ALTAIR Pathfinder Orbital Debris Assessment Report (ODAR)

In accordance with NPR 8715.6A, this report is presented as compliance with the required reporting format per NASA-STD-8719.14, APPENDIX A.

Note: This analysis only covers Millennium Space Systems spacecraft, ALTAIR Pathfinder.

No analysis is implied for the launch vehicle or other systems.

Report Version: 1.0

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DAS Software Version Used In Analysis: v2.0.2

This document is a part of the ALTAIR Pathfinder Satellite Project Documentation, which is controlled by the ALTAIR Pathfinder Project Configuration Manager.

SUBMITTED TO:

Vince Deno
President and COO
Millennium Space Systems

APPROVED BY:

Matt Baker
ALTAIR Pathfinder Program Manager
Millennium Space Systems

SUBMITTED BY:

Michael L. Miller, P.E.
Consulting Engineer
Sterk Solutions Corporation

Eric Drucker
Space Vehicle Systems Engineer
Millennium Space Systems

Record of Revisions

REV	DATE	AFFECTED PAGES	DESCRIPTION OF CHANGE	AUTHOR (S)
1.0	April 7, 2016	All	Original Release	Eric Drucker Mike Miller

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Self Assessment of ODAR Requirements (per Appendix A.2 Of NASA-STD-8719.14):

The orbital debris self-assessment matrix following, summarizes the result of this report. The template for this table is provided in Appendix A.2 of NASA-STD-8719.14. This is provided for the convenience of those to whom it may concern

Orbital Debris Self-Assessment Report Evaluation: ALTAIR Pathfinder Mission

Requirement #	Launch Vehicle (Not Applicable (see note 1))				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No intentional release of debris in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No intentional release of debris in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	N/A - LEO. See note 1.
4.4-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-2	☐	☐	☒	☐	☒	☐	☐	ALTAIR Pathfinder only has batteries that will be passivated at mission end.
4.4-3	☐	☐	☒	☐	☒	☐	☐	Compliant. No planned breakups. See note 1.
4.4-4	☐	☐	☒	☐	☒	☐	☐	Compliant. No planned breakups. See note 1.
4.5-1	☐	☐	☒	☐	☒	☐	☐	Compliant. See note 1.
4.5-2	☐	☐	☒	☐	☒	☐	☐	Compliant. See note 1.
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					☒	☐	☐	NA. No tethers used.

Notes:

1. The launch vehicle is the responsibility of others.

Assessment Report Format

ODAR Technical Sections Format Requirements:

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the required content in each section, 2 through 8, below for the Millennium Space Systems ALTAIR Pathfinder satellite. Sections 9 through 14 of the standard apply to the launch vehicle ODAR and are not covered here since the launch vehicle is the responsibility of a separate project.

ODAR Section 1: Program Management and Mission Overview

ALTAIR Pathfinder Project manager: Matt Baker

Senior Management: Vince Deno, President

Foreign government or space agency participation: None.

Summary of NASA's responsibility under the governing agreement(s): N/A.

Schedule of mission design and development milestones from mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates:

Mission Preliminary Design Review:	March 2, 2016
Mission Critical Design Review:	April 15, 2016
MRR:	May 3, 2016
PSRR:	May 23, 2016
Launch:	June 24, 2016

Mission Description:

The ALTAIR Pathfinder satellite launches as cargo manifested by Nanoracks, Inc., to the International Space Station (ISS). ALTAIR Pathfinder will be deployed from the ISS into Low Earth Orbit (LEO). The primary experiment functions include testing the attitude control system, and an experimental radio receiver. These experiments will be completed within 6 months of launch. Data from the experiments are recovered daily via ground stations. The satellite will operate in its elliptical orbit using an active Attitude Determination and Controls System (ADCS) (star tracker, reaction wheel, and magnetorquers) for stabilization until natural orbit decay results in reentry. There are no propellants.

Launch vehicle and launch site:

Antares CRS-OA-5 resupply flight, launching from Wallops Flight Facility, Virginia, USA

Proposed launch date and Mission Duration:

Launch Date: June 24, 2016 (estimated).

Mission Duration: (6 months active mission, orbital life estimated at 1.2 years by DAS analysis.)

From the time of launch, the spacecraft is expected to remain in LEO for about 1.2 years, prior to reentry after natural decay of the orbit. However, the planned mission operations are to last only six months after launch. Upon the decision to stop active operations, commands will be sent to the spacecraft to lower the battery voltage setpoint such that the energy stored in the battery is

decreased to 25% or less of full charge. This leaves the spacecraft inactive and de-energized. It will re-enter through natural decay of its orbit.

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

ALTAIR Pathfinder launches from the Nanoracks deployer on the ISS.

