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February 22, 2019

Mr. Jose P. Albuquerque
Chief, Satellite Division, International Bureau
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20010

Re: *Hiber, Inc., Petition for Declaratory Ruling Access U.S. Market Using the Hiberband Low-Earth Orbit System;*
Call Sign S3038, IBFS File No. SAT-PDR-20180910-00069

Dear Mr. Albuquerque:

Hiber Inc. ("Hiber") hereby responds to the letter dated November 20, 2018 ("Division Letter"),[1] from the Satellite Division ("Division") of the International Bureau requesting additional information regarding Hiber's Petition for Declaratory Ruling ("PDR") seeking U.S. market access for a non-voice, non-geostationary ("NVNG") mobile-satellite service ("MSS") system in the 399.9-400.05 MHz and 400.15-401 MHz frequency bands ("Hiberband® System").[2] Specifically, Hiber provides answers to Questions 1-6 regarding its orbital debris analysis report ("ODAR").

Question 1: *The Orbital Debris Assessment Report does not appear to be fully executed in the signature block. The version of the Debris Assessment Software utilized is not a current version. Please update.*

Response: Attached is a fully executed copy of Hiber's updated ODAR.

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[1] *See* Letter from Jose P. Albuquerque, Chief, Satellite Div., Int'l Bur., FCC, to Lynne Montgomery, Wilkinson Barker Knauer, LLP, Counsel to Hiber, Inc., IBFS File No. SAT-PDR-20180910-00069, Call Sign S3038 (Nov. 20, 2018) ("Division Letter").

[2] *See* Hiber, Inc., Petition for Declaratory Ruling to Access U.S. Market Using the Hiberband Low-Earth Orbit System, IBFS File No. SAT-PDR-20180910-00069 (Call Sign S2979) (filed Sept. 10, 2018) ("PDR").

As previously noted, Hiber has been unable to obtain a current version of the Debris Assessment Software 2.1.1 ("DAS") from NASA.[3] Due to difficulty with processing pending and additional requests, NASA has been unable to provide a timeframe for providing Hiber with the current DAS version. Consequently, Division staff has indicated that alternative debris assessment software may be used. Hiber has chosen to use the National Centre for Space Studies's ("CNES") Semi-analytic Tool for End of Life Analysis ("STELA") and the European Space Agency's ("ESA") Debris Risk Assessment and Mitigation Analysis ("DRAMA") software applications to assess risk probabilities, as noted in the attached ODAR.

Question 2: *In its Orbital Debris Assessment Report, Hiber identifies two failure modes that may be inversely related. The first – "lithium plating on the anode" – is caused by operation below recommended temperatures, while the second – "gas generation" – is caused by use above recommended temperatures. Please provide recommended temperature range and any steps to avoid operations above or below this range.*

The recommended temperature ranges are set forth in Section 3.4 of the attached ODAR. In particular, the recommended temperature ranges for the battery cells are:

- Charge : 0 to +45° C
- Discharge : -20 to +60° C
- Storage : -20 to +50° C

Hiber will continuously monitor the battery cell temperatures on Hiber-1 and Hiber-2. To ensure that operations remain within the recommended temperature ranges, Hiber can turn the heaters on or off to adjust the battery cell temperature

Question 3: *In its Orbital Debris Assessment Report, no calculations or data are included to support Hiber's conclusions regarding the probability of collision with space objects. Please provide additional information on these calculations.*

Hiber used ESA's DRAMA software to assess the probability of collision with space objects in Section 3.5 of the attached ODAR. DRAMA allows Hiber to assess the compliance of its mission with international safety and debris requirements. DRAMA computes the annual collision probability. The probability of collision was calculated for each satellite's orbital lifetime.

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[3] *See* Letter from Lynne Montgomery, Wilkinson Barker Knauer, LLP, Counsel to Hiber, Inc., to Jose P. Albuquerque, Chief, Satellite Div., Int'l Bur., FCC, IBFS File No. SAT-PDR-20180910-00069 (Call Sign S3038) (Dec. 12, 2018); Letter from Lynne Montgomery, Wilkinson Barker Knauer, LLP, Counsel to Hiber, Inc., to Jose P. Albuquerque, Chief, Satellite Div., Int'l Bur., FCC, IBFS File No. SAT-PDR-20180910-00069 (Call Sign S3038) (Jan. 29, 2019) ("Jan. 29 Letter"); *see also* Division Grant Stamp.

