Centennial-1 Orbital Debris Assessment Report (ODAR)

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

Report Version: 1, 6/1/2014

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

DAS Software Version Used in Analysis: v2.0.2

VERSION APPROVAL and/or FINAL APPROVAL*:

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Signature of Official Date Signed

*Approval signatures indicate acceptance of the ODAR-defined risk.

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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.

Orbital Debris Self-Assessment Report Evaluation: Centennial-1 Mission

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1b	☐	☐	☒	☐	☒	☐	☐	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 Booz Allen Hamilton spacecraft is not the primary mission.

Assessment Report Format:

ODAR Technical Sections Format Requirements:

As Booz Allen Hamilton 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 Centennial-1 satellite. Section 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Program Management and Mission Overview

Project Manager: William Hojnowski

Foreign government or space agency participation: None.

Schedule of upcoming mission milestones:

FRR:	August 2014
Launch:	October 2014

Mission Overview:

Centennial-1 will be ejected from the International Space Station into a circular orbit 420km at 51.65 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 (8.4 months after 6 months of nominal operations, as calculated by DAS 2.0.2).

Launch vehicle and launch site: Antares, Wallops Island, VA

Proposed Launch Date: October 3, 2014

Mission duration: Maximum Nominal Operations: 6 months, Post-Operational Orbit Lifetime: 8.4 months until reentry via atmospheric orbital decay (14.4 months total).

Launch and deployment profile, including all parking, transfer and operational orbits with apogee, perigee and inclination:

The Antares rocket, being able to restart to perform orbital change maneuvers, will be delivering supplies to the International Space Station. Centennial-1 will be deployed from the International Space Station.

The Centennial-1 satellite will deploy to, and decay naturally from, a circular orbit defined as follows:

Apogee: 420 km

Perigee: 420 km

Inclination: 51.65 degrees

Centennial-1 has no propulsion and therefore does not actively change orbits. There is no parking or transfer orbit.

<u>ODAR Section 2: Spacecraft Description</u>

Physical description of the spacecraft:

Centennial-1 conforms to the 1U CubeSat specification, with a launch mass of 1.3kg. Basic physical dimentions are 100mm x 100 mm x 100 mm with a deployable antenna.

The Centennial-1 load bearing structure is comprised of three 100mm x 100mm skeleton plates, with L rails along each 100mm corner edge. The solar arrays are body mounted.

Power storage is provided by Lithium-Polymer cells. The batteries will be recharged by solar cells mounted on the body of the satellite.

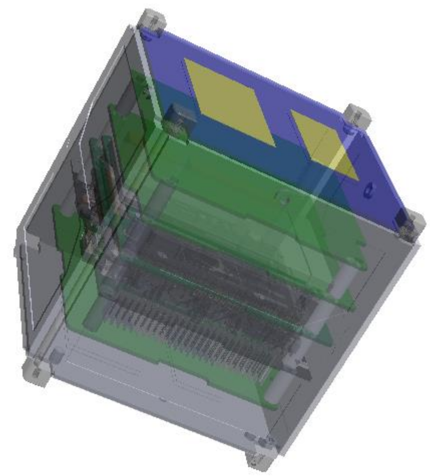

Figure 1: Centennial-1 Configuration

Centenial-1 attitude will be controlled by a Z-axis permanent magnet and determined by 3-axis gyroscope.

Total satellite mass at launch, including all propellants and fluids: ~1.3 kg.

Dry mass of satellite at launch, excluding solid rocket motor propellants: ~1.3kg

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

Identification, including mass and pressure, of all fluids (liquid and gasses) 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. Centennial-1 uses an unpressurized standard COTS Lithium-Polymer battery cell.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: Centennial-1 utilizes permanent magnet passive stabilization, which will orient the spacecraft into a predictable configuration for antennas and sensors. The nominal attitude will be the Z axis aligning to the magnetic poles with the +Z face pointing north and the X and Y axes free to rotate. There is no active attitude control on Centennial-1.

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

Description of the electrical generation and storage system: Standard COTS Lithium-Ion battery cells are charged before payload integration and provide electrical energy during the mission. The cells are recharged by solar cells mounted on the deployable arrays. The battery cell protection circuit manages the charging cycle.

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 Requirements 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. The deployment of the UHF/VHF antenna will feature a simple spring system, released by a simple burn-wire. The probability of a detachment during deployment is negligible.

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:

None. The battery will not be passivated at End of Mission due to the low risk and low impact of explosive rupturing. The maximum total energy stored in the battery is 36kJ.

