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Kepler Orbital Debris Assessment Report (ODAR)

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

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DAS Software Version Used in Analysis: v3.0.1

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1 Self-Assessment of Orbital Debris Requirements

NASA Standard Requirements:

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

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			**X**		**X**			No debris released in LEO
4.3-1.b			**X**		**X**			No debris released in LEO
4.3-2			**X**		**X**			No debris released in GEO
4.4-1			**X**		**X**			No credible scenario of explosion
4.4-2			**X**		**X**			No credible scenario of explosion
4.4-3			**X**		**X**			No planned breakups
4.4-4			**X**		**X**			No planned breakups
4.5-1			**X**		**X**			Collision probability within compliance requirements
4.5-2			**X**		**X**			Collision probability within compliance requirements
4.6-1(a)			**X**		**X**			Atmospheric re-entry within 15.8 year from start of mission
4.6-1(b)			**X**		**X**			Atmospheric re-entry within 15.8 year from start of mission
4.6-1(c)			**X**		**X**			Atmospheric re-entry within 15.8 year from start of mission
4.6-2			**X**		**X**			Spacecraft not in GEO
4.6-3			**X**		**X**			Spacecraft not between LEO and GEO
4.6-4			**X**		**X**			No EOM subsystem required
4.7-1			**X**		**X**			No controlled re-entry
4.8-1			**X**		**X**			No tethers used

FCC Part 25 Requirements:

An assessment is provided below in accordance with applicable sections of the proposed amendment to Title 47 of the US Code of Federal Regulations, Part 25.114, as issued under Report and Order FCC 20-54 (Apr. 24, 2020).

Requirement # 25.114(d)	Description	Compliant	Document Section	Comments
i	**Active deployment devices**	**X**	4	No active deployment devices
ii	**Small debris collision risk**	**X**	6	Per spacecraft, 12 kg variant, p=0.006143
iii	**Accidental explosions/droplet release**	**X**	5	No droplet release possible. Accidental explosion p<<0.001
iv(A)1	**Large debris collision risk**	**X**	6	Per spacecraft, worst-case (12 kg variant, failed deploy at 600 km): p=0.000004
iv(A)2	**Debris characteristics of orbit**	**X**	6	Popular orbit, good debris cleaning characteristics, no significant debris fields
iv(A)3	**Risk to human-inhabited space**	**X**	7	Spacecraft will be maneuverable until atmospheric demise
iv(A)4	**Orbit maintenance/accuracy**	**X**	2	No stationkeeping. Rideshare launches lead to slight variance in orbit parameters
iv(A)5	**Conjunction assessment certification**	**X**	6	Certification of conjunction warning assessments and action steps
v	**Trackability**	**X**	3	Base (excl. deployables) spacecraft size exceeds 10 cm in smallest dimension
v(A)	**Tracking/identification method**	**X**	3	Passive tracking. Identification via radio callsign
v(B)	**Registration with SSA entity**	**X**	3	All spacecraft will be registered with 18th SCS or successor entity
v(C)	**Extent of shared information**	**X**	3	Identification, initial deployment, planned maneuvers, ephemeris, where available
vi	**Proximity operations**	**X**	4	None
vii(B)	**Disposal**	**X**	7	Atmospheric demise in 1.9 – 10.9 years post-mission. No direct retrieval
vii(D)1	**Probability of disposal success**	**X**	7	Probability of disposal within 25 years, p=1
vii(D)2a	**Controlled Re-entry?**	**X**	7	No
vii(D)2b	**Casualty Risk**	**X**	8	p=~0

Assessment Report Format

ODAR Technical Sections Format Requirements

As Kepler Communications Inc. (Kepler) is a Canadian company, this ODAR follows the format recommended in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 for the satellites in the Kepler system. Section 9 through 14 apply to the launch platform, and are not covered here.

This report satisfies all applicable criteria required under US 47 C.F.R. § 25.114(d)(14).

2 Program Management and Mission Overview

Project Manager: Kepler Communications

Foreign government or space agency participation: N/A

Mission Milestones:

Launch 1:	January 19th, 2018	1 Satellite
Launch 2:	November 29th, 2018	1 Satellite
Launch 3:	No earlier than Aug 2020	1 Satellite
Launch 4:	No earlier than Sep 2020	2 Satellites
Launch 5:	No earlier than Nov 2020	2 Satellites
Launch 6:	No earlier than Dec 2020	8-10 Satellites
Launch 7:	No earlier than Feb 2021	2+ Satellites
Launch 8:	No earlier than June 2021	2+ Satellites
Launch 9:	No earlier than July 2021	4+ Satellites
Launch 10:	No earlier than Dec 2021	12+ Satellites

Mission Overview:

The Kepler system will be delivered to sun-synchronous orbits (SSO) or polar orbits (PO) at an altitude between 500-600 km. The satellites will be deployed in tandem, and the mission operational lifetime is at least 3 years, with the time until disposal a maximum of 15.8 years after start of mission with deployed solar panels.