To determine the evolution of the satellite's orbital parameters, Hiber used CNES' STELA software. STELA allows the user to propagate orbits over time and provides a complete report of the evolution of the orbital parameters throughout the satellite's lifetime.

Question 4: *In its Orbital Debris Assessment Report, Hiber provides the probability of collision for a proposed satellite system of two satellites. Please provide orbital debris mitigation information for Hiber's proposed twenty-four space station constellation.*

In Section 3.5 of the attached ODAR, Hiber calculated that the collision probability of an initial two-satellite constellation is 1.3485×10^{-4}, which is lower than NASA's 0.0001 threshold probability.[4] When considering the entire 24-satellite system (consisting of two 6U satellites and 22 3U satellites), the total collision probability is calculated as 2.2383×10^{-3}, which exceeds the 0.001 threshold.[5] However, the 22 3U satellites are expected to be equipped with propulsion modules. The propulsion modules will enable Hiber to conduct collision avoidance maneuvers as needed.

Question 5: *The Schedule S lists the estimated lifetime of the satellites as three years from date of launch. There is no further documentation regarding the length of time these satellites will be in orbit through natural decay. Please provide additional information supporting Hiber's conclusion regarding the lifetime of the satellites. This information should be provided showing altitude and time data band may be submitted in a graph format.*

Hiber performed simulations using CNES' STELA software to assess how long it would take for the Hiber-1 and Hiber-2 satellites to effectuate an atmospheric reentry. The results show that the satellites will take 4.54 years and 16.74 years, respectively, to re-enter the atmosphere after the end useful life. This is compliant with the guidelines that specify that satellites de-orbiting through atmospheric reentry do so within 25 years of the satellite's end-of-life. The results are demonstrated in Figures 1 and 2 below.

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[4] *See* NASA Technical Standard, Safety and Mission Assurance Acronyms, Abbreviations, and Definitions, NASA-STD 8709.22 at 32, Requirement 4.5-1 (with Change 2) (Oct. 31, 2012) (setting standard that the probability of a spacecraft colliding with a large object during the satellite's orbital lifetime should be no greater than 0.001).

[5] As noted in its application, Hiber is finalizing the design for the 22 3U satellites and will submit a separate ODAR when the design is complete.