ALTAIR Pathfinder is deployed to, operates in, and decays naturally from, the orbit defined as follows:

Orbital Lifetime: 1.2 Years (Per DAS 2.0.2)
Perigee: 409 km
Apogee: 416 km
Inclination: 51.65 degrees
RAAN: 343.26 degrees
Argument of perigee: 94.93 degrees
Ecc: 0.0007016
Period: 92.69 minutes
Mass: 14.07 kg

Reasons for Selection of the Operational Orbit:

The orbit was selected because of accessibility from the ISS. It allows timely passive disposal of the spacecraft by natural decay of orbit.

Identification of interaction or potential physical interference with other operational spacecraft:

The collision probability with the ISS, is assumed to be included in a separate jettison analysis for all CubeSats deployed from the ISS, performed by the JSC-TOPO team, to verify there is no risk of re-contact with the ISS upon deployment. A minimum interval of 3 hours between deployments, is provided.

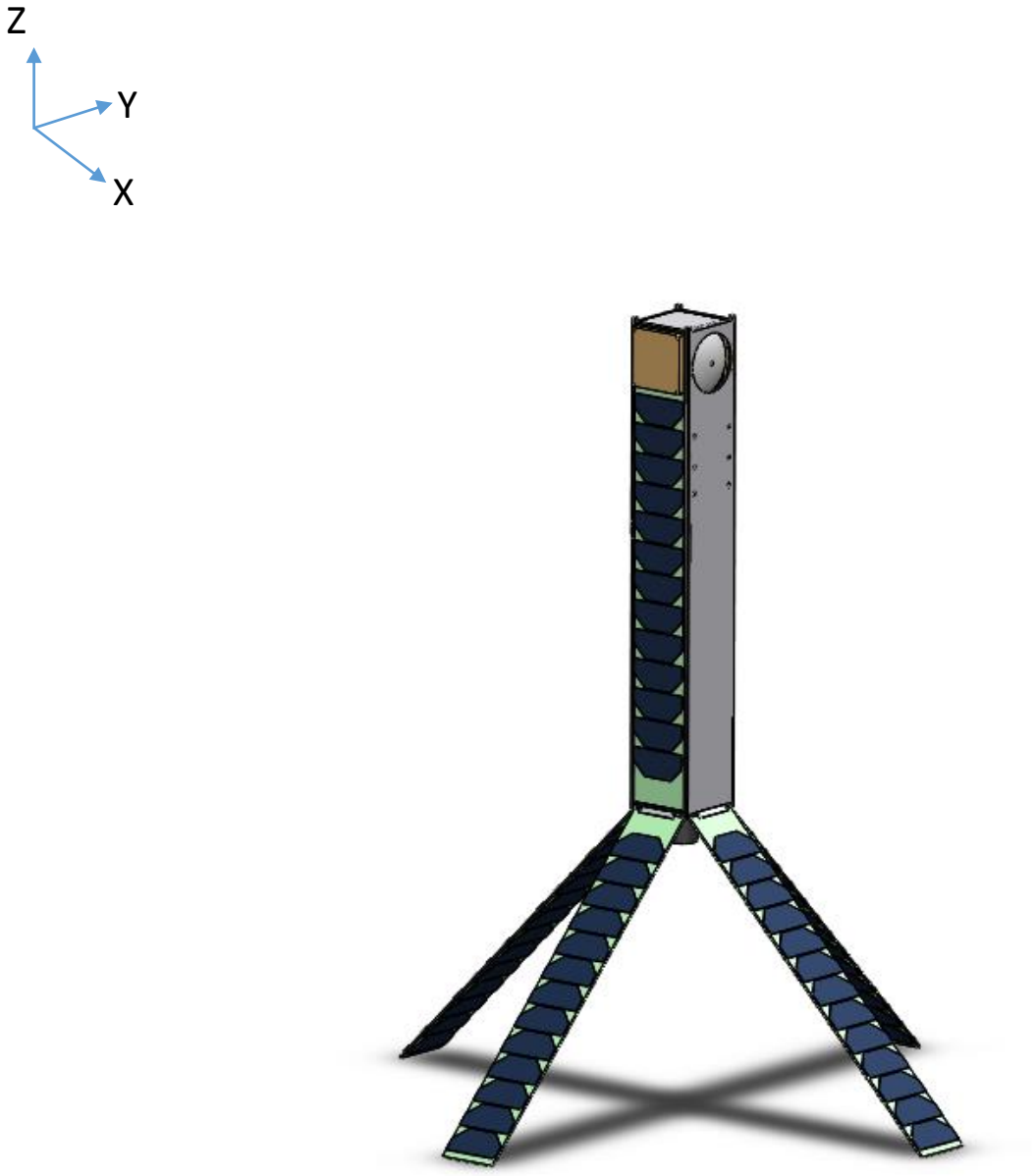
ALTAIR Pathfinder has no propulsion and therefore does not actively change orbits. There is no parking or transfer orbit.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

ALTAIR Pathfinder is a Cubesat with stowed outer dimensions of 10 cm x 10 cm x 68 cm. The satellite structure is thermoplastic polymer composite material, with 2 6061-T6 aluminum panel/rails.