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

Centennial-1 battery charge circuits include overcharge protection to limit the risk of battery failure. However, in the unlikely event that the battery cell does explosively rupture, the small size, mass, and potential energy, of this small battery 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.

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, the program 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: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing **AND** functional charge/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 of flight-like configurations to determine like likelihood and impact of an out of control thermal rise in the cell. Cells were also tested in a hot environment to test the upper limit of the cells capability. No failures were seen.

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 4: 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 protoqualification and acceptance environmental tests (shock, 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 4: Inoperable vents.

Mitigation 5: Battery vents are not inhibited by the battery holder design or the spacecraft.

Combined effects required for realized failure: The final assembler fails to install proper venting.

Failure Mode 5: Crushing.

Mitigation 6: 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: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

Mitigation 7: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.

Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators **AND** dislocation of battery packs **AND** failure of battery terminal insulators **AND** failure to detect such failure modes in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.

Mitigation 8: 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 which are well below temperatures of concern for explosions.

Combined faults required for realized failure: Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** overcurrent 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 cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement:
Centennial-1 battery charge circuits include overcharge 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:

Centennial-1; Collision Probability: 0.000000; COMPLIANT.

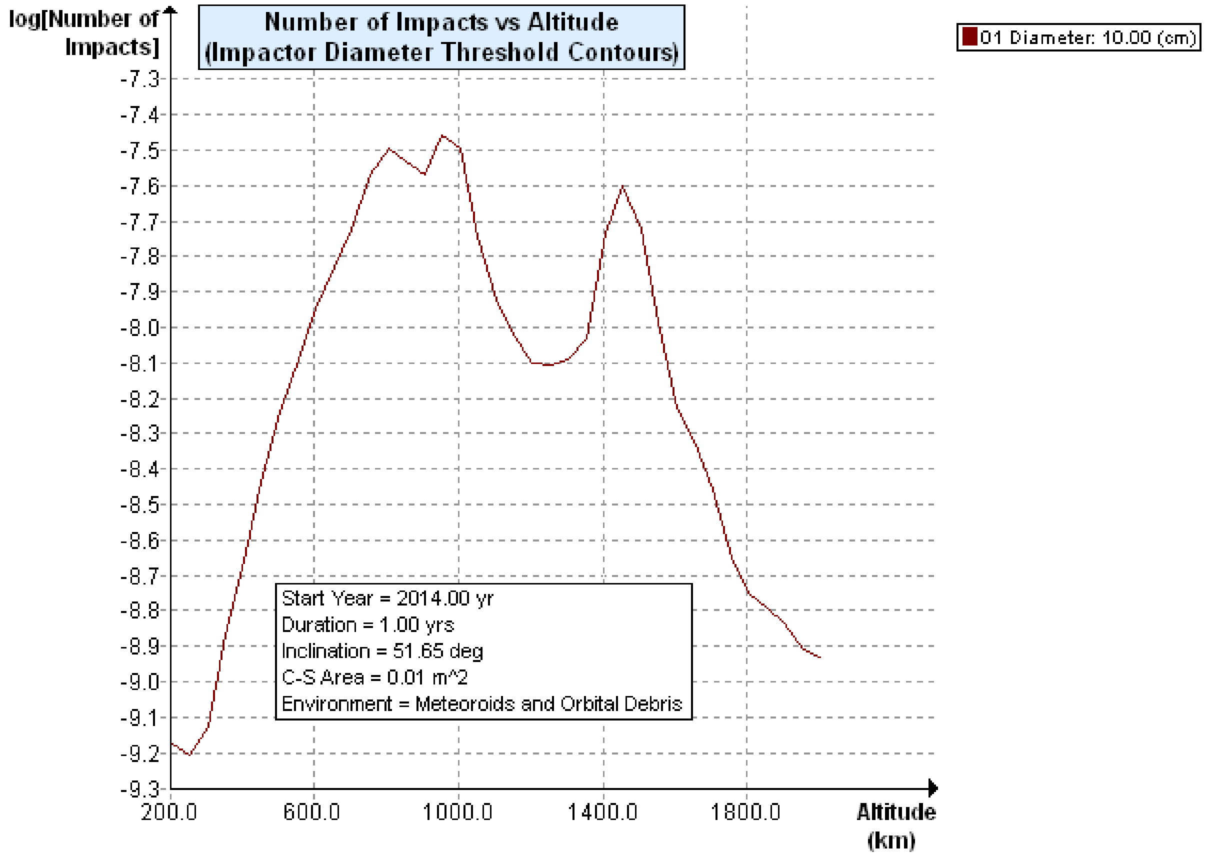

Figure 2: Number of Impacts vs. Altitude.