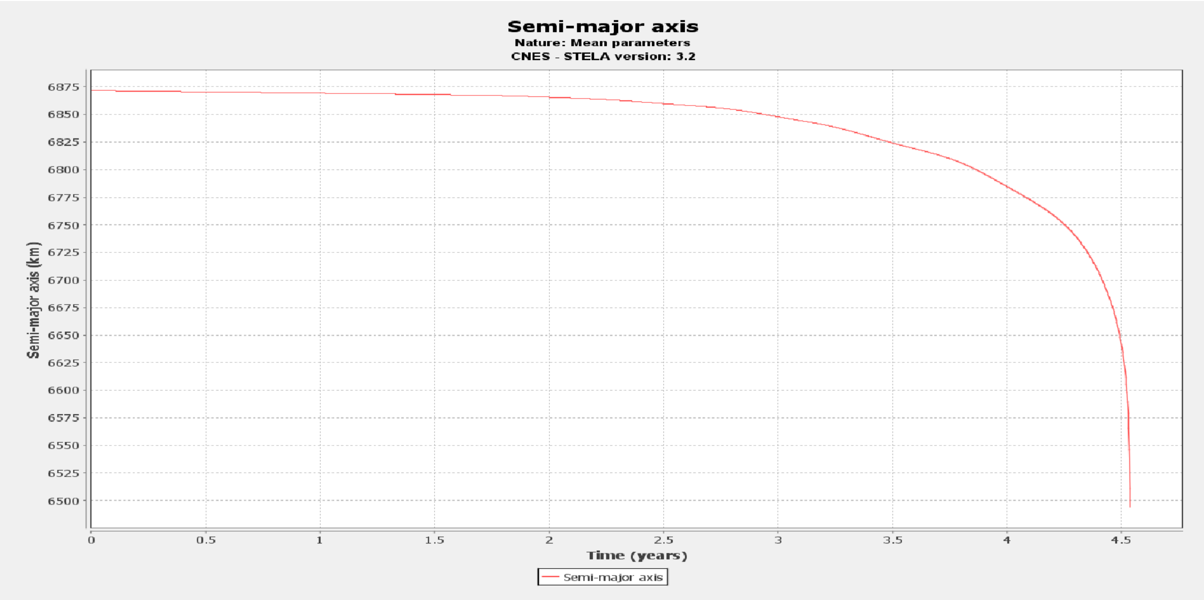

Figure 1 : Hiber-1 altitude evolution

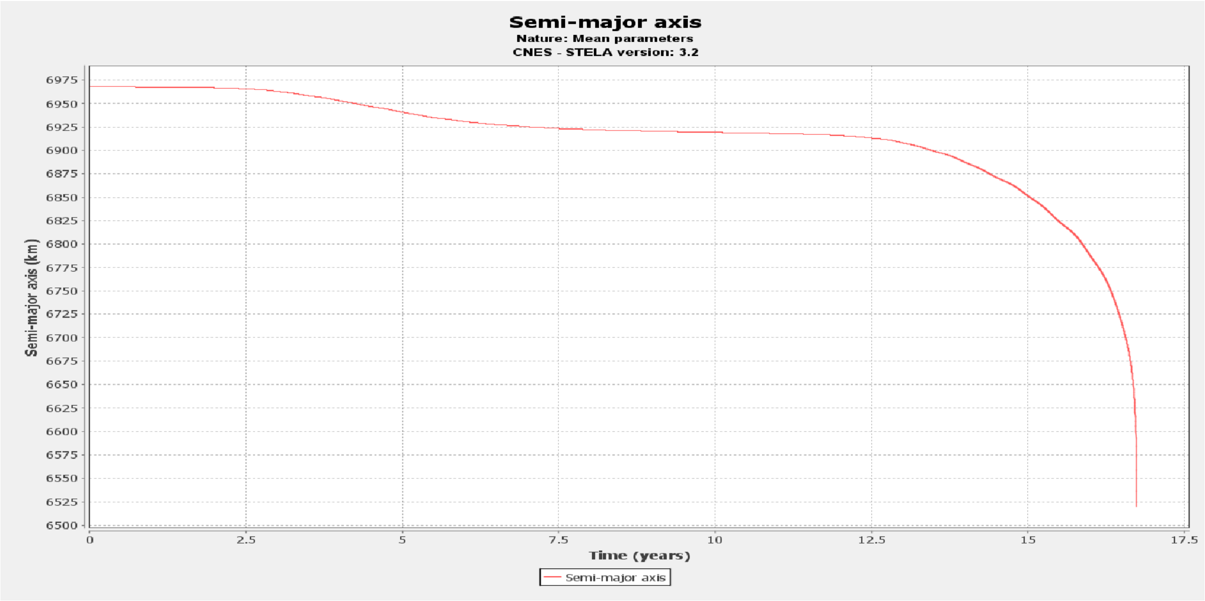

Figure 2 : Hiber-2 altitude evolution

Question 6: *Section 3.7 of the Orbital Debris Assessment Report includes an incomplete table of spacecraft components. Please provide a complete list of spacecraft components.*

Section 3.7 of the attached ODAR has been updated with a complete list of spacecraft components.

Should the Commission require additional information about the foregoing or otherwise in connection with the PDR, please contact the undersigned.

Sincerely,

/s/ Lynne M. Montgomery
Lynne M. Montgomery
Counsel to Hiber, Inc.

cc: Jose Albuquerque
Karl Kensinger
Stephen Duall
Alyssa Roberts

hiber®

Orbital Debris Assessment Report

Hiber-1 & Hiber-2

Revision nr2

22/02/2018

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Hiber Orbital Debris Assessment Report

	Name
Prepared by	Hiber Inc.
Version Approved by	Maarten Engelen, Program Executive/Project Manager
Signature	
Date	February 22, 2019

Revisions

Revision	Description	Date
1	Initial release	16/08/2018
2	First revision	20/11/2018
3	Use of STELA and DRAMA instead of DAS 2.1.1 Updated launch dates and orbit parameters of Hiber-1 and 2 Specified recommended temperature range for battery cells Completed the probability of collision chapter Computed time before reentry for Hiber-1 and 2 Completed table for spacecraft components	06/02/2018

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose

The scope of this document is to assess the different causes and risks related to orbital debris. Only the risks related to Hiber's satellites, and not the launch vehicle, are being investigated in this report. This study was conducted in concordance with the requirements stated in NASA-STD-8719.14A.

