EDSN Orbital Debris Assessment Report (ODAR) and End of Mission Plan (EOMP)

This report is presented as compliance with NASA-STD-8719.14, APPENDICES A and B.

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Record of Revisions

REV	DATE	AFFECTED PAGES	DESCRIPTION OF CHANGE	AUTHOR (S)
-	8 August 2012	All	Initial PDR draft	Watson Attai
A	19 November 2012	All	Second PDR draft	Watson Attai
B	21 March 2013	All	First CDR draft	Watson Attai
C	11 February 2014	All	Updated documented per 9/13 EPMC package	Robert Barber Watson Attai
D	26 February 2014	All	Updated to Rev D since Rev C was already signed. Updates for launch dates and mission architecture.	Robert Barber Watson Attai

Table of Contents

Self-assessments of the ODAR and EOMP using the formats defined in Appendices A.2 and B.2 of NASA-STD-8719.14:

Self-assessments are provided below in accordance with the assessment formats provided in Appendices A.2 and B.2 of NASA-STD-8719.14. In the final ODAR/EOMP document, these assessments will reflect any inputs received from OSMA as well.

Orbital Debris Self-Assessment Report Evaluation: EDSN Mission

Requirement #	Launch Vehicle				Spacecraft			ODAR Comments
	Compliant	Not Compliant	Not Applicabe	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	No Debris Released in GEO.
4.4-1	☐	☐	☒	☐	☒	☐	☐	
4.4-2	☐	☐	☒	☐	☒	☐	☐	Only passivate RF systems.
4.4-3	☐	☐	☒	☐	☒	☐	☐	No planned breakups.
4.4-4	☐	☐	☒	☐	☒	☐	☐	No planned breakups.
4.5-1	☐	☐	☒	☐	☒	☐	☐	
4.5-2					☒	☐	☐	
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	N/A. No ability to maneuver to higher orbit.
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	N/A. Atmospheric re-entry.
4.6-2	☐	☐	☒	☐	☒	☐	☐	N/A. Not in GEO
4.6-3	☐	☐	☒	☐	☒	☐	☐	N/A. Orbit not between LEO and GEO.
4.6-4	☐	☐	☒	☐	☒	☐	☐	No operation is required to execute atmospheric re-entry
4.7-1	☐	☐	☒	☐	☒	☐	☐	
4.8-1					☒	☐	☐	No tethers used.

Notes:

1. This is not a NASA primary mission. All of the other portions of the launch stack are non-NASA and EDSN is not the lead. The EDSN satellite payloads belong to Montana State University.

Pre-Launch EOMP Evaluation: EDSN Mission

Requirement #	Compliant	Spacecraft Not Compliant	Incomplete	EOMP Comments
4.3-1.a				
4.3-1.b				
4.3-2				
4.4-1				
4.4-2	☒	☐	☐	Passivate RF systems. No planned breakups. Very low probability of breakup or debris generation due to explosion.
4.4-3	☒	☐	☐	No planned breakups.
4.4-4				
4.5-1				
4.5-2	☒	☐	☐	
4.6-1(a)	☒	☐	☐	
4.6-1(b)	☒	☐	☐	N/A. No ability to maneuver to higher orbit.
4.6-1(c)	☒	☐	☐	N/A. Atmospheric re-entry.
4.6-2	☒	☐	☐	N/A. Not in GEO
4.6-3	☒	☐	☐	N/A. Orbit not between LEO and GEO.
4.6-4	☒	☐	☐	No operation is required to execute atmospheric re-entry
4.7-1				
4.8-1				

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 EDSN satellites. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here due to launch vehicle being provided by a non-NASA entity.

Content of several ODAR sections are also used to show pre-launch EOMP compliance.

EDSN

ODAR Section 1: Program Management and Mission Overview

Mission Directorate: Office of Chief Technologist (OCT)

Program Executive: Andrew Petro, HQ

Program/project manager: Deborah Westley, Project Manager, ARC

Senior Management: Dave Korsmeyer, ARC

Foreign government or space agency participation: None.

Summary of NASA's responsibility under the governing agreement(s): None.

