AeroCube-7 + AeroCube-5c

Orbital Debris Assessment Report (ODAR)

Report Version: 1.3, 14 March 2013

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

Software used in this analysis: NASA DAS v2.0.2

Revision	Date	Pages	Description	Author
1.0	10 Sep 2013	14 + appendices	First version, requires signatures	J. Gangestad, Astrodynamics Dept.
1.1	12 Sep 2013	14 + appendices	Signatures added, minor corrections	J. Gangestad, Astrodynamics Dept.
1.2	14 Feb 2014	15 + appendices	Update for CDR	J. Gangestad, Astrodynamics Dept.
1.3	14 Mar 2014	15 + appendices	Minor corrections from CDR	J. Gangestad, Astrodynamics Dept.
2.0	1 Nov 2014	17 + appendices	Updating for public release	D. Hinkley PICOSAT Program
3.0	2 Feb 2015	17 + appendices	Change to GRACE launch from UltraSat launch; Swap out one AeroCube-7 for an AeroCube-5c	D. Hinkley PICOSAT Program
4.0	15 Apr 2015	16 + appendices	Updated per change requests	D. Hinkley PICOSAT Program
5.0	9 Jun 2015	15 + appendices	Updated debris section	D. Hinkley PICOSAT Program

VERSION APPROVAL and FINAL APPROVAL*:

The Aerospace Corporation

____

Dr. Siegfried Janson
AeroCube-7
Principal Investigator
The Aerospace Corporation

____

Dr. Richard Welle
AeroCube-7
Program Manager
The Aerospace Corporation

____

Dr. James Nokes
Principal Director
Space Materials Laboratory
The Aerospace Corporation

* 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	6.5 years (DAS2.02)
4.3-1b	The total object-time product shall be no larger than 100 object-years per mission.	Compliant	65 object-years (DAS2.02)
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	N/A-LEO mission
4.4-1	For each spacecraft a 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	On board energy source (batteries) incapable of debris-producing failure
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	On board energy source (batteries) incapable of debris-producing failure
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	No planned breakups.
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	No planned breakups.
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	DAS2.02
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	DAS2.02
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	DAS2.02
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	N/A-LEO mission
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	N/A-LEO mission
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	Passive disposal
4.7-1	For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001.	Compliant	DAS2.02
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	No tethers

NOTE: When manifested for flight, AeroCube-7 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: Space Technology Mission Directorate

Program Executive: Andrew Petro

Principal Investigator: Siegfried Janson, The Aerospace Corporation

Program Manager: Richard Welle, The Aerospace Corporation

Foreign government or space agency participation: none

Nominal Schedule of Mission Design and Development:

Event	Date
Project initiation	1 Oct 2012
System Requirements Review (SRR)	4 Mar 2013
Preliminary Design Review (PDR)	19 Sep 2013
Critical Design Review (CDR)	13 Mar 2014
System integration begins	26 Mar 2014
Test Readiness Review (TRR)	1 Dec 2014
System integration complete	15 Feb 2015
Flight Readiness Review (FRR)	15 Mar 2015
Delivery	23 Mar 2015
Target launch date	1 Aug 2015

Brief Description of the Mission:

This mission will consist of one AeroCube-7 (2.2 kg) and one AeroCube-5c (2 kg) Nano class satellite, each about 4x4x6 inches in dimension to be simultaneously ejected from a single tube that will be lifted into a 500 km x 780 km with 64 degree inclination orbit on an Atlas V vehicle planned for August 2015. The two satellites will not collide and will separate naturally from each other due the slight difference in their balistic coefficients. The mission of AeroCube-7 will perform its mission of demonstrating laser communications from space to the Mt. Wilson optical ground station on earth and the AeroCube-5c will separately perform tracking experiments.

The AeroCube-7, also known as the Optical Communications and Sensor Demonstration (AeroCube-OCSD) mission will demonstrate the: high-speed optical transmission of data: 20-Mbytes over 60-seconds with a bit error rate (BER) of 10-4 or better to a 30-cm diameter telescope from low Earth orbit (LEO). AeroCube-5c will study tracking of the AC7. It is a repeat to a prior mission (call sign WG2XVZ). This flight demonstration will consist of one

AeroCube-7- and one AeroCube-5c that are ejected from a CubeSat deployer. The two vehicles will not be doing any proximity operations.