Anticipate Launch Vehicle and Site:

Launch 1:	LM-11. Jiquan Space Center, China
Launch 2:	PSLV, Satish Dhawan Space Centre, India
Launch 3:	Vega, Guiana Space Center, French Guiana
Launch 4:	Soyuz+ Fregat, Plesetsk Cosmodrome, Russia
Launch 5:	Soyuz+ Fregat, Baikonur Cosmodrome, Russia
Launch 6:	Falcon 9, Cape Canaveral (40), USA
Launch 7:	TBD
Launch 8:	TBD
Launch 9:	TBD
Launch 10:	TBD

Description of the launch and deployment profile: The Kepler satellites will deploy into SSO, from which they will naturally decay due to atmospheric drag. Currently the satellites are not equipped with propulsion and thus do not actively change orbits, nor employ stationkeeping, and there are no parking or transfer orbits used. Future satellites may include propulsion for orbit phasing and de-orbit capability. If this is decided, the technical details of the propulsive subsystems will be discussed in an updated version of this report. After at least 3 years' mission duration, each spacecraft will transition into an aerodynamic breaking attitude to allow for re-entry within preferential time limits. The deployment altitude will depend on the final launch vehicle selection, and as such the altitude ranges below are considered for this analysis:

High insertion case: **Apogee:** 600 km **Perigee:** 600 km
Low insertion case: **Apogee:** 500 km **Perigee:** 500 km
Inclination: 97.4-97.6 degrees (SSO)

Satellites will likely make use of 'rideshare' launches. In these cases, final apogee and perigee are dependent on the characteristics of the primary payload of these launches, and are generally beyond the control of any secondary payloads. In general, target insertion will be a circular orbit between 500 and 600 km altitude, with nominal deployment occurring at 575 km. Final RAANs may also be subject to variance, depending on the characteristics of available launches. In general, inclinations will maintain a high degree of accuracy, given that many available rideshare launches deliver their payloads specifically to sun-synchronous orbits.

Reason for orbit selection: Global coverage density and launch availability.

3 Spacecraft Description

Physical Description:

The Kepler satellites will have a mass of 12.0 kg. A basic outline of satellite dimensions is provided in Table 1 below. All satellites will contain two deployable solar arrays.

Table 1: Kepler satellite physical parameters

Mass (kg)	Stowed Dimensions (mm)	Deployed Solar Array Area (mm^2)
12	365 x 226 x 100	365 x 1114

For all spacecraft, the load bearing structure for each bus is comprised of 6 aluminum plates with machined integrated rails and rigidizing features of hardened aluminum. Solar arrays are deployed through spring loaded hinges actuated via a non-explosive actuator. Actuation of solar arrays is enabled post deployment.

Power storage will be provided by Lithium-Ion batteries with total stored capacity ranging from 80 – 300 W-hr. The batteries will be recharged via solar cells mounted on the external chassis, and the deployed solar arrays.

The spacecraft bus (excl. deployables) exceeds the FCC minimum threshold for presumed trackability (10 cm in the smallest dimension).[1] Kepler will register all spacecraft with the 18th SCS or equivalent successor entity post-deployment, and will primarily use passive tracking methods for sourcing ephemeris data. Spacecraft will be identified via unique callsign transmitted within a regular beacon signal. Kepler will generally share information, when available, regarding identification, initial deployment, and/or planned maneuvers (such as entering the braking configuration for deorbit) with the 18th SCS or successor entity. Kepler will also share ephemeris data with the 18th SCS, as well as with other operators, when available and as requested.

Total satellite mass at launch, incl. propellants and fluids: 12 kg

Dry mass at launch, exl. propellants and fluids: 12 kg

Description of propulsion systems: 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: N/A. Satellite batteries are unpressurized standard COTS Li-Ion cells.

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[1] US C.F.R., 47 § 25.114(d)(v).

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: Satellite attitude is controlled by a combination of magnetorquers and reaction wheels. Mission operations includes four attitude modes, three of which are shown in Figure 3-1. Nominal mission operational attitude includes a combination of the other three demonstrated attitudes, resulting in an average between. The three shown attitude states include Nadir-normal, Low Drag, and Brake. The brake attitude is the passive dynamically stable response of all spacecraft variants and is used during end-of-life de-orbit operations.

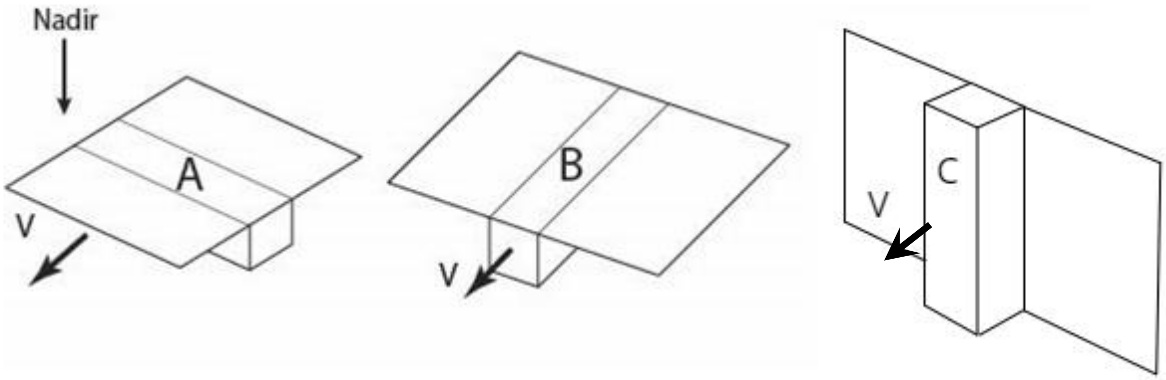

Figure 3-1: Attitude modes used for Kepler satellites. A – Nominal, B – Low Drag, C – Brake

The analysis in latter sections considers two principle grouped attitude states required to derive the drag cross-sectional area:

- Operational Pointing/Tumble:

  The controlled state of the spacecraft is a combination of an inertial-locked attitude combined with a body/Solar array pointed state to both ground and space targets. Averaged over time this resembles that of a random tumbling spacecraft neglecting any gravity gradient or aerodynamic effects. For these models, the average tumbling cross section of 0.13 m^2 is used for the 12-kg class spacecraft.

