Preliminary Orbital Debris Assessment Report
for Kineis constellation satellites IAW NASA-STD 8719.14A

REFERENCES:

A. Process for Limiting Orbital Debris, NASA-STD-8719.14A, 25 May 2012

GENERAL REVIEW

The following table summarizes the compliance status of the Kineis 25 satellites constellation with the NASA requirements for limiting orbital debris generation (ref A). The 25 satellites have launches planned for late 2022 and all satellites are designed to be fully compliant with all applicable requirements. A mass of 26 kg is the upper limit on the satellite design and hence will be assumed to be the worst-case ballistic coefficient.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	**Compliance**	**Comments**
4.3-1a Debris Passing Through LEO: 25-Year Maximum Lifetime	Not applicable	No Planned Debris Release.
4.3-1b Debris Passing Through LEO: Total Object-Time Product	Not applicable	No Planned Debris Release.
4.3-2 Debris Passing Near Geosynchronous Altitude	Not applicable	No Planned Debris Release and apogee significantly lower than GEO.
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	Compliant	Onboard energy source (batteries) incapable of debris-producing failure. There is no pressurized item in the propulsion system.
4.4-2 Design for passivation after completion of mission operations while in orbit about Earth or the Moon:	Compliant	Onboard energy source (batteries) incapable of debris-producing failure. Electrical passivation performed at EOM.
4.4-3 Limiting the long-term risk to other space systems from planned breakups:	Not applicable	No Planned breakups.
4.4-4 Limiting the short-term risk to other space systems from planned breakups	Not applicable	No Planned breakups.
4.5-1 Limiting debris generated by collisions with large objects when operating in Earth orbit	Compliant	Probability of collision : 0.000481 including mission and postmission orbital lifetime.
4.5-2 Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit	Not applicable	No plan for end-of-mission disposal spec §4.5.4.3
4.6-1(a) Disposal for space structures in or passing through LEO: Atmospheric reentry option	Compliant	The maximum perigee of 656 km and apogee of 673 km results in 15.75 years, which is within 25-year requirement.
4.6-1(b) Disposal for space structures in or passing through LEO: Storage orbit	Not applicable	

4.6-1(c) Disposal for space structures in or passing through LEO: Direct retrieval	Not applicable	
4.6-2 Disposal for space structures near GEO	Not applicable	
4.6-3 Disposal for space structures between LEO and GEO	Not applicable	
4.6-4 Reliability of post-mission disposal operations in Earth orbit	Not applicable	Passive atmospheric reentry disposal is planned.
4.7-1 Limit the risk of human casualty	Compliant	Non-credible risk of human casualty, no components will survive reentry. Analyse DEBRISK.
4.8-1 Mitigate the collision hazards of space tethers in Earth or Lunar orbits	Not applicable	No use of tethers.

ORBITAL DEBRIS ASSESSMENT

Section 1: Program Management and Mission Overview

All satellites will be deployed in groups of 5 at each orbital plane as required. The launcher dispersions will be corrected and every satellite will join its operational argument of latitude by drift orbits. The 2022 planned launches will use 5 launches. Kineis may use dedicated launches for the activities to follow as the constellation is built out.
The operational orbits targeted are heliosynchronous, and located at a mean altitude of 650 km. This resulted from a trade-off between mission needs, total DV available and the 25 years' reentry duration requirement.
Hemeria Nano-satellites has been selected as the supplier of satellites for Kineis. Satellites will be built with support from French space agency CNES.
Replenishment strategies will be implemented to sustain the constellation once it is fully deployed to account for decommissioning of satellites.

The satellites will be able to maneuver during the expected 8 years lifetime duration allowing for collision avoidance and constellation synchronization maneuvers. In particular, collision risk will be monitored and should a risk be confirmed, a collision avoidance maneuver will be possible.

Program manager at Kineis: Michel Sarthou

Section 2: Spacecraft Description

Overview

The Kineis satellite is based on ANGELS, the first nanosatellite of HEMERIA product line. ANGELS fully complies with the French Space Operation Act (FSOA) and will be launched end 2019 from the French Guyana launch base.
It is worth mentioning that the Kineis constellation will be also submitted to the FSOA and will comply with all its requirements.