Identification of the anticipated launch vehicle and launch site: One AeroCube-7 and one AeroCube-5c will fly as a secondary payload on a rideshare mission. They are currently manifested in a P-POD on the NROL-55 Atlas V mission launching in Q3 CY2015. This launch will deliver them to an approximately 500 x 780 km altitude orbit at an inclination of 64 deg.

Identification of the proposed launch date and mission duration: We anticipate a launch as a secondary payload in Q3 CY2015. The mission duration is nominally 180 days.

Description of the launch and deployment profile: As a secondary payload, the AeroCubes 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: The orbit is selected for adequate mission lifetime and the inclination is requested above 35 deg to ensure that the spacecraft pass over The Aerospace Corporation's ground stations in the continental United States.

Identification of any interaction or potential physical interference with other operational spacecraft: The AeroCube-7 mission's optical-communication objectives require the in-space operation of a laser. All events planned with the AeroCube-7 laser system will be cleared with the United States Air Force Laser Clearinghouse before operation to ensure no undesirable illumination of other operational spacecraft. There is no planned relative proximity maneuvers between AeroCube-7 and AeroCube-5c.

Section 2: Spacecraft Description

Physical Description:

The AeroCube-7 satellite is a one-and-a-half unit (1.5U) CubeSat with dimensions 10 x 10 x 15 cm. The vehicle has two wings that are deployed on orbit with dimensions of 10 x 15 cm. The wing plane is parallel to the bus diagonal, as depicted in Figure 1.

The AeroCube-7 satellite contains multiple Sun sensors and Earth sensors, a star tracker, RF communications antenna, GPS receiver, optical-beacon detector, fisheye camera, and narrow-field camera. No components of the spacecraft except the wings extend beyond the dimensions of the 1.5U bus.

The AeroCube-5c satellite is a one-and-a-half unit (1.5U) CubeSat with dimensions 10 x 10 x 15 cm. The vehicle (Figure 2) contains one Flight Computer system, one GPS system, one

Advanced Radio system, one Attitude control system, one optical beacon, and one Solar Power system.

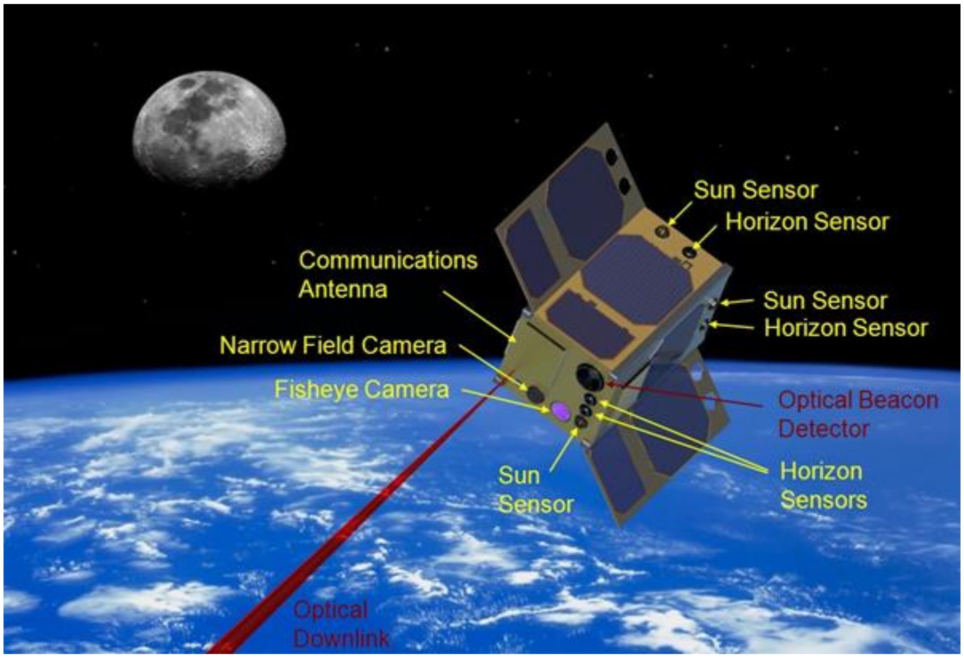

Figure 1. The AeroCube-7 spacecraft.