Figure 1 ALTAIR Pathfinder Satellite Overview



ALTAIR Pathfinder has one radio transceiver, one experimental receiver, a battery pack, attitude determination and control system and flight computer system. Four deployable solar arrays, with cells on both sides, are shown attached to the sides.

There is no propulsion system.

Total satellite mass at launch, including all propellants and fluids: 14.07 kg.

Dry mass of satellite at launch, excluding solid rocket motor propellants: 14.07 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. ALTAIR Pathfinder uses unpressurized COTS Panasonic NCR18650B, lithium cobalt battery cells.

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

ALTAIR Pathfinder uses one single axis reaction wheel and four electromagnetic torque coils for attitude control.

An inertial measurement unit (IMU) provides rate sensing. A 3-Axis Magnetometer (TAM) senses local magnetic field to enable coarse vehicle attitude estimate. It is used to compute magnetic torque to unload stored momentum.

External attitude determination is periodically performed with a star tracker.

A GPS receiver is used to determine position, velocity and ephemeris.

Normal attitude is +Z axis (see Figure 1) in direction of travel.

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

Description of the electrical generation and storage system: The electric generation and storage system is a direct energy transfer system using a solar array producing approximately 16W of orbit average power to charge the 6.4 A-hr battery system. The solar arrays utilize standard SolAero photovoltaic cells; the batteries are COTS Panasonic 18650B cells.

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)

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

***Requirement 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 planned intentional breakup and 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:

Failure of a battery cell or 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 the 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:

Only the battery pack contains stored energy. Passivation is implemented by use of a commanded "Disposal Mode", which is initiated in the on board software. When in disposal mode the system reduces the stored energy in the batteries to about 25% of full charge.

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

Not applicable.

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 (0.1%) excluding small particle impacts (Requirement 56449).

Compliance statement:

Required Probability: 1E-03, or lower.

Expected probability: 3.65E-05 total probability sum from Table 1

Supporting Rationale and FMEA details:

Payload Pressure Vessel Failure:

NA. There are no pressurized components.

Battery explosion:

Effect: All failure modes discussed below, and summarized in Table 1 below, might result in battery explosion with the possibility of orbital debris generation.

Probability: Very Low. The overall probability of an event leading to battery explosion is estimated to be less than 0.0000365 (0.00365 %) given that any of the independent (not common mode) faults listed in Table 1, can cause the ultimate effect (explosion).

Table 1: Battery Explosion Failure Modes and Probabilities

Independent Failure Mode #	P_f	
1	1.20E-05	
2	1.20E-05	
3	1.44E-10	
4	1.20E-11	
5	5E-07	
6	1.2E-08	
7	1.2E-05	
Total Probability (sum):	**3.65E-05**	**(1:27,400)**

Failure mode 1: Battery cell internal short circuit.

Mitigation 1: Complete proto-qualification and acceptance random vibration and vacuum tests followed by overvoltage and undervoltage tests, 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.

Expected Probability: 1.2E-5 based on millions of cells in circulation.

Calculation: We assume 1:10,000,000 as a baseline for manufacturer defects that could lead to internal short circuit in space use, but we derate by a factor of 10 to further

account for launch and space environment effects when added to stresses caused during screening and environmental testing.

Hence, given that we will fly 12 cells, the failure probability estimate is:

P_f = 1E-7*10*12 = 1.2E-5

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

Mitigation 2: The LiNiMnCoO2 battery chemistry is inherently insensitive to internal thermal rise even under very high discharge rates of 20C (>40 Amps) through full discharge. Normal discharge is expected to be less than 1.67 Amps for the heaviest loaded mode. Also, protection devices are provided for each cell, per NASA requirement JSC 20793, as implemented by NanoRacks NR-SRD-139, for battery protection at the cell level.

This device limits the current flow through the cell, to less than 3.571 Amps.

Combined faults required for realized failure: Battery manufacture must be flawed resulting in gross differences in thermal sensitivity relative to what is normal for LiNiMnCoO2 cells, **AND** the overcurrent limiting feature of the cell protection device must fail.

Expected Probability: 1.2E-5 based on millions of cells in circulation. (See failure mode 1 for calculation.)

Failure Mode 3: Excessive charge rate, or over-voltage charging.

Mitigation 3:

Excessive Charge Rate: Charge current limits cannot be exceeded since solar panels can generate no more than about 1.41 Amps. The battery pack is rated for 3.2 Amps of charge current for fast charging, so there is no design failure mode related to charge rate.

Over Voltage Charging: The charge control circuit design eliminates the possibility of over voltage charging if this circuit function nominally. This circuit will be proto-qualification tested for survival in vibration and thermal-vacuum environments. In addition, protection devices are provided for each cell, per NR-SRD-139 as described above. This device limits the cell voltage to less than 4.275 Volts, and disconnects the cell from the string if the voltage exceeds that limit.

