AeroCube-10 (AC10)

Orbital Debris Assessment Report (ODAR)

Report Version: 1.0, 12 Oct 2018

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

This document is suitable for public release.

Software used in this analysis: NASA DAS v2.0.2

Revision	Date	Pages	Description	Author
1.0	12 Oct 2018	16	Initial Release	D. Hinkley
1.1				
1.2				
1.3				
1.4				

VERSION APPROVAL and FINAL APPROVAL*:

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* Approval signatures indicate responsibility that the information in the ODAR is correct.

** 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	AC10 will release no debris.
4.3-1b	The total object-time product shall be no larger than 100 object-years per mission.	Compliant	AC10 will release atmosphere probes on command, but altogether <25 object-year lifetime
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	AC10 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	AC10 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 10e-6.	Compliant	AC10 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	
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	AC10 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	AC10 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	AC10 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	AC10 has no tether system.

NOTE: The AeroCube-10a and 10b spacecraft are currently manifested to 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, Technology Demonstration Center
Program Executive: Ms. Lynn Friesen

Mission Director: David Hinkley, The Aerospace Corporation
Program Manager: William Chavez, The Aerospace Corporation

Foreign government or space agency participation: none

Nominal Schedule of Mission Design and Development:

Event	**Date**
Project initiation	Apr 2017
System Requirements Review (SRR)	Jun 2017
Design Review (DR)	Mar 2018
Mission Readiness Review (MRR)	Feb 2019
Delivery	Mar 2019
Target launch date	Apr 2019

Brief Description of the Mission: The AeroCube-10 mission consists of two nanosatellites, called AeroCube-10a and 10b that will demonstrate 1) precision satellite-to-satellite pointing, 2) deployment of atmospheric probes for in-situ measurement of air density, 3) small-spacecraft proximity operations using propulsion from a steam thruster (no docking is planned).

Identification of the anticipated launch vehicle and launch site: The AeroCube-10a and 10b spacecraft are manifested as part of an upcoming Commercial Resupply Service mission to the International Space Station (ISS). They will be deployed directly from the resupply spacecraft at the end of its mission. The resupply mission will launch from the Mid-Atlantic Regional Spaceport on Antares 230/Cygnus. The orbit will be circular between 400 km to 500 km altitude with an inclination of 51.6°.

Identification of the proposed launch date and mission duration: The AeroCube-10 mission anticipates a launch in April 2019. The main mission phase is approximately 12 months.

Description of the launch and deployment profile: The AeroCube-10a and 10b spacecraft will be deployed from the launch vehicle from a single 3U CubeSat dispenser. Typically, the launch vehicle will optimize separation timing to reduce the likelihood of collision between CubeSats.

Reason for selection of operational orbit: As a secondary payload, AeroCube-10a and 10b spacecraft have no control over the selection of their operational orbit. They can perform the 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 deployment vehicle and its payloads will be delivered satisfies that requirement.

Identification of any interaction or potential physical interference with other operational spacecraft: As one of many CubeSats deployed on the mission, there is a small risk of contact between the AeroCube-10a and 10b spacecraft and another CubeSat. The timing of satellite deployments from the dispenser is intended to mitigate this risk as much as possible. Debris mitigation for the deployment process is the responsibility of the launch vehicle. In the event of contact 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). There is no anticipated risk to any other operational spacecraft.

Section 2: Spacecraft Description

Physical Description: The AeroCube-10a and 10b spacecraft are 1.5U CubeSats with outer dimensions of 17 cm x 11 cm x 11 cm. Deployable solar panels extend off the long axis of the spacecraft with dimensions 14 cm x 8 cm. The exterior bus is made from 6061-T6 aluminum and houses all payload and electronics components.

Total spacecraft mass at launch: The AeroCube-10a and 10b spacecraft are tuned to weigh the same at launch, about 2.1 kg.

Dry mass of spacecraft at launch: The AeroCube-10a spacecraft has no propulsion system; dry mass is 2.1 kg. The AeroCube-10b spacecraft has the water propulsion system with at most 30 grams of water; dry mass is therefore 2.070 kg.

