AeroCube-8

Orbital Debris Assessment Report (ODAR)

Report Version: 1.0, 19 May 2014

Prepared for NASA in compliance with NPR 8715.6A by The Aerospace Corporation.

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Software used in this analysis: NASA DAS v2.0.2

Revision	Date	Pages	Description	Author
1.0	19 May 2014	14 + appendices	First version, requires signatures	K. Gates, Astrodynamics Dept.
2.0	1 Nov 2014	15 + appendices	Edited for public release	D. Hinkley PICOSAT Program

VERSION APPROVAL and FINAL APPROVAL*:

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* Approval signatures indicate acceptance of the ODAR-defined risk.

** Signatures required only for Final ODAR

Self-Assessment of Requirements per NASA-STD 8719.14A

Requirement		Compliance Assessment	Comments
4.3-1a	All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release.	Compliant	AeroCube-8 will release no debris.
4.3-1b	The total object-time product shall be no larger than 100 object-years per mission.	Compliant	AeroCube-8 will release no debris.
4.3-2	For missions leaving debris in orbits with the potential of traversing GEO, released debris with diameters of 5 cm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO-200 km.	Compliant	AeroCube-8 will not operate in or near GEO.
4.4-1	For each spacecraft employed for a mission, the program or project shall demonstrate…that the integrated probability of explosion for all credible failure modes of each spacecraft is less than 0.001.	Compliant	
4.4-2	Design of all spacecraft shall include the ability and a plan 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 cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.	Compliant	
4.4-3	Planned explosions or intentional collisions shall: a) be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years, and b) not generate debris larger than 1 mm that remains in Earth orbit longer than one year.	Compliant	AeroCube-8 has no planned explosions or intentional collisions.
4.4-4	Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10-6.	Compliant	AeroCube-8 has no planned explosions or intentional collisions.
4.5-1	For each spacecraft in or passing through LEO, the program shall demonstrate that, during the orbital lifetime of each spacecraft, the probability of accidental collision with space objects larger than 10 cm in diameter is less an 0.001.	Compliant	
4.5-2	For each spacecraft, the program 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.	Compliant	AeroCube-8 will use natural orbit decay.
4.6-1	A spacecraft with a perigee altitude below 2000 km shall be disposed of by one of the following three methods: a) leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years, b) maneuver the space structure into a controlled de-orbit trajectory, c) maneuver the space structure into an orbit with perigee altitude above 2000 km and apogee less than GEO-500 km.	Compliant	AeroCube-8 will use natural orbit decay.
4.6-2	A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO.	Compliant	AeroCube-8 will not operate in or near GEO.
4.6-3	For space structures between LEO and GEO, a spacecraft shall be left in an orbit with a perigee greater than 2000 km above the Earth's surface and apogee less than 500 km below GEO, and a spacecraft shall not use nearly circular disposal orbits near regions of high-value operational space structures.	Compliant	AeroCube-8 will not operate in or near MEO.
4.6-4	NASA space programs shall ensure that all post-mission disposal operations to meet the above requirements are designed for a probability of success of no less than 0.90 at EOM.	Compliant	
4.7-1	For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001.	Compliant	
4.8-1	Intact and remnants of severed tether systems in Earth orbit shall meet the requirements limiting the generation of orbital debris from on-orbit collisions and the requirements governing post-mission disposal.	Compliant	AeroCube-8 has no tether system.

NOTE: When manifested for flight, AeroCube-8 will fly as a secondary payload. Compliance with requirements levied by NASA-STD 8719.14A on the launch vehicle will be the responsibility of the primary payload and/or launch provider.