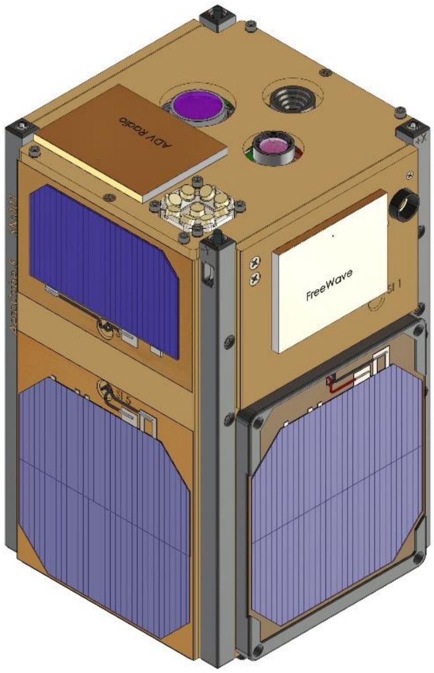

Figure 2: AeroCube-5 1.5U CubeSat

More detail about AeroCube-5c is as follows:

- The Flight computer system is the central processing system of the satellite to coordinate commands between the subsystems.
- The GPS system will have a patch antenna and control electronics. It only receives.
- The Advanced Radio system will have a patch antenna and control electronics. It operates at 915 MHz and produces 1.3W.
- The Attitude control system will have triaxial reaction wheels, triaxial torque coils, triaxial magnetometers, one rate gyro, and earth and sun sensors.
- The beacon will have one beacon module, one MoliCel IBR18650B Lithium Ion battery and control electronics. It is 808 nm wavelength, 6 W in optical power and divergent (6 degrees full-width-half-maximum). It acts like a flashlight.
- The Solar Power system will have two MoliCel ICR18650J Lithium Ion batteries and control electronics.
- ~~The CSTT is a 12 meter long x 75 mm wide ribbon stowed under a panel on the outside of the spacecraft.~~ This was taken off the AeroCube-5c spacecraft (but it had been on the prior versions – reference 0339-EX-PL-2013).

An exploded view of AeroCube-5c is shown in Figure 3.