Description of all propulsion systems: The AeroCube-10b spacecraft has a steam propulsion system. The water propellant is heated to 40 deg Celsius and then the water vapor is expelled. The 30 grams of water on a 2 kg satellite produces ideally a 10 meter per second delta velocity in total.

Identification of all fluids planned to be on board: The AeroCube-10a spacecraft carries no fluids on board. The AeroCube-10b spacecraft carries 30 grams of water on board inside its propulsion system.

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-10a and 10b spacecraft have 3-axis attitude control via 3 torque rods and 3 miniature 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 0.15-0.2 $A\text{-}m^2$ when the spacecraft passes current through the wire. The rods generate negligible magnetic field when powered off. Attitude sensors include (4) earth limb sensors, (5) sun sensors on various orthogonal spacecraft surfaces, (1) 3-axis magnetometer, and (2) star trackers. A high-accuracy 3-axis rate gyro will be used to provide an inertial attitude reference when pointing accuracy is required while the sun and earth sensors are not available. 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: The AeroCube-10a and 10b spacecraft have no pyrotechnic devices.

Description of the electrical generation and storage system: Power for the AeroCube-10a and 10b spacecraft is generated by solar cells mounted onto panels that will be deployed from both sides of the bus, as well as cells affixed to the spacecraft bus. The total installed solar cells are 22 W of power however only half of that can be pointed at the sun at any given time. Power is stored on-board in 4 lithium-ion 18650 batteries. The batteries are mounted in a thermoplastic plastic structure as a unit in a way that they are shock and thermally isolated from the main satellite structure. The four 18650 cells combined can store 40 W-hr of energy per spacecraft. More battery details of the appear in Section 4.

Identification of any other sources of stored energy: There are no other sources of stored energy on the AeroCube-10a and 10b spacecraft.

Identification of any radioactive materials on board: The AeroCube-10a and 10b spacecraft carry 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: The AeroCube-10b spacecraft intends to release 29 identical atmospheric probes during its 1-year lifetime. The probes unfold into three 9.8 cm diameter aluminum discs arranged orthogonal to each other, approximating a sphere in corss-section. Each probe weighs 16 grams.

Rationale/necessity for release of each object: The objective is to measure the neutral atmospheric density variations between ~100-400 km (thermosphere). This will 1) improve data assimilated into drag models at lower altitudes where there is a dearth of data, and 2) determine small-scale density variations (< orbit average) to improve understanding of dynamics in the region. This experiment will provide data to support or refute the theory that small scale density variations associated with gravity waves couple to the ionosphere (plasma) and may act as seeding mechanisms for plasma irregularities that are capable of adversely affecting navigation, communication, over-the-horizon radars.

Time of release of each object, relative to launch time: On command by ground operators.

Release velocity of each object with respect to spacecraft: 1 cm/second

Expected orbital parameters (apogee, perigee, inclination) of each object after release: 500 km x 500 km x 51.6º.

Calculated orbital lifetime of each object, including time spent in LEO: Each has a predicted lifetime of 0.74 years when released at the highest possible altitude of 500 km. The Total Object-Time calculated by DAS 2.0.2 is 20.2 years.

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 that 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 because of exposure over extended 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, the AeroCube-10a and 10b spacecraft 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.” Underwriters Laboratories (UL) certifies the batteries used on the AeroCube-10a and 10b spacecraft. In general, these batteries are similar in size and power to cell phone batteries.

Model Number (UL Listing)	Manufacturer	Number of Cells	Energy Stored
ICR18650M	Molicel	4	<=10 W-hr per cell (2 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 are incorporated in these batteries including pressure release valves, over-current charge protection, and over-current discharge protection.

The fact that the AeroCube-10a and 10b spacecraft 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 the AeroCube-10a and 10b spacecraft will 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° F (100° C) safe operation limit. Continual charging with 2 to 6 W average power from the solar panels over an orbital life span greater than 15 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 result in fragmentation of the spacecraft.