Section 1: Program Management and Mission Overview

Mission Directorate: The Aerospace Corporation, Picosatellite Group

Program Executive: James Nokes

Principal Investigator: Timothy Graves, The Aerospace Corporation

Program Manager: Andrea Hsu, The Aerospace Corporation

Foreign government or space agency participation: none

Nominal Schedule of Mission Design and Development:

Event	Date
Project initiation	13 Jun 2013
System Requirements Review (SRR)	8 Aug 2013
Preliminary Design Review (PDR)	7 Nov 2013
Critical Design Review (CDR)	19 Mar 2014
Flight Readiness Review (FRR)	21 Nov 2014
Delivery	1 Dec 2014
Target launch date	1 May 2015

Brief Description of the Mission:

The AeroCube-8 (AC8) mission shall demonstrate R&D products in space. AeroCube-8's mission is a multifaceted technology demonstration for a Scalable ion Electrospray Propulsion (SiEPro) system and novel Carbon Nanotube Technology (CNT). Two identical 1.5U CubeSats will be utilized towards this goal. AeroCube-8 will carry several payloads. The primary payload for the satellite is SiEPro. The secondary payloads are CNT harnesses, a CNT-filled PolyEther Ether Ketone (PEEK) material, a CNT radiation shielding material, and advanced solar cells.

AeroCube-8 is the first known (scalable) electric propulsion demonstration for CubeSat technology. It is also the first known demonstration of multi-cube satellite propulsion maneuvering, providing innovative insight into iEPS satellite operations and control and the development of satellite control and guidance during microthrust maneuvers.

The CNT material carried onboard will be used to test this technology's efficacy at radiation shielding of electronics in the space environment. Harnesses shielded by CNT-filled PEEK will be exposed to space and their performance degradation compared to control harnesses housed within the satellite bus. Other dosimeters onboard will compare radiation measurements with and without CNT-based shielding.

Figure 1. The AeroCube-8 spacecraft with radiation shield, assorted sensors, solar cells, and antenna.

Identification of the anticipated launch vehicle and launch site: AeroCube-8 has been manifested on ULTRASat, which will fly as a secondary payload on AFSPC-5, an Atlas V launch scheduled for May 2015. The launch vehicle will deploy AeroCube-8 to a roughly 350 x 700 km altitude orbit inclined at 57 degrees.

Identification of the proposed launch date and mission duration: The AeroCube-8 mission anticipates a launch as a secondary payload in May 2015. The main mission phase is approximately 3 months. The stretch mission will extend the operational lifetime to > 1 year.

Description of the launch and deployment profile: As a secondary payload, the AeroCube-8 spacecraft will be deployed from the launch vehicle to minimize risk to the primary payload and upper-stage space structures. Depending on the launch provider, deployment may occur before or after deployment of the primary payload. Typically, after deploying the primary payload, the upper stage performs a small burn to alter the orbit (eliminating the risk of collision with the primary) before releasing any secondary payloads.

Reason for selection of operational orbit: As a secondary payload, AeroCube-8 has minimal control over the selection of operational orbit. AeroCube-8 can perform its mission in any LEO orbit, although the altitude must be low enough to ensure natural decay and reentry within the timeframe specified by NPR8751.6A. The altitude to which the ULTRASat CubeSats will be delivered (including AeroCube-8) satisfies that requirement.

Identification of any interaction or potential physical interference with other operational spacecraft: As one of several CubeSats deployed by ULTRASat, there is a small risk of recontact whether between the two AeroCube-8 vehicles or between AeroCube-8 and another CubeSat. The timing of satellite deployments from ULTRASat is intended to mitigate as much of this as possible. Debris mitigation for the deployment process is the responsibility of ULTRASat. In the event of recontact shortly after deployment, the relative velocities between CubeSats is on the order of centimeters per second, which would not provide enough force to cause catastrophic breakup of the satellites or generate significant amounts of debris (the glass coverings of solar cells may crack). The launch vehicle trajectory and mission plan is designed to ensure there is no risk to the primary payload. There is no anticipated risk to any other operational spacecraft.

