DAILI (DAILI)

Orbital Debris Assessment Report (ODAR)

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

This document is suitable for public release.

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Revision	Date	Pages	Description	Author
1.0	5 May 2021	12	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	DAILI will release no debris.
4.3-1b	The total object-time product shall be no larger than 100 object-years per mission.	Compliant	
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	DAILI 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	DAILI 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	DAILI 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	DAILI 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	DAILI 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	DAILI 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	DAILI has no tether system.

NOTE: The DAILI 3.1.0spacecraft is 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	Oct 2018
Design Review (DR)	May 2020
Delivery	July 2021
Target launch date	Dec 2021

Brief Description of the Mission: The Daytime Atmospheric and Ionospheric Limb Imager (DAILI) program consists of one linear 6U nanosatellite that will implement a newly developed technique to measure the absolute O_2 density profiles between approximately 140 and 180 km during daytime at mid and low latitudes.

Identification of the anticipated launch vehicle and launch site: The DAILI spacecraft is manifested as part of an upcoming Commercial Resupply Service mission to the International Space Station (ISS). The resupply mission will launch from the KSC on SPx24. The orbit will be circular between 410 km with an inclination of 51.6°.

Identification of the proposed launch date and mission duration: The DAILI mission anticipates a launch in Dec 2021. The main mission phase and the predicted orbit lifetime are approximately 12 months.

Description of the launch and deployment profile: The DAILI spacecraft will be deployed from the launch vehicle from a single 6U CubeSat dispenser. Typically, the launch provider will optimize separation timing to reduce the likelihood of collision between CubeSats.

Reason for selection of operational orbit: DAILI 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 DAILI 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 provider. 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 DAILI spacecraft is 6U with outer dimensions of 11 cm x 11 cm x 76 cm. Deployable solar panels extend off the long axis of the spacecraft with dimensions 0.1 cm x 16 cm x 49 cm. The exterior bus is made from 6061-T6 aluminum and houses all payload and electronics components. The solar panels are FR4.

Total spacecraft mass at launch: The DAILI spacecraft is 5.7 kg.

Dry mass of spacecraft at launch: The DAILI spacecraft has no propulsion system; dry mass is 5.7 kg.

Description of all propulsion systems: The DAILI spacecraft has no propulsion.

Identification of all fluids planned to be on board: The DAILI spacecraft carries no fluids on board.

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 DAILI 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-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, (4) sun sensors on various orthogonal spacecraft surfaces, (1) 3-axis magnetometer, and (3) 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 DAILI spacecraft has no pyrotechnic devices.

Description of the electrical generation and storage system: Power for the DAILI 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 62 W of power most of which 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 DAILI spacecraft.

Identification of any radioactive materials on board: The DAILI spacecraft 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: The DAILI spacecraft will not release any objects.

Rationale/necessity for release of each object: Not applicable.

Time of release of each object, relative to launch time: Not applicable.

Release velocity of each object with respect to spacecraft: Not applicable.

Expected orbital parameters (apogee, perigee, inclination) of each object after release: Not applicable.

Calculated orbital lifetime of each object, including time spent in LEO: Not applicable.

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 DAILI 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 DAILI 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**
INR18650A	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 DAILI 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 DAILI 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 >10 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 DAILI 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 DAILI 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 DAILI 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 DAILI 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 DAILI 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 DAILI spacecraft have no plans for intentional breakups, explosions, or collisions.

List of components, which are passivated at EOM: No systems on The DAILI 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 DAILI 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 3.1.0 for a 410 km x 410 km altitude orbit at 51.6° inclination. The spacecraft mass is 5.7 kg with a 0.0107 m^2/kg area-to-mass ratio - the mission orientation of the spacecraft. DAILI lifetime is less than 1 year and it will spend almost all that time in the mission orientation.

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 3.1.0.

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 DAILI mission has selected atmospheric reentry for disposal. The DAILI spacecraft is 11 x 11 x 76 cm in dimension and 5.7 kg in mass. DAS 3.1.0 predicts a lifetime of <1 year 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 DAILI 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: The spacecraft mass is 5.7 kg with a 0.0107 m^2/kg area-to-mass ratio - the mission orientation of the spacecraft. DAILI lifetime is less than 1 year and it will spend almost all that time in the mission orientation.

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 DAILI spacecraft is 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 the spacecraft is shown below.

