Aeneas Summary Orbital Debris Assessment Report

(ODAR)
Summary Revision 0.1
July 11, 2012

In accordance with NPR 8715.6A, this report is presented as compliance with the reporting format per requirement set by Launch Provider and Mission Integrator

DAS Software Used in This Analysis: DAS V2.0

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Record of Revisions

Revision	Date	Pages	Description	Author

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Self-assessment and OSMA assessment of the ODAR using the format in the 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. In the final ODAR document, this assessment will reflect any inputs received from OSMA as well.

Orbital Debris Self-Assessment Report Evaluation: Aeneas Mission

Requirement	**Compliance Assessment**	**Comments**
4.3-1a	Compliant	No planned debris release
4.3-1b	Compliant	No planned debris release
4.3-2	Compliant	No planned debris release
4.4-1	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	Compliant	No planned breakups
4.4-4	Compliant	No planned breakups
4.5-1	Compliant	
4.5-2	Compliant	
4.6-1(a)	Compliant	Worst case lifetime 22 yrs, nominal lifetime of 9 years
4.6-1(b)	Compliant	
4.6-1(c)	Compliant	
4.6-2	Compliant	
4.6-3	Compliant	
4.6-4	Compliant	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	

ODAR Section 1: Program Management and Mission Overview

The Aeneas flight program is the result of 3 years of effort by the Space Engineering Research Center. It is part of the Information Sciences Institute which is the applied research arm of the University of Southern California. The SERC is directed by Dr. Joe Kunc, overseen by some ex-aerospace staff with the spacecraft build executed by students. The Aeneas spacecraft's primary emphasis is to demonstrate a proof-of-concept communications link with a ½ meter deployable dish requiring 3-axis pointing and surface tracking in a nano-satellite form factor. Mr. Tim Barrett is the project manager of the mission and can be reached at 310-448-8644. Dr. Mike Obal serves as program manager working for the future directions and support of the SERC.

A nano-satellite is commonly defined as a satellite whose total wet mass is 10 kg or less. The nano-satellite is intended to receive communications from a 1W transmitter on the ground and then downlink with another station on the ground. To achieve these goals, the satellite attempt to deploy the largest antenna made to date for a nano-satellite. The Aeneas ~ 2.4 GHz optimized antenna is ~0.5 m in diameter and deployable from a small form factor cylindrical container located forward of the center-of-mass of the satellite in the ram direction. The antenna will consist of a mesh constrained by 30 ribs with 2 joints each, as well as a deployable central mast housing the transceiver. The rib and mesh design will allow the packaged antenna to fit within the small form factor required to fit inside the payload section of the Colony I 3U Cubesat, about 10x10x16 cm. The deployment of the antenna and transceiver is accomplished using a spring. Demonstrating the successful deployment and operation of this size antenna from a nano-satellite will significantly contribute to space communication technology involving fractionated satellites, adaptive sparse aperture clusters, operational responsive space and intelligence community applications.

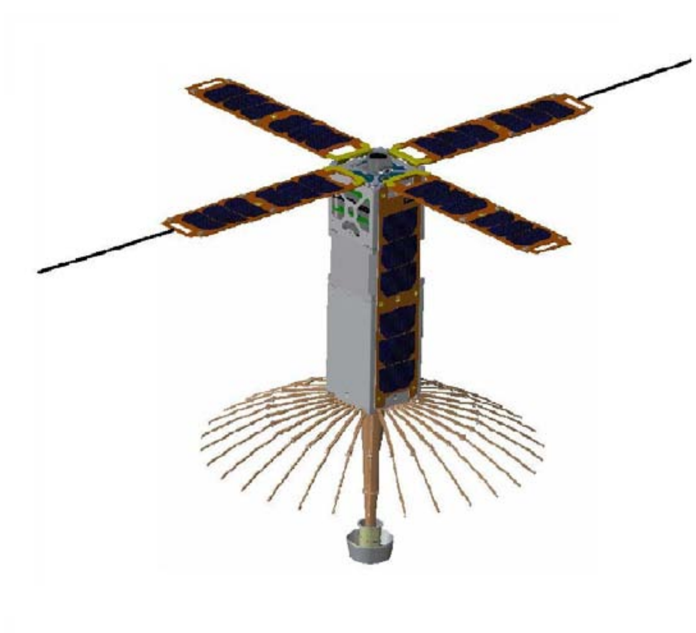


Figure: Aeneas CubeSat in Fully Deployed Configuration

ODAR Section 2: Spacecraft Description

Aeneas 3U Cubesat
Stowed ~ 10x10x30cm
Deployable panels are full body length, two have 23 cm construction tape whips on the ends.
Deployable mesh reflector is 0.5 meter diameter, with 22 cm feedhorn stalk.
04-02-2012, rev 0.1