Section 2: Spacecraft Description

Physical Description: The AeroCube-8 mission consists of a pair of one-and-a-half unit (1.5U) CubeSats with dimensions 10.25 x 10.25 x 17 cm. Each satellite contains multiple Sun sensors and Earth sensors, RF communications antennae, GPS receiver, a medium-field camera, and narrow-field camera. No components of the spacecraft extend beyond the dimensions of the 1.5U bus.

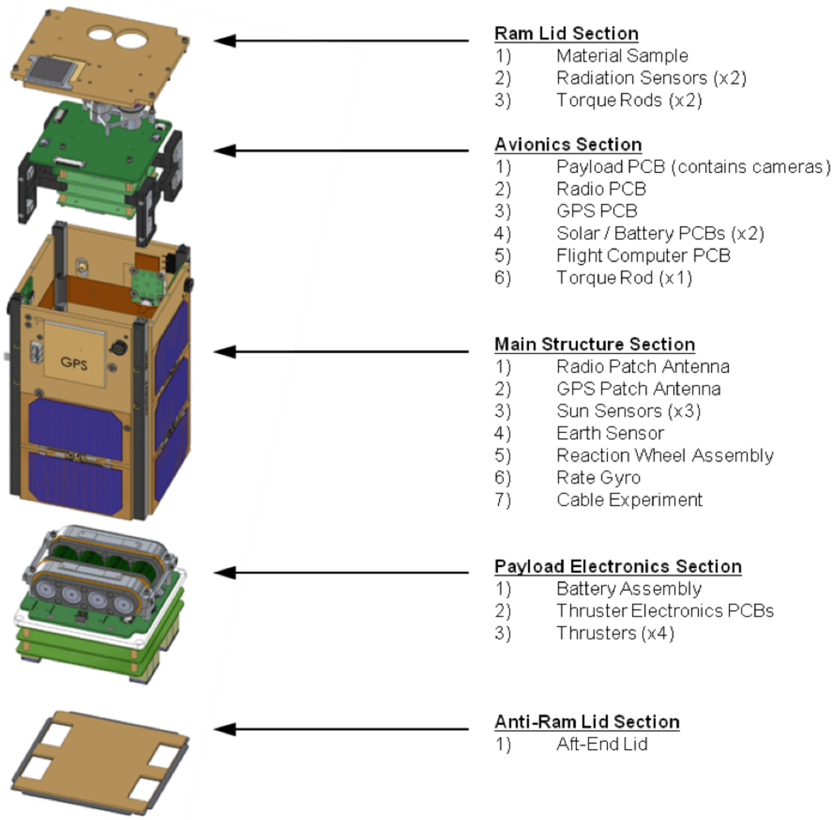

Figure 2. Exploded isometric view of AeroCube-8.

Total spacecraft mass at launch: <2.2 kg

Dry mass of spacecraft at launch: <2.2 kg

Description of all propulsion systems: AeroCube-8 carries an electric propulsion system, SiEPRO. The working principle behind ion electrosprays is based on the electrostatic extraction and acceleration of positive and negative ions from an ionic liquid—a zero-vapor pressure conductive salt that remains in the liquid phase at room temperature. In order to extract these ions, electric fields on the order of 1 V/nm are required. Such intense fields are routinely achieved at the tip of electrically stressed liquid menisci or Taylor Cones, which have sizes from a fraction to several micrometers and are produced at the end of sharp emitter structures, such as sharpened capillaries or needles biased with respect to a downstream extractor aperture.

The thruster system comprises four thruster pairs, or 8 thruster heads, each of which comprises a small PEEK (Polyether ether ketone) reservoir, which is filled completely in a vacuum with an ionic liquid. The reservoir contains a porous substrate with pores that are ~1 micron in size with a field of micromachined emitter tips. In operation, an electric field is created between this substrate and an extractor grid above to accelerate ions away from the spacecraft, producing thrust.