The A4NG satellite utilizes Hemeria Nano-satellite's avionics architecture for power generation and management, telemetry and commanding (TMTC), Command and Data Handling (CDH), thermal management, and Guidance Navigation and control (GNC). The power system uses Power, Conditioning and Distribution boards, lithium-ion battery modules and deployable solar arrays for power generation. The TMTC consists of a RF receiver and a S-band transmitter. The CDH and GNC consists of On Board Computer (OBC) boards, three magnetotorquers, three reaction wheels, a magnetometer, one or two sun sensors, and a star tracker. An electrical propulsion system (one thruster) is used for initial orbit disposal and orbit station keeping.

A primary payload for data collection of ARGOS-like message will be embedded on each satellite of the constellation. This payload is composed of an electronic modules and a deployable UHF & S-band antennas system. S-band antenna is located on top of UHF payload antenna.

A secondary payload for data collection of AIS maritime message will be embedded on a satellite subset of the constellation. This payload is composed of an electronic modules and a VHF deployable antenna.

Most of the units are based on off the shelf products except solar panels, payloads and S-Band transmitter.

External volume of the satellite without appendages is 450*260*240 mm. Maximum volume when deployed is 1200*1200*1200 mm. Solar panels are fixed after initial deployment.
Maximal mass estimation is below 26 kg. The satellite is attached to the launched with a 8 inches diameter separation device.

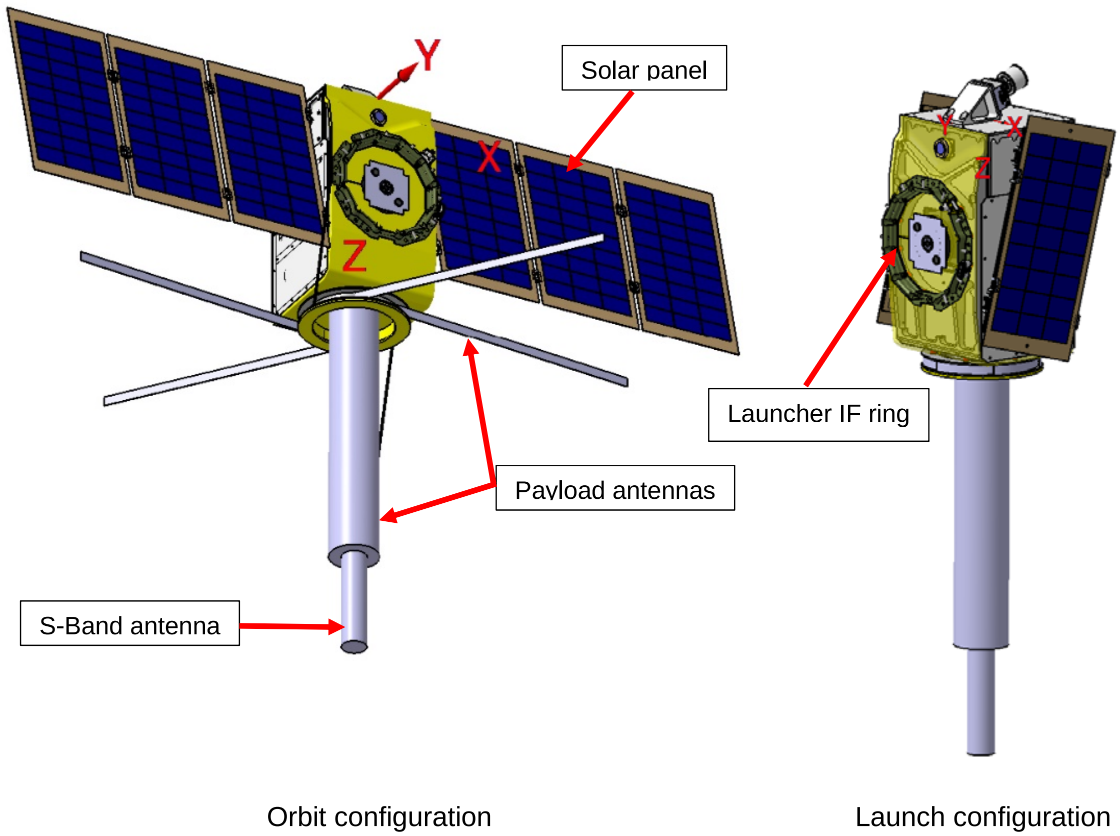

Figure 1: satellite 3D view in flight configuration

The attitude of the satellite in normal operation in flight is the following:

- The payload antennas are earth pointed.
- A Yaw Steering is done to continuously optimize the electrical power generated by the solar panels, or to provide the correct attitude for the orbital manoeuvers.