The charge control circuit disconnects the incoming current when battery voltage indicates full charge at 4.1 V per cell (or less, depending on software adjustable full charge voltage setpoint). If this circuit fails to disconnect the incoming current when the battery voltage reaches setpoint, continuing charge will not cause gas generation, and in any case, the batteries include vents that allow any gas that would form to escape, thus avoiding pressurization. Also, the cell protection device will disconnect the cell from the string, and consequently open circuit the entire string, if the cell voltage exceeds 4.275 V.

Combined faults required for realized failure:

1) For excessive charge rate: As discussed previously, there is no credible failure mode that would allow excessive charge rate. The solar panels cannot generate current beyond the allowable charge rate of the battery cells.

2) For over-voltage charging: The charge control circuit must fail to function, **AND** the overvoltage protection circuit must fail to function, **AND** gasses must be generated contrary to specified behavior, **AND** the vent must be inadequate to vent any such generated gasses at acceptable rates to avoid explosion.

Estimated Probability: 1.2E-11 based on millions of cell vents in circulation and necessity of concurrent failure of the charge controller and overvoltage protection circuit.

> Calculation: Again, we assume 1:10,000,000 as a baseline for generic failure probability of the vents, but we derate by a factor of 10 to further account for launch and space environment effects when added to stresses caused during screening and environmental testing. We also assume 1:10,000,000 failure probability for simultaneous failure of the charge control circuit and an overvoltage protection circuit, and again we derate by a factor of 10 to further account for launch and space environment effects when added to stresses caused during screening and environmental testing.
>
> Hence, given that we will fly 12 cells with one overvoltage protection circuit for each cell, where one cell vent must fail AND the charge controller / overvoltage protection combination must fail, the failure probability is no greater than:
>
> P_f = 1E-7*10*12*1E-7*10*12 = 1.44E-10.

Failure Mode 4: Excessive discharge rate from 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 mitigated by a) proto-qualification tested overcurrent protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces or conductive panels 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 and thermal-vacuum tests), and d) protection devices are provided for each cell, per NR-SRD-139 as described above.

Combined faults required for realized failure: Battery vent of a cell must fail **AND** an external circuit must fail/short-circuit **AND** the current limiting feature of the cell protection device must fail, to enable this failure mode.

Estimated Probability: Based on millions of cells in use, and proto-qualification verified reliability of payloads and subsystems.

Calculation: Again, we assume 1:10,000,000 as a baseline for generic failure probability of the vents, but we derate by a factor of 10 to further account for launch and space environment effects when added to stresses caused during screening and environmental testing. The generic failure probability of a cell associated protection device current limiting feature is estimated to be 1:10,000,000, derated to 1:1,000,000.

Hence, given 12 cells, the failure probability is:

P_f = (1E-7*10/cell *1E-7*10/Cell protection Device*12 cells = 1.2E-11.

Failure Mode 5: Crushing

Mitigation 5: This mode is nearly negated by spacecraft design and by use of LiNiMnCoO2 cell technology. However, there is a remote probability of secondary explosion due to crushing that might be caused by large orbital debris impacts. Therefore, DAS calculations for requirement 4.5-1 will be used to estimate probability of failure due to crushing.

Combined faults required for realized failure: A debris or meteorite impact must cause a catastrophic failure in an external system **AND** the failure must allow for 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.

Estimated Probability: Less than 0.0000005, or 5E-7, based on a worst case large object collision probability calculated in requirement 4.5-1.

Failure Mode 6: Excess temperatures due to orbital environment and high discharge rate 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 which are well below temperatures of concern for explosions. Also, protection devices that limit current flow are provided for each cell, per NR-SRD-139 as described above.

Combined faults required for realized failure: Thermal analysis models **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** individual cell protection device over-current monitoring and control function, must all fail for this failure mode to occur.

Expected Probability: The generic failure probability of an individual cell protection device overcurrent control function is estimated as 1:10,000,000, but will be derated to 1:1,000,000 as an environmental derating assumption for space applications. Given that thermal modeling and margined environmental test are human operated procedures, there is some probability of modeling, design and test performance error which could leave a latent failure mode

unscreened. This procedural failure probability will be assessed as 3E-3 assuming peer reviews of designs, models, testing, and validated checklists applied to procedures (NUREG/CR-1278).

Hence, failure probability is: P_f = 1E-7*10*12*1E-3= 1.2*E-8.

Failure Mode 7: Polarity reversal due to over-discharge caused by continuous load during periods of negative power generation vs. consumption, combined with battery voltage differences. Under this condition, the battery cell that discharges completely, to zero voltage, first will have current forced through opposite the usual direction of flow, by batteries that are still capable of discharging. This is, in effect, reverse charging and it will damage the weakest cell.

Mitigation 7: Individual cell protection devices that limit low voltage to no less than 2.8 V, by disconnecting the cell, are provided for each cell, per NR-SRD-139 as described above.

*Combined faults required for realized failure: S*ignificant loads must be commanded/stuck "on" **AND** cell protection device low voltage protection function must fail.

Expected Probability: 1E-6. The generic failure probability of the cell protection device low voltage failure is estimated to be 1:10,000,000, but will be derated to 1:1,000,000 to match the environmental derating assumptions used for battery cells in circulation.