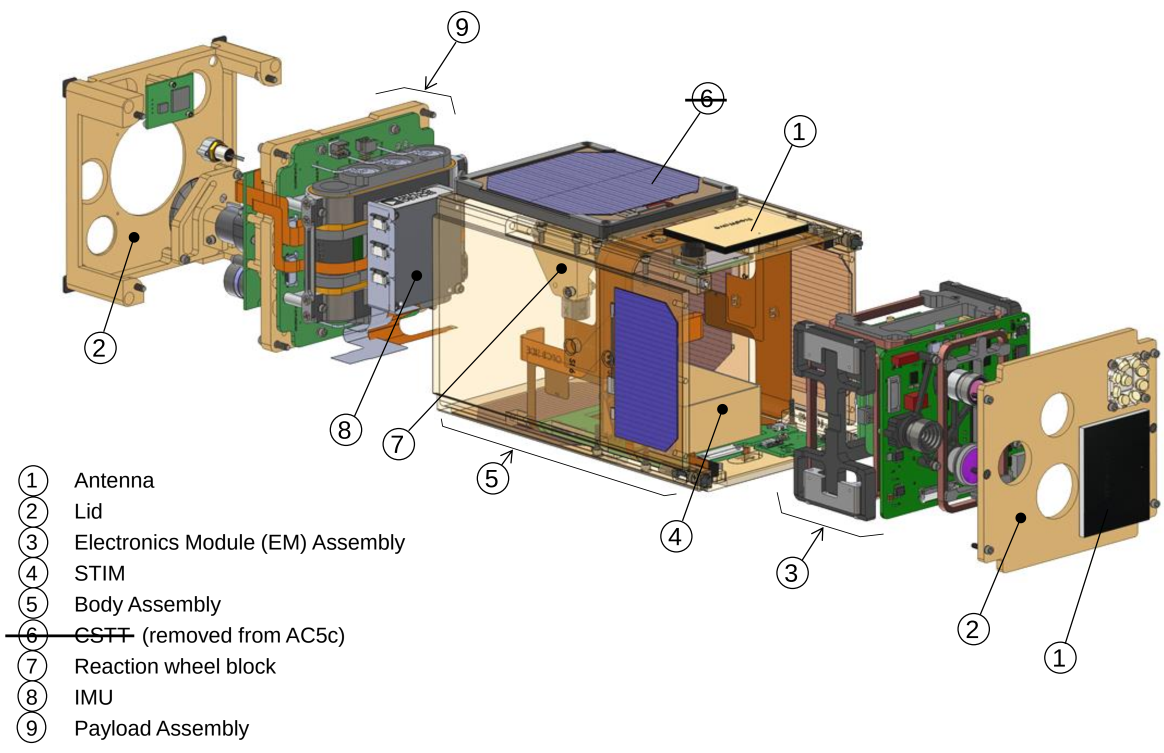

Figure 3: AeroCube-5c Expanded View

Total spacecraft mass (dry and wet) at launch: ~2.2 kg for AeroCube-7 and ~2.0 kg for AeroCube-5c.

Description of all propulsion systems: Neither AeroCube-7 or AeroCube-5c has a propulsion system for this mission.

Identification of all fluids planned to be on board: None.

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: Both the AeroCube-7 and AeroCube-5c spacecraft have 3-axis attitude control via three magnetic torquers and three "pico" reaction wheels. 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, a 3-axis magnetometer in the main body, a 3-axis magnetometer and two or more experimental star trackers (on AeroCube-7 only). 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.

Description of any range safety or other pyrotechnic devices: Neither AeroCube-7 or AeroCube-5c has pyrotechnic devices.

Description of the electrical generation and storage system: Power for AeroCube-7 is generated by solar cells mounted on four faces of the spacecraft bus and on the two extended wings. These cells are capable of producing up to 16 W of power. Power is stored on-board with lithium-ion batteries. The bus power has redundant power circuits that each control and limit the charging and discharging from a single 4.2V ICR18650H battery. Each circuit can produce up to 20W of power. The laser communications system battery consists of two 4.2V ICR18650B cells in series, each with 6 W-hr. A power circuit controls this as a single battery and limits charging and discharging.

Power for AeroCube-5c is generated by body mounted solar cells mounted on four faces of the spacecraft bus. These cells are capable of producing up to 10 W of power. Power is stored on-board with lithium-ion batteries. The bus power has redundant power circuits that each control and limit the charging and discharging from a single 4.2V ICR18650H battery. Each circuit can produce up to 10W of power. Specific details of the batteries' manufacture appear in Section 4.

Identification of any other sources of stored energy: None on AeroCube-7 or AeroCube-5c.

Identification of any radioactive materials on board: None on AeroCube-7 or AeroCube-5c.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material. Section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

AeroCube-7 will release no objects into space during normal operations.

Analyses from the NASA DAS2.02 program predicts a lifetime product of <99 object-years when calculating and adding together the lifetime of the AeroCube-7 and AeroCube-5c spacecraft. This is acceptable because it is less than the 100 year limit listed in NASA-STD-8719.14 Requirement 4.3-1b: “The total object-time product shall be no larger than 100 object-years per mission.”

Rationale/necessity for release of each object: For AeroCube-5c only, tracking is part of the science to be gathered.

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 or lithium polymer 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-7 and AeroCube-5c still meet 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 are certified by Underwriters Laboratories (UL). In general, these batteries are similar in size and power to cell-phone batteries.

Model Number (UL Listing)	Manufacturer	Number of Cells	Energy Stored per Cell
ICR18650H	Molicel	2	<8 W-hr
IBR18650BC	Molicel	2	<6 W-hr

The batteries are all 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 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 <u>Projectile Test</u> 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 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 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 batteries against explosion, ten potential failure modes for lithium batteries and their applicability or mitigation in AeroCube-7 are addressed in the following table:

	Failure Mode	**Applicability or Mitigation**
1	Internal short circuit	The AeroCube-7 or AeroCube-5c 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-7 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. The laser (i.e., payload) batteries are of mixed-spinel chemistry and do not have such an internal device due to their high-rate capability; they have been tested in the lab to verify no cell rupture, venting, fire, or explosion occurs during external short circuit conditions.
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-7 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-7 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: None

Detailed plan for any designed breakup, including explosions and intentional collisions: AeroCube-7 and AeroCube-5c have no plans for intentional breakups, explosions, or collisions.