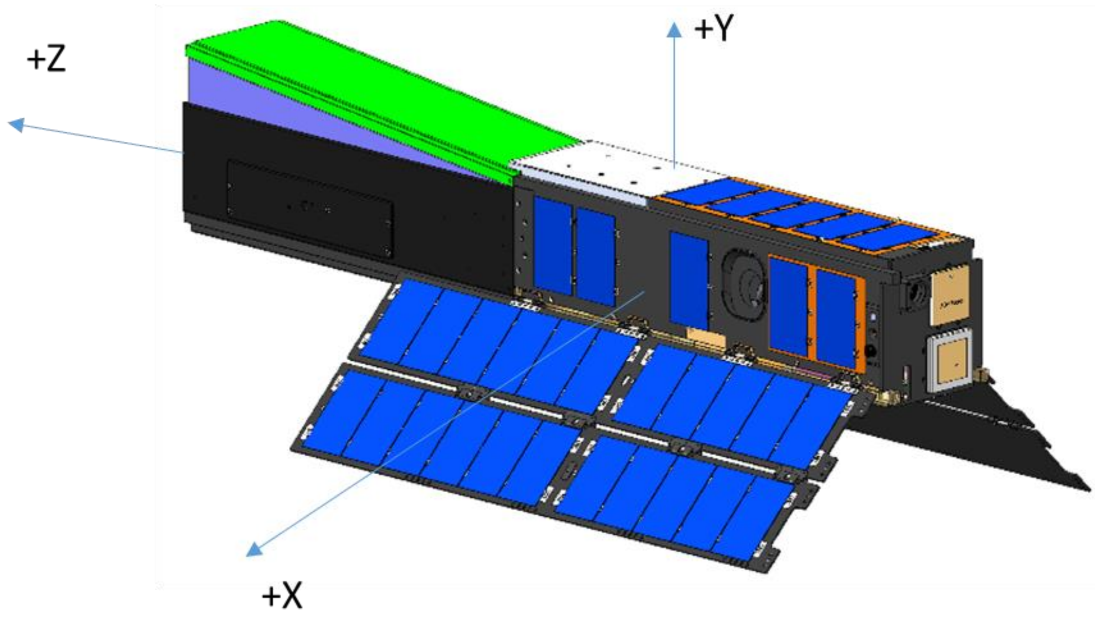

Figure 1: DAILI spacecraft shown with solar arrays deployed.

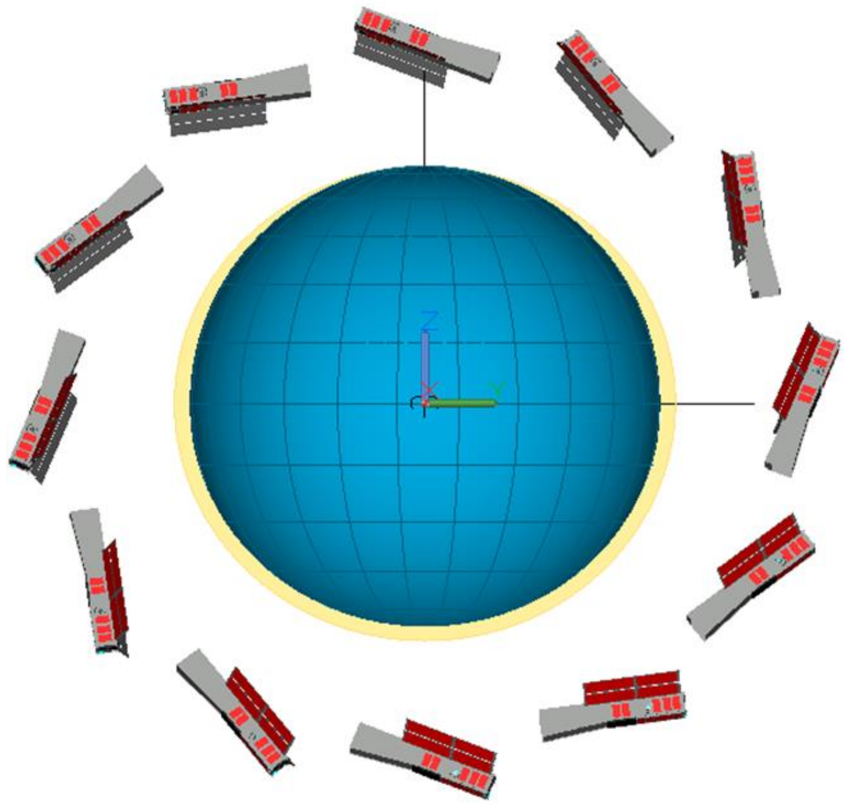

Figure 2: The nominal flight orientation of DAILI is LVLH with the sunshade pointed anti-RAM and tilted down by a constant 15 degrees.

Below are constituent elements of the satellite that were entered into DAS 3.1.0.

DAILI											
	Item	Parent	Qty	Shape	mass (kg)	dia/width (m)	Length (m)	Height (m)	Material	Avg area m*m	Area/mass m*m/kg
DAILI Satellite	1	0	1	box	5.712	0.109	0.765	0.114	varies	0.0610	0.0107
Nadir Lid Assembly	2	1	1	box	0.259	0.106	0.112	0.052	6061-T6	0.0077	0.0299
GPS + ADV antenna	3	2	2	box	0.032	0.044	0.044	0.007	ceramic	0.0009	0.0266
Backplate	4	1	1	box	0.346	0.104	0.394	0.022	6061-T6	0.0173	0.0500
SDR antenna	5	4	1	box	0.014	0.044	0.044	0.007	ceramic	0.0009	0.0608
NFOV star camera	6	4	2	box	0.117	0.045	0.095	0.045	6061-T6	0.0035	0.0301
Power module	7	4	1	box	0.350	0.082	0.088	0.03	varies	0.0041	0.0117
Bus electronics	8	7	1	box	0.329	0.073	0.073	0.072	FR4	0.0053	0.0160
Torque rod	9	8	3	cylinder	0.022	0.008	0.079		HyMu80	0.0006	0.0287
Walls	10	4	2	box	0.209	0.090	0.394	0.009	6061-T6	0.0133	0.0635
Reaction wheel	11	10	1	cylinder	0.082	0.028	0.044		stainless steel	0.0012	0.0150
Roof	12	10	1	box	0.118	0.086	0.247	0.010	6061-T6	0.0082	0.0694
Reaction wheel	13	12	2	cylinder	0.082	0.028	0.044		stainless steel	0.0012	0.0150
Wing assembly	14	4	2	box	0.335	0.163	0.485	0.002	FR4	0.0268	0.0800
Instrument	15	4	1	box	1.395	0.057	0.177	0.111	6061-T6	0.0120	0.0086
Sunshade	16	10	1	box	1.273	0.109	0.362	0.11	6061-T6	0.0304	0.0239

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 3.1.0 analysis predicts that no objects from DAILI will reach the ground after reentry.

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 DAILI mission has no tether. All requirements are COMPLIANT.

Sections 9–14: Assessment of Launch Vehicle Debris

The DAILI 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.