In order to determine risk probabilities, Hiber used the National Centre for Space Studies' (CNES) Semi-analytic Tool for End of Life Analysis (STELA) software and the European Space Agency's (ESA) Debris Risk Assessment and Mitigation Analysis (DRAMA) software.

1.2 References

Ref #	Document / software	Version
1	NASA-STD-8719.14A	
2	STELA	3.2
3	DRAMA	2.2.1

Table 1: List of referenced documents

2 General Review

The following table summarizes the different requirements recommended by NASA. As can be seen, Hiber's spacecraft meet all requirements.

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant or N/A	Not Compliant	Incomplete	
4.3-1.a			X		X			No intentional debris released
4.3-1.b			X		X			No intentional debris released
4.3-2			X		X			No intentional debris released
4.4-1			X		X			
4.4-2			X		X			No passivation
4.4-3			X		X			No intentional breakup
4.4-4			X		X			No intentional breakup
4.5-1			X		X			
4.5-2			X		X			
4.6-1.a			X		X			
4.6-1.b			X		X			
4.6-1.c			X		X			
4.6-2			X		X			
4.6-3			X		X			
4.6-4			X		X			
4.7-1			X		X			
4.8-1			X		X			No tether system

Table 2 : ODAR review check sheet

3 Orbital Debris Assessment

3.1 *Program Management and Mission Overview*

- **Identification of the Headquarters Mission Directorate sponsoring the mission and the Program Executive**: The Headquarter Mission Directorate is Hiber and the Program Executive is Maarten Engelen.

- **Identification of the responsible program/project manager and senior scientific and management personnel**: The responsible project managers are Tom Schreuder and Maarten Engelen.

- **Identification of any foreign government or space agency participation in the mission and a summary of NASA's responsibility under the governing agreement(s)**: None.

- **Clear schedule of mission design and development milestones from NASA mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates:** N/A

- **Brief description of the mission**: The first two 6U satellites of the Hiber constellation, Hiber-1 and Hiber-2, have been deployed in a LEO orbit. Their mission lifetime will be 3 years. 22 additional satellites will be launched to form a 24-satellite constellation. These additional satellites will be 3U in size, and will be studied in a separate ODAR as their design will differ.

- **Identification of the anticipated launch vehicle and launch site:** Hiber-1 was launched on a PSLV-C43 from the Satish Dhawan Space Centre (Sriharikota, India) and Hiber-2 on a Falcon 9 from the Vandenberg Air Force Base (California, USA).

- **Identification of the proposed launch date and mission duration:** Hiber-1 was launched on November 29th, 2018 and Hiber-2 on December 3rd, 2018. Both satellites are designed for a mission duration of three years.

- **Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:** Hiber-1 was launched into an orbit with a perigee at 479.7 km, apogee at 507.6 km and a 97.5° inclination. Hiber-2 was launched into an orbit with a perigee at 580.3 km, apogee at 599.9 km and inclination at 97.8°.

The satellites will then naturally decay because of atmospheric drag forces.

- **Reason for selection of operational orbit(s) (such as ground track, SSO, GEO sync, instrument resolution, co-locate with other spacecraft, …)**: These orbits were chosen because they are sun-synchronous. The exact orbital planes are based on the placements by the launch vehicle providers.

- **Identification of any interaction or potential physical interference with other operational spacecraft (Note: This does not include potential for RF interaction unless it affects the risk of generating orbital debris.):** None

3.2 *Spacecraft Description*

- **Physical description of the spacecraft, including spacecraft bus, payload instrumentation, and all appendages, such as solar arrays, antennas, and instrument or attitude control booms:**

The Hiber-1 and Hiber-2 spacecraft are typical 6U CubeSats, with outside dimensions of 100 mm x 200 mm x 340.5 mm. There are two large solar panels (200 mm x 340.5 mm) and two smaller ones (100 mm x 340.5 mm), which will deploy once in orbit. Four antennas (550 mm long) serve for TTC, and two other antennas (one 330 mm long deployable antenna and one patch antenna) provide payload functionalities.