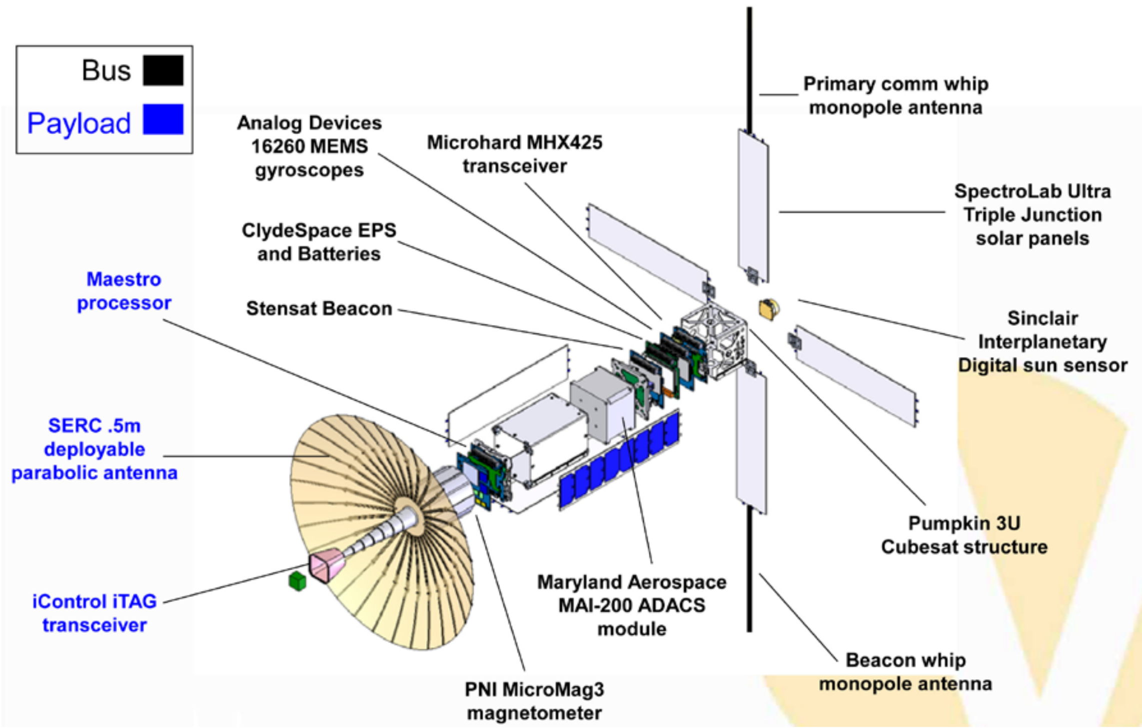


Figure: Aeneas Exploded View

The primary CubeSat structure is made of Aluminum 2219-T31. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