In addition to the UL certification of the AeroCube-10a and 10b spacecraft batteries against explosion, ten potential failure modes for lithium batteries and their applicability or mitigation are addressed in the following table:

	Failure Mode	**Applicability or Mitigation**
1	Internal short circuit	The AeroCube-10a and 10b spacecraft 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 the AeroCube-10a and 10b spacecraft have charge interrupt devices that activate during cell internal pressure buildup (due to cell internal chemistry 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. That stops the cell output current during external short circuit event.
5	Inoperable vents	Vents have access through the structure that holds them and into the larger satellite volume. Cell venting is not inhibited.

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 the AeroCube-10a and 10b spacecraft 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 AC10 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: The AeroCube-10a and 10b spacecraft have no plans for intentional breakups, explosions, or collisions.

List of components, which are passivated at EOM: No systems on The AeroCube-10a and 10b spacecraft 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-10a and 10b spacecraft 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 2.0.2 for a 500 km x 500 km altitude orbit at 51.6° inclination. The spacecraft masses are 2.1 kg each with a 0.025 m^2/kg area-to-mass ratio (the average area-to-mass configuration of the spacecraft post-mission). The 29 AeroCube-10a probes are part of this assessment.

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 2.0.2 for both orbit regimes.

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 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 Post-Mission Disposal Plans and Procedures

Description of spacecraft disposal option selected: The AeroCube-10 mission has selected atmospheric reentry for disposal. The AeroCube-10a and 10b spacecraft are each 17 x 11 x 11 cm in dimension and 2.1 kg in mass. Each satellite has a minimum cross-sectional area of ~100 cm^2, a maximum of ~400 cm^2 and an average of ~225 cm^2. DAS 2.0.2 predicts a lifetime of 2-3 years for 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: As discussed in Section 4, no disposal or passivation is planned for the AeroCube-10a and 10b spacecraft. Natural orbit decay is sufficient to deorbit the spacecraft.

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-10a and 10b spacecraft are primarily constructed of aluminum and PCB electronic board material. Components with a higher density or resistance to melting are specifically input as individual components to specifically assess their survivability. A table of the breakdown of components for both spacecraft is shown below.