Schedule of upcoming mission milestones:

PSR:	August 1, 2014
FRR:	August 1, 2014
Launch:	October 1, 2014

Mission Overview:
The EDSN mission is a group of eight 1.5U CubeSats that will launch as secondary payloads on the ORS-4 mission. Each 1.5U CubeSat measures 10 cm x 10 cm x 15 cm in size. Each spacecraft weighs approximately 1.7kg. All eight satellites are identical excluding unique IDs.

EDSN is a technology demonstration of a swarm of eight low-cost CubeSats in Low Earth Orbit (LEO) with cross-link and downlink communications capability, suitable as a platform for Space Weather or other science applications requiring geographically distributed, synchronized data acquisition. Each unit has identical hardware and software, excluding unique IDs. The mission operations phase is planned to be 60 days.

All eight EDSN satellites are shipped to ORS facilities in Albuquerque, NM to be integrated with the ORS-4 launch vehicle – a Super Strypi procured by ORS from Sandia National Labs. The eight EDSN satellites will be stowed in NLAS Dispensers that eject the spacecraft based on a pre-set sequence controlled by the launch vehicle and NLAS Sequencer. Once ejected by the launch vehicle, the eight EDSN satellites will operate in the same elliptical orbit. The satellites have no propulsion systems, and therefore no station-keeping operations need to be performed. The mission ends with natural atmospheric reentry of all eight spacecraft within 496 days from launch (see ODAR Section 6).

Launch vehicle and launch site: Super Strypi, Kauai Test Facility, Hawaii.

Proposed launch date: 10/1/2014

Mission duration: 60 Days in LEO operations.

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

EDSN is a secondary payload on the ORS-4 mission.

The ORS-4 Super Strypi will launch into an elliptical orbit. All eight EDSN satellites will be deployed with a small delta-V in the plane normal to the launch vehicle upper stage final velocity vector. The deployment pattern will be such that NLAS deployment mechanisms will simultaneously eject 4 satellites (NLAS Bays 1 and 4) from the same side of the launch vehicle upper stage with a 2 second delay until the ejection of the remaining 4 spacecraft from Bays 2 and 3 on the same side of the upper stage. Ejection velocity will be ~1.5 m/s.

The nominal elliptical orbit will be:

Apogee: 505 km

Perigee: 430 km

Inclination: 94.8 degrees.

The EDSN satellites have no propulsion and therefore do not actively station keep. There is no parking or transfer orbit.

ODAR Section 2: Spacecraft Description

Description of spacecraft:

The EDSN mission consists of eight satellites. Each spacecraft is a standard 1.5U CubeSat form factor, 10cm x 10cm x 15cm. Each weighs approximately 1.7kg.

Each spacecraft has four Lithium-Ion batteries (3.7 V, 2800 mAh). Solar panels cover all 6 faces for battery charging. None of the satellite have titanium parts.

During the 60 day mission, each satellite in the network will use an average of 1.1 Watts.

Each satellite has two short “tape measure” antennas, about 6 inches in length, deployed after the launch vehicle ejects the satellites into orbit. The tape-measure antennas are the only protrusions from the flat faces of the satellites (see Figure 2-1 below). The satellites are RF quiet for 30 minutes after deployment from the launch vehicle.

Figure 2-1: EDSN Spacecraft

Total mass (8 spacecraft) at launch (contain no liquid or solid propellants): ~13.576 kg

Satellite 1 Mass: ~1.697 kg
Satellite 2 Mass: ~1.697 kg
Satellite 3 Mass: ~1.697 kg
Satellite 4 Mass: ~1.697 kg
Satellite 5 Mass: ~1.697 kg
Satellite 6 Mass: ~1.697 kg
Satellite 7 Mass: ~1.697 kg
Satellite 8 Mass: ~1.697 kg

Propulsion System: None.

Fluids: Electrolyte in batteries (<65 ml/spacecraft). No other fluids used.

Fluids in Pressurized Batteries: Batteries are COTS LG 18650 Li Ion cells that contain a LiPF6 electrolyte that is at atmospheric pressure when the batteries are manufactured. The batteries do not contain a pressure equalization vent to equalize pressure during ascent, therefore the batteries will develop a pressure delta of approximately 14.7 psia during launch to on-orbit phase. Note that this model of battery has flown on previous Phonesat and other cubesat missions with no issues identified related to pressure during or after launch. The batteries have also undergone vacuum chamber testing at predicted thermal extremes for the mission.