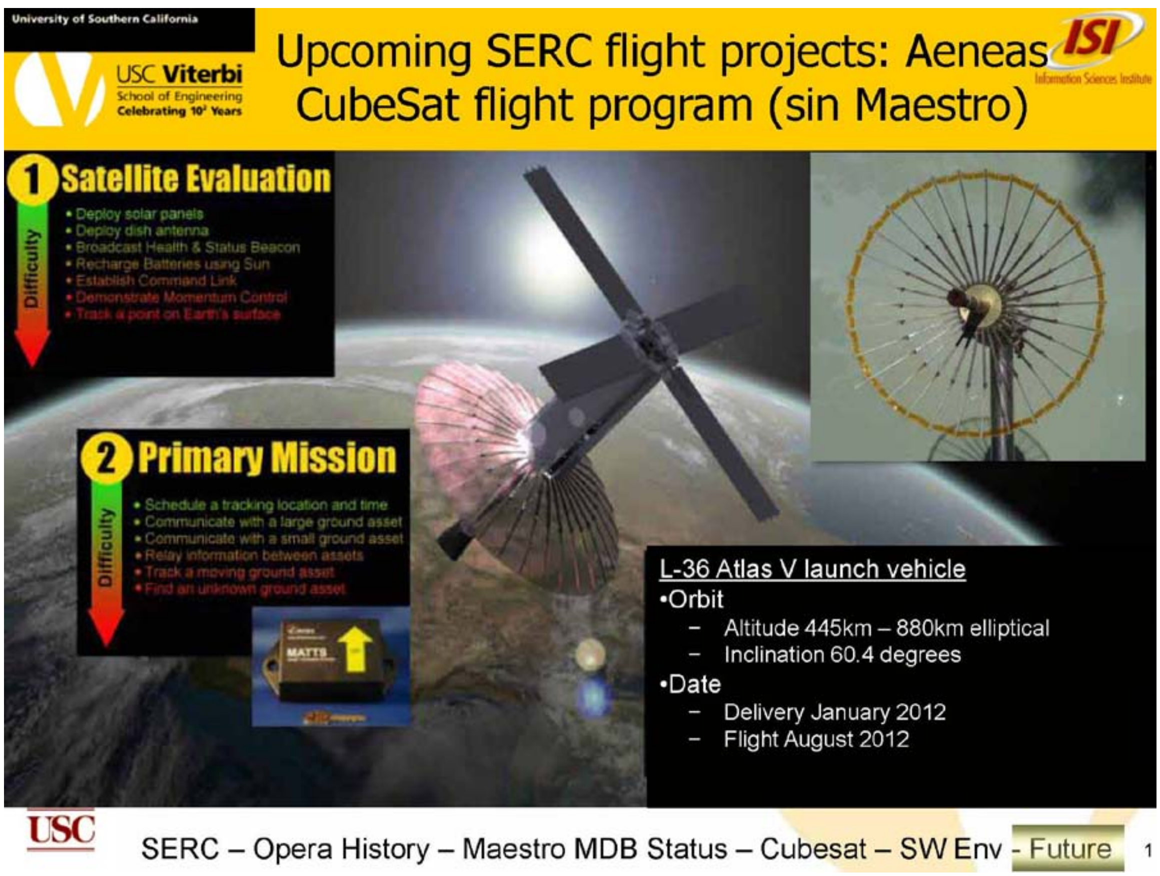
There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry.

Concept of Operations

1. Satellite Operations
    a. Deploy from PPOD – Wait 45 minutes, then until Sun, (135 minutes max)
    b. Deploy solar panels
    c. Deploy parabolic dish
    d. Broadcast health and status beacon
    e. Recharge batteries with sun

f. Establish command link
g. Demonstrate momentum control
h. Track a point on earth's surface
2. Primary Mission
a. Schedule a tracking location and time
b. Communicate with a larger ground asset (iGate transceiver)
c. Communicate with a small ground asset tracking tag (iTag transceiver)
d. Relay information between assets
e. Track a moving ground asset
f. Find an unknown ground asset



ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

The section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2. No releases are planned on the Aeneas CubeSat mission therefore this section is not applicable.

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

A possible malfunction of Lithium ion or Lithium polymer batteries or of the control circuit has been identified as potential causes for spacecraft breakup during deployment and mission operations.

While no passivation of batteries will be attempted natural degradation of the solar cell and battery properties will occur over the post mission period, which may be as long as 22 years worst case. These conditions pose a possible increased chance of the existence of several contributors to undesired battery energy release. The battery capacity for storage will degrade over time, possibly leading to changes in the acceptable charge rate for the cells. Individual cells may also change properties at different rates due to time degradation and temperature changes. The control circuit may also malfunction as a result of exposure over long periods of time. The cell pressure relief vents could be blocked by small contaminants. Any of these individual or combined effects may theoretically cause an electro-chemical reaction that result in rapid energy release in the form of combustion.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the Aeneas mission.