A safe mode is also implemented for the initial acquisition and for contingency cases.

CONOPS

When separated from the launcher, spacecraft initial acquisition will occur autonomously after an on board programmable delay (typically 30 to 45 minutes). An inhibit mechanism is actuated by separation devices to start the count down from the launch separation until this delay occurs. Then the solar arrays are deployed and the GNC start controlling the spacecraft to put it in a safe mode. TM transmission is performed later on, following a subsequent programmable delay. The earth pointing mode is initiated few hours later in order to start a full commissioning sequence and the final in orbit positioning using the electrical propulsion.

The spacecraft has been designed to self-resolve from anomalies requiring minimal operator intervention, with a safe mode activation at the last stage of recovery actions.

The satellites will primarily operate in a reverse link mode, used as a relay for user terminals. Customer data will be transmitted from ground terminals, received by satellite and downloaded to the ground in a store and forward approach. A forward link mode allows for data to be transmitted to terminals on the ground.

Materials

The primary structure for the satellite and for the majority of unit's structures are composed of Aluminum alloy. The rest of the spacecraft is largely composed of well-known components which consist of electrical components, PCB and solar cells. Steel fasteners with high melting temperature will be used on the satellite.

Few materials have fusion temperature above 1000°C:

- Stainless steel for fasteners, reaction wheels rotors, parts of batteries and magnetotorquers,
- Tungsten and Tantalum for thruster emitter.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Propulsion

The propulsion is an electrical system based on Indium FEEP thruster. This technology has been developed with the support of European Space Agency.
The thruster contains a tank with 250 g of Indium in solid state at ambient temperature. Indium is heated slightly above fusion temperature (157 °C) to operate the thruster. There are no pressurized vessels and no sealed fluids.

Batteries

The electrical power storage system consists of lithium-ion cells with overcharge/current protection circuitry. Battery is constituted with strings of 4 cells each.
The theoretical peak energy storage of the battery is 144 Whrs (beginning of life).

Each cell is equipped with two protection systems : an overcharge disconnect device and a "Safety vent".

The overcharge disconnect device is an internal system which electrically disconnect the cell by detection of overpressure inside the cell, rendering the cell in an open circuit. The cell is then definitively insulated from the rest of the battery (irreversible)..

In case the internal pressure still increases, in particular due to external cause, the Safety vent system will operate (Leak Before Burst system).

Reaction wheels

The three reaction wheels are identical and provided by SINCLAIR. This product has an extensive flight experience.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

No releases are planned for the Kineis satellites; therefore, this section is not applicable.

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions for the Kineis Satellites.

The satellites satisfy Requirements 4.4-1 and 4.4-2 by the batteries being equipped with protection circuitry and the full satellite being passivated then disconnected from the solar generator at EOM. This electrical passivation is a requirement of the French Space Operation Act (FSOA): at the end of life, satellite will be discharged, and Solar array will be definitively disconnected from the battery and from the power distribution lines of the satellite. This operation will definitely passivate all electrical and mechanical energy sources (battery, reaction wheels). This passivation process will be also autonomously initiated in case of non-recoverable on board failure.

The probability of battery explosion is very low, due to cells Leak Before Burst protection.
About battery protection: see details of Circuit Breaker and Safety Vent systems in section 2.

Section 5: Limiting debris generated by 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 area and orbital lifetime.

The equation for the mean cross-sectional area for complex shapes is most appropriate, and has been done with STELA tool. This tool is used by CNES to cope with the French Space Operation Act (FSOA) and the calculation of the mean area uses exactly the same formula than the one presented in Ref A.