Attitude control system: All of the EDSN satellites have active two axis control with three orthogonal sets of two magnetorquer coils and during point demonstrations are three-axis attitude control by means of three orthogonal reaction wheels. The spacecraft are rectangular in shape consistent with 1.5U standard (10cmx10cmx15cm) – the four side surface areas are 15cm x 10cm and the two end surface areas are 10cm x 10cm.

When passing over ground station at Santa Clara University at approx. 37.349 degrees N Latitude, 121.938 degrees W Longitude, the spacecraft will be oriented along the Earth magnetic field lines. A pointing demo will be performed once per 25 hour cycle during the mission where a single spacecraft points to the sun using sensors and reaction wheels. Note for purposes of atmospheric re-entry modeling (Sect 6.4 of this report) a random attitude orientation is modeled.

Range safety or other pyrotechnic devices: The EDSN system is launched powered off. A Remove-Before-Flight (RBF) pin is used to prevent accidental activation during ground processing. The RBF pin is removed prior to integration of spacecraft with the NLAS Dispensers. Upon integration with the NLAS Dispensers a foot switch on the spacecraft is engaged which disables power. During the short period (<10 sec) between removal of the RBF pin and engagement of the foot switch the spacecraft powers on into a 30-minute wait state. The wait state is reset to zero when foot switch is engaged. The foot switch remains engaged until deployment from the launch vehicle. No pyrotechnic devices are used.

Electrical generation and storage system: COTS Lithium-Ion battery cells, 3.7 V, 2800 mAh, are charged before payload integration and provide electrical energy during the mission. For all EDSN spacecraft, the battery holder and protection circuit is a COTS item designed for the Lithium-Ion 18650 cell format batteries. For all EDSN spacecraft, the solar panels and charging circuit recharge the batteries. All EDSN spacecraft carry 4 Lithium-Ion battery cells in the 18650 cell format.

Each battery is cylindrical in shape measuring 18.29 mm in diameter and 65.05 mm long. Safety testing by manufacturer is performed per UL-1642. This testing includes over-charge, over-discharge, heating, and short circuit without explosion or fire. EDSN has also tested circuit protection. In additional EDSN has demonstrated operation of the battery circuit under vacuum and expected temperature extremes.

Other sources of stored energy not noted above: The two deployable "tape measure" antennas previously described contained stored energy until the spacecraft is released by launch vehicle with the NLAS Dispenser.

Radioactive materials on board: None**.**

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

Objects >1 mm expected to be released from the spacecraft: None. There are no intentional releases from the spacecraft.

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 (>1mm diameter): Compliant. No debris released >1 mm while passing through LEO.

4.3-2, Mission Related Debris Passing Near GEO: Compliant. No debris released that will transverse GEO.

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential 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. A battery explosion is considered the most significant energy-producing event on the spacecraft, however the likelihood of an explosion occurring is very small (see failure modes below). In addition, if a battery did explode the debris generated would be contained within the spacecraft enclosure and no spacecraft breakup would occur.

Summary of failure modes and effects analyses:

Failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to explosion. The rationale is true for all batteries onboard all spacecraft.

There is no credible scenario in which the reaction wheel energy would exceed the breakup/explosion energy required for the reaction wheel material to breakup/explode. The supporting analysis is described in the FMEA below.

Plan for any designed spacecraft breakup:

There are no planned breakups other than during atmospheric entry for disposal.

Components that are passivated at End of Mission (EOM):

There are no systems that require passivation that cannot be passivated.

The RF transmitters on a spacecraft will be deactivated by a “kill command” sent to a spacecraft at the end of mission. Each individual spacecraft will need to receive this command independently when it assumes the captain role and attempts communication with the ground station. The RF transmitters cannot be re-enabled autonomously by onboard software unless it achieves a “lock” signal with the ground station. In the event mission operations cannot contact the spacecraft for a continuous period of 18 days a watchdog timer will timeout and inhibit RF transmitter operation.

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: <0.001.