Hence, failure probability is: P_f = 1E-6*12 = 1.2E-5

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 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 (Requirement 56450).

Compliance statement:
Compliant. The spacecraft Electrical Power Subsystem (EPS) provides partial passivation capability. The passivation occurs when "EPS Disposal Mode" is commanded. This mode reduces the voltage setpoint such that the energy stored in the battery is reduced by 75 percent.

In addition, compliance with the requirement "control (battery charge) to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft" is met, by virtue of the assessment associated with requirement 4.4.1.

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, 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).

- **DAS 2.0.2 Calculation:**

  Large Object Impact and Debris Generation Probability:

  Less than 0.0000005; COMPLIANT.

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 post mission disposal requirements is less than 0.01 (Requirement 56507).

- **DAS 2.0.2 Calculation:**

  Probability of Damage from Small Debris:

  Probability of Penetration = 0.000001; COMPLIANT

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

  As there is no propellant, no maneuvering is possible.

  Systems required for accomplishing post-mission passivation: Passivation via ground command requires radio and spacecraft processor, along with adequate power to operate these systems.

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

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal: None

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

Spacecraft Mass: 14.07 kg

Cross-sectional Area: 0.1504 m^2 for the configuration described in section 2, figure 1, assuming the +Z axis is in the direction of travel.

Area to mass ratio: 0.1504/14.7 = 0.0102 m^2/ kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0 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 ALTAIR Pathfinder satellite reentry is COMPLIANT using method "a. Atmospheric reentry option." ALTAIR Pathfinder will be left in a near circular orbit at the end of the 6 month mission: apogee 375 km; perigee 370 km, reentering about 1.2 years after launch with orbit history as shown in Figure 2.

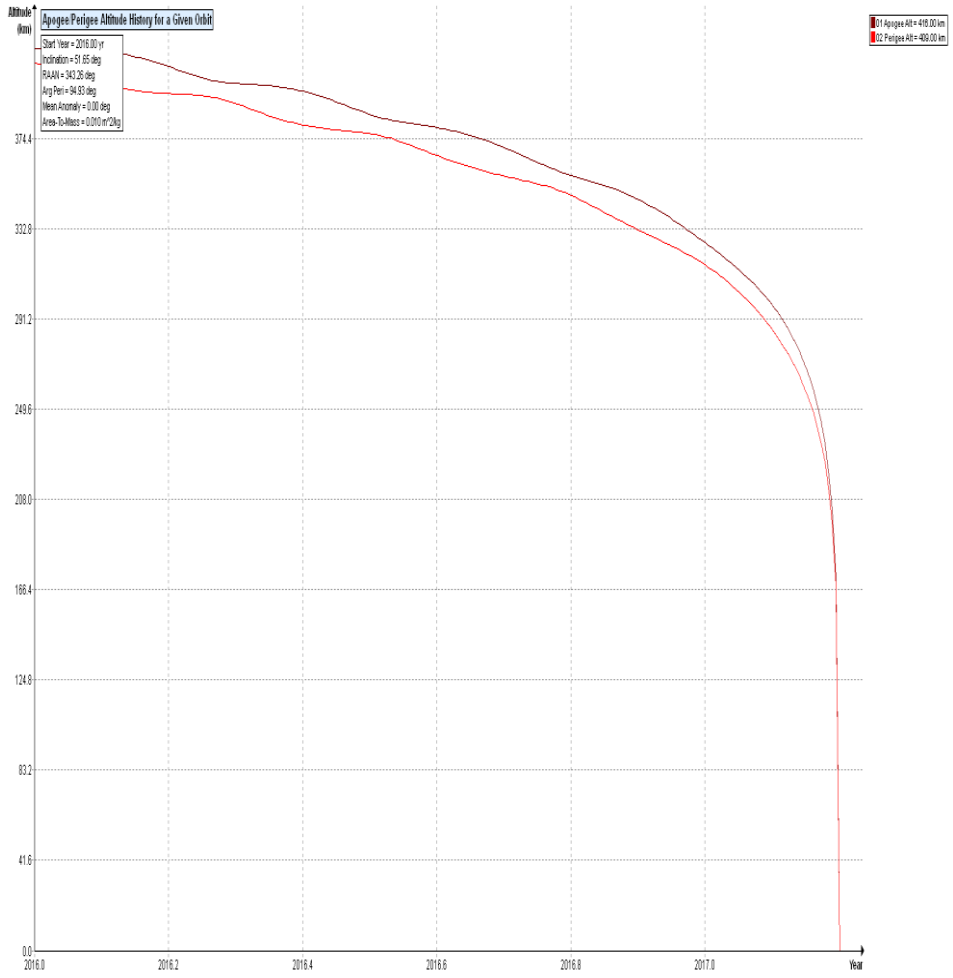


Figure 2, ALTAIR Pathfinder Projected Orbit History

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

Analysis: Not applicable. ALTAIR Pathfinder orbit is LEO.