Section 4 asks for a list of components which shall be passivated at End of Mission (EOM), as well as the method of passivation and description of the components which cannot be passivated. No passivation of components is planned at the End of Mission for Aeneas.

Rationale for all items which are required to be passivated, but cannot be due to their design is as follows. Since the batteries used do not present a debris generation hazard (see assessment directly below), passivation of the batteries is not necessary in order to meet the requirement 4.4-2 (56450) for passivation of energy sources “to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.” Because passivation is not necessary, and in the interest of not increasing the complexity of the CubeSats, there was no need to modify their electrical generation and storage systems.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that the Aeneas CubeSat are compliant. Requirements 4.4-3 and 4.4-4 are not applicable.

The following addresses requirement 4.4-2. The CubeSats that have been selected to fly on the NRO L-36 mission have not been designed to disconnect their onboard storage energy devices (lithium ion and lithium polymer batteries). However, the CubeSat batteries still meet Req. 56450 by virtue of the fact that they cannot “cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft”.
The batteries used in the Aeneas CubeSat are UL certified. In general, these batteries are similar in size and power to cell phone batteries.

Table: Aeneas CubeSat Li-Ion Cells

CubeSat Name	Model Number (UL Listing)	Manufacturer	Number of Cells	Total Energy Stored
Aeneas	PLF 503759C (MH13654)	Varta (pack)	6	30 W-hr

The batteries are all consumer-oriented devices. The batteries have been recognized as Underwriters Laboratories (UL) tested and approved. UL recognition has been determined through the UL Online Certifications Directory, which clearly shows that these cell batteries have undergone and passed the UL Standards. Furthermore, safety devices incorporated in these batteries include pressure release valves, over current charge protection and over current discharge protection.

The fact that the Aeneas batteries are UL recognized indicates that they have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA Req. 56450 is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 (ref. (e)) subjects the test battery to heat by flame while within an aluminum and steel wire mesh octagonal box, “[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out”(UL 1642 20.5). To pass the test, “no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen” (UL 1642 20.1).

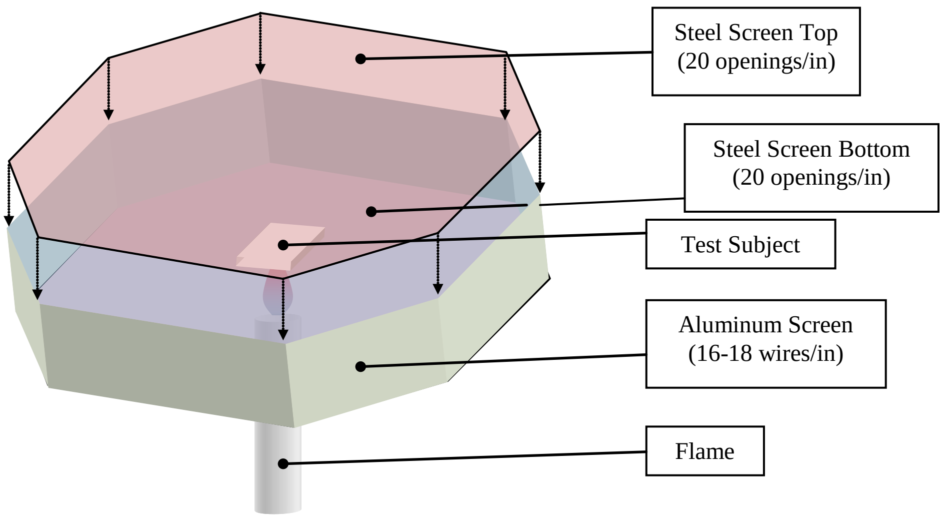


Figure: Underwriters Laboratory Explosion Test Apparatus

It is acceptable to expect the batteries being launched via CubeSat to experience similar conditions during their orbital life span. While the source of failure would not be external heat on orbit, analysis of the expected mission thermal environment performed by NASA LSP Flight Analysis Division shows that given the very low (<=30 W-h, maximum for Aeneas) power dissipation for CubeSats, the batteries will be exposed to a maximum temperature that is well below their 212^{o}F safe operation limit (ref. (f)). Continual charging with 2 to 6 W of average power from the solar panels over an orbital life span greater than 12 years may expose the six batteries to overcharging which could cause similar heat to be generated internally. Through the UL recognition and testing, it has been shown that these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