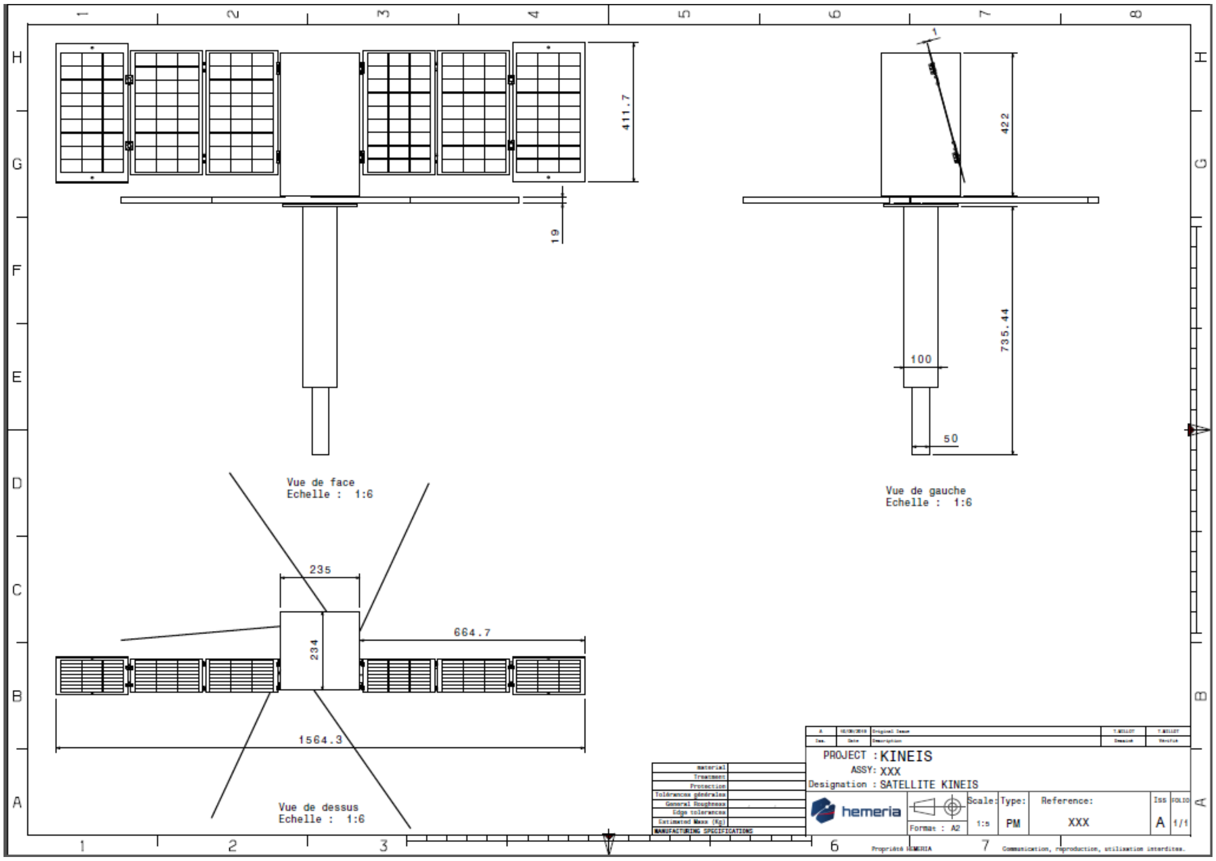

Figure 2: satellite external volume in deployed state

Mean area deployed: $A_{mean} = 0.45m^2$ in random tumbling.

The design mass for each satellite is 26 kg, resulting in an Area to mass ratio of 0.0173 m_2/kg

An apogee of 673 km and perigee at an upper limit of 656 km were used, as this is the maximum altitude of any launch option presently being considered for these satellites with 3 sigma uncertainties added on the semi-major axis. The difference between apogee and perigee corresponds to the frozen eccentricity of the mission orbit, meaning that the eccentricity evolution over time will be stable.