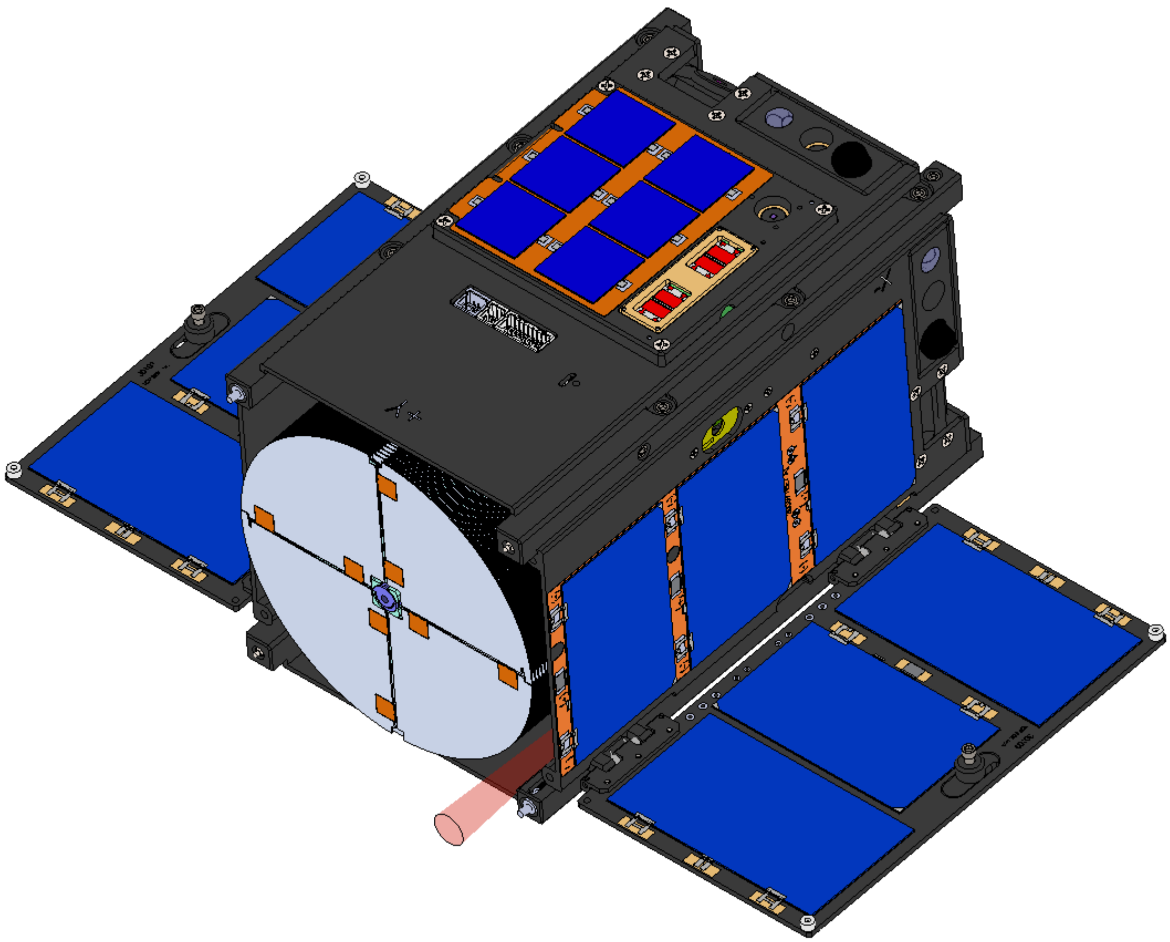

Figure 1: AeroCube-10a spacecraft shown with solar arrays deployed. 1.5U. 2.1 kg. The dispenser is visible as is the optical beacon output (beam shown as a red cone).