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

Analysis: Not applicable. ALTAIR Pathfinder orbit is LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: For purposes of performing a margined analysis, we will assume that the operational mission becomes extended up to one (1) year post-launch, and the ALTAIR Pathfinder battery passivation will occur at the end of the one year period when commanded by the ground. This is doubly conservative, in that it is planned to execute the end of mission operation after six months,

and also, at about 1.2 years after launch, the spacecraft is expected to deorbit regardless of any end of mission action.

Reliability of this function is exceeds 99%, based on combined reliability of COTS electronics to functionally survive after 1 year of space exposure.

Radiation design factor (RDF) is estimated to be very large (greater than 5) using SPENVIS and SHIELDOSE-2 trapped particle, *Bremsstralung*, and Solar Protons, plus estimated GCR. The SPENVIS data is the result of a worst case aluminum sphere shielding assumption around a silicon target. The RDF estimate is based on a generally accepted rule of thumb that COTS electronics can typically withstand 5 kRAD exposures ("Spacecraft Systems Engineering", 3ed; c. John Wiley and Sons, Ltd.; P. Fortescue, J. Stark, and G. Swinerd editors.).

To exceed 5 kRAD dose, multiple large Solar Particle Events (SPE's) resulting in >4 kRAD additional dose would have to occur within the 1 year period. This represents more than eight (8) times the predicted solar proton dose for the shielding model analyzed and is therefore a negligible possibility.

Therfore, the reliability of the electronics needed to passivate the batteries is best derived from the generic reliability of COTS electronics after burn-in testing and environmental stress screening tests, rather than from the much lower random probability of a disabling GCR hit. In this regard, any one of eight (8) independent critical electronics boards would need to fail to prevent the passivation function from occurring. These circuit boards have been assessed to have generic life failure probability of ~1E-8/hr each. So, for a one year mission, the total failure probability due to component life failure is estimated as:

Pf = (8*1E-8/hr)*(8760 hr/yr)*(1 yr)*100 = 0.07%

That is, there is roughly one (1) chance of functional failure of the battery passivation "disposal" design in 1,484 design-identical 1 year missions based on generic design reliability expectations.

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 ALTAIR Pathfinder is COMPLIANT with demise altitudes above 48 km for all components. **Total human casualty probability is reported by the DAS software as 1:0, which is interpreted as zero probability (no probability could be calculated given that no impacts are expected).** As seen in the analysis outputs provided in Appendix A below, the impact kinetic energy is 0.0 Joules and Debris Casualty Area is 0.0 m^2.

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because ALTAIR Pathfinder does 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).

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the ALTAIR Pathfinder mission.

****

END of ODAR for ALTAIR Pathfinder.