A NASA Glenn Research Center guideline entitled Guidelines on Lithium-ion Battery Use in Space Applications (ref. (d)) explains that the hazards of Li-Ion cells in an overcharge situation result in the breakdown of the electrolyte found in Li-ion cells causing an increase internal pressure, formation of flammable organic solvents, and the release of oxygen from the metal oxide structure. From a structural point of view a battery in an overcharge situation can expect breakage of cases, seals, mounting provisions, and internal components. The end result could be "unconstrained movement of the battery" (RP-08-75 pg 13). The relevant information to the NASA requirement being that only battery deformation and the escape of combustible gasses will be seen in an overcharging situation. It is important to note that the NASA guide to Li-ion batteries makes no mentions of the batteries causing explosions of any magnitude whatsoever.

Through a combination UL certification, compliance with AFSPCMAN 91-710 V3 requirements, and an understanding of the general behavior of the failure modes associated with these types of batteries it is possible to conclude that Requirement 56450 is satisfied. Specifically, these batteries will "not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft" (Requirement 56450).

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

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

The largest mean cross sectional area (CSA) for Aeneas is (10 X 30 cm X 4 deployed panels with 10 X 30 cm body):
mean CSA = [4 X (0.1 m X 0.3 m) + (0.1 m X 0.3 m)] = 0.15 m^2. The Aeneas orbit at deployment is 800 km apogee altitude X 495 km perigee altitude, with an inclination of 66.4 degrees. With an area to mass (4.15 kg) ratio of 0.031 kg/m^2, DAS yields 9 years for orbit lifetime which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime, CubeSats see an average of 10^{-6} probability of collision.

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Run Data
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INPUT

Space Structure Name = Aeneas
Space Structure Type = Payload
Perigee Altitude = 495.000000 (km)
Apogee Altitude = 800.000000 (km)
Inclination = 66.400000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.031000 (m^2/kg)
Start Year = 2012.500000 (yr)
Initial Mass = 4.150000 (kg)
Final Mass = 4.150000 (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 = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

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=============== End of Requirement 4.5-1 ===============

The probability of the spacecraft collision with debris and meteoroids, greater than 10 cm in diameter and capable of preventing post-mission disposal, is about 10^{-6} which meets the 0.001 maximum probability requirement 4.5-1.

Since the CubeSat has no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows Aeneas to be compliant. Requirement 4.5-2 is not applicable to this mission.

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

The spacecraft will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst case post-mission disposal for the Aeneas CubeSat requires all deployables to remain in an **undeployed state**. This assumes that all 4 Aeneas solar panel arrays do not deploy and the 0.5m dish also does not deploy as well. This worst case scenario is highly unlikely. The area-to-mass is calculated as follows: [1 X 0.1 m X 0.34 m] / 4.15 kg = 0.008 m^2 / kg.

The assessment of the spacecrafts illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.01 Orbital Lifetime Calculations:

Absolute Worst Case Analysis:
DAS inputs are: 495 km maximum perigee X 800 km maximum apogee altitudes with an inclination of 66.4 degrees at deployment in the year 2012. A area to mass ratio of 0.008 m^2/kg for the Aeneas CubeSat was imputed. DAS 2.01 yields a 22 year orbit lifetime for Aeneas in its undeployed state. This assumes all 4 solar panel arrays and 0.5m dish does not deploy.

