = 80.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.008107 (m^2/kg)
      Initial Mass = 24.670000 (kg)
      Final Mass = 24.670000 (kg)
      Station Kept = No
      Start Year = 2013.000000 (yr)
      Duration = 0.500000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 0.685800 (g/cm^2)
      CS Surface Area = 0.039000 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 1.577000 (g/cm^2)  Separation: 0.100000 (cm)
      Outer Wall 2   Density: 0.296000 (g/cm^2)  Separation: 0.584200 (cm)

**OUTPUT**

      Probabilty of Penitration = 0.000032
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

==================================================
Spacecraft = CUSat Nanosatellite
Critical Surface = Battery Box
==================================================

**INPUT**

      Apogee Altitude = 1500.000000 (km)
      Perigee Altitude = 325.000000 (km)
      Orbital Inclination = 80.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.008107 (m^2/kg)
      Initial Mass = 24.670000 (kg)
      Final Mass = 24.670000 (kg)
      Station Kept = No
      Start Year = 2013.000000 (yr)
      Duration = 0.500000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 0.891540 (g/cm^2)
      CS Surface Area = 0.103000 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
```

```
      Outer Wall 1   Density: 1.577000 (g/cm^2)  Separation: 0.100000 (cm)
      Outer Wall 2   Density: 0.296000 (g/cm^2)  Separation: 0.584200 (cm)

**OUTPUT**

      Probabilty of Penitration = 0.000063
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

==================================================
Spacecraft = CUSat Nanosatellite
Critical Surface = GPS Box
==================================================

**INPUT**

      Apogee Altitude = 1500.000000 (km)
      Perigee Altitude = 325.000000 (km)
      Orbital Inclination = 80.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass = 0.008107 (m^2/kg)
      Initial Mass = 24.670000 (kg)
      Final Mass = 24.670000 (kg)
      Station Kept = No
      Start Year = 2013.000000 (yr)
      Duration = 0.500000 (yr)
      Orientation = Random Tumbling
      CS Areal Density = 0.342900 (g/cm^2)
      CS Surface Area = 0.025000 (m^2)
      Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 1.577000 (g/cm^2)  Separation: 0.100000 (cm)
      Outer Wall 2   Density: 0.296000 (g/cm^2)  Separation: 0.584200 (cm)

**OUTPUT**

      Probabilty of Penitration = 0.000036
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range


02 09 2013; 14:04:20PM  Processing Requirement 4.6    Return Status :  Passed

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

**INPUT**

      Space Structure Name = CUSat Nanosatellite
      Space Structure Type = Payload

      Perigee Altitude = 325.000000 (km)
      Apogee Altitude = 1500.000000 (km)
      Inclination = 80.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
```

```
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.008107 (m^2/kg)
      Start Year = 2013.000000 (yr)
      Initial Mass = 24.670000 (kg)
      Final Mass = 24.670000 (kg)
      Duration = 0.500000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 329.903533 (km)
      PMD Apogee Altitude = 1442.868096 (km)
      PMD Inclination = 79.995772 (deg)
      PMD RAAN = 158.994207 (deg)
      PMD Argument of Perigee = 226.969261 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 329.903533 (km)
      Suggested Apogee Altitude = 1442.868096 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

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

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

=============== End of Requirement 4.6 ===============
02 09 2013; 15:04:55PM  *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = CUSat Nanosatellite
quantity = 1
parent = 0
materialID = 8
type = Cylinder
Aero Mass = 24.670000
Thermal Mass = 24.670000
Diameter/Width = 0.256540

name = Solar Panels
quantity = 6
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.105800
Thermal Mass = 0.105800
Diameter/Width = 0.209550
Length = 0.228600

name = Bottom Wall
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 1.713200
```

```
Thermal Mass = 1.713200
Diameter/Width = 0.395720
Length = 0.395720

name = Wall 4
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.272000
Thermal Mass = 0.272000
Diameter/Width = 0.177800
Length = 0.228600

name = Wall 1
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.231000
Thermal Mass = 0.231000
Diameter/Width = 0.177800
Length = 0.228600

name = STR Backplane
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.509000
Thermal Mass = 0.509000
Diameter/Width = 0.177800
Length = 0.443780

name = STR Stiffener
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.326000
Thermal Mass = 0.326000
Diameter/Width = 0.177800
Length = 0.187000

name = STR Connector
quantity = 6
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.003900
Thermal Mass = 0.003900
Diameter/Width = 0.025400
Length = 0.025400

name = Top/Bottom Panel
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
```