- Brake Configuration:

  The Kepler spacecraft configuration allows for passive aerodynamic stabilization into a Brake configuration wherein the largest drag cross section is aligned with the velocity vector. For these models a brake cross section of 0.37 m^2 is used for 12 kg class spacecraft.

  All spacecraft are equipped with articulated Solar arrays. For these systems, a “jogged” lever is used to entice aerodynamic stability through separation of center-of-mass (CoM) and the center of aerodynamic pressure (Cp) at any rotational angle of the array, as shown below in Figure 3-4. The worst-case drag area formed by the rotational angle between the array and the body is conservatively used for all brake configurations considered later within this report:

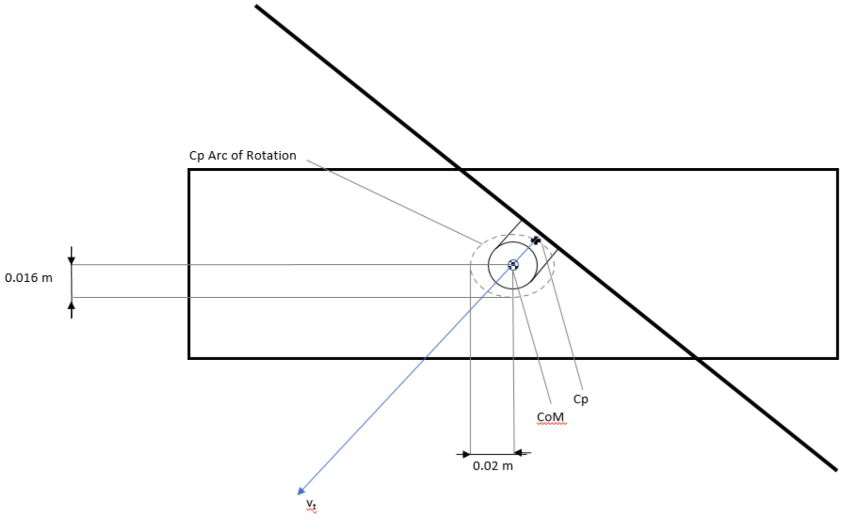

Figure 3-2: Passive Stability Configuration

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

Description of the electrical generation and storage system: Electrical power is generated via body mounted Ga-As solar panels and the two deployed arrays. Power storage utilizes Li-Ion batteries. The electrical power subsystem manages battery charging, battery balancing, solar string balancing, and protects against over/under current conditions.

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

Identification of any radioactive materials on board: None**.**

4 Assessment of Spacecraft Debris Release during Normal Operations

Not applicable as there are no intentional releases of debris. Spacecraft will be deployed directly from the launch vehicle. No intermediate deployment systems (such that they could present a separate source of debris) will be used. No proximity or active retrieval operations are planned.

5 Assessment of Space Intentional Breakups and Potential for Explosions

Potential causes of spacecraft breakup during deployment and mission operations:

There is no foreseen scenario in which the spacecraft would 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:

The first foreseen risk of explosion would be as a result of battery overheating and the resulting low probability of cell explosion. A FMEA (failure mode and effects analysis) was done to demonstrate the combined, mutually exclusive failures that must occur in order to result in the potential for accidental explosion of the batteries. Seven independent scenarios were analyzed to consider the risk that battery explosion could occur, with an exceptionally low cumulative probability that explosion will occur (see subheading *Supporting Rationale and FMEA details* below).

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions: No planned breakups

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated: None. Batteries will not be passivated at end-of-mission as all spacecraft will de-orbit within the 25-year guideline. The total combined stored energy of the batteries will be less than 650 kJ.

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

Chemical storage devices, such as batteries, are required to be passivated at EOM. However, the short orbit lifetime and low total stored energy combined greatly reduce the risk of occurrence of a fault. The lithium-ion cells are mechanically constrained within their own machined clamshell housing, which is in turn constrained by the primary spacecraft structure, a machined container, further reducing the chance of debris generation if a fault were to occur, while also reducing the possibility of a piercing. Thus, batteries will not be passivated at EOM.

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 Orbital Debris explosions during deployment and mission operations while in orbit about Earth or the Moon:

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

Compliance statement: As per the current design, the expected probability of any accidental explosion caused by failure on board the spacecraft is predicted to be significantly less than that required. Kepler maintains this as a top requirement for ongoing trade-studies and FMEA.

Required Probability: 0.001.

Expected probability: << 0.001.

Supporting Rationale and FMEA details:

Battery explosion:

Effect: The following presents all failure modes that may theoretically result in battery explosion, with the possibility of debris generation. However, in the unlikely event of battery explosion the low stored chemical energy combined with being located internal to the spacecraft container minimizes the risk of debris generation because of the lack of penetration energy.