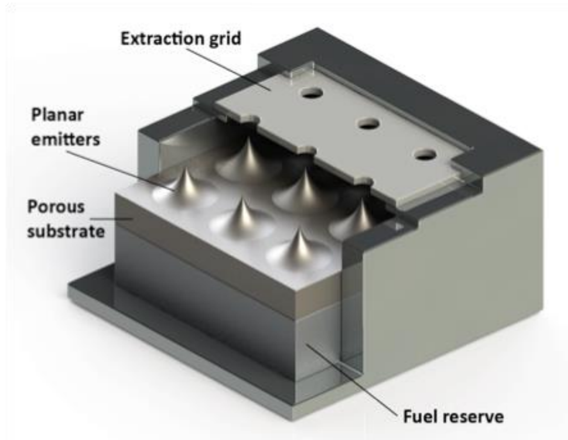

Figure 3. Scalable ion Electrospray Propulsion (SiEPRO) system.

The thruster operates using a dense array of emitters, firing in parallel. This is achieved by merging the working principles behind ion electrospray thrusters with recent developments in Micro Electro Mechanical Systems (MEMS) materials and processes. Emitters are fabricated on porous materials, so that propellant can flow via capillarity through the bulk of the material and driven by the ion evaporation process. **Therefore, no pressurization is required for pumping (or storing) the propellant.** These characteristics allow ion electrospray thrusters to achieve high specific impulse (Isp > 2000 s) at high efficiency in a compact package only a few mm thick. Performance for the thruster is estimated at greater than 50 m/s, assuming an Isp > 2000s, propulsion system mass of 90g, and using 0.2g propellant. Another characteristic of ion electrospray thrusters is that both positive and negative species can be emitted. In consequence, there is no need for an electron-neutralizing cathode. In its current configuration, the thruster consists of two separate head modules or two groups of modules emitting oppositely charged ions of comparable mass and producing similar thrust.

This system meets CubeSat specifications for on-board propulsion systems, namely it is non-toxic, non-flammable, and operates with no pressurization.

Identification of all fluids planned to be on board: The AeroCube-8 electric SiEPRO propulsion system uses ionic liquid, a zero-vapor pressure conductive salt that remains in the liquid phase at room temperature. The liquid is stored on board with no pressurization (not sealed). The total mass of propellant carried by AeroCube-8 is 12 grams.

Description of all active and/or passive attitude control systems with an indication of the normal attitude of the spacecraft with respect to the velocity vector: Each AeroCube-8 spacecraft has 3-axis attitude control via three torque rods and three “pico” reaction wheels. The torque rods are a mutually orthogonal triad of coiled wire, wrapped around a high magnetic permeability alloy that can generate a magnetic dipole of 0.15 to 0.2 Amp-m^2 when the satellite passes current through the wire but generate negligible magnetic field when powered off. The torque rods are made from 14 inch-diameter mu-metal rods that are 2.16 inches long. The pico reaction wheels have flight heritage on three AeroCube-4 and two AeroCube-5 spacecraft. Attitude sensors include eight infrared thermometer arrays on various spacecraft surfaces, two-axis sun sensors on various spacecraft surfaces, and a 3-axis magnetometer in the main body. A high-accuracy 3-axis rate gyro will be used to provide an inertial attitude reference when 0.7 deg or better pointing accuracy is required and the sun and Earth are not simultaneously visible by an appropriate sensor, and a medium-resolution 3-axis rate gyro and 3-axis magnetometer will serve as a backup.

Description of any range safety or other pyrotechnic devices: AeroCube-8 has no pyrotechnic devices.

Description of the electrical generation and storage system: Power for AeroCube-8 is generated by solar cells mounted on the spacecraft bus. These cells are capable of producing up to 10 W of power (predicted 4 W max and 2 W of orbit-averaged power due to vehicle attitude and shading). Power is stored on-board with lithium-ion batteries. The satellite has 4 batteries mounted in an aluminum 6061-T6 structure as a unit and they are shock and thermally isolated by a low-outgassing rubber grommet. Each battery is composed of a single cell storing 9.25 W-hr, for a total of 37 W-hr on the spacecraft. Specific details of the batteries' manufacture appear in Section 4. AeroCube-8 has a single transmitter at 915 MHz, which is half-duplex with the up and down frequency being the same. This reduces the average power at the cost of downlink speed. The radio output power at the radio is less than 2 W.

