AeroCube Micro Dosimeter Experiment

(AeroCube-6)

Orbital Debris Assessment Report (ODAR)

Report Version: 1.0, 31 March 2014

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

This document contains proprietary information of The Aerospace Corporation and is not suitable for public release.

Software used in this analysis: NASA DAS v2.0.2

Revision	Date	Pages	Description	Author
1.0	31 Mar 2014	12	First version, requires signatures	D. Hinkley AeroCube-6, SE

VERSION APPROVAL and FINAL APPROVAL*:

The Aerospace Corporation

Paul O'Brien
AeroCube-6 Principal Investigator
The Aerospace Corporation

Richard Welle
PICOSAT Group Manager
The Aerospace Corporation

Catherine Venturini
Mission Executive
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	AeroCube-6 will release no debris.
4.3-1b	The total object-time product shall be no larger than 100 object-years per mission.	Compliant	AeroCube-6 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-6 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	ODAR
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	ODAR
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-6 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-6 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	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	AeroCube-6 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-6 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-6 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	Natural decay
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	AeroCube-6 has no tether system.

NOTE: AeroCube-6 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
Program Executive: Catherine Venturini

Principal Investigator: Paul O'Brien, 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
Preliminary Design Review (PDR)	24 Jan 2013
Critical Design Review (CDR)	11 July 2013
Flight Readiness Review (FRR)	17 April 2014
Integration to LV	1 June 2014
Target launch date	15 June 2014

Brief Description of the Mission:

The Aerospace Corporation's AeroCube-6 picosatellite is a 0.5U CubeSat launched into a 650 km circular orbit at 98 degrees inclination. It is expected to weigh less than 700 grams per satellite. For this mission, two of them will fly together to make temporal and spatial in-situ measurements of the radiation environment.

The AeroCube-6 mission will feature new variations of micro dosimeter devices (Figure 1) that will enhance discrimination of particle types contributing to the space radiation total dose impinging on spacecraft. Someday, these sensors will become part of a special purpose instrument that will assist with host vehicle anomaly investigations.

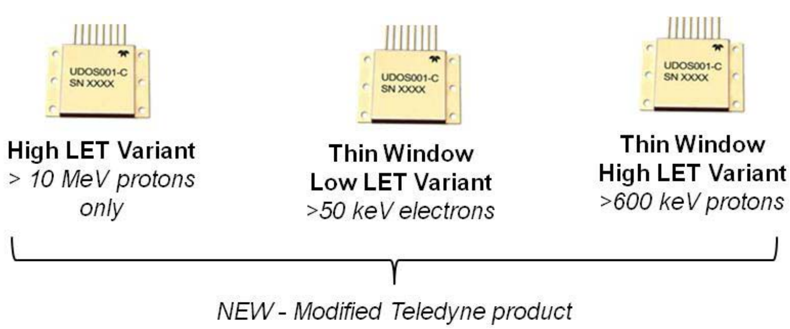

Figure 1. New Aerospace Micro Dosimeters - payloads on AeroCube-6 "AeroCube-6"

Each AeroCube-6 is identical. Each 0.5U CubeSat consist of three major subassemblies that assemble together as shown in Figure 2 (left). The First subassembly containst the electronics and batteries. The electronics consist of a payload circuit board, a power management board, an attitude control board and a flight computer-GPS-radio combo board. The batteries are Molicel ICR18650H. The other subassemblies are the body housing which is just a square tube and the bottom wing control assembly. When the satellite is in space, there will be wings deployed as shown in Figure 2 (right).

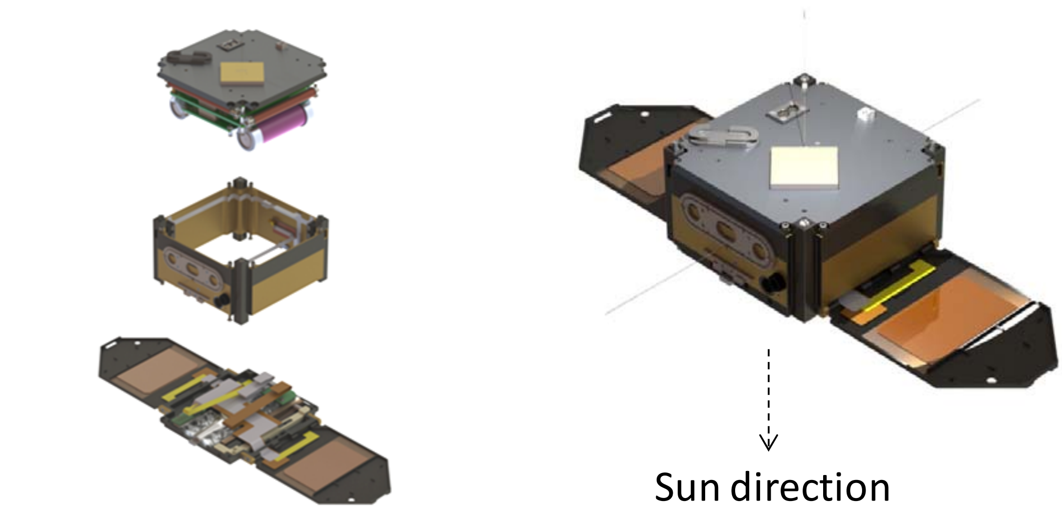

Figure 2. AeroCube-6 satellite subassemblies (left) and assembled satellite (right). Two of these identical spacecraft will fly together for this mission.