Probability: Extremely low. Battery explosion in all failure modes requires two simultaneous faults or systematic user failure that are of extremely low probability in themselves.

Failure mode 1: Short circuit
Mitigation: Functional testing of charge/discharge, as well as environmental testing including shock, vibration, thermal cycling, and vacuum testing to prove no internal short circuit sensitivity exists. Cells & protection circuits are COTS which have flight heritage.
Combined Faults Required: Failure of environmental testing **AND** failure for functional testing to discover short circuit sensitivities **AND** failure of COTS vendor in testing components.

Failure Mode 2: Above-nominal current draw inducing battery thermal rise
Mitigation: Thermal cycling on cells to test upper temperature limits, testing of batteries at above-nominal discharge levels. All cells and assemblies include features to allow for prevention and physical safety for conditions such as over-temperature, over-discharge, etc.
Combined Faults Required: Inaccurate spacecraft thermal design **AND** over-current failure to detect off-nominal discharge rates

Failure Mode 3: Terminal contact with conductors not at battery voltage levels causing above-nominal current draw.
Mitigation: Qualification-test short circuit protection on each circuit, design of battery holders to ensure to unintended conductor contact without mechanical failure, minimize risk of mechanical failures via shock, vibration testing.
Combined Faults Required: Mechanical failure induced short circuit **AND** failure of over-current protection.

Failure Mode 4: Inoperable vents on battery holders.
Mitigation: Battery vents are not inhibited by the battery holder design or the spacecraft.
Combined Faults Required: Final assembler fails to install proper venting.

Failure Mode 5: Batteries are crushed during operation
Mitigation: Spacecraft is tested to simulate launch loadings to ensure no damage to cells. All components in proximity to battery are constrained to the rigid primary structure.
Combined Faults Required: A catastrophic mechanical failure has occurred via impact **AND** the failure must be sufficient to cause a crushing of the batteries, leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time of crushing.

Failure Mode 6: Low level current leakage or short circuit through battery holder due to moisture-induced degradation of insulators
Mitigation: Non-conductive plastic for battery holders, operation in vacuum thus moisture cannot affect insulators
Combined Faults Required: Failure of battery insulators **AND** dislocation of batteries in holder **AND** failure to detect fault in environmental testing

Failure Mode 7: Thermal rise due to space environment and high discharge combined
Mitigation: Spacecraft thermal design to prevent situation, testing of batteries above expected operating conditions, use of COTS components with flight heritage. FDIR implements latching current limiters in response to high temperature event detection.
Combined Faults Required: Inaccurate thermal design **AND** failure to detect fault in thermal cycling and environmental testing **AND** failure of COTS supplier to provide qualified batteries.

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

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

Compliance statement:

In the unlikely event of battery explosion, the low stored chemical energy combined with being located internal to the spacecraft container minimizes the risk of debris generation because of the lack of penetration energy.

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

Compliance statement:
N/A as there are no planned breakups

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

Compliance statement:
N/A as there are no planned breakups

6 Assessment of Spacecraft Potential for On-Orbit Collision

Kepler has assessed and limited the probability of spacecraft becoming a source of debris by collisions with both large and small debris, as well as other operational space stations. When considering collision risk, certain characteristics of the target orbit are worth noting:

- Sun-synchronous orbits are relatively popular, due to their unique intrinsic characteristics. Consequently, demand for this orbit is likely to remain steady into the future, especially among small satellites without propulsion.
- Many rideshare missions launch to sun-synchronous orbits. Since it is often a destination orbit (as opposed to a transfer orbit), a slightly higher presence of launch or deployment-related debris is expected.
- The orbit contains a moderately sized population of Resident Space Objects (RSO), including both active and inactive spacecraft, as well as large and small debris.
- Standard ground-based space situational awareness tracking facilities have inherently better performance at low altitudes, due to finite radar/optical resolving power. This may reduce the likelihood of inaccuracies in space situational awareness information leading to collisions at lower orbits.
- The presence of trace atmosphere permits passive atmospheric disposal of Kepler spacecraft within 25 years with probability of success of 100%.
- No significant debris fields exist in this range (e.g. RORSAT coolant droplets, major collision events).

Further noting that:

- Deployment variance within the 500 – 600 km range is generally determined by availability of rideshare launches, which may not always deploy at the nominal 575 km altitude.
- Kepler spacecraft cannot conduct orbit raising after deployment, and will passively descend throughout mission lifetime.
- Kepler spacecraft will not use stationkeeping.

Kepler certifies that, upon receipt of a conjunction warning from the 18th SCS or civilian successor, that it will review and take all possible steps to assess the risk of the warning. Kepler further certifies that it will take action to mitigate the collision risk if deemed necessary.

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).

A probability of collision analysis was performed using NASA's DAS 3.0.1 software. This analysis was done for the entire constellation sustained over a constellation duration of 15 years. The constellation of 140 operational orbiting spacecraft will be built and replenished through a launch cadence of approximately 50 spacecraft per year. This culminates in approximately 750 individual spacecraft over the course of 15 years. This analysis caps injection altitude at 600 km, with increased emphasis on 575 km and 500 km orbits.

Each spacecraft assumes a mission duration equivalent to its expected orbit lifetime. Using passive disposal, most scenarios result in all spacecraft configurations de-orbiting within 6 years. The maximum expected lifetime prior to re-entry expected for any mass-configuration is 15.2 years, assuming worst case solar-flux and failures in passive braking. As density of space objects decreases steadily below 800 km altitude, the high insertion scenario of 600 km apogee was considered as a worst-case scenario with probability of conjunction decreasing from there. This analysis does not include additional hypothesized constellations in the density analysis.