Identification of any other sources of stored energy: There are no other sources of stored energy on AeroCube-8.

Identification of any radioactive materials on board: AeroCube-8 carries no radioactive materials.

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: AeroCube-8 will release no objects into space during normal operations.

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, inclination) of each object after release: N/A

Calculated orbital lifetime of each object, including time spent in LEO: N/A

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2:

Requirement 4.3-1a: COMPLIANT

Requirement 4.3-1b: COMPLIANT

Requirement 4.3-2: COMPLIANT

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

Identification of all 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:

Battery risk: A possible malfunction of the lithium ion batteries or of the control circuit has been identified as a potential, but low probability, cause of accidental breakup or explosion. Natural degradation of the solar cells and batteries will occur over the post-mission period and poses an increased chance of undesired battery-energy release. The battery capacity for storage will degrade over time, possibly leading to changes in the acceptable charge rate for the cells. Individual cells may also change properties at different rates due to time degradation and temperature changes. The control circuit may also malfunction as a result of exposure over long periods of time. The cell pressure relief vents could be blocked by small contaminants. Any of these individual or combined effects may theoretically cause an electro-chemical reaction that results in rapid energy release in the form of combustion.

Notwithstanding these potential sources of energy release, AeroCube-8 still meets Requirement 4.4-2 as the on-board batteries cannot "cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft." The batteries used on AeroCube-8 are certified by Underwriters Laboratories (UL). In general, these batteries are similar in size and power to cell-phone batteries.

CubeSat Name	Model Number (UL Listing)	Manufacturer	Number of Cells	Energy Stored
AeroCube-8	ICR18650H (BBCV2.MH27672)	Molicel	1	9.25 W-hr per cell (4 batteries total)

The batteries are consumer-oriented devices. The batteries have been recognized as UL tested and approved. UL recognition has been determined through the UL Online Certifications

Directory, which clearly shows that these cell batteries have undergone and passed UL Standards. Furthermore, safety devices incorporated in these batteries include pressure release valves, over-current charge protection, and over-current discharge protection.

The fact that the AeroCube-8 batteries are UL recognized indicates that they have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 subjects the test battery to heat by flame while within an aluminum- and steel-wire-mesh octagonal box, "[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out" (UL 1642 20.5). To pass the test, "no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen" (UL 1642 20.1).

It is reasonable to expect the batteries on AeroCube-8 to experience similar conditions during their orbital life span. While the sources of failure would not be external heat on orbit, analysis of the expected mission thermal environment shows that given the low power dissipation for CubeSats, the batteries will be exposed to a maximum temperature well below their 212 deg F safe operation limit. Continual charging with 2 to 6 W average power from the solar panels over an orbital life span greater than 12 years may expose the batteries to overcharging, which could cause similar heat to be generated internally. Through the UL recognition and testing, it has been shown that these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

In addition to the aforementioned certification of the AeroCube-8 batteries against explosion, ten potential failure modes for lithium batteries and their applicability or mitigation in AeroCube-8 are addressed in the following table:

	Failure Mode	**Applicability or Mitigation**
1	Internal short circuit	The AeroCube-8 body and internal design prevents deformation or crushing of the batteries that could lead to internal short circuit.
2	Internal thermal rise due to high load discharge rate	See Failure Mode #4.
3	Overcharging and excessive charge rate	The battery cells on AeroCube-8 have charge interrupt devices that activate during cell internal pressure buildup (due to cell internal chemical that forms a gas) that occurs during overcharging conditions.
4	Excessive discharge rate or short circuit due to external device failure	The bus batteries have an internal positive temperature coefficient (PTC) device that acts as a resettable fuse during external short circuit that limits the cell output current during such an event.
5	Inoperable vents	Vents have access through the structure that holds them and into the larger satellite volume. Venting will not be inhibited by physical obstructions.
6	Crushing	Satellite body and internal design prevent loads on battery cases.

