CELTEE-1
Orbital Debris Assessment Report (ODAR)

This report is presented in compliance with NASA-STD-8719.14, APPENDIX A.

Report Version: 1.1, 5/26/2016

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This document contains no proprietary, ITAR, or export controlled information.

DAS Software Version Used In Analysis: v2.0.2

Table of Contents

Self-assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14:

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14.

	Launch Vehicle				**Spacecraft**			
Req #	Compliant	Not Compliant	Incomplete	Standard Non-Compliant	Compliant	Not Compliant	Incomplete	**Comments**
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	No Debris Released in GEO. See note 1.
4.4-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-2	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-3	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See note 1.
4.4-4	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See note 1.
4.5-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.5-2								No critical subsystems needed for EOM disposal.
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-2	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-3	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-4	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-5	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.7-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.8-1								No tethers used.

Notes:

1. This launch has several spacecraft manifested and the CELTEE-1 spacecraft is not the primary mission.

Assessment Report Format:

ODAR Technical Sections Format Requirements:

As M42 Technologies, LLC is a US company, this ODAR follows the format recommended in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the CELTEE-1 satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Program Management and Mission Overview

Project Manager: Nestor Voronka

Foreign government or space agency participation: None.

Schedule of upcoming mission milestones:

FRR:	July 2016
Launch:	No Earlier Than September 2016

Mission Overview:
CELTEE-1 will be ejected from a CubeSat dispenser into a planned orbit of 580 x 550 km at 98 degrees. The experiment will operate for a maximum duration of 6 months.

ODAR Summary: No debris released in normal operations; no credible scenario for breakups; the collision probability with other objects is compliant with NASA standards; and the estimated nominal decay lifetime due to atmospheric drag is under 25 years following operations (17.1 years after 0.5 years of nominal operations, as calculated by DAS 2.0.2).

Launch vehicle and launch site: Atlas 5, SLC-3E, Vandenberg Air Force Base, California.

Proposed launch date: No Earlier Than September 15, 2016.

Mission duration: Maximum Nominal Operations: 6 months, Post-Operations Orbit lifetime: 15.5 years until reentry via atmospheric orbital decay (16.1 years in total).

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination: The CELTEE-1 satellite will deploy to, and decay naturally from, an elliptical 580 x 550 km 98 degree orbit. CELTEE-1 has no propulsion and therefore does not actively change orbits. There is no parking or transfer orbit.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:
CELTEE-1 conforms to the 1U CubeSat specification, with a launch mass of 1.44 kg. Basic physical dimensions are 100mm x 100mm x 100mm.

The CELTEE-1 load bearing structure is Pumpkin's CubeSat Kit 1U structure that is comprised of a bent metal frame, with deployment rails along 4 edges.

Power storage is provided by primary (non-rechargable) lithium-ion cells. The batteries are and will power the satellite until the cells are discharged.

The CELTEE-1 spacecraft is passively magnetically stabilized.

Total satellite mass at launch, including all propellants and fluids: 1.44 kg.

Dry mass of satellites at launch, excluding solid rocket motor propellants: 1.44 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): None.

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Fluids in Pressurized Batteries: None.
CELTEE-1 uses unpressurized standard COTS Lithium-Ion battery cells. Each battery has a height of 61mm, a diameter of 34mm and a weight of 115 grams.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:

The spacecraft will employ a passive magnetic stabilization Attitude Determination Control System (ADCS). A permanent cylindrical magnet will be nadir-pointing to align with earth's magnetic field lines in our polar orbit. Hysteresis rods will be aligned along the orthogonal axes to dampen rotation in the remaining two degrees of freedom.

Description of any range safety or other pyrotechnic devices: No pyrotechnic devices are used.

Description of the electrical generation and storage system: Standard primary (non-rechargeable) COTS Lithium-Ion battery cells are installed during spacecraft integration and provide electrical energy during the mission. Both the battery cells and the battery pack have current limiting protection circuits for short protection.

Identification of any other sources of stored energy not noted above: None.

Identification of any radioactive materials on board: None.

ODAR 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, including object dimensions, mass, and material: There are no intentional releases.