Several collision risk analyses were performed on the constellation. The following driving assumptions were used across all analyses:

- Over the course of 15 years, 750 Kepler spacecraft are placed into operational orbit
- Spacecraft solar array deployment reliability equals 99% (conservative, in reality it exceeds 99%)
- Spacecraft solar array deployment failure rate equals 1% (conservative)
- All failed spacecraft are assumed to be inserted at a 600 km altitude (worst case)
- Deployed spacecraft are assumed to be actuating regularly throughout their lifetime. This results in an average aerodynamic profile that is modelled as a “tumbling drag area”
- The use of braking attitudes is not considered. In reality, these will be used to hasten post-mission disposal and therefore reduce overall collision risk.
- Injection altitudes are distributed as follows: 50% at 575 km or below, 40% at 550 km or below, and 10% at 600 km or below (375, 300, 75 spacecraft, respectively)
- Failed spacecraft are not actively replaced.

The following aggregate risk profile is obtained:

single satellite risk of collision of 0.0000043428 (600 km deployment) assuming no maneuverability[2]
total constellation risk of collision of 0.001384 assuming no maneuverability for 100% of satellites[3]
total constellation risk of collision of 0.0000347 assuming maneuverability and adequate notice

The no-maneuverability risk values are overly conservative and are not an accurate reflection of the real operational environment, given that 99% of spacecraft are capable of maneuvering out of a

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[2] Demonstration of compliance with requirement § 25.114(d)(14)(ii) as modified by FCC 20-54 (IB Docket No. 18-313), (Apr 24, 2020).

[3] This assessment assumes that 100% of the satellites that Kepler deploys would become debris immediately post deployment – a scenario that would never happen.

collision trajectory. The real mission risk is reflected by the 1%, or 8 spacecraft, that do not have maneuverability and result in a combined constellation collision risk closer to 3.47×10^{-5}.

In the extremely improbable scenario of a spacecraft control reliability of 90%, the largest contributor to overall mission risk is reflected by these satellites. We assume that the failed 10% will be deployed at the worst-case altitude of 600 km.[4] These 75 satellites can be accounted for by including the 8 spacecraft that we presume failed prior to solar-array deployment and the additional 67 satellites presumed deployed at 600 km. This unlikely scenario results in an aggregate probability of collision of 4.285×10^{-4}.

These sum risk values for the constellation remain well below NASA requirements for a **single satellite**, less than 0.001 as required by NASA Orbit Debris Requirement 4.5.2.1, despite the conservative assumption of all failed satellites being deployed at 600 km.

Table 2: Lifetime collision risk of different injection altitudes assuming no maneuverability

Spacecraft Size	Injection Orbit Altitude (km)	Lifetime Spacecraft Collision Risk	No. of Spacecraft	Total Orbit Aggregate Risk (DAS)
12 kg	**600 (deployment Failure)**	4.3428E-06	8	0.0000347
12 kg	**600**	5.8764E-06	67	0.0003937
12 kg	**575**	1.7933E-06	375	0.0006725
12 kg	**550**	9.4434E-07	300	0.0002833

It is worth noting that Kepler has conducted this analysis over the **total sum of foreseen spacecraft** required to replenish the constellation over a 15-year span while demonstrating compliance to a requirement designed to guide the design of **single spacecraft missions**.

Active Collision Avoidance:

While only required to operate for 3 years, Kepler designs all systems with adequate margin to account for model and analysis error. Consequently, the built-in design margin includes allowance for the extension of operator control of the spacecraft for the total orbit lifetime duration. Additionally, current Kepler spacecraft have the capability to conduct conjunction avoidance through the use of their adaptive drag profile.

All operational satellites have sufficient control authority to conduct differential drag maneuvers to adequately to respond Conjunction Data Message (CDM) events with Normal and Radial components greater than zero if provided 48 to 72 hours' notice. Kepler is registered for CDM notification with CSpOC and has the capability to command a spacecraft attitude change within a maximum of 6 hours (average 2 hours) upon learning of a possible CDM. Each spacecraft has the capability of controlling its attitude to acquire a low or high drag configuration to facilitate this maneuver.

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[4] Demonstration of compliance with proposed requirement under § 25.114(d)(14)(iv)(A)(1) as discussed in Appendix D, FCC 20-54 (IB Docket No. 18-313), (Apr. 24, 2020).

First order analysis demonstrates that an along-track maneuver of 10 km separation from the original CDM can be obtained if a drag profile maneuver is initiated 2 days prior to the predicted conjunction. A maximum of 50 km phasing from the conjunction can be obtained if the maneuver is initiated 5 days in advance.

Following the deployment scheme and lifetime analysis, Kepler targets to maintain a total simultaneous number of spacecraft above 500 km at 150. In the worst case, analysis demonstrates a year with 200 spacecraft simultaneously above 500 km.