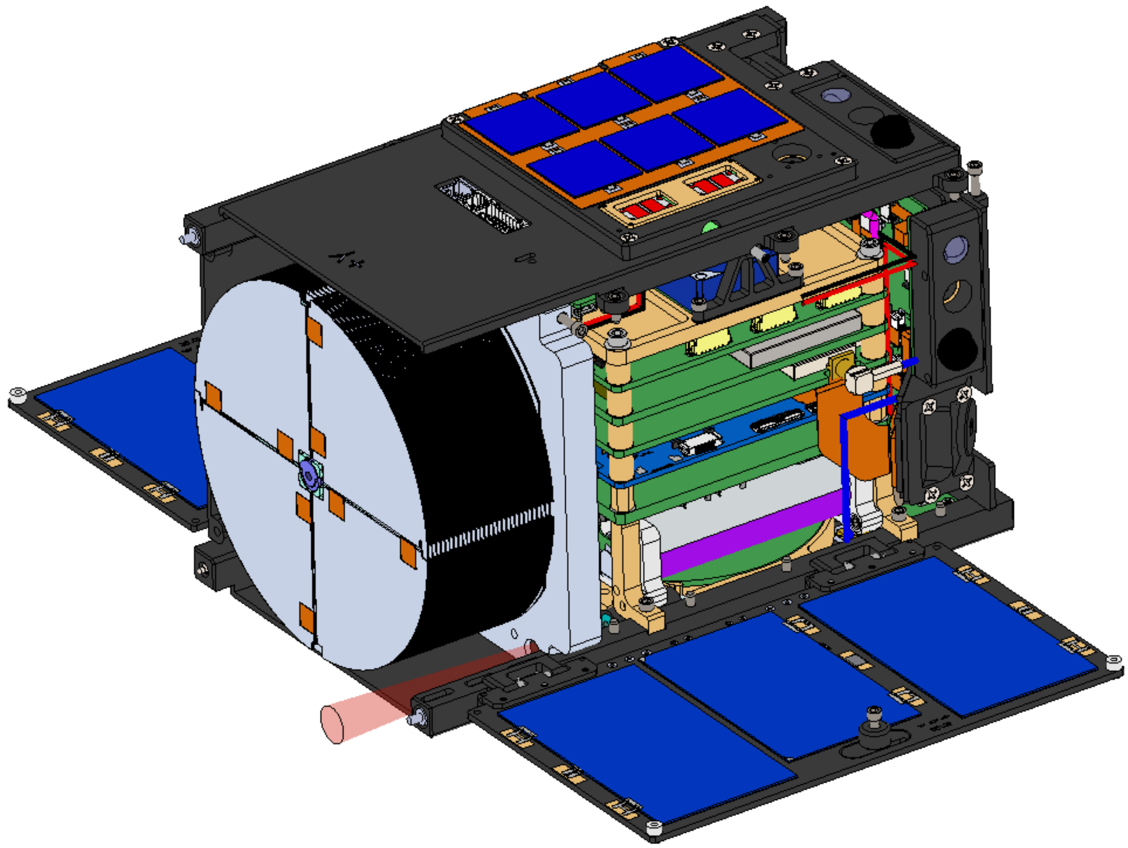

Figure 2: AeroCube-10a spacecraft with one sidewall hidden. The avionics are a stack of circuit boards to the right. Even further right, on the end cover that we cannot see are the attitude control sensors, including the star cameras. The payload volume is to the left of the avionics. The payload in AeroCube-10a consists of the dispenser unit with 29 stowed discs shown and the optical beacon (located on the bottom wall for heat sinking, below the avionics circuit board stack) with its output shown as a red cone.