STELA yields 15.75 years orbit lifetime with this orbit, which in turn is used to obtain the collision probability.
STELA is a reference tool recommended by FSOA to compute the post mission orbital lifetime. It uses a semi analytical propagator, with a solar activity that can be constant or variable. Since the solar activity is hard to predict and that the mission can end in a maximum or minimum solar activity, a constant mean solar activity was taken into account, as recommended by FSOA.

<u>Probability of collision.</u>

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.
In order to compute the probability of collision during satellite orbital lifetime, DRAMA tool was used. This tool is a reference tool developed by ESA to compute collision risk, based upon MASTER 8 which present an updated orbital population with respect to the former version.

Given the satellites dimensions a sphere with a 0.75m radius was considered, which includes a significant margin.

The probability of collision over 1 year is given by the following formula:

$$P = 1 - e^{-\lambda} \sim \lambda$$

Where $\lambda = \Delta t . F . A$

Note that it varies almost linearly with time with the approximation above.

The probability of collision during 1 year has been computed and is equal to of 0.00002025.
Thus, the probability of collision during post mission (during the 15.75 years of reentry), is equal to of 0.000319.

Note that during mission, every tracked orbital object leading to a risk should be avoided by maneuvering, meaning that the probability of collision during mission should be considered equal to 0. These collision avoidance operations will be performed in coordination with CNES collision team CAESAR, depending on the results the monitoring performed on a daily basis.
However, we can also compute a probability taking into account both mission duration and post mission orbital lifetime, leading to a 23.75 years global lifetime. This duration leads to a probability of collision of 0.000481 that stays well below the threshold indicated in requirement 4-5-1.

Since the natural decay of the orbit allows the satellite to perform its reentry in less than 25 years, there will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable (requirement 4-5-2).