Collision Risk Output:

Provided below are the DAS logs for the collision risk assessments.

```
==============
Run Data
==============
```

600 Km Injection (Deployment Failure) – 12 kg variant:

```
**INPUT**

Space Structure Name = KC-600
        Space Structure Type = Payload
        Perigee Altitude = 600.000 (km)
        Apogee Altitude = 600.000 (km)
        Inclination = 97.740 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.00410 (m^2/kg)
        Start Year = 2020.000 (yr)
        Initial Mass = 12.000 (kg)
        Final Mass = 12.000 (kg)
        Duration = 3.000 (yr)
        Station-Kept = False
        Abandoned = True

**OUTPUT**

        Collision Probability = 4.3428E-06
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass
```

600 Km Injection – 12 kg variant:

```
**INPUT**

Space Structure Name = KC-600
        Space Structure Type = Payload
        Perigee Altitude = 600.000 (km)
        Apogee Altitude = 600.000 (km)
        Inclination = 97.740 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.0180 (m^2/kg)
        Start Year = 2020.000 (yr)
        Initial Mass = 12.000 (kg)
        Final Mass = 12.000 (kg)
        Duration = 3.000 (yr)
        Station-Kept = False
        Abandoned = True

**OUTPUT**

        Collision Probability = 5.8764E-06
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass
```

575 Km Injection – 12 kg variant:

```
**INPUT**

Space Structure Name = KC-575
        Space Structure Type = Payload
        Perigee Altitude = 575.000 (km)
        Apogee Altitude = 575.000 (km)
```

```
          Inclination = 97.740 (deg)
          RAAN = 0.000 (deg)
          Argument of Perigee = 0.000 (deg)
          Mean Anomaly = 0.000 (deg)
          Final Area-To-Mass Ratio = 0.0180 (m^2/kg)
          Start Year = 2020.000 (yr)
          Initial Mass = 12.000 (kg)
          Final Mass = 12.000 (kg)
          Duration = 3.000 (yr)
          Station-Kept = False
          Abandoned = True

**OUTPUT**

          Collision Probability = 1.7933E-06
          Returned Message: Normal Processing
          Date Range Message: Normal Date Range
          Status = Pass
```

550 Km Injection – 12 kg variant:

```
**INPUT**


          Space Structure Name = KC-550
          Space Structure Type = Payload
          Perigee Altitude = 550.000 (km)
          Apogee Altitude = 550.000 (km)
          Inclination = 97.740 (deg)
          RAAN = 0.000 (deg)
          Argument of Perigee = 0.000 (deg)
          Mean Anomaly = 0.000 (deg)
          Final Area-To-Mass Ratio = 0.0180 (m^2/kg)
          Start Year = 2020.000 (yr)
          Initial Mass = 12.000 (kg)
          Final Mass = 12.000 (kg)
          Duration = 3.000 (yr)
          Station-Kept = False
          Abandoned = True

**OUTPUT**

          Collision Probability = 9.4434E-07
          Returned Message: Normal Processing
          Date Range Message: Normal Date Range
          Status = Pass

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

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

> *For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).*

The Kepler satellites are to be deployed into a low Earth orbit, where the density of resident space objects, and therefore the probability of collisions, reduces with altitudes below about 800 km. Therefore, the “high insertion” scenario, where satellites are deployed at 600 km, represents the highest collision probability insertion scenario, and the DAS analysis was performed for this scenario.

Small Object Impact and Debris Generation Probability per Spacecraft:

Lifetime Probability of PMD Failure (12 kg variant): 0.0006143 COMPLIANT

```
==================================================
Spacecraft = KC-600
Critical Surface = Avionics+X
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 2.900 (g/cm^2)
    CS Surface Area = 0.0200 (m^2)
    Vector = (0.000000 (u), 0.000000 (v), 1.000000 (w))
    CS Pressurized = No
    Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 2.000 (cm)

**OUTPUT**

    Probability of Penetration = 2.0517E-06 (2.0517E-06)
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = Avionics -X
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 2.900 (g/cm^2)
    CS Surface Area = 0.0200 (m^2)
```

```
    Vector = (0.000000 (u), 0.000000 (v), 1.000000 (w))
    CS Pressurized = No
    Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 2.000 (cm)

**OUTPUT**

    Probability of Penetration = 2.0517E-06 (2.0517E-06)
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = Avionics -Y
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 2.900 (g/cm^2)
    CS Surface Area = 0.0220 (m^2)
    Vector = (0.000000 (u), -1.000000 (v), 0.000000 (w))
    CS Pressurized = No
    Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 10.000 (cm)
    Outer Wall 2   Density: 2.900 (g/cm^2)  Separation: 8.000 (cm)
    Outer Wall 3   Density: 2.900 (g/cm^2)  Separation: 2.000 (cm)

**OUTPUT**

    Probability of Penetration = 1.3635E-10 (1.3635E-10)
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = Avionics+Y
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 2.900 (g/cm^2)
    CS Surface Area = 0.0220 (m^2)
```

```
    Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
    CS Pressurized = No
    Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 1.000 (cm)

**OUTPUT**

    Probability of Penetration = 6.0967E-04 (6.0985E-04)
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = Avionics+Z
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 0.029 (g/cm^2)
    CS Surface Area = 0.0500 (m^2)
    Vector = (1.000000 (u), 0.000000 (v), 0.000000 (w))
    CS Pressurized = No
    Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 2.000 (cm)

**OUTPUT**

    Probability of Penetration = 1.6781E-07 (1.6781E-07)
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = Avionics-Z
==================================================