Supporting Rationale and FMEA details:

Battery explosion:

Effect: Failure modes listed below might result in battery explosion with a low probability 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 debris from the battery rupture should be contained within the closed vessel due to the lack of penetration energy. The rationale is true for all batteries onboard the spacecraft.

Probability: Very Low. It is believed to be less than 0.1% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion) with debris released. Although battery explosions and fires have been reported for these types of battery cells, the number of explosions reported each year appears to be extremely small compared to the greater than one billion battery cells operating daily in laptops and other devices. Many reported failures have been caused by mis-use and mis-handling of the batteries, including operation in unprotected circuits. EDSN provides circuit protection.

Failure mode 1: Internal short circuit
Mitigation 1: Complete battery subassembly functional test, vibration, thermal and vacuum cycling tests followed by functional testing of the spacecraft to prove that no internal short circuit sensitivity exists.
Combined faults required for realized failure: Subassembly functional test and Environmental testing and system functional tests must both be ineffective in discovery of the failure mode. Failure must also result in the creation of debris with enough energy to penetrate the combination of multiple spacecraft enclosures and structural items. The least resistive paths on the spacecraft to an exploding battery (considered highest energy failure) are narrow channels consisting of the battery holder and solar panels. These

paths provide a minimum of ~0.107" of solid polypropylene and FR4 material. This "minimum path of material" provides significantly more material for debris stoppage than is used in the UL-1642 Projectile Test (aluminum mesh enclosure consisting of 0.010" dia wire at 16-18 wires/square inch). The UL-1642 Projectile Test requires that no part of an exploding cell shall penetrate or protrude through the mesh enclosure.

Failure Mode 2: Internal thermal rise due to high load discharge rate.
Mitigation 2: Cells were tested in lab for high load discharge rates in a variety of flight like configurations to assess potential for thermal runaway. Cells did not exhibit potential for runaway in flight configuration and operation. Cells were also tested in a hot environment to test the upper limit of the cells capability. No failures were seen for either set of tests. COTS 18650 lithium ion cells incorporate several features to protect against thermal runaway. First, each contains a Positive Temperature Coefficient (PTC) polyswitch device that reduces current if temperature rises excessively. Second, these batteries have a Current Interrupter Device (CID) that will disconnect the battery on overpressure and vent. In addition, this cell design has undergone an over-discharge test per UL-1642 with no explosion or fire.
*Combined faults required for realized failure: S*pacecraft thermal design must be incorrect and external over current detection and disconnect function must fail to enable this failure mode, and battery PTC and CID devices must fail to enable this failure mode (see figure 4-1). Adiabatic testing of similar LG 18650 cells showed that thermal runaway did not start until a temperature of approximately 142 C was reached (Journal of Hazardous Materials, May 2011). Max temperature expected for EDSN batteries is <60 C. Thermal vacuum testing is conducted up to 60 C. Failure must also cause debris generation and penetration of battery holder, spacecraft shell and solar panels. This is highly unlikely due to rationale provided in Failure mode 1.

Failure Mode 3: Excessive discharge rate or short-circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).
Mitigation 4: This failure mode is negated by a) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, b) use of the COTS battery protection circuit on the battery holder for the 18650 cell format Lithium-Ion batteries, c) obviation of system-related mechanical failures by qualification and acceptance environmental tests (vibration and thermal vacuum cycling tests). In addition, the design of this series of battery undergoes an over-discharge and external short circuit test per UL-1642 with no explosion or fire.
Combined faults required for realized failure: An external load must fail/short-circuit and external over-current detection and disconnect function, and battery PTC and CID devices must all fail to result in this failure mode. Failure must also result in the creation of debris with enough energy to penetrate multiple spacecraft enclosures and structural items. This is highly unlikely due to rationale provided in Failure mode 1.