- **Detailed illustration of the entire spacecraft in the mission operation configuration with clear overall dimensional markings and marked internal component locations:**

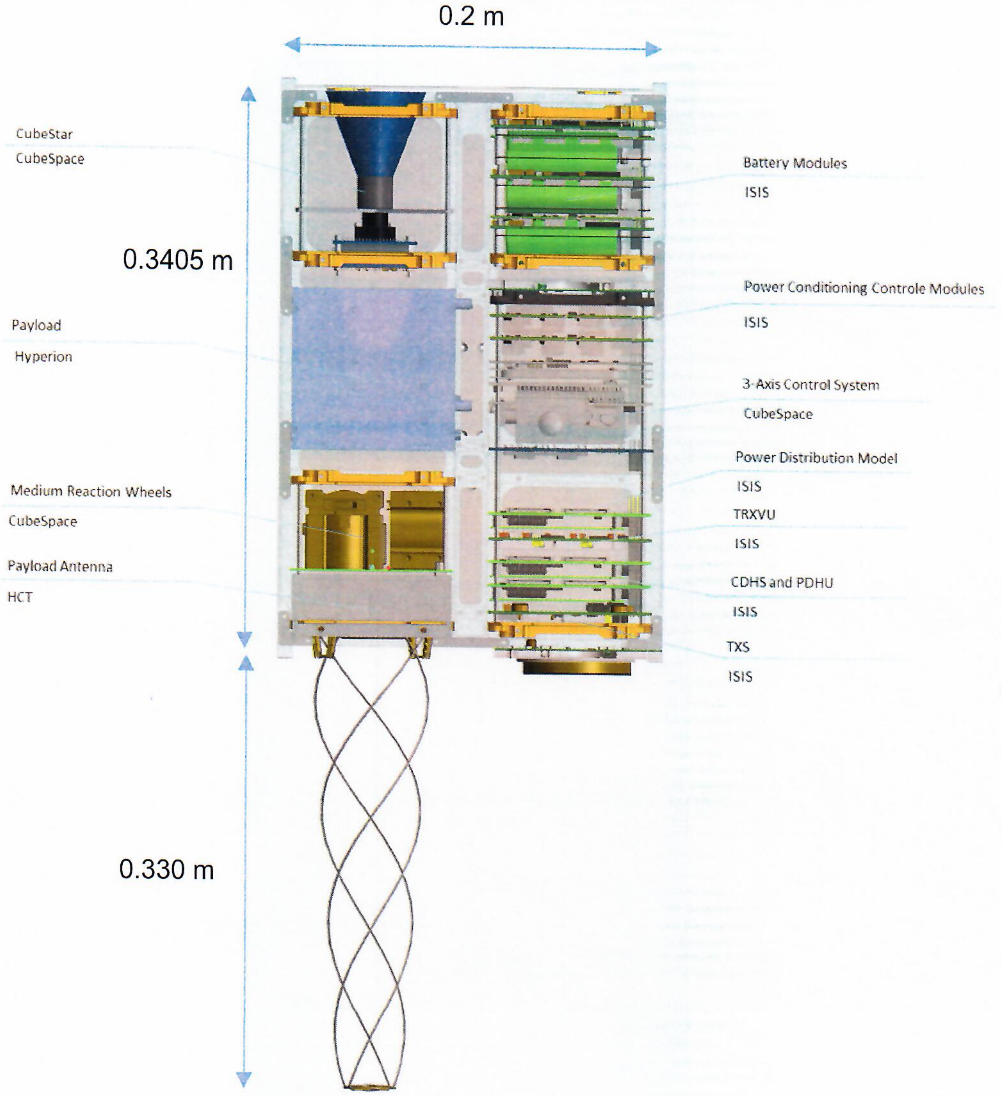

Figure 1 : Hiber's satellite

- **Total spacecraft mass at launch, including all propellants and fluids:** 7.23 kg

- **Dry mass of spacecraft at launch, excluding solid rocket motor propellants:** 7.23 kg

- **Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear):** Hiber-1 and Hiber-2 do not include a propulsion system.