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

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Req. 4.3-1 and 4.3-2 (per DAS v2.0.2)

4.3-1, Mission Related Debris Passing Through LEO: COMPLIANT

4.3-2, Mission Related Debris Passing Near GEO: COMPLIANT

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions

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:

In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to explosion.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:

There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

The CELTEE-1 mission will continue to operate till the primary batteries are discharged and therefore End of Mission (EOM) is reached (no later than 6 months). The batteries will be therefore be passivated at EOM.

Rationale for all items which are required to be passivated, but cannot be due to their design:

N/A

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

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

For each spacecraft and launch vehicle orbital stage employed for a mission, theprogram or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

Compliance statement:

Required Probability: 0.001.

Expected probability: 0.000.

Supporting Rationale and FMEA details:

Battery explosion:

Effect: All failure modes below might theoretically result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of the selected COTS batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Probability: Extremely Low. It is believed to be a much less than 0.1% probability that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion).

Failure mode 1: Internal short circuit.

Mitigation 1: Protoqual vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited discharge to prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing AND functional discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: Cells were tested in lab for high load discharge rates in a variety configurations to determine like likelihood and impact of an out of control thermal rise in the cell. Cells have current-limiting positive temperature coefficient (PTC) protection devices. Battery pack interconnects have additional per-cell PTCs. Spacecraft avionics have over-current detection and disconnection protection circuitry.

Combined faults required for realized failure: Spacecraft thermal design must be incorrect AND external over-current detection and disconnect function must fail to enable this failure mode.

Failure Mode 3: Excessive discharge rate or short-circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

Mitigation 3: This failure mode is negated by a) qualification-tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests (vibration, thermal cycling, and thermal-vacuum tests).

Combined faults required for realized failure: An external load must fail/short- circuit AND external over-current detection and disconnect function failure must all occur to enable this failure mode.

Failure Mode 5: Crushing.

Mitigation 5: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.

Combined faults required for realized failure: A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Excess temperatures due to orbital environment and high discharge combined.

Mitigation 6: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures that are well below temperatures of concern for explosions.

Combined faults required for realized failure: Thermal analysis AND thermal design AND over- current monitoring and control must all fail for this failure mode to occur.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon:

Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement:

CELTEE-1 battery charge circuits include short-circuit and overcurrent protection and a parallel design to limit the risk of battery failure. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable. There are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable. There are no planned breakups.

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

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0.2, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

Requirement 4.5-1: Limiting debris generated by collisions with large objects when operating in Earth orbit:

For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Large Object Impact and Debris Generation Probability:

CELTEE-1 Collision Probability: 0.00000; COMPLIANT.

(The above analysis results are a product of NASA's DAS 2.0.2 software.)

Requirement 4.5-2: Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:

For each spacecraft, the program or project 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 postmission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability:

CELTEE-1 Collision Probability: 0.00000; COMPLIANT.

(The above analysis results are a product of NASA's DAS 2.0.2 software.)

Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering:

None.

ODAR Section 6: Assessment of Spacecraft Post-mission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. At the end of CELTEE-1's operational life (i.e. at EOM) the spacecraft will continue to naturally decay until it re-enters. The spacecraft is passively magnetically stabilized and therefore there is no change in the spacecraft's attitude control scheme or drag configuration.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal:

The spacecraft is passively magnetically stabilized and therefore there is no change required in the spacecraft's attitude control scheme or drag configuration for posmission disposal.

6.3 Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:

Spacecraft Mass: 1.44 kg

Cross-sectional Area: 0.01 m^2 (random tumbling)

Area to mass ratio: 0.0068 m^2/kg (random tumbling)

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0.2 and NASA-STD-8719.14 section):

Requirement 4.6-1: Disposal for space structures passing through LEO:

A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option:

- *Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or*
- *Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.*

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

Analysis: The CELTEE-1 satellite reentry is COMPLIANT using method "a".