AeroCube-6 pair will be launched from a launch tube installed into the Italian UniSat-6 satellite and launched from a Russian Dnepr launch vehicle in June, 2014. Once on orbit, the pair (Figure 3) will fly near each other. The AeroCube-6 experiment will serve as a pathfinder towards a constellation of space-weather Cubesats.

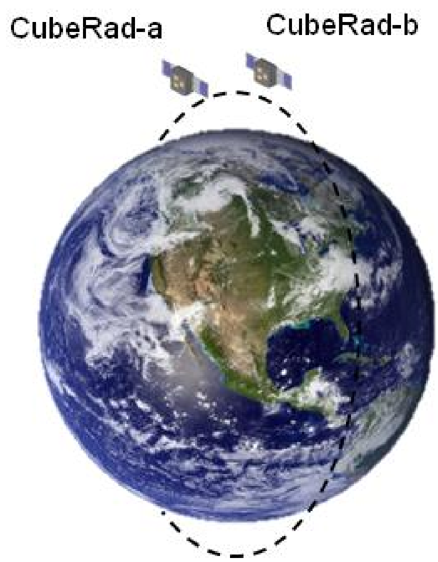

Figure 3. Two AeroCube-6s will fly in close proximity. No station keeping required.

The satellite has only one radio, called the ADVradio, which is unchanged from the prior AeroCube-4 and AeroCube-5 missions. It broadcasts at 915 MHz with 1.3W of RF power. Unlike the prior missions, this satellite uses dipole antennas and the radio switches between them and the stronger one is selected. The goal is to provide an almost spherical pattern albeit with 0 dBi maximum gain. Another change is that the the satellites have the ability to cue each other. When one satellite detects high particle fluxes, such as with a solar flare, it will signal the other satellite with a brief RF message. No data is passed between the satellites other than the cueing message and a confirmation back.

Identification of the anticipated launch vehicle and launch site: AeroCube-6 will fly as a secondary payload on a rideshare mission. AeroCube-6 is currently slated to occupy a P-POD installed into the Italian UniSat-6 satellite which is launching on the DNEPR mission in June 2014. This launch will deliver AeroCube-6 to an approximately 650 km altitude orbit at an inclination of ~98 deg.

Identification of the proposed launch date and mission duration: The AeroCube-6 mission anticipates a launch as a secondary payload in June 2014. The mission duration is 1 year.

Description of the launch and deployment profile: As a secondary payload, the AeroCube-6 spacecraft will be deployed from the launch vehicle to minimize risk to the primary payload and upper-stage space structures.

Reason for selection of operational orbit: The AeroCube-6 science benefits from a high inclination and high altitude orbit.

Identification of any interaction or potential physical interference with other operational spacecraft: The AeroCube-6 mission is independent of other spacecraft. The two AeroCube-6 satellites will cue each other for science purposes. The risk of physical interference between the AeroCube-6 spacecraft is discussed in Section 5 of this ODAR. There is no anticipated risk to any other operational spacecraft.

Section 2: Spacecraft Description

Physical Description: The AeroCube-6 mission consists of a pair of half unit (0.5U) CubeSats each with dimensions 10 x 10 x 5 cm. Each vehicle has two wings that are deployed on orbit each wing has dimensions of 10 x 10 cm. Each satellite contains multiple Sun sensors and Earth sensors, RF communications antenna, GPS receiver, power system, batteries, solar cells and an electronic payload. No components of the spacecraft except the wings extend beyond the dimensions of the 0.5U bus.

Total spacecraft mass at launch: ~0.7 kg (x2)

Dry mass of spacecraft at launch: ~0.7 kg (x2)

Description of all propulsion systems: AeroCube-6 has no propulsion system.

Identification of all fluids planned to be on board: AeroCube-6 has no fluids.

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: The AeroCube-6 will fly with the payload always facing away from the sun as shown in Figure 2. Attitude is sensed by earth sensor, sun sensors and magnetometers. Attitude is controlled by torque rods.

Description of any range safety or other pyrotechnic devices: AeroCube-6 has no pyrotechnic devices.