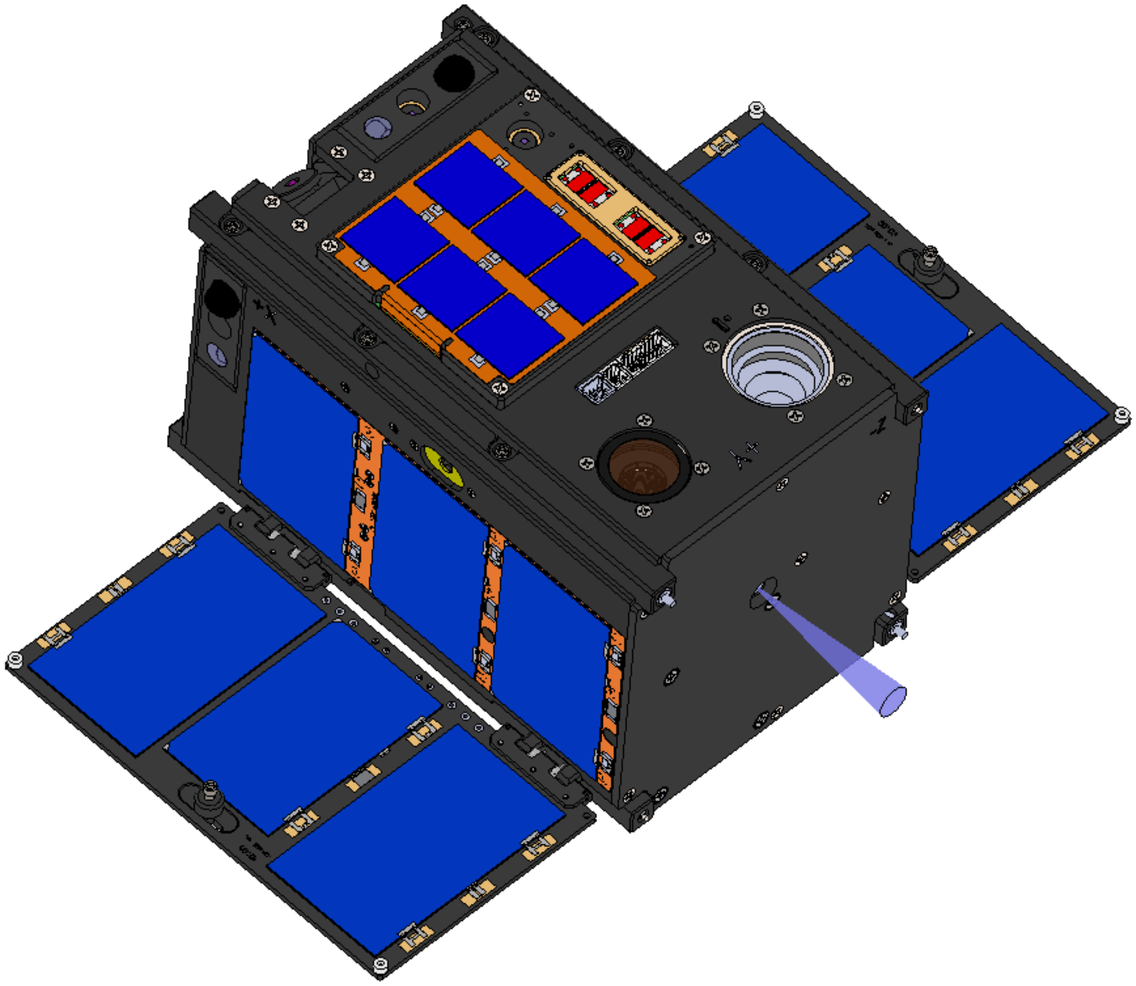

Figure 3: AeroCube-10b spacecraft shown with solar arrays deployed. 1.5U. 2.1 kg. The circular payload apertures visible in this view belong to the Camera360 (on the left) and the uCPT (on the right).