List of components which are passivated at EOM: No systems on AeroCube-7 will be passivated at EOM. No systems on AeroCube-5c require passivation 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-7 or the AeroCube-5c power systems, 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 for a 500 x 780 km altitude, 64 deg inclination orbit containing one AeroCube-7 satellite and one AeroCube-5c satellite.

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: Both AeroCube-5c and AeroCube-7 do not have or need active mission disposal capability.

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: Passive.

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 calculates a lifetime of 18 yr for AeroCube-7 and 21 yr for AeroCube-5c, using the orbit assumptions listed at the beginning of Section 5. This lifetime is compliant with ODAR requirements.

Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering: 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-7 and AeroCube-5c 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, and three small stainless steel reaction wheels. The spacecraft components used in the DAS 2.0.2 analysis are listed below**Error! Reference source not found.**. The DAS analysis shows these materials pose no risk per the ODAR requirement.

Summary of objects expected to survive an uncontrolled reentry: The higher-risk materials mentioned above have flown or will fly on several AeroCube missions, including AeroCube-4, AeroCube-5, and AeroCube-6. A DAS 2.0.2 analysis shows these materials pose no risk per the ODAR requirement.

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-7 /5c mission has no tether. All requirements are COMPLIANT.

Sections 9–14: Assessment of Launch Vehicle Debris

AeroCube-7 /5c satellites 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-7 / 5c.