```
Aero Mass = 0.138000
Thermal Mass = 0.138000
Diameter/Width = 0.304800
Length = 0.304800

name = CAM Crossbeam
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.007200
Thermal Mass = 0.007200
Diameter/Width = 0.009000
Length = 0.052000
Height = 0.006350

name = CAM Mount Short
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.024400
Thermal Mass = 0.024400
Diameter/Width = 0.028500
Length = 0.072000
Height = 0.011430

name = Battery Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.416100
Thermal Mass = 0.713900
Diameter/Width = 0.133000
Length = 0.141000
Height = 0.063000

name = Lid
quantity = 1
parent = 12
materialID = 8
type = Box
Aero Mass = 0.327600
Thermal Mass = 0.327600
Diameter/Width = 0.133000
Length = 0.141000
Height = 0.033000

name = Bottom
quantity = 1
parent = 12
materialID = 8
type = Box
Aero Mass = 0.323400
Thermal Mass = 0.323400
Diameter/Width = 0.133000
Length = 0.141000
Height = 0.030000
```

```
name = Cell Holder
quantity = 1
parent = 12
materialID = 8
type = Flat Plate
Aero Mass = 0.051200
Thermal Mass = 0.051200
Diameter/Width = 0.133000
Length = 0.141000

name = HAM Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.405800
Thermal Mass = 0.202900
Diameter/Width = 0.055000
Length = 0.142240
Height = 0.025400

name = Box Body
quantity = 1
parent = 16
materialID = 8
type = Box
Aero Mass = 0.127500
Thermal Mass = 0.127500
Diameter/Width = 0.055000
Length = 0.142240
Height = 0.025400

name = Box Cover
quantity = 1
parent = 16
materialID = 8
type = Flat Plate
Aero Mass = 0.044400
Thermal Mass = 0.044400
Diameter/Width = 0.055000
Length = 0.142240

name = Grounding Plate
quantity = 1
parent = 16
materialID = 8
type = Flat Plate
Aero Mass = 0.031000
Thermal Mass = 0.031000
Diameter/Width = 0.049000
Length = 0.107000

name = PPU
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.241000
```

```
Thermal Mass = 0.620500
Diameter/Width = 0.120396
Length = 0.154940
Height = 0.073660

name = Enclosure Body
quantity = 1
parent = 20
materialID = 8
type = Box
Aero Mass = 0.359100
Thermal Mass = 0.359100
Diameter/Width = 0.120396
Length = 0.154940
Height = 0.073660

name = Enclosure Lid
quantity = 1
parent = 20
materialID = 8
type = Flat Plate
Aero Mass = 0.128200
Thermal Mass = 0.128200
Diameter/Width = 0.120396
Length = 0.154940

name = Shield
quantity = 1
parent = 20
materialID = 8
type = Flat Plate
Aero Mass = 0.042000
Thermal Mass = 0.042000
Diameter/Width = 0.071120
Length = 0.149860

name = Sideplate
quantity = 1
parent = 20
materialID = 8
type = Flat Plate
Aero Mass = 0.091200
Thermal Mass = 0.091200
Diameter/Width = 0.071120
Length = 0.154940

name = EBP Stiffener
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.194500
Thermal Mass = 0.194500
Diameter/Width = 0.101600
Length = 0.342900

name = EBP Box Body
quantity = 1
parent = 1
```

```
materialID = 8
type = Flat Plate
Aero Mass = 0.208700
Thermal Mass = 0.208700
Diameter/Width = 0.106680
Length = 0.326000

name = Walls
quantity = 4
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.270200
Thermal Mass = 0.270200
Diameter/Width = 0.177800
Length = 0.228600

name = EBP Cover
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.297200
Thermal Mass = 0.297200
Diameter/Width = 0.177800
Length = 0.326000

name = GPS
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.334600
Thermal Mass = 0.167300
Diameter/Width = 0.067000
Length = 0.142240
Height = 0.022860

name = CAM Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.514700
Thermal Mass = 0.514700
Diameter/Width = 0.099000
Length = 0.142240
Height = 0.022860

name = PWR Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.504900
Thermal Mass = 0.504900
Diameter/Width = 0.107950
Length = 0.142240
Height = 0.022860
```