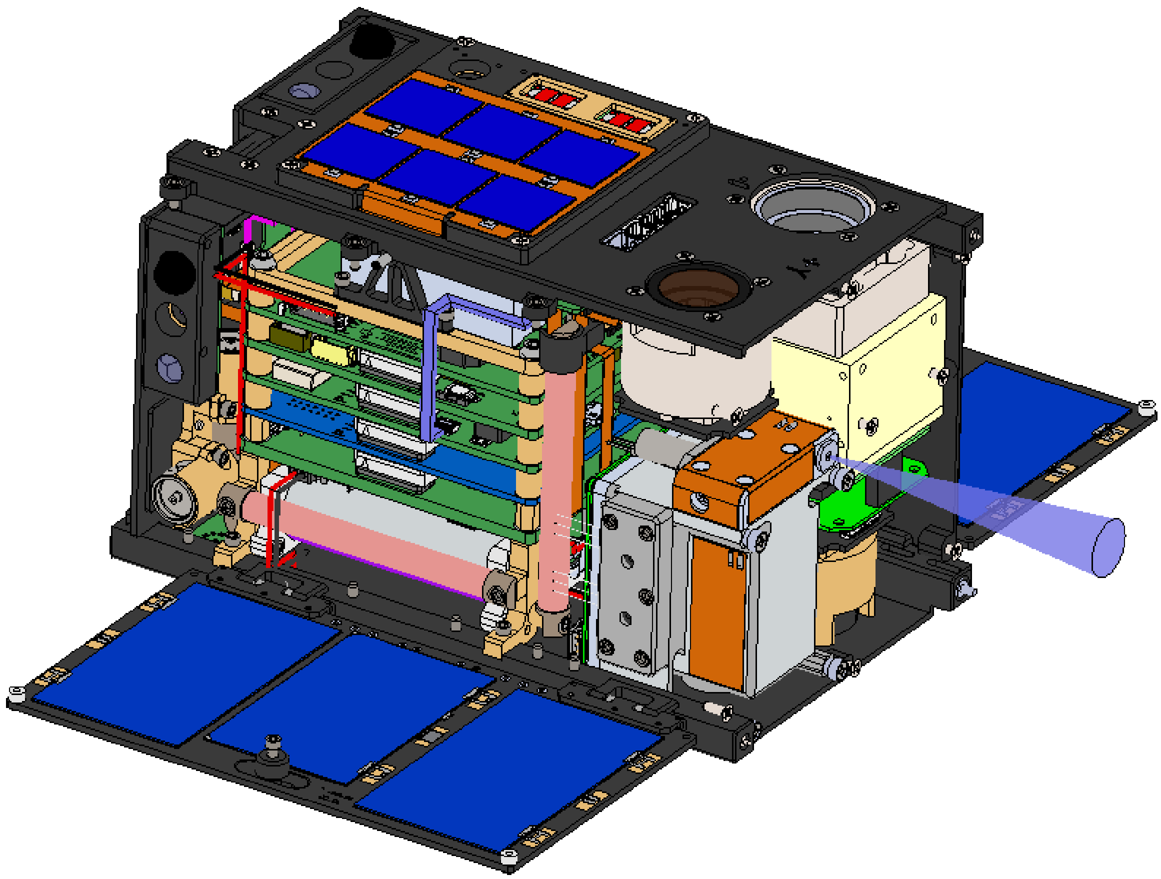

Figure 4: AeroCube-10b spacecraft with one sidewall and one end cover hidden. The avionics are a stack of circuit boards to the left. Even further left, on the end cover we cannot see are the attitude control sensors, including the star cameras. The payload volume is to the right of the avionics. The payload shown consists of the propulsion unit (with the orange heaters shown and the water vapor plume in blue), the beacon camera (gold colored mount in the lower right corner), the Camera360 (beige colored mount above the propulsion unit) and the uCPT (light yellow colored box with a beige color mount above the beacon camera and to the right of the camera360). Most parts are aluminum except that the pink rods (torquers) are HyMu80 and the two beige parts shown (Camera360 housing and uCPT mount) are stainless steel.

Below are constituent elements of each satellite that were entered into DAS 2.0.2.

AC10A											
	Item	Parent	Qty	Shape	mass	dia/width	Length	Height	Material	Avg area	Area/mass
					(kg)	(m)	(m)	(m)		m*m	m*m/kg
AC10 satellite	**1**	**0**	1	box	2.078	0.109	0.170	0.104	varies	0.0158	0.0076
Nadir Lid Assembly	**2**	**1**	1	box	0.225	0.100	0.100	0.017	6061-T6	0.0045	0.0199
Reaction wheel	**3**	**2**	3	cylinder	0.004	0.012	0.009		stainless steel	0.0001	0.0270
Patch antenna	**4**	**2**	3	box	0.011	0.041	0.041	0.006	ceramic	0.0007	0.0658
Backplate	**5**	**1**	1	box	0.114	0.078	0.170	0.010	6061-T6	0.0052	0.0460
Power module	**6**	**5**	1	box	0.315	0.080	0.080	0.028	varies	0.0036	0.0115
Bus electronics	**7**	**6**	1	box	0.315	0.080	0.080	0.037	FR4	0.0041	0.0130
Torque rod	**8**	**7**	3	cylinder	0.018	0.008	0.079		HyMu80	0.0006	0.0351
Walls	**9**	**5**	3	box	0.095	0.078	0.170	0.010	6061-T6	0.0052	0.0552
Wing assembly	**10**	**5**	2	box	0.057	0.079	0.138	0.003	FR4	0.0039	0.0676
Beacon assembly	**11**	**5**	1	box	0.050	0.083	0.083	0.008	6061-T6	0.0027	0.0548
Dispenser assembly	**12**	**5**	1	box	0.136	0.100	0.100	0.051	6061-T6	0.0067	0.0495
Atmosphere probe	**13**	**12**	29	box	0.016	0.090	0.090	0.090	6061-T6	0.0081	0.5063
					2.073						