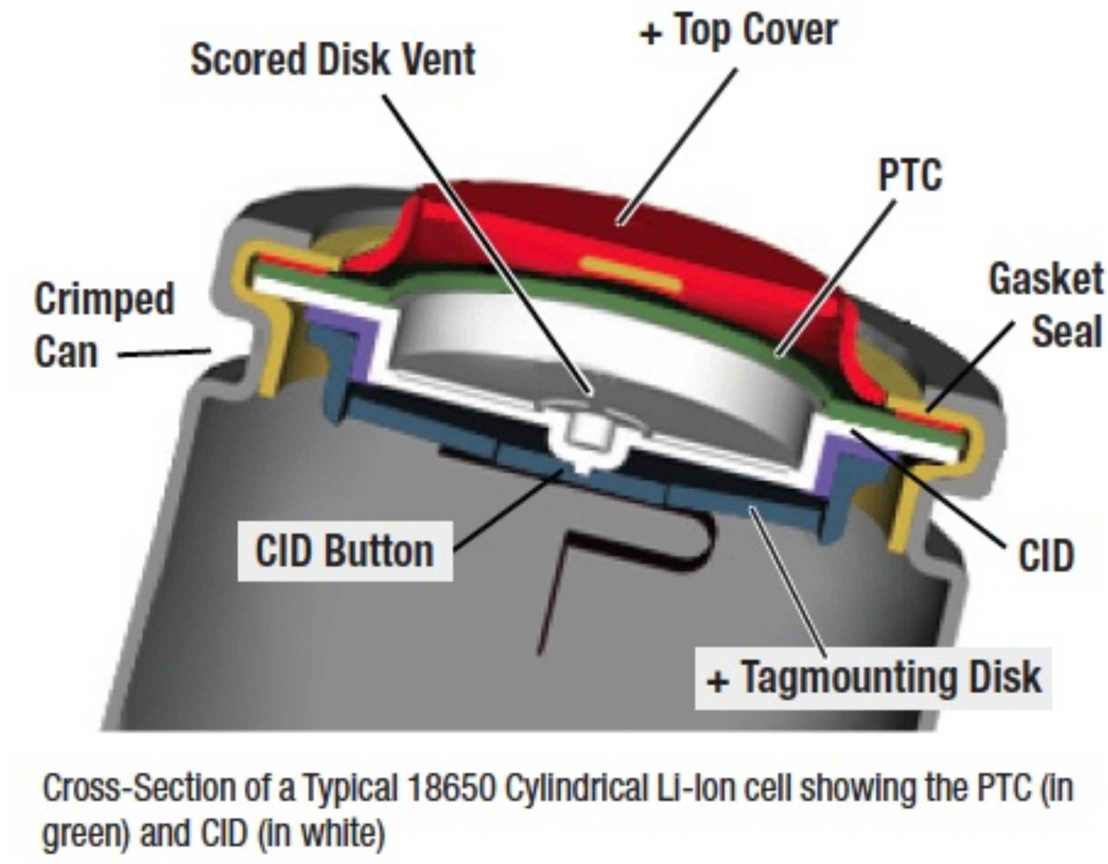

Figure 4-1: from NESC Technical Bulletin No. 09-02

Failure Mode 4: Inoperable vents.
Mitigation 5: Battery overpressure vents are not inhibited by the battery holder design or spacecraft design.
Combined effects required for realized failure: The manufacturer fails to install proper venting or venting capability fails to operate properly. Failure must also result in the creation of debris with enough energy to penetrate multiple spacecraft enclosures and structural items. This is highly unlikely due to rationale provided in Failure mode 1. In addition all EDSN spacecraft undergo qualification or acceptance environmental tests (vibration and thermal vacuum cycling tests).
Failure Mode 5: Battery Crush.
Mitigation 6: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries. In addition, the design of this series of battery undergoes a crush test per UL-1642 with no explosion or fire.
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 spacecraft must be in a naturally sustained orbit at the time the crushing occurs. Failure must also result in the creation of debris with enough energy to penetrate multiple spacecraft enclosures and structural items. This is highly unlikely due to rationale provided in Failure mode 1.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.
Mitigation 7: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators. In addition, the design of this series of battery undergoes a short circuit test per UL-1642 with no explosion or fire.
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 must also result in the creation of debris with enough energy to penetrate multiple spacecraft enclosures and structural items. This is highly unlikely due to rationale provided in Failure mode 1.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 8: 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 that are well below temperatures of concern for explosions. In addition, the design of this series of battery undergoes an over-discharge and heating test per UL-1642 with no explosion or fire.
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. Failure must also result in the creation of debris with enough energy to penetrate multiple spacecraft enclosures and structural items. This is highly unlikely due to rationale provided in Failure mode 1.