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:

Centennial-1; Collision Probability: 0.00000; COMPLIANT.

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

Centennial-1 will decay within 1.2 years without any active systems. The spacecraft orbit prediction is based on the non-deployable or maneuverable cube geometry and mass properties of Centennial-1 using DAS 2.0.2.

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected:

Centennial-1 will de-orbit naturally by atmospheric re-entry within 1.2 years. At the end of Centennial-1's operational life (i.e. at EOM) the satellite orbit will decay naturally without control input. Centennial-1 is a dynamically stable configuration that requires no positioning for reentry.

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

The cube configuration of Centennial-1 does not require maneuvers to accomplish a stable reentry. Postmission disposal will occur as a result of normal atmospheric drag.

6.3 Calculation of area-to-mass ratio after post mission disposal, if the controlled reenter option is not selected:

Spacecraft Mass: ~1.3kg

Cross-sectional Area: 0.01 m2 (dynamically stable)

Area to mass ratio: 0.0077 m2/kg (dynamically stable)

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 Centennial-1 satellite reentry is COMPLIANT using method “a”.

Satellite Name: Centennial-1
BOL Orbit: 420x420 km
EOL Orbit*: 370x388 km
Total Lifetime: 1.2 years
Post-Ops Life: 0.7 years

**EOM orbit was calculated using DAS 2.0.2 output of orbit history over the 6 months mission duration.*

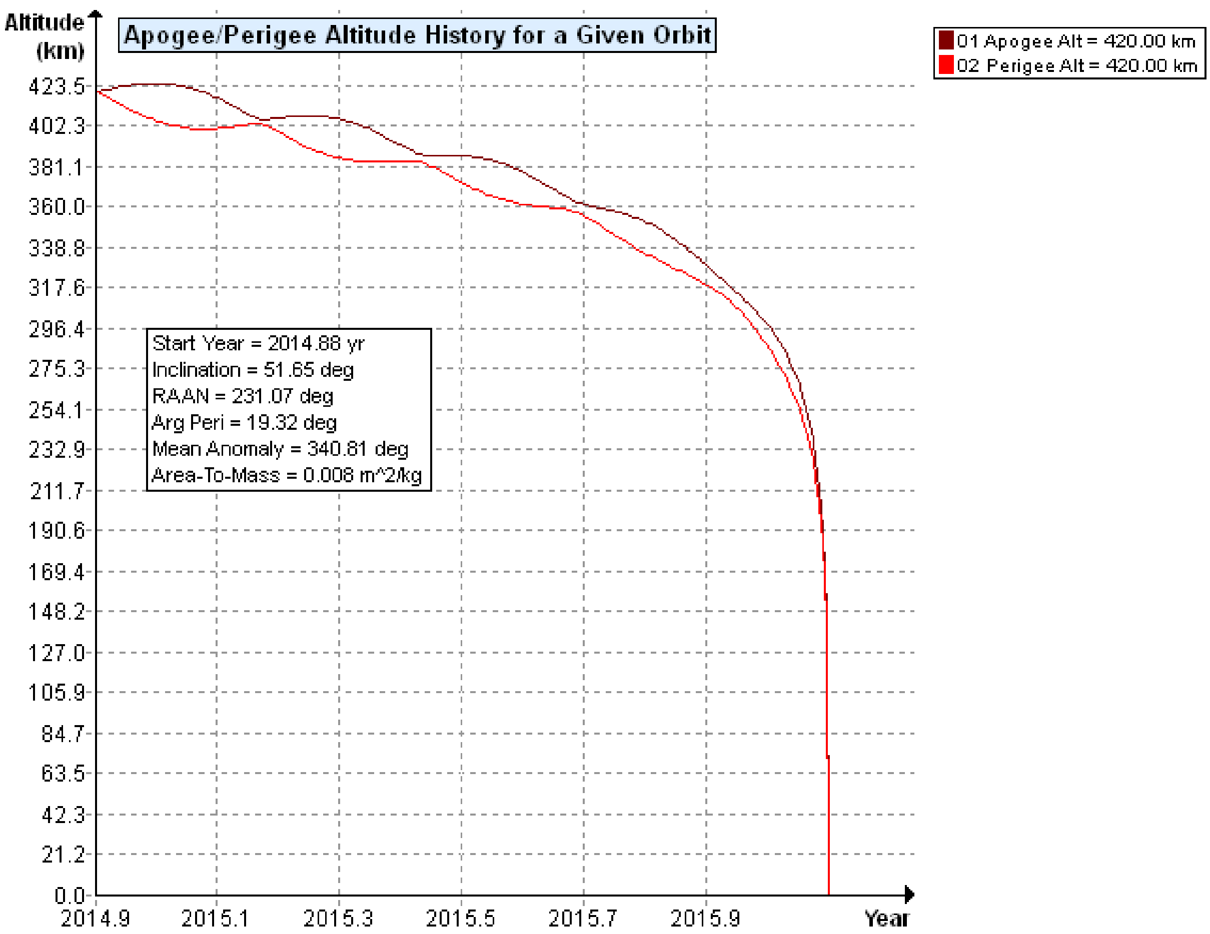

Figure 3: Altitude History of Centennial-1.

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 Post Mission Disposal Operations

Analysis: The normal configuration is the aerodynamically stable state, meaning that even under massive subsystem failure we would eventually assume this orientation.

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 Centennial-1 is compliant with the requirement. Total human casualty probability is reported by the DAS software as less than **1:10,000** for Centennial-1. This is expected to represent the absolute maximum casualty risk, as calculated with DAS's limited modeling capability.

Analysis (per DAS v2.0.2):

05 23 2014; 10:53:38AM DAS Application Started
05 23 2014; 10:53:40AM Opened Project C:\Program Files (x86)\NASA\DAS 2.0\Centennial-1\
05 23 2014; 10:54:57AM Mission Editor Changes Applied
05 23 2014; 10:55:12AM Mission Editor Changes Applied
05 23 2014; 10:55:15AM Mission Editor Changes Applied
05 23 2014; 10:55:25AM Processing Requirement 4.3-1: Return Status : Not Run

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-1 ===============
05 23 2014; 10:55:29AM Processing Requirement 4.3-2: Return Status : Passed

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-2 ===============