Appendix A: Analysis per DAS v2.0.2

```
04 05 2016; 20:53:31PM   DAS Application Started
04 05 2016; 20:53:33PM   Opened Project C:\Users\Mike\Documents\All
SatLicensing\MillSpace\ODAR\DAS\
04 05 2016; 20:53:39PM   Opened Project C:\Users\Mike\Documents\All
SatLicensing\MillSpace\ODAR\DAS\
04 05 2016; 20:54:43PM   Processing Requirement 4.5-1: Return Status :
Passed

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

**INPUT**

     Space Structure Name = Altair
     Space Structure Type = Payload
     Perigee Altitude = 409.000000 (km)
     Apogee Altitude = 416.000000 (km)
     Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass Ratio = 0.010200 (m^2/kg)
     Start Year = 2016.000000 (yr)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Duration = 1.000000 (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 ==============
04 05 2016; 20:55:17PM   Requirement 4.5-2:  Compliant

=================================================
Spacecraft = Altair
Critical Surface = Antenna
=================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.001020 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No

**OUTPUT**

     Probabilty of Penitration = 0.000001
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

=================================================
Spacecraft = Altair
Critical Surface = Radio
=================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
```

```
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.003000 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 0.432000 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

================================================
Spacecraft = Altair
Critical Surface = Battery 1
================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.008190 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
```

```
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 10.033000 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

================================================
Spacecraft = Altair
Critical Surface = Battery 2
================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.008190 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 12.776200 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

================================================
Spacecraft = Altair
Critical Surface = Battery 3
================================================
```

```
**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.008190 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 56.235600 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

================================================
Spacecraft = Altair
Critical Surface = Battery 4
================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
```

```
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.008190 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 58.978800 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range

================================================
Spacecraft = Altair
Critical Surface = Level 0 Board
================================================

**INPUT**

     Apogee Altitude = 416.000000 (km)
     Perigee Altitude = 409.000000 (km)
     Orbital Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.010200 (m^2/kg)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Station Kept = No
     Start Year = 2016.000000 (yr)
     Duration = 1.000000 (yr)
     Orientation = Fixed Oriented
     CS Areal Density = 2.700000 (g/cm^2)
     CS Surface Area = 0.008190 (m^2)
     Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
     CS Pressurized = No
     Outer Wall 1   Density: 2.700000 (g/cm^2)  Separation: 16.713200 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000000
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range
```

```
04 05 2016; 20:55:21PM   Processing Requirement 4.6    Return Status :
Passed

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

**INPUT**

     Space Structure Name = Altair
     Space Structure Type = Payload

     Perigee Altitude = 409.000000 (km)
     Apogee Altitude = 416.000000 (km)
     Inclination = 51.650000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Area-To-Mass Ratio = 0.010200 (m^2/kg)
     Start Year = 2016.000000 (yr)
     Initial Mass = 14.070000 (kg)
     Final Mass = 14.070000 (kg)
     Duration = 1.000000 (yr)
     Station Kept = False
     Abandoned = True
     PMD Perigee Altitude = 320.809029 (km)
     PMD Apogee Altitude = 327.852598 (km)
     PMD Inclination = 51.639646 (deg)
     PMD RAAN = 312.312220 (deg)
     PMD Argument of Perigee = 110.197728 (deg)
     PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

     Suggested Perigee Altitude = 320.809029 (km)
     Suggested Apogee Altitude = 327.852598 (km)
     Returned Error Message = Passes LEO reentry orbit criteria.

     Released Year = 2017 (yr)
     Requirement = 61
     Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
04 05 2016; 20:55:51PM   *********Processing Requirement 4.7-1
```

```
     Return Status :  Passed

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

name = Altair
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 14.070000
Thermal Mass = 14.070000
Diameter/Width = 0.118000
Length = 0.685800
Height = 0.118000

name = Heat Spreader
quantity = 3
parent = 1
materialID = 8
type = Box
Aero Mass = 0.172365
Thermal Mass = 0.172365
Diameter/Width = 0.091400
Length = 0.096500
Height = 0.021000

name = Radio
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.371945
Thermal Mass = 0.371945
Diameter/Width = 0.082600
Length = 0.082600
Height = 0.046200

name = Patch Antenna
quantity = 2
parent = 1
materialID = 19
type = Box
Aero Mass = 0.077111
Thermal Mass = 0.077111
Diameter/Width = 0.082600
```

```
Length = 0.082600
Height = 0.012700

name = 6U Printed Structure
quantity = 1
parent = 1
materialID = 77
type = Box
Aero Mass = 0.816000
Thermal Mass = 0.816000
Diameter/Width = 0.096500
Length = 0.685800
Height = 0.096500

name = Side Panel
quantity = 2
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.385550
Thermal Mass = 0.385550
Diameter/Width = 0.096500
Length = 0.660400

name = Solar Panel
quantity = 4
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.498950
Thermal Mass = 0.498950
Diameter/Width = 0.086400
Length = 0.584200

name = Generic Boards
quantity = 12
parent = 1
materialID = 77
type = Flat Plate
Aero Mass = 0.081600
Thermal Mass = 0.081600
Diameter/Width = 0.091400
Length = 0.096500

name = Batteries
quantity = 6
```

```
parent = 1
materialID = 54
type = Box
Aero Mass = 0.081647
Thermal Mass = 0.081647
Diameter/Width = 0.019100
Length = 0.066000
Height = 0.019100

name = PIC Bracket
quantity = 1
parent = 1
materialID = 54
type = Box
Aero Mass = 4.127687
Thermal Mass = 4.127687
Diameter/Width = 0.050000
Length = 0.235000
Height = 0.050000

name = PIC Board
quantity = 1
parent = 1
materialID = 5
type = Flat Plate
Aero Mass = 0.317514
Thermal Mass = 0.317514
Diameter/Width = 0.114300
Length = 0.114300

name = MAST Heat Sink
quantity = 1
parent = 1
materialID = 19
type = Flat Plate
Aero Mass = 0.127000
Thermal Mass = 0.127000
Diameter/Width = 0.063500
Length = 0.096500

name = GPS Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.113398
```

```
Thermal Mass = 0.113398
Diameter/Width = 0.066000
Length = 0.066000
Height = 0.019100

name = RW Assembly
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.326796
Thermal Mass = 0.226796
Diameter/Width = 0.063500
Length = 0.076200
Height = 0.043200

name = Wheel
quantity = 1
parent = 14
materialID = 54
type = Cylinder
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.063000
Length = 0.028000

name = PIC Heatsink
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.529990
Thermal Mass = 0.529990
Diameter/Width = 0.114300
Length = 0.235000
Height = 0.009500

name = Body Mounted Arrays
quantity = 2
parent = 1
materialID = 24
type = Box
Aero Mass = 0.099990
Thermal Mass = 0.099990
Diameter/Width = 0.030000
Length = 0.660400
```

```
Height = 0.001000

name = SA Hinges
quantity = 4
parent = 1
materialID = 8
type = Box
Aero Mass = 0.019999
Thermal Mass = 0.019999
Diameter/Width = 0.038100
Length = 0.076200
Height = 0.025400

name = MAST
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.319900
Thermal Mass = 0.319900
Diameter/Width = 0.076200
Length = 0.076200
Height = 0.050800

name = PIC PIM
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.299990
Thermal Mass = 0.299990
Diameter/Width = 0.108000
Length = 0.108000
Height = 0.023000

name = SOM
quantity = 1
parent = 1
materialID = 19
type = Box
Aero Mass = 0.099990
Thermal Mass = 0.099990
Diameter/Width = 0.050800
Length = 0.076200
Height = 0.006400
```

```
name = GPS Receiver
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.024000
Thermal Mass = 0.024000
Diameter/Width = 0.045700
Length = 0.071100
Height = 0.011000

name = Ballast
quantity = 1
parent = 1
materialID = 54
type = Box
Aero Mass = 1.680000
Thermal Mass = 1.680000
Diameter/Width = 0.061000
Length = 0.088900
Height = 0.050800

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

name = Altair
Demise Altitude = 77.998074
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Heat Spreader
Demise Altitude = 75.221511
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Radio
Demise Altitude = 72.302050
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Patch Antenna
Demise Altitude = 76.586019
Debris Casualty Area = 0.000000
```

```
Impact Kinetic Energy = 0.000000

************************************
name = 6U Printed Structure
Demise Altitude = 77.673582
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Side Panel
Demise Altitude = 76.438761
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Panel
Demise Altitude = 77.078152
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Generic Boards
Demise Altitude = 77.632465
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Batteries
Demise Altitude = 71.764566
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PIC Bracket
Demise Altitude = 48.348823
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PIC Board
Demise Altitude = 72.599816
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = MAST Heat Sink
```

```
Demise Altitude = 75.544910
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS Antenna
Demise Altitude = 75.017254
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = RW Assembly
Demise Altitude = 74.383308
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Wheel
Demise Altitude = 66.965784
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PIC Heatsink
Demise Altitude = 74.038121
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Body Mounted Arrays
Demise Altitude = 77.764387
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SA Hinges
Demise Altitude = 77.480832
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = MAST
Demise Altitude = 73.241339
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = PIC PIM
Demise Altitude = 77.264465
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SOM
Demise Altitude = 75.604902
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS Receiver
Demise Altitude = 77.845293
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Ballast
Demise Altitude = 53.532147
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************

=============== End of Requirement 4.7-1 ===============
04 05 2016; 20:56:46PM   Science and Engineering - Apogee/Perigee History
for a Given Orbit

**INPUT**

     Perigee Altitude = 409.000000 (km)
     Apogee Altitude = 416.000000 (km)
     Inclination = 51.650000 (deg)
     RAAN = 343.260000 (deg)
     Argument of Perigee = 94.930000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Area-To-Mass Ratio = 0.010200 (m^2/kg)
     Start Year = 2016.000000 (yr)
     Integration Time = 5.000000 (yr)

**OUTPUT**

     Plot
04 05 2016; 20:56:59PM   Science and Engineering - Orbit Lifetime/Dwell
```

```
Time

**INPUT**

     Start Year = 2016.000000 (yr)
     Perigee Altitude = 409.000000 (km)
     Apogee Altitude = 416.000000 (km)
     Inclination = 51.650000 (deg)
     RAAN = 343.260000 (deg)
     Argument of Perigee = 94.930000 (deg)
     Area-To-Mass Ratio = 0.010200 (m^2/kg)

**OUTPUT**

     Orbital Lifetime from Startyr = 1.210130 (yr)
     Time Spent in LEO during Lifetime  = 1.210130 (yr)
     Last year of Propagation = 2017 (yr)
     Returned Error Message: Object reentered
```