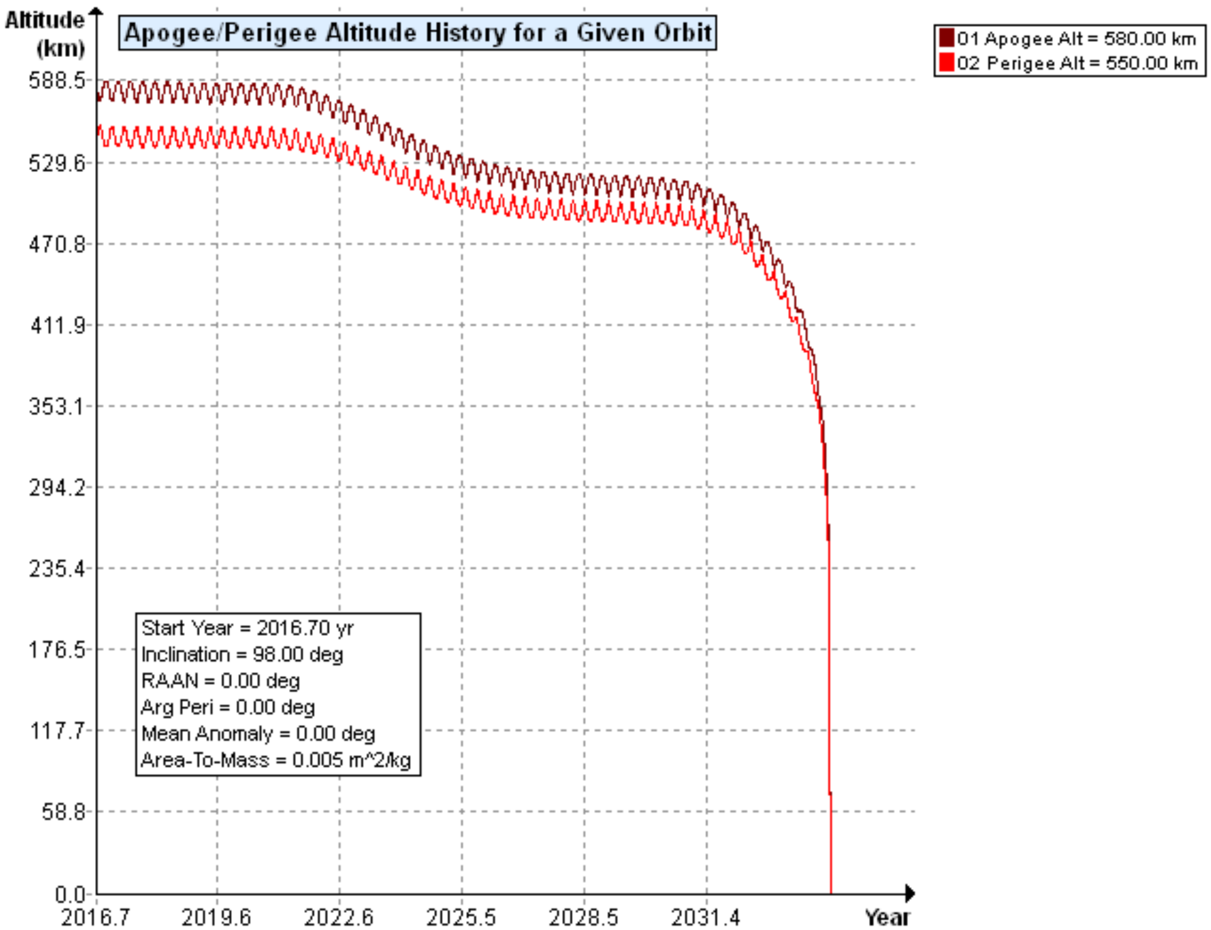

Figure 1. Apogee/Perigee Altitude History for CELTEE-1. *The DAS 2.0.2 analysis shows that CELTEE-1 has a 16.14 year orbital lifetime (0.5 mission, 15.64 postmission disposal).*

Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

Analysis: Not applicable.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: There is no discernible difference between the nominal mission drag configuration and a random tumbling configuration, meaning that even under massive subsystem failure the reliability of postmission disposal operations will not be affected.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1: Limit the risk of human casualty:

The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Summary Analysis Results: DAS v2.0.2 reports that CELTEE-1 is compliant with the requirement. There is a low probability (1:0) of any CELTEE-1 components reaching the ground.

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the CELTEE-1 mission.

END of ODAR for CELTEE-1