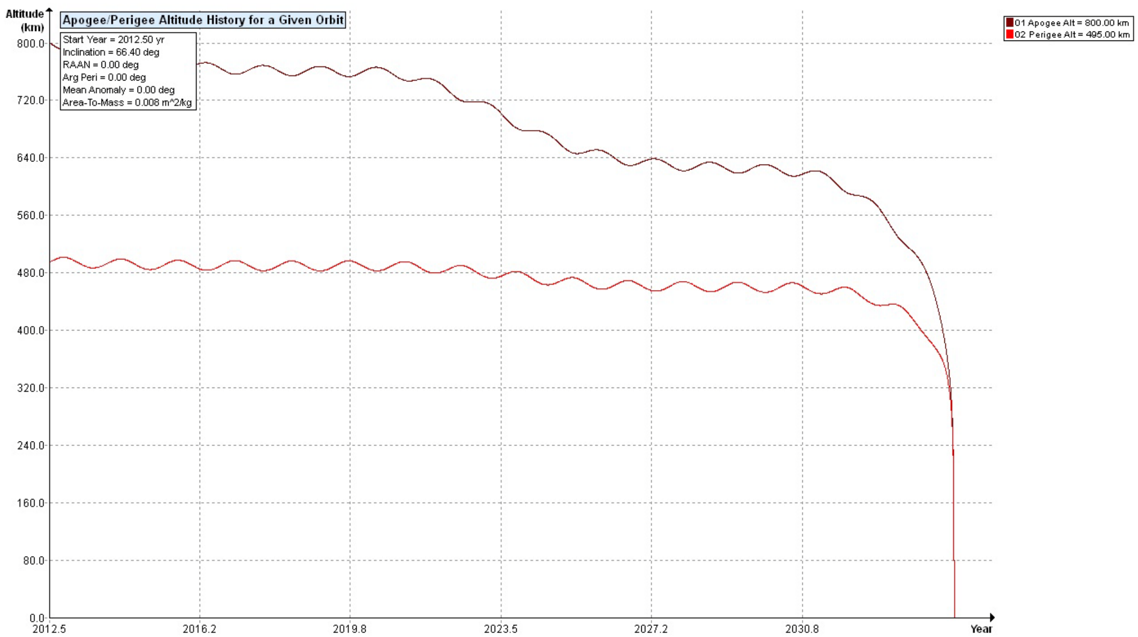

Figure: Worst Case Deorbit Analysis for Aeneas

Nominal Deorbit Analysis:
DAS inputs are: 495 km maximum perigee X 800 km maximum apogee altitudes with an inclination of 66.4 degrees at deployment in the year 2012. A area to mass ratio of 0.031 m^2/kg for the Aeneas CubeSat was imputed. DAS 2.01 yields a 9 year orbit lifetime for Aeneas in its nominal deployed state. This assumes all 4 solar panel arrays and 0.5m dish did deploy as expected.

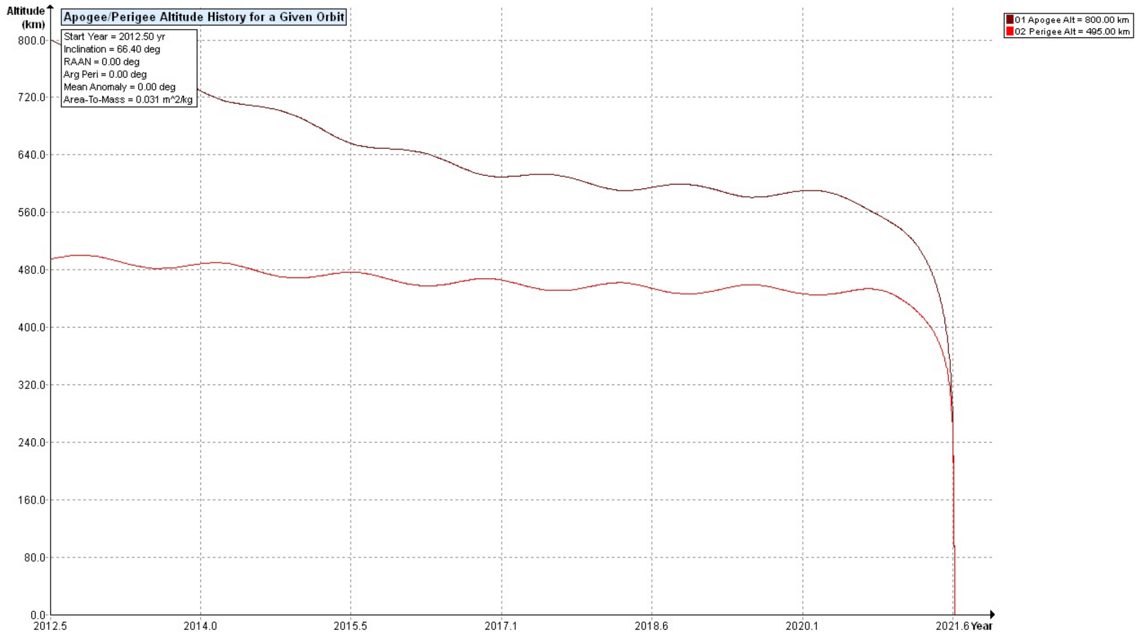

Figure: Nominal Case Deorbit Analysis for Aeneas

Assessment results show compliance and meets requirement 4.6-1.