Appendix B: Acronyms

ADCS	Attitude Determination and Control Subsystem
Arg peri	Argument of Perigee
CDR	Critical Design Review
cm, cm^2	Centimeter, centimeters squared
COTS	Commercial Off-The-Shelf (items)
DAS	Debris Assessment Software
EOM	End Of Mission
EPS	Electrical Power Subsystem
GEO	Geosynchronous Earth Orbit
ALTAIR Pathfinder	ALTAIR Pathfinder Spacecraft Bus and Payloads
ITAR	International Traffic In Arms Regulations
kg	kilogram
km	kilometer
LEO	Low Earth Orbit
LiNiMnCoO2	Lithium Nickel Manganese Cobalt Dioxide
m^2	Meters squared
MSS	Millennium Space Systems
mm	millimeter
MRR	Mission Readiness Review
N/A	Not Applicable.
NASA	National Aeronautics and Space Administration
OBCS	On Board Computer System
ODAR	Orbital Debris Assessment Report
ODPO	Orbital Debris Program Office
ORR	Operations Readiness Review
OSMA	(NASA) Office of Safety and Mission Assurance
PDR	Preliminary Design Review
PSIa	Pounds Per Square Inch, absolute
PSRR	Pre-Ship Readiness Review
RAAN	Right Ascension of the Ascending Node
SC	Spacecraft Bus and Payloads
SIP	Separation Imager Payload
SMA	Safety and Mission Assurance
Telecom	Telecommunications Subsystem
yr	year