**INPUT**

    Apogee Altitude = 600.000 (km)
    Perigee Altitude = 600.000 (km)
    Orbital Inclination = 97.740 (deg)
    RAAN = 0.000 (deg)
    Argument of Perigee = 0.000 (deg)
    Mean Anomaly = 0.000 (deg)
    Final Area-To-Mass = 0.0018 (m^2/kg)
    Initial Mass = 12.000 (kg)
    Final Mass = 12.000 (kg)
    Station Kept = No
    Start Year = 2023.000 (yr)
    Duration = 3.000 (yr)
    Orientation = Fixed Oriented
    CS Areal Density = 2.900 (g/cm^2)
    CS Surface Area = 0.0500 (m^2)
    Vector = (-1.000000 (u), 0.000000 (v), 0.000000 (w))
    CS Pressurized = No
```

```
        Outer Wall 1   Density: 2.900 (g/cm^2)  Separation: 2.000 (cm)

**OUTPUT**

        Probability of Penetration = 4.1107E-09 (4.1107E-09)
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = SA1-Keep alive
==================================================

**INPUT**

        Apogee Altitude = 600.000 (km)
        Perigee Altitude = 600.000 (km)
        Orbital Inclination = 97.740 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass = 0.0018 (m^2/kg)
        Initial Mass = 12.000 (kg)
        Final Mass = 12.000 (kg)
        Station Kept = No
        Start Year = 2023.000 (yr)
        Duration = 3.000 (yr)
        Orientation = Fixed Oriented
        CS Areal Density = 2.900 (g/cm^2)
        CS Surface Area = 0.0290 (m^2)
        Vector = (-1.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No

**OUTPUT**

        Probability of Penetration = 9.7730E-08 (9.7730E-08)
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range

==================================================
Spacecraft = KC-600
Critical Surface = SA2- keep alive
==================================================

**INPUT**

        Apogee Altitude = 600.000 (km)
        Perigee Altitude = 600.000 (km)
        Orbital Inclination = 97.740 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass = 0.0018 (m^2/kg)
        Initial Mass = 12.000 (kg)
        Final Mass = 12.000 (kg)
        Station Kept = No
        Start Year = 2023.000 (yr)
        Duration = 3.000 (yr)
        Orientation = Fixed Oriented
        CS Areal Density = 2.900 (g/cm^2)
        CS Surface Area = 0.0290 (m^2)
        Vector = (1.000000 (u), 0.000000 (v), 0.000000 (w))
        CS Pressurized = No

**OUTPUT**
```

```
Probability of Penetration = 2.6625E-07 (2.6625E-07)
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
```

=============== End of Requirement 4.5-2 ===============

Identification of all systems or components required to accomplish any post mission disposal operation, including passivation and maneuvering: None.

7 Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry within a maximum of 15.8 years after start of mission, as described below.

Plan for any spacecraft maneuvers required to accomplish post mission disposal:
Passive Disposal:
Nominal operational lifetime of the spacecraft is three years from the date of deployment. At which time the spacecraft will be oriented into its Brake configuration via on-board attitude control system to ensure rapid atmospheric reentry within a maximum of 1.9 years after end of mission duration. In a random tumble configuration, reentry will occur at a maximum of 10.9 years after end of mission operations. However, as the Brake configuration is the dynamically stable configuration, in the event of attitude control failure the spacecraft will passively orient in this attitude.

Spacecraft will remain controllable throughout their entire lifetime, including deorbit, up until atmospheric demise. Spacecraft will continue to be able to execute differential drag maneuvers throughout the deorbit phase, should they be necessary to resolve a conjunction notice. As they descend through inhabited space, this will significantly reduce overall risk to manned spacecraft, such as the ISS.

While every commercially sensible action is taken to reduce the risk of failure of the spacecraft and its deployment, no spacecraft is capable of reaching 100% system reliability. Kepler and its partners use rigorous testing and analysis of deployment chain activities to target greater than 99.0% full system reliability. This reliability considers those items necessary to achieve complete deployment such that the spacecraft can enter the brake configuration if/when needed.

Fault-tolerant redundant mechanisms are used to ensure a reliable deployment of solar panels. In the event that a spacecraft is injected dead-on-arrival (DOA), these systems will provide the mechanism for a faster de-orbit.

Active Disposal:
Spacecraft will be actively oriented into the Brake attitude configuration to hasten post-mission disposal.

Calculation of area-to-mass ratio after post mission disposal, if the controlled reentry option is not selected:
As per Section 3, the spacecraft all assume passive braking attitudes when uncontrolled. The resultant area-to-mass ratios are shown.

Table 3: Area-to-mass Ratios

Disposal Mass (kg)	Brake Configuration Area (m^2)	Final Area-to-mass ratio (m^2/kg)
12	0.37	0.0308

The brake configuration is the dynamically stable orientation of the satellite, and thus in a state of control loss the spacecraft will naturally assume this configuration.

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 3.0.1 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

At the end of operational life, the Kepler satellites will immediately be oriented via on-board attitude control systems to the Brake configuration, which will allow for atmospheric reentry. No direct retrieval methods will be used. End of operational life will commence after 3 years of on-orbit operations, during which time the spacecraft is in Nominal configuration. Re-entry location will be uncontrolled; however, spacecraft will fully demise upon atmospheric re-entry.

In the event of an actuator failure, the spacecraft will passively orient towards a Brake configuration as per *Section 7 - Passive Disposal*. In a worst-case, post-mission scenario where the Brake configuration fails to stabilize the spacecraft, the maximum possible lifetime is 13.4 years, which is well within the disposal requirements.

More realistic spacecraft orbit lifetimes are listed for both spacecraft variants in Table 4. The spacecraft orbit lifetime is generated with a number of tools as a means of determining variation of prediction. It is noted that the average lifetime as generated by DAS aligns with the result of the SGP4 propagated lifetime of KIPP using on-orbit drag data for KIPP, as gathered via CSpOC. Consequently, the lifetime predictions generated by DAS will be considered the status-quo.

Table 4: Predicted average orbit lifetimes for risk analysis with brake configuration

Spacecraft Class	Orbit Insertion Altitude (km)	Orbit Lifetime (years)	Time Above 500 km (years)
12 kg	600	4.9	4.3
12 kg	575	4.2	3.7
12 kg	550	3.7	3.2

Lifetime models assume that active pointing concludes after the 3rd year of operation, after which the spacecraft passively assumes the Brake configuration.

Requirement 4.6-2. Disposal for space structures near GEO.
Analysis: Not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.
Analysis: Not applicable.

Requirement 4.6-4. Reliability of Postmission Disposal Operations
Analysis: Not applicable.

8 Assessment of Spacecraft Re-entry Hazards

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 re-entry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Analysis performed using DAS v3.0.1 shows that no part of the satellite is expected to survive re-entry, therefore the risk of human casualty is ~0.