ODAR Section 7: Assessment of Spacecraft Re-entry Hazards

A detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle, is provided below when/if the atmospheric reentry option is selected. The Aeneas CubeSat is primarily constructed of aluminum and PCB electronic board material. The only components with a higher density are the stainless steel screws used to hold the CubeSat together. These screws will not survive reentry and Aeneas does not contain any exotic high density materials.

The Aeneas CubeSat satisfies the 4.7-1 Requirement, Reentry Debris Casualty Risk as determined by DAS using standard CubeSat dimensions. This assessment completes the summary of objects expected to survive an uncontrolled reentry, using NASA Debris Assessment Software (DAS), NASA Object Reentry Survival Analysis Tool (ORSAT), or comparable software.

Probability calculations of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination show that there is no credible risk of human casualty. In the highly unlikely event that any object from a CubeSat does survive reentry, the necessarily small mass of the component along with the types of materials used in the CubeSats virtually ensure that the impact energy of the debris object will be less than 15 J. See assessment below.

Aeneas does not plan for any spacecraft controlled reentry. No preliminary plan for spacecraft controlled reentry is provided.

Assessment of spacecraft compliance with Requirement 4.7-1 shows compliance. The total debris casualty area is zero. Casualty Expectation is zero. The following section addresses this requirement in detail.

The reentry risk for CubeSats can be assessed by doing analysis on bounding cases so as to determine what object size is required to reach the DCA limit and what kind of object properties (size, material, and mass distribution) can attain the 15 J impact energy threshold. Then the size and mass of these object cases can be evaluated relative to what is possible and/or realistic in terms of mass and size for an object or component that is part of the assembled 1 kg or 3kg CubeSat system. Finally, the likelihood of violating both of the requirements simultaneously can also be assessed in terms of whether realistic scenarios that violate the DCA limit can be compatible with those that violate the 15 J threshold.

In the very unlikely event that a piece of debris or a fraction of a component object reaches the ground, the necessarily small mass of the component along with the types of materials used in the CubeSats virtually ensure that the impact energy of the debris object will be less than 15 J. An analysis using DAS was conducted to determine the mass and size required for a component to reach Earth with energy greater than 15 J. This analysis shows that a titanium box shell the size of a CubeSat would require a mass of 0.14 kg, or 14% of the total CubeSat mass, in order to have an impact energy of 15 J. In addition, a solid titanium cylinder with a diameter of 1 cm, a length of 10 cm (the length of each side of the CubeSat) and a mass of .04 kg will also impact with 15 J. That also is the case for one with a diameter of 0.7 cm, a length of 30 cm (the length of the longest side of a 3 kg CubeSat) and a mass of .06 kg. Components made of less durable materials will generally not survive at all. For example, a solid stainless steel rod 4 cm in diameter and 10 cm long, with a mass of 1 kg, will not reach the Earth's surface based on the DAS analysis. That also is the case for one 4 cm in diameter and 30 cm long, with a mass of 3 kg.

When the bounding impact energy cases are combined with the casualty area assessment in the previous paragraph, it is clear that only under very specific circumstances would a CubeSat violate this requirement. Specifically, in order to violate this requirement, a CubeSat would have to be composed almost entirely of approximately 20 roughly equally-sized titanium components – fewer components would result in DCA that does not violate the casualty risk requirement, and more components would be too small to exceed the 15 J energy criteria due to the size and mass constraints placed on the CubeSat design.

In conclusion, violation of the subject criteria for a CubeSat mission is not credible, and it can be seen via inspection that the specific Aeneas CubeSat addressed in this assessment does not reflect the types of design elements that would be required to produce a violation.

ODAR Section 8: Assessment for Tether Missions

Since the Aeneas CubeSat does not involve tether deployments Section 8's requirement 4.8-1 are not applicable