```
name = CDH Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.376200
Thermal Mass = 0.376200
Diameter/Width = 0.107950
Length = 0.142240
Height = 0.022860

name = TC Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.342300
Thermal Mass = 0.342300
Diameter/Width = 0.107950
Length = 0.142240
Height = 0.022860

name = PPT
quantity = 4
parent = 1
materialID = 8
type = Box
Aero Mass = 0.994900
Thermal Mass = 0.994900
Diameter/Width = 0.096000
Length = 0.203000
Height = 0.022860

name = GPS Box Body
quantity = 1
parent = 29
materialID = 8
type = Box
Aero Mass = 0.109200
Thermal Mass = 0.109200
Diameter/Width = 0.067000
Length = 0.142240
Height = 0.022860

name = GPS Box Cover
quantity = 1
parent = 29
materialID = 8
type = Flat Plate
Aero Mass = 0.058100
Thermal Mass = 0.058100
Diameter/Width = 0.067000
Length = 0.142240

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

name = CUSat Nanosatellite
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```
Demise Altitude = 77.998191
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels
Demise Altitude = 77.624855
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Bottom Wall
Demise Altitude = 73.190511
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Wall 4
Demise Altitude = 76.440004
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Wall 1
Demise Altitude = 76.679363
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = STR Backplane
Demise Altitude = 76.325504
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = STR Stiffener
Demise Altitude = 75.701972
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = STR Connector
Demise Altitude = 77.385519
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Top/Bottom Panel
Demise Altitude = 77.673043
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CAM Crossbeam
Demise Altitude = 77.190332
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
```

```
name = CAM Mount Short
Demise Altitude = 77.100433
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Battery Box
Demise Altitude = 73.939949
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lid
Demise Altitude = 70.738722
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Bottom
Demise Altitude = 70.694058
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Cell Holder
Demise Altitude = 73.307753
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = HAM Box
Demise Altitude = 75.797043
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Box Body
Demise Altitude = 74.194347
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Box Cover
Demise Altitude = 74.932324
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Grounding Plate
Demise Altitude = 74.970105
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PPU
Demise Altitude = 74.889050
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
*************************************
name = Enclosure Body
Demise Altitude = 72.579777
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Enclosure Lid
Demise Altitude = 73.392972
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Shield
Demise Altitude = 74.224871
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Sideplate
Demise Altitude = 73.454691
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = EBP Stiffener
Demise Altitude = 76.850488
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = EBP Box Body
Demise Altitude = 76.783894
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Walls
Demise Altitude = 76.458426
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = EBP Cover
Demise Altitude = 76.771238
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = GPS
Demise Altitude = 76.276824
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CAM Box
Demise Altitude = 73.249996
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = PWR Box
Demise Altitude = 73.442550
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = CDH Box
Demise Altitude = 74.582097
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = TC Box
Demise Altitude = 74.884621
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PPT
Demise Altitude = 71.225277
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS Box Body
Demise Altitude = 74.930886
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS Box Cover
Demise Altitude = 75.273418
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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=============== End of Requirement 4.7-1 ===============
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Requirements 4.7-1b and 4.7-1c below are non-applicable requirements because CUSat does not use controlled reentry.

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

12. ODAR Section 8: Assessment for Tether Missions

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

END of ODAR for CUSat.

AFRL	Air Force Research Lab
cm	centimeters
COTS	Commercial Off-The-Shelf (items)
CUSat	Cornell University Satellite
DAS	Debris Assessment Software
EOM	End Of Mission
GEO	Geosynchronous Earth Orbit
ITAR	International Traffic in Arms Regulations
kg	kilogram
km	kilometer
LEO	Low Earth Orbit
Ni-Cd	Nickel-Cadmium (battery)
m^2	Meters squared
mm	millimeter
N/A	Not Applicable
ODAR	Orbital Debris Assessment Report
OSMA	Office of Safety and Mission Assurance
PSC	Planetary Systems Corp
RAAN	Right Ascension of the Ascending Node
Ti	Titanium
Yr	year