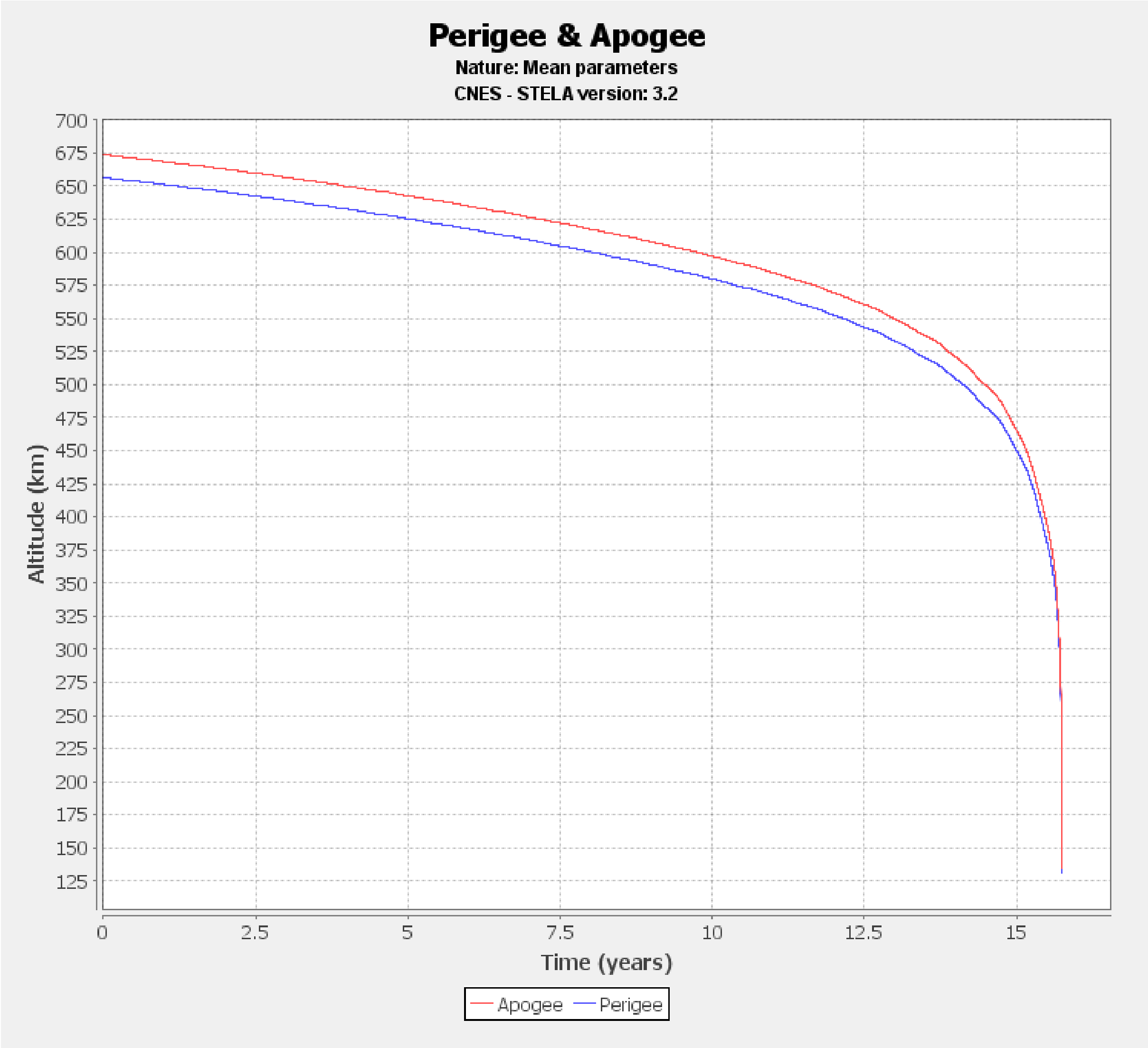

Figure 3: Atmospheric Demise from 650km for Kineis satellites

STELA inputs:

- Apogee altitude ~ 673 km
- Perigee altitude ~ 653 km
- Inclination = 97.9 deg
- Mass = 26 kg
- Area = 0.45 m²
- F10.7 = 145
- Ap = 15

The probability of any Kineis satellite collision with debris and meteoroids greater than 10cm in diameter and capable of preventing post-mission disposal is less than the 0.001 maximum probability requirement 4.5-1.
Since the satellites have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Section 6: Assessment of Spacecraft Post Mission Disposal Plans and Procedures

It is planned that Kineis satellites will naturally decay from orbit within 25 years (actually 15.75 years, see above) after the end of the mission. Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculation of the post-mission disposal area to mass ratio leads to the following value:
$$ratio = \frac{Area}{mass} = \frac{0.45}{26} = 0.0173\ m^2/kg$$

Assessment of spacecraft compliance: the satellite being in LEO orbit, only requirement 4.6-1 is applicable.

Requirement 4.6-1: the satellite is left in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission. Therefore, Kineis satellites are compliant.

Section 7: Assessment of Spacecraft Reentry Hazards

Material selection of components for the satellites will be influenced to ensure all requirements are satisfied. The assessment used DEBRISK, a conservative tool used by European Space Agencies to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a satellite component during re-entry.

The following steps are used to identify and evaluate a component's potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the component survives reentry.

- Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty.
- The remaining high-temperature materials are shown to pose negligible risk to human casualty through a bounding DEBRISK analysis of the highest temperature components: mainly stainless steel (1500°C), and with very small mass Tungsten (3422°C) and Tantalum (3017°C).

Table 2: Kineis Satellite High Melting Temperature Materials

Component Name	Material	Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Fasteners	Steel	0.5)	73	0
Payload (miscellaneous : fasteners, connectors parts, antenna stands, …)	Steel	0,42	75	0
Payload (miscellaneous : brackets, fasteners)	Titane	0,05	73	0
Reaction Wheel Rotors	Steel	3 x 0.112	76	0
Magnetotorquer	Steel	3 x 0.18	14	0
Batteries	Steel	8 x 0.115	38	0
Thruster	Tungsten	< 0.002	13.7	0
	Tantalum (cylinder, 1mm thickness wall)	< 0.015	5.6	0

The DEBRISK analysis predicts that all high melting temperature components demise upon reentry.

The Kineis Satellites have a 0 probability of human casualty, as no components survive reentry.

All Kineis Satellites will be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

No Kineis Satellite will be deploying any tether, so Requirement 4.8-1 is not applicable.

If you have any questions, please contact Kineis.