- **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. Description of all fluid systems, including size, type, and qualifications of fluid containers such as propellant and pressurization tanks, including pressurized batteries:** N/A

- **Description of all active and/or passive attitude control systems with an indication of the normal attitude of the spacecraft with respect to the velocity vector:** The satellite is controlled via 3 reaction wheels and 3 magnetorquers. The normal attitude of the spacecraft consists of the long axis nadir-aligned, as the payload antennas need to be nadir-pointing. This is the naturally stable attitude of the satellite.

- **Description of any range safety or other pyrotechnic devices:** Hiber-1 and Hiber-2 do not contain any range safety or pyrotechnic devices.

- **Description of the electrical generation and storage system:** Hiber-1 and Hiber-2 contain Li-ion battery cells that provide energy, and are recharged by GaAs solar cells.

- **Identification of any other sources of stored energy not noted above:** There are no additional sources of stored energy.

- **Identification of any radioactive materials on board or make a positive statement that there are no radioactive materials onboard:** There are no radioactive materials onboard.

3.3 Assessment of Spacecraft Debris Released during Normal Operations

No object will be released intentionally.

3.4 Assessment of Spacecraft Intentional Breakups and Potential for Explosions

- **Identification of all potential causes of spacecraft breakup during deployment and mission Operations:** There is no credible scenario which would lead to a spacecraft breakup.

- **Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion:**

The only potential source of explosion on the satellite is from the Li-ion battery cells. Explosion can occur due to overheating or venting.

Metal scraps that are left over from the manufacturing process, shocks, damages, over-discharging and overcharging, fast charging and using the batteries outside of the recommended temperature ranges could lead to an explosion.

- **Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:** N/A

- **List of components which are passivated at EOM. List includes method of passivation and amount which cannot be passivated:** No items will be passivated. The batteries do not need to be passivated because, as the failure mode analysis shows, they do not present a high or credible risk of explosions during the mission.

- **Rationale for all items which are required to be passivated, but cannot be due to their Design:** N/A

- **Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4**

Requirement 4.4-1: *Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts)*

The following failure modes were assessed regarding the battery cells. They can all potentially lead to explosion.

Failure mode	Effects of failure	Causes of failure	Recommended action
Short circuit	Overheating	Metal scraps, shock, physical damage, over-discharge, overcharge, external system failure	Quality check, vibration test, shock test, charge and discharge cycling tests, discharge and overcharge protection, short circuit protection on external circuits
Overcharging	Overheating	No overcharging protection	Overcharging protection Charge cycling test
Overpressure	Venting	Ultra-fast charging	Nominal charging
Lithium plating on anode	Physical damage / venting / short circuit	Use below recommended temperatures	Maintain battery cells at recommended temperatures
Gas generation	Venting	Use above recommended temperatures	Maintain battery cells at recommended temperatures

Table 3 : Battery failure modes

The recommended actions listed above were taken during the manufacture and operation of the satellites, hence mitigating the risk of battery cell explosions. Through these actions, Hiber has effectively mitigated against the risk of failure.

Note: The recommended temperature range for the battery cells are:

- Charge: 0 to +45° C
- Discharge: -20 to +60° C
- Storage: -20 to +50° C

The battery cell temperature is continuously monitored. Hiber can turn the heaters on or off to adjust the battery cell temperature to ensure that operations remain within the recommended temperature range.

Requirement 4.4-2: Passivate to limit probability of accidental explosion after EOM: N/A

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

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

3.5 *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 (compliance with requirement 4.5-1):

To determine the evolution of the satellite's orbit parameters, Hiber used CNES' STELA software. STELA allows the user to propagate orbits over time and provides a complete report of the evolution of the orbital parameters throughout the satellite's lifetime.

Hiber used DRAMA to compute the annual collision probability. DRAMA allows Hiber to assess the compliance of its mission with international safety and debris requirements. The collision probability was calculated consistent with the orbital life of each satellite, each time with the updated orbit parameters.

According to STELA, the evolution of the orbital parameters for Hiber's constellation is:

Time	Parameter	Hiber-1	Hiber-2	Hiber 3-24
	Launch date	11/29/18	12/03/18	10/01/19
	Lifetime	4.54 years	16.74 years	4.58 years
Year 0	Semi-major axis (km)	6871.65	6968.10	6978
	Eccentricity	0.00125	0.00121	0.00122
	Inclination (°)	97.5	97.8	97.8
	Arg. of perigee (°)	91.5	91	87.5
Year 1	Semi-major axis (km)	6869.25	6967.62	6976.50
	Eccentricity	0.001245	0.001205	0.001235
	Inclination (°)	97.54	97.84	97.79
	Arg. of perigee (°)	91	91	86.5
Year 2	Semi-major axis (km)	6865.62	6966.89	6968.99
	Eccentricity	0.001235	0.001215	0.001255
	Inclination (°)	97.57	97.87	97.77
	Arg. of perigee (°)	90.5	91.25	87.5
Year 3	Semi-major axis (km)	6847.89	6963.04	6939.11
	Eccentricity	0.001185	0.00119	0.001325
	Inclination (°)	97.60	97.91	97.76
	Arg. of perigee (°)	90	91.25	88
Year 4	Semi-major axis (km)	6784.71	6952.99	6870.15
	Eccentricity	0.001145	0.00118	0.001515
	Inclination (°)	97.61	97.94	97.74
	Arg. of perigee (°)	87.5	90.5	87.5
Year 5	Semi-major axis (km)		6940.79	
	Eccentricity		0.00118	
	Inclination (°)		97.97	
	Arg. of perigee (°)		90	
Year 6	Semi-major axis (km)		6930.81	
	Eccentricity		0.00120	
	Inclination (°)		97.98	
	Arg. of perigee (°)		89.25	
Year 7	Semi-major axis (km)		6925.26	
	Eccentricity		0.00122	
	Inclination (°)		97.97	
	Arg. of perigee (°)		88.75	
Year 8	Semi-major axis (km)		6922.20	
	Eccentricity		0.00122	
	Inclination (°)		97.94	
	Arg. of perigee (°)		88.75	
Year 9	Semi-major axis (km)		6920.51	
	Eccentricity		0.001225	
	Inclination (°)		97.91	
	Arg. of perigee (°)		88.5	
Year	Semi-major axis (km)		6919.28	
	Eccentricity		0.00123	

	Inclination (°)		97.87	
	Arg. of perigee (°)		88.25	
Year 11	Semi-major axis (km)		6918.06	
	Eccentricity		0.00123	
	Inclination (°)		97.85	
	Arg. of perigee (°)		88.25	
Year 12	Semi-major axis (km)		6915.94	
	Eccentricity		0.00124	
	Inclination (°)		97.84	
	Arg. of perigee (°)		88.25	
Year 13	Semi-major axis (km)		6908.09	
	Eccentricity		0.00127	
	Inclination (°)		97.85	
	Arg. of perigee (°)		88	
Year 14	Semi-major axis (km)		6887.22	
	Eccentricity		0.001305	
	Inclination (°)		97.87	
	Arg. of perigee (°)		88	
Year 15	Semi-major axis (km)		6851.48	
	Eccentricity		0.00134	
	Inclination (°)		97.90	
	Arg. of perigee (°)		89	
Year 16	Semi-major axis (km)		6787.42	
	Eccentricity		0.00136	
	Inclination (°)		97.91	
	Arg. of perigee (°)		90.75	

Table 4 : Orbit parameters evolution

The annual collision probabilities are given on DRAMA:

Collision probability	**Hiber-1**	**Hiber-2**	**Hiber 3-24**
Year 0-1	0.1513 x 10-4	0.2694 x 10-4	0.3815 x 10-4
Year 1-2	0.1849 x 10-4	0.3342 x 10-4	0.3238 x 10-4
Year 2-3	0.1727 x 10-4	0.3039 x 10-4	0.3279 x 10-4
Year 3-4	0.1482 x 10-4	0.2137 x 10-4	0.2180 x 10-4
Year 4-5	0.6072 x 10-5	0.2135 x 10-4	0.1603 x 10-4
Year 5-6		0.1948 x 10-4	
Year 6-7		0.2120 x 10-4	
Year 7-8		0.2071 x 10-4	
Year 8-9		0.2094 x 10-4	
Year 9-10		0.2340 x 10-4	
Year 10-11		0.2031 x 10-4	
Year 11-12		0.1966 x 10-4	
Year 12-13		0.2132 x 10-4	
Year 13-14		0.1979 x 10-4	
Year 14-15		0.1932 x 10-4	
Year 15-16		0.1488 x 10-4	
Year 16-17		0.5802 x 10-5	
Total	0.71782 x 10-4	3.60282 x 10-4	1.4115 x 10-4

Table 5 : Annual collision probabilities

The total collision probability for both Hiber-1 and Hiber-2 is 4.32064 x 10-4, which is under the 0.001 threshold.

When considering the 24 satellite system the total collision probability becomes 3.5374 x 10-3, thus exceeding the 0.001 threshold. However, the 22 3U satellites, for which Hiber will submit a separate

ODAR, are expected to be equipped with propulsion modules. The propulsion modules will enable Hiber to conduct collision avoidance maneuvers as needed, thus mitigating the possibility of collision.

- **Calculation of spacecraft probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent post-mission disposal (compliance with requirement 4.5-2):** Post-mission disposal is done naturally, via drag forces. Therefore, there are no vital systems needed to ensure it. Similarly, no systems will be passivated, so once again there will be no vital systems needed to ensure it.

3.6 Assessment of Spacecraft Post-mission Disposal Plans and Procedures

- **Description of spacecraft disposal option selected:** The spacecraft will decay because of atmospheric drag and de-orbit naturally via atmospheric re-entry.

Simulations were run on CNES' STELA software to assess how long it would take for the satellites to effectuate an atmospheric reentry.

Results show that it will take Hiber-1 4.54 years and Hiber-2 16.74 years to reenter the atmosphere. This is compliant with the guidelines that specify that satellites de-orbiting through atmospheric reentry do so within 25 years of the satellite's end-of-life. The results are demonstrated in Figures 2 and 3.

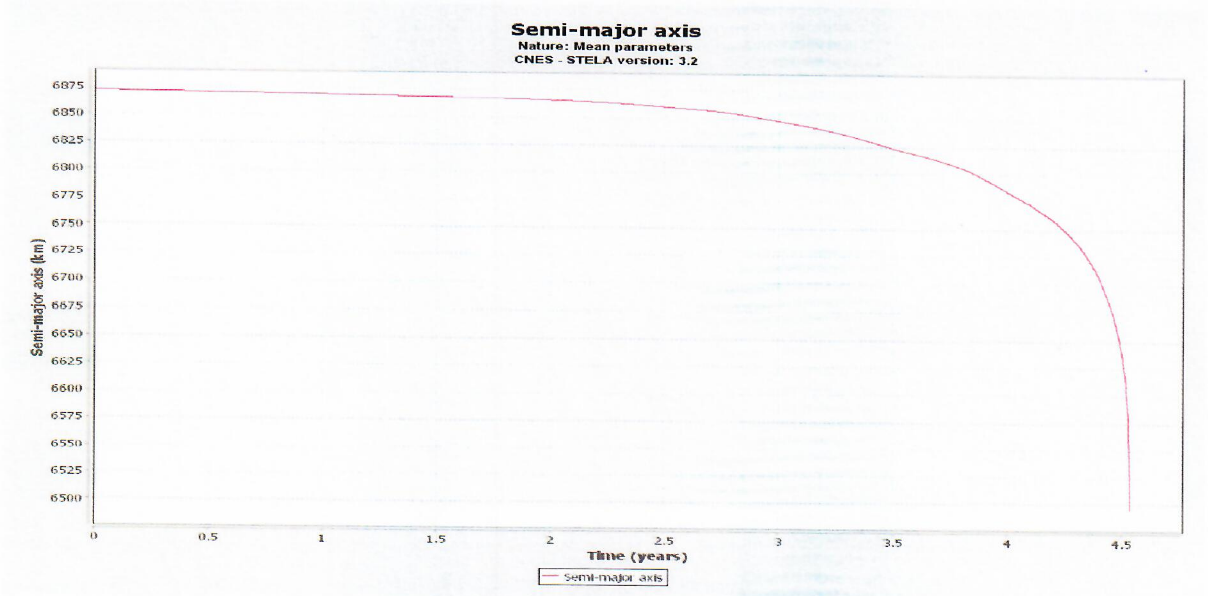

Figure 2: Hiber-1 altitude evolution