AC10B											
			Qty	Shape	mass	dia/width	Length	Height	Material	Avg area	Area/mass
					(kg)	(m)	(m)	(m)		m*m	m*m/kg
AC10 satellite	**1**	**0**	1	box	2.078	0.109	0.170	0.104	varies	0.0158	0.0076
Nadir Lid Assembly	**2**	**1**	1	box	0.225	0.100	0.100	0.017	6061-T6	0.0045	0.0199
Reaction wheel	**3**	**2**	3	cylinder	0.004	0.012	0.009		stainless steel	0.0001	0.0270
Patch antenna	**4**	**2**	3	box	0.011	0.041	0.041	0.006	ceramic	0.0007	0.0658
Backplate	**5**	**1**	1	box	0.114	0.078	0.170	0.010	6061-T6	0.0052	0.0460
Power module	**6**	**5**	1	box	0.315	0.080	0.080	0.028	varies	0.0036	0.0115
Bus electronics	**7**	**6**	1	box	0.315	0.080	0.080	0.072	FR4	0.0060	0.0190
Torque rod	**8**	**7**	3	cylinder	0.018	0.008	0.079		HyMu80	0.0006	0.0351
Walls	**9**	**5**	3	box	0.095	0.078	0.170	0.010	6061-T6	0.0052	0.0552
Camera 360	**10**	**9**	1	cylinder	0.134	0.034	0.027		stainless steel	0.0009	0.0069
Flux camera	**11**	**9**	1	cylinder	0.037	0.031	0.022		6061-T6	0.0007	0.0184
Wing assembly	**12**	**5**	2	box	0.057	0.079	0.138	0.003	FR4	0.0039	0.0676
Zenith lid	**13**	**9**	1	box	0.025	0.104	0.111	0.01	6061-T6	0.0045	0.1816
uCPT box	**14**	**13**	1	box	0.130	0.041	0.041	0.031	6061-T6	0.0014	0.0108
uCPT vault	**15**	**13**	1	box	0.024	0.024	0.024	0.008	stainless steel	0.0003	0.0133
uCPT vault shield	**16**	**13**	1	box	0.015	0.024	0.024	0.002	tantalum	0.0002	0.0145
uCPT cover	**17**	**13**	1	box	0.115	0.041	0.041	0.024	stainless steel	0.0012	0.0106
uCPT baffles	**18**	**13**	1	cylinder	0.000	0.028	0.000		tantalum	0.0000	0.0560
Prop assembly	**19**	**13**	1	box	0.163	0.044	0.054	0.414	6061-T6	0.0143	0.0878
					2.068						

Summary of objects expected to survive an uncontrolled reentry: Requirement 4.7-1 states that all surviving debris from an uncontrolled spacecraft reentry must have a risk of human casualty of less than 1:10,000. Human casualty is defined as an impact from an object with an energy of at least 15 J. DAS 2.0.2 analysis predicts that three objects from AeroCube-10b will reach the ground after reentry: 1) a 316-stainless steel uCPT cover, 2) six tantalum uCPT baffles and 3) a tantalum uCPT Vault Shield. Their impact kinetic energies are 82, 0.0003 and 8 Joules, respectively. While the tantalum parts are required for shielding the uCPT instrument, we minimized their mass to be sure their kinetic impact energy was below the 15 Joule threshold that NASA uses to define life-threatening debris. DAS predicted the stainless steel uCPT cover would reach the ground, however this was unexpected. Therefore, we analyzed it using the high fidelity "Atmospheric Heating and Breakup" (AHaB) analysis tool. The Aerospace Corporation uses this code to model and analyze breakup sequences and reentry survivability for National Security Space programs for the United States Air Force Space and Missile Systems Center (SMC). AHaB predicted that the stainless steel uCPT cover will not survive reentry - see the table below.

Part	DAS		AHaB	
	Impact Energy (J)	Casualty Area (m^2)	Impact Energy (J)	Casualty Area (m^2)
uCPT cover	82	0.41	0	0

Calculation of probability of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination: 1: 10,000

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1: COMPLIANT

Section 8: Assessment for Tether Missions

The AeroCube-10 mission has no tether. All requirements are COMPLIANT.

Sections 9–14: Assessment of Launch Vehicle Debris

The AeroCube-10a and 10b spacecraft will fly as a secondary payload. Assessment of launch-vehicle debris is the responsibility of the primary payload. These sections are therefore N/A.