05 23 2014; 10:55:32AM Requirement 4.4-3: Compliant

=============== End of Requirement 4.4-3 ===============
05 23 2014; 10:55:35AM Processing Requirement 4.5-1: Return Status : Passed

==============
Run Data
==============

INPUT

Space Structure Name = Centennial-1
Space Structure Type = Payload
Perigee Altitude = 420.000000 (km)
Apogee Altitude = 420.000000 (km)
Inclination = 51.645600 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.007700 (m^2/kg)
Start Year = 2014.875000 (yr)
Initial Mass = 1.300000 (kg)
Final Mass = 1.300000 (kg)
Duration = 0.500000 (yr)
Station-Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Collision Probability = 0.000000
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
05 23 2014; 10:55:38AM Requirement 4.5-2: Compliant
05 23 2014; 10:55:39AM Processing Requirement 4.6 Return Status : Passed

==============
Project Data
==============

INPUT

Space Structure Name = Centennial-1
Space Structure Type = Payload

Perigee Altitude = 420.000000 (km)
Apogee Altitude = 420.000000 (km)
Inclination = 51.645600 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.007700 (m^2/kg)
Start Year = 2014.875000 (yr)
Initial Mass = 1.300000 (kg)
Final Mass = 1.300000 (kg)
Duration = 0.500000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 383.968096 (km)
PMD Apogee Altitude = 391.769883 (km)
PMD Inclination = 51.639558 (deg)
PMD RAAN = 169.106414 (deg)
PMD Argument of Perigee = 146.521649 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Suggested Perigee Altitude = 383.968096 (km)
Suggested Apogee Altitude = 391.769883 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2016 (yr)
Requirement = 61
Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
05 23 2014; 10:56:33AM *********Processing Requirement 4.7-1
Return Status : Passed

***********INPUT****
Item Number = 1

name = Centennial-1
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 1.300000
Thermal Mass = 1.300000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Centennial-1
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.300000
Thermal Mass = 1.300000
Diameter/Width = 0.100000
Length = 0.100000

Height = 0.100000

**************OUTPUT****
Item Number = 1

name = Centennial-1
Demise Altitude = 77.996918
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Centennial-1
Demise Altitude = 65.210062
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

=============== End of Requirement 4.7-1 ===============

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because Centennial-1does not use controlled reentry.

4.7-1, b) **NOT APPLICABLE**. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

4.7-1 c) **NOT APPLICABLE**. For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

<u>ODAR Section 8: Assessment for Tether Missions</u>

Not Applicable. There are no tethers in the Centennial-1 mission.

END of ODAR for Centennial-1