7	Low level current leakage or short circuit through battery pack case or due to moisture-based degradation of insulators	Satellites are stored in a controlled environment.
8	Excess temperatures due to orbital environment and high discharge combined	Thermal sensors on the batteries provide telemetry on battery temperature. There is no cutoff for overheating batteries except whatever is inherent in the cell itself. However, as noted earlier in this section of the ODAR, the batteries on AeroCube-8 are UL-certified as non-explosive in over-heating scenarios.
9	Polarity reversal due to over-discharge	A 2.7 V discharge cutoff threshold circuit in AeroCube-8 has been verified in acceptance tests for the electric power system.
10	Excess battery temperatures due to post-mission orbital environment and constant overcharging	The circuit that charges the batteries cannot exceed 4.1 V and therefore will never overcharge the batteries.

Through a combination of UL certification, compliance with AFSPCMAN 91-710 V3 requirements, and an understanding of the general behavior of the failure modes associated with these types of batteries, it is possible to conclude that the batteries meet Requirement 4.4-2.

Propulsion-system risk: The propulsion system is free-venting, including the propellant reservoir, which is assumed to be completely filled with propellant and capped with a porous substrate. Therefore, it will not become a pressure vessel upon launch as it contains no gas and the vapor pressure of the ionic liquid propellant is immeasurably small. The electric ion propulsion system aboard AeroCube-8 contains no pressurized liquids, and therefore poses no explosion risk.

Detailed plan for any designed breakup, including explosions and intentional collisions: AeroCube-8 has no plans for intentional breakups, explosions, or collisions.

List of components, which are passivated at EOM: Before EOM, AeroCube-8 will deplete any remaining propellants from its electric ion propulsion system. However, as described above, failure to deplete propellant does not risk explosion or debris-producing events. No other systems on AeroCube-8 will be passivated at EOM.

Rationale for all items which are required to be passivated, but cannot due to their design: As described above, the batteries do not present a debris-generation hazard per Requirement 4.4-2, and in the interest of not increasing the complexity of the AeroCube-8 power system, it was decided not to passivate the batteries at EOM.

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

Requirement 4.4-1: COMPLIANT

Requirement 4.4-2: COMPLIANT

Requirement 4.4-3: COMPLIANT

Requirement 4.4-4: COMPLIANT

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

Collision probabilities have been calculated using DAS v2.0.2 with the assumptions: 389 km x 700 km orbit, 57 deg inclination, 2 kg mass (initial and final), and 0.01233 m^2/kg area-to-mass ratio (the maximum-area configuration).

In addition to the DAS analysis, The Aerospace Corporation has performed additional analysis looking at the collision probability of AeroCube-8 with 0^{th}-, 1^{st}-, and 2^{nd}-generation debris objects with 95^{th}-, 50^{th}-, and 5^{th}-percentile solar cycle assumptions. The probability of collision for all cases considered is below the 0.001 requirement. A summary of the Aerospace analysis is appended to this ODAR.

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft: Probability = 0.00000, per DAS v2.0.2

Calculation of spacecraft probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent post-mission disposal: Because the mission has selected natural de-orbit (see Section 6) for disposal and no systems will be passivated at EOM (see Section 4), small debris do not pose a threat to prevent post-mission disposal.