```
==============
Project Data
==============
**INPUT**

        Space Structure Name = KC-600
        Space Structure Type = Payload

        Perigee Altitude = 600.000000 (km)
        Apogee Altitude = 600.000000 (km)
        Inclination = 97.740000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Area-To-Mass Ratio = 0.018000 (m^2/kg)
        Start Year = 2020.000000 (yr)
        Initial Mass = 12.000000 (kg)
        Final Mass = 12.000000 (kg)
        Duration = 3.000000 (yr)
        Station Kept = False
        Abandoned = True
        PMD Perigee Altitude = 531.451199 (km)
        PMD Apogee Altitude = 536.741822 (km)
        PMD Inclination = 97.768061 (deg)
        PMD RAAN = 10.911044 (deg)
        PMD Argument of Perigee = 44.290036 (deg)
        PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

        Suggested Perigee Altitude = 531.451199 (km)
        Suggested Apogee Altitude = 536.741822 (km)
        Returned Error Message = Passes LEO reentry orbit criteria.

        Released Year = 2032 (yr)
        Requirement = 61
        Compliance Status = Pass

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

=============== End of Requirement 4.7-1 ===============
08 24 2020; 11:56:00AM      Project Data Saved To File
08 24 2020; 11:59:11AM      *********Processing Requirement 4.7-1
        Return Status :  Passed

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

name = KC-600
```

```
quantity = 1
parent = 0
materialID = 9
type = Box
Aero Mass = 12.000000
Thermal Mass = 12.000000
Diameter/Width = 0.226000
Length = 0.450000
Height = 0.120000

name = Structure
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 8.600000
Thermal Mass = 2.000000
Diameter/Width = 0.226000
Length = 0.450000
Height = 0.120000

name = Payload
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 2.000000
Thermal Mass = 2.000000
Diameter/Width = 0.107000
Length = 0.220000
Height = 0.087000

name = Battery
quantity = 1
parent = 2
materialID = 64
type = Box
Aero Mass = 2.000000
Thermal Mass = 2.000000
Diameter/Width = 0.083000
Length = 0.200000
Height = 0.083000

name = Avionics
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 2.000000
Thermal Mass = 2.000000
Diameter/Width = 0.150000
Length = 0.200000
Height = 0.100000

name = ReactionWheels
quantity = 3
parent = 2
materialID = 58
type = Cylinder
Aero Mass = 0.200000
Thermal Mass = 0.200000
Diameter/Width = 0.045000
Length = 0.025000

name = SolarArray Deployment Mechanism
quantity = 2
```

```
parent = 1
materialID = 59
type = Cylinder
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.015000
Length = 0.050000

name = Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.220000
Length = 0.260000
Height = 0.020000

name = Solar Array
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 1.020000
Thermal Mass = 1.000000
Diameter/Width = 0.360000
Length = 0.360000

name = cells
quantity = 20
parent = 9
materialID = 24
type = Flat Plate
Aero Mass = 0.002000
Thermal Mass = 0.002000
Diameter/Width = 0.040000
Length = 0.080000

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

name = KC-600
Demise Altitude = 77.995338
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure
Demise Altitude = 75.005051
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload
Demise Altitude = 66.474861
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Battery
Demise Altitude = 72.445839
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
```

```
name = Avionics
Demise Altitude = 66.554977
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = ReactionWheels
Demise Altitude = 63.417500
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SolarArray Deployment Mechanism
Demise Altitude = 72.553047
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Antenna
Demise Altitude = 73.063438
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Array
Demise Altitude = 75.736847
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = cells
Demise Altitude = 75.699699
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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

Requirement 4.7-1, b) *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).*

Not applicable as the spacecraft will not be controlled up to and during reentry. There are not predicted surviving elements of debris.

Requirement 4.7-1 c) *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).*

Not applicable as the spacecraft will not be controlled up to and during reentry.

9 Assessment for Tether Missions

Not applications as there are no tethers in this mission.