Table 1. Spacecraft Components used for DAS 2.0.2 Analysis

Row Num	Name	Parent	Qty	Material	Body Type	Thermal Mass	Diameter/Width	Length	Height
1	AC5C complete	0	1	Aluminum 6061-T6	Box	2	0.1	0.15	0.1
2	AC5C shell	0	1	Aluminum 6061-T6	Box	0.213	0.1	0.15	0.1
3	Battery bracket 5C inside shell	2	1	Aluminum 6061-T6	Box	0.012	0.026	0.09	0.013
4	Reaction wheel block 5C inside shell	2	1	Aluminum 6061-T6	Box	0.015	0.028	0.029	0.028
5	Antenna 5C inside shell	2	1	Alumina	Flat Plate	0.007	0.04	0.05	
6	Battery 5C inside shell	2	1	Stainless Steel 17-4 ph	Cylinder	0.017	0.016	0.033	
7	AVO 5C inside shell	2	1	Stainless Steel 17-4 ph	Cylinder	0.023	0.026	0.04	
8	Circuit Boards 5C inside	2	1	Fiberglass	Flat Plate	0.03	0.056	0.056	
9	ADIS 5C inside shell	2	1	Aluminum 6061-T6	Box	0.049	0.044	0.047	0.014
10	AC5C Lids inside shell	2	1	Aluminum 6061-T6	Flat Plate	0.086	0.096	0.105	
11	Payload interface plate 5C inside shell	2	1	Aluminum 6061-T6	Flat Plate	0.092	0.097	0.097	
12	STIM 5C inside shell	2	1	Aluminum 6061-T6	Box	0.11	0.048	0.053	0.026
13	Pea Placer 5C inside shell	2	1	Aluminum 6061-T6	Cylinder	0.117	0.037	0.043	
14	EM Assembly 5C inside shell	2	1	Fiberglass	Box	0.275	0.078	0.089	0.047
15	Payload Assembly 5C inside shell	2	1	Aluminum 6061-T6	Box	0.573	0.097	0.097	0.092
16	Body Structure 5C inside shell	2	1	Aluminum 6061-T6	Box	0.582	0.105	0.165	0.105
17	pea 5C inside shell	2	10	Brass- Cartridge	Cylinder	0.0012	0.008	0.013	
18	Battery bracket 5C	0	1	Aluminum 6061-T6	Box	0.012	0.026	0.09	0.013
19	Reaction wheel block 5C	0	1	Aluminum 6061-T6	Box	0.015	0.028	0.029	0.028
20	Antenna 5C	0	1	Alumina	Flat Plate	0.007	0.04	0.05	
21	Battery 5C	0	1	Stainless Steel 17-4 ph	Cylinder	0.017	0.016	0.033	
22	AVO 5C	0	1	Stainless Steel 17-4 ph	Cylinder	0.023	0.026	0.04	
23	Circuit Boards 5C	0	1	Fiberglass	Cylinder	0.03	0.056	0.056	
24	ADIS 5C	0	1	Aluminum 6061-T6	Box	0.049	0.044	0.047	0.014
25	AC5C Lids	0	1	Aluminum 6061-T6	Flat Plate	0.086	0.096	0.105	
26	Payload interface plate 5C	0	1	Aluminum 6061-T6	Flat Plate	0.092	0.097	0.097	
27	STIM 5C	0	1	Aluminum 6061-T6	Box	0.11	0.048	0.053	0.026
28	Pea Placer 5C	0	1	Aluminum 6061-T6	Cylinder	0.117	0.037	0.043	
29	EM Assembly 5C	0	1	Fiberglass	Box	0.275	0.078	0.089	0.047
30	Payload Assembly 5C	0	1	Aluminum 6061-T6	Box	0.573	0.097	0.097	0.092
31	Body Structure 5C	0	1	Aluminum 6061-T6	Box	0.582	0.105	0.165	0.105
32	AeroCube7 Complete	0	1	Aluminum 6061-T6	Box	2.2	0.1	0.15	0.1
33	AeroCube7 shell	0	1	Aluminum 6061-T6	Box	0.213	0.1	0.15	0.1
34	Wing Assembly AC7 inside shell	33	2	Aluminum 6061-T6	Box	0.055	0.079	0.15	0.025
35	Anti-Nadir Lid Assembly AC7 inside shell	33	1	Aluminum 6061-T6	Box	0.0583	0.103	0.108	0.002
36	Camera Lens (Xenoplan/Schneider) AC7 inside shell	33	1	Aluminum 7075-T6	Cylinder	0.0872	0.032	0.039	
37	Rate Gyro Assembly AC7 inside shell	33	1	Aluminum 6061-T6	Box	0.095	0.048	0.06	0.025
38	Nadir Lid Assembly AC7 inside shell	33	1	Aluminum 6061-T6	Flat Plate	0.187	0.102	0.108	
39	Laser Comm Plate AC7 inside shell	33	1	Aluminum 6061-T6	Box	0.2207	0.102	0.103	0.019
40	Laser Isolator AC7 inside shell	33	1	HyMu80	Cylinder	0.227	0.027	0.072	
41	Body Assembly AC7 inside shell	33	1	Aluminum 6061-T6	Box	0.45	0.113	0.16	0.106
42	Electronics module with batteries AC7 inside shell	33	1	Fiberglass	Box	0.514	0.08	0.08	0.07
43	Wing Assembly AC7	0	1	Aluminum 6061-T6	Box	0.055	0.079	0.15	0.025
44	Anti-Nadir Lid Assembly AC7	0	1	Aluminum 6061-T6	Box	0.0583	0.103	0.108	0.002
45	Camera Lens (Xenoplan/Schneider) AC7	0	1	Aluminum 7075-T6	Cylinder	0.0872	0.032	0.039	
46	Rate Gyro Assembly AC7	0	1	Aluminum 6061-T6	Box	0.095	0.048	0.06	0.025
47	Nadir Lid Assembly AC7	0	1	Aluminum 6061-T6	Flat Plate	0.187	0.102	0.108	
48	Laser Comm Plate AC7	0	1	Aluminum 6061-T6	Box	0.2207	0.102	0.103	0.019
49	Laser Isolator AC7	0	1	HyMu80	Cylinder	0.227	0.027	0.072	
50	Body Assembly AC7	0	1	Aluminum 6061-T6	Box	0.45	0.113	0.16	0.106
51	Electronics module with batteries AC7	0	1	Fiberglass	Box	0.514	0.08	0.08	0.07
52	pea 5C	0	10	Brass- Cartridge	Cylinder	0.0012	0.008	0.013	