Reaction wheel breakup/explosion:

There is no credible scenario that would result in the reaction wheels to breakup during normal deployment and operations. Each of the three reaction wheels are COTS with a moment of inertia of 81e-06 kg.m^2 and a maximum spin rate of 7000 RPM. The subsequent maximum stored energy in the Reaction Control System is 21.8 Joules; which is substantially less than the breakup/explosion energy required for a reaction wheel assembly breakup leading to material ejection. In addition, the Reaction Control System is enclosed within the spacecraft shell and the solar panels.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon:

The EDSN End of Mission Plan (EOMP) is contained herein.

At end of mission EDSN will disable the RF transmission systems of the spacecraft by either one of two means: 1) sending a “transmitter disable command” to the satellite from the ground or 2) discontinuing further contact with the satellite which will result in the onboard disable command reaching zero and disabling the satellite. The satellite then inhibits the transmitters of the RF systems.

In the event the mission operations team loses communications with an individual spacecraft for a continuous period of 18 days the onboard satellite timer will timeout and inhibit the transmitters of the RF systems. The timer is reset whenever the system detects a contact ("lock") with the ground station. Only the satellite that is captain will turn on the receiver and attempt a "lock" with the groundstation. The captain changes with each cycle of 25 hours. Therefore, under worst-case conditions (continuous loss of comm at EOM), an individual spacecraft RF transmitters will be passivated no later than 78 days after deployment (assuming planned EOM is 60 days).

Neither the batteries nor the reaction wheel system are passivated at EOM based on the very low probability that they could cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (per rationale provided in write-up for Failure Mode 1). This approach is consistent with the approach approved for previous Cubesats using these batteries and reaction wheels (as documented in ODAR for Cubesats on ORS3/ELaNa-4 Mission).

EDSN utilizes atmospheric re-entry for disposal as described in requirement 4.6-1.

Compliance statement:

EDSN is compliant. Maximum available stored energy at EOM is not sufficient to cause an explosion or deflagration large enough to release orbital debris or breakup the spacecraft.

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.

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 v2.0.2, 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: 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 sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).
Small Object Impact and Debris Generation Probability: Compliant.

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

Spacecraft disposal plan: The spacecraft will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

Disposal at end of mission will be evaluated as part of "In-Flight, Pre-Decommissioning, and Pre-Disposal EOMP Evaluation" as defined in 8719.14A, Appendix B.2, Figure B.2-2.

Systems required for accomplishing post-mission passivation: Passivation via ground command requires S-band radio and spacecraft processor along with adequate power to operate these systems. Passivation by onboard timer requires powered processor only.

Spacecraft maneuvers required to accomplish post-mission disposal: None.

Calculation of area-to-mass ratio after post-mission disposal/passivation:

Spacecraft Mass: ~1.697 kg

Cross-sectional Area: 0.02457 m^2 (Calculated using mean CSA per 8719.14).

Mean CSA = (Amax + A1 + A2)/2

Area to mass ratio: 0.02457/1.697 = 0.01448 m^2/kg

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0.2 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 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 within 10 years after completion of mission.
Analysis: The EDSN spacecraft reentry is COMPLIANT using method "a.". The EDSN spacecraft will be left in a 430 km, 505 km elliptical orbit, reentering 496 days after launch with orbit history as shown in Figure 6-1 (analysis assumes an approximate random tumbling behavior).

Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable. The spacecraft orbits are in LEO.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

Analysis: Not applicable. The spacecraft orbits are in LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: Not applicable. The spacecraft will reenter passively without post mission disposal operations within allowable timeframe.