Description of the electrical generation and storage system: Power for AeroCube-6 is generated by solar cells mounted on the two extended wings. These cells are capable of producing up to 4 W of power. Power is stored on-board by two lithium-ion batteries each is independently managed with the appropriate safety circuitry to protect against overdischarge and overcharge. Each battery stores <9 W-hr of energy.

Identification of any other sources of stored energy: There no other sources of stored energy on AeroCube-6.

Identification of any radioactive materials on board: AeroCube-6 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-6 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 result in rapid energy release in the form of combustion.

Notwithstanding these potential sources of energy release, AeroCube-6 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-6 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 per Cell
AeroCube-6	ICR18650H	Molicel	2	<9 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.

In addition to the aforementioned certification of the AeroCube-6 batteries against explosion, ten potential failure modes for lithium batteries and their applicability or mitigation in AeroCube-6 are addressed in the following table:

	Failure Mode	Applicability or Mitigation
1	Internal short circuit	The AeroCube-6 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-6 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-6 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-6 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.

Detailed plan for any designed breakup, including explosions and intentional collisions: AeroCube-6 has no plans for intentional breakups, explosions, or collisions.

List of components which are passivated at EOM: No systems on AeroCube-6 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-6 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: 650 km altitude, 98 deg inclination, 0.7 kg mass (initial and final), and 0.0214 m^2/kg area-to-mass ratio (the maximum drag configuration).

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft: Probability = 0.000001, 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 AeroCube6 mission has selected atmospheric reentry for disposal. The vehicle is a 30 x 10 x 5 cm bus with two wings extended (see Figure 2). Each vehicle's mass is approximately 0.7 kg. After EOM, the vehicles will tumble with an "average" cross-sectional area of 0.03 m^2 for a solar-panel deployed satellite. The DAS analysis used a lower average tumble cross-sectional area assuming the solar panels did not deploy. DAS predicts a lifetime of 17.3 years, using the orbital assumptions listed at the beginning of Section 5 (using the lower area-to-mass ratio value). However, the increased drag area from the deployed solar panels will further reduce orbital lifetime. In either event, the lifetime is below the 25-year requirement.

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-6. 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-6 vehicles are primarily constructed of aluminum and PCB electronic board material. Figure 4 shows an assembled interior. The two batteries are green (ICR18650H) and two of the three torque rods are visible (orange color). The four satellite circuit boards are visible. On the bottom of the photograph, in silver color is on end cap of the satellite: all of the electronics are bolted down to it. The only high density materials in the satellite are the stainless steel screws (all 2-56 size or smaller) and torque rod cores (HyMu 80, 3” long x 0.15 inch diameter) wrapped with copper wire.

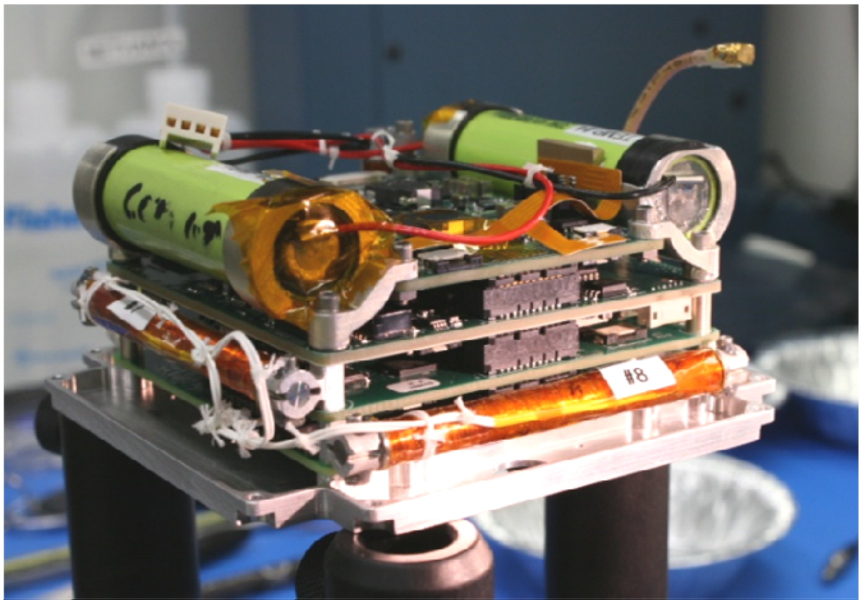

Figure 4. Interior components of the AeroCube-6 satellite.

Summary of objects expected to survive an uncontrolled reentry: 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: DAS 2.0.2 analysis predicts less than 1/10000, which meets the requirement.

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1: COMPLIANT

Section 8: Assessment for Tether Missions

The AeroCube-6 mission has no tether. All requirements are COMPLIANT.

Sections 9–14: Assessment of Launch Vehicle Debris

AeroCube-6 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-6.