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2:

Requirement 4.5-1: COMPLIANT

Requirement 4.5-2: COMPLIANT

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

Description of spacecraft disposal option selected: The AeroCube-8 mission has selected atmospheric reentry for disposal. The vehicle is a 10.25 x 10.25 x 17 cm bus. Each vehicle's mass is approximately 2 kg. The longest possible orbital lifetime occurs if the vehicle were permanently aligned with the smallest face pointing in the direction of motion, with a cross-sectional area of 105 cm^2. Although in practice after EOM the vehicle will tumble with a higher "average" cross-sectional area, the analysis in DAS assumed the worst-case low-drag configuration for lifetime. DAS evaluates a lifetime of 8.16 yr, using the orbit assumptions listed at the beginning of Section 5 (except for using a lower area-to-mass ratio of .00525 m^2/kg). This lifetime is compliant with ODAR requirements.

In addition to the DAS analysis, The Aerospace Corporation has performed additional analysis looking at the orbital lifetime of AeroCube-8 assuming the ULTRASat (March 2015) launch and an alternate GRACE (December 2015) launch. For both cases (with 95th- and 50th-percentile solar cycle assumptions), the lifetime is below the 25-year requirement. A summary of the Aerospace analysis is appended to this ODAR.

Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering: As discussed in Section 4, no disposal or passivation is planned for AeroCube-8. Natural orbit decay is sufficient to terminate the mission.

Plan for any spacecraft maneuvers required to accomplish post-mission disposal: None

Calculation of area-to-mass ratio after post-mission disposal, if the controlled reentry option is not selected: N/A

Preliminary plan for spacecraft controlled reentry: N/A

Assessment of compliance with Requirements 4.6-1 through 4.6-4:

Requirement 4.6-1: COMPLIANT

Requirement 4.6-2: COMPLIANT

Requirement 4.6-3: COMPLIANT

Requirement 4.6-4: COMPLIANT

Section 7: Assessment of Spacecraft Reentry Hazards

Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle, if the atmospheric reentry option is selected: The AeroCube-8 vehicles are primarily constructed of aluminum and PCB electronic board material. The only components with a higher density or resistance to melting are stainless steel screws, ceramic path antennas, three nickel-iron alloy torque rods, and three small stainless steel reaction wheels. The spacecraft components used in the DAS 2.0.2 analysis are shown in Table 1. The DAS analysis shows these materials pose no risk per the ODAR requirement.

Table 1. Spacecraft Components used for DAS 2.0.2 Analysis

Description	Shape	No. Used (Per Satellite)	Material	Dia or Width (m)	Length (m)	Height (m)	Mass ea. (kg)
Reaction Wheel Block	Box	1	6061-T6	0.028	0.029	0.028	0.015
Antenna-1	Box	1	Ceramic	0.044	0.046	0.003	0.012
Antenna-2	Box	1	Ceramic	0.025	0.050	0.003	0.012
Batteries	Cylinder	4	SS	0.018	0.065	-	0.045
Torque Rods	Cylinder	3	Mu-Metal	0.004	0.055	-	0.005
Circuit Boards	Box	1	FR4	0.056	0.056	0.002	0.030
Lids	Box	2	6061-T6	0.096	0.105	0.004	0.086
Payload Interface Plate	Box	1	6061-T6	0.097	0.097	0.006	0.120
VectorNav IMU	Box	1	6061-T6 and other materials	0.042	0.048	0.025	0.053
Bus Electronics Assembly	Box	1	FR4	0.078	0.089	0.055	0.310
Payload Assembly	Box	1	FR4/6061-T6	0.097	0.097	0.052	0.350
Body Structure	Box	1	6061-T6	0.105	0.165	0.105	0.595

Summary of objects expected to survive an uncontrolled reentry: No objects are expected to survive uncontrolled reentry.

Calculation of probability of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination: Zero

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1: COMPLIANT

Section 8: Assessment for Tether Missions

The AeroCube-8 mission has no tether. All requirements are COMPLIANT.

Sections 9–14: Assessment of Launch Vehicle Debris

AeroCube-8 will fly as a secondary payload. Assessment of launch-vehicle debris is the responsibility of the primary payload. These sections are N/A for AeroCube-8.