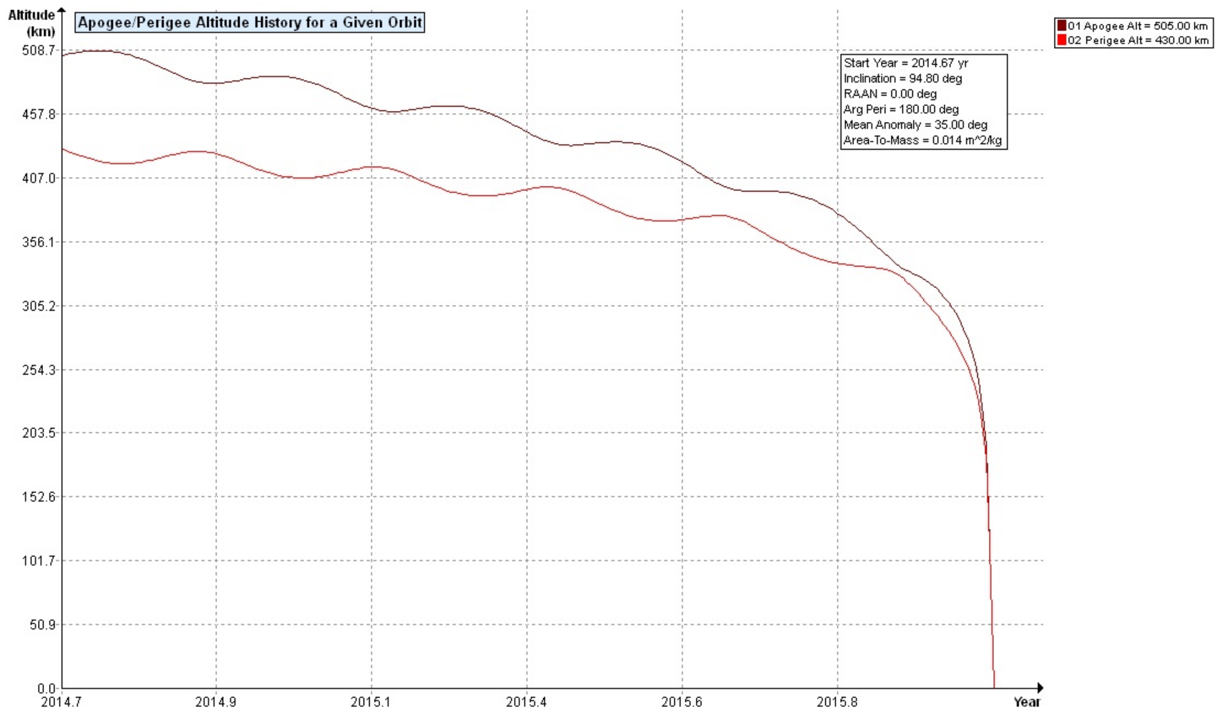

Figure 6-1. EDSN Orbit History (Identical for all eight Spacecraft).

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 v2.0.2 reports that the EDSN spacecraft are compliant with the requirement (human casualty <0.0001).

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

Requirement 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).
Requirement 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).

ODAR Section 8: Assessment for Tether Missions

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

ODAR Sections 9-14: Launch Vehicle

Since the EDSN launch vehicle is managed through the Department of Defense, the orbital debris assessment for the launch vehicle will be performed by the Operationally Responsive Space Office. The following note from NPR 8715.6A, Paragraph P.2.2, is applied, *"Note: It is recognized that NASA has no involvement or control in the design or operation of Federal Aviation Administration (FAA)-licensed launches or foreign or Department of Defense (DoD)-furnished launch services, and, therefore, these are not subject to the requirements in this NPR for the launch portion."*

Appendix A: Acronyms

ARC	Ames Research Center
Arg peri	Argument of Perigee
CDR	Critical Design Review
cm	centimeter
COTS	Commercial Off-The-Shelf (items)
DAS	Debris Assessment Software
EOM	End Of Mission
FRR	Flight Readiness Review
GEO	Geosynchronous Earth Orbit
ITAR	International Traffic In Arms Regulations
kg	kilogram
km	kilometer
LEO	Low Earth Orbit
Li-Ion	Lithium Ion
m^2	Meters squared
ml	milliliter
mm	millimeter
N/A	Not Applicable.
NLAS	Nanospacecraft Launch Adapter System
ODAR	Orbital Debris Assessment Report
ORS	Operationally Responsive Space program office –Kirtland AFB
OSMA	Office of Safety and Mission Assurance
PDR	Preliminary Design Review
PL	Payload
ISIPOD	ISIS CubeSat Deployer
PSIa	Pounds Per Square Inch, absolute
RAAN	Right Ascension of the Ascending Node
SMA	Safety and Mission Assurance
Ti	Titanium
USAF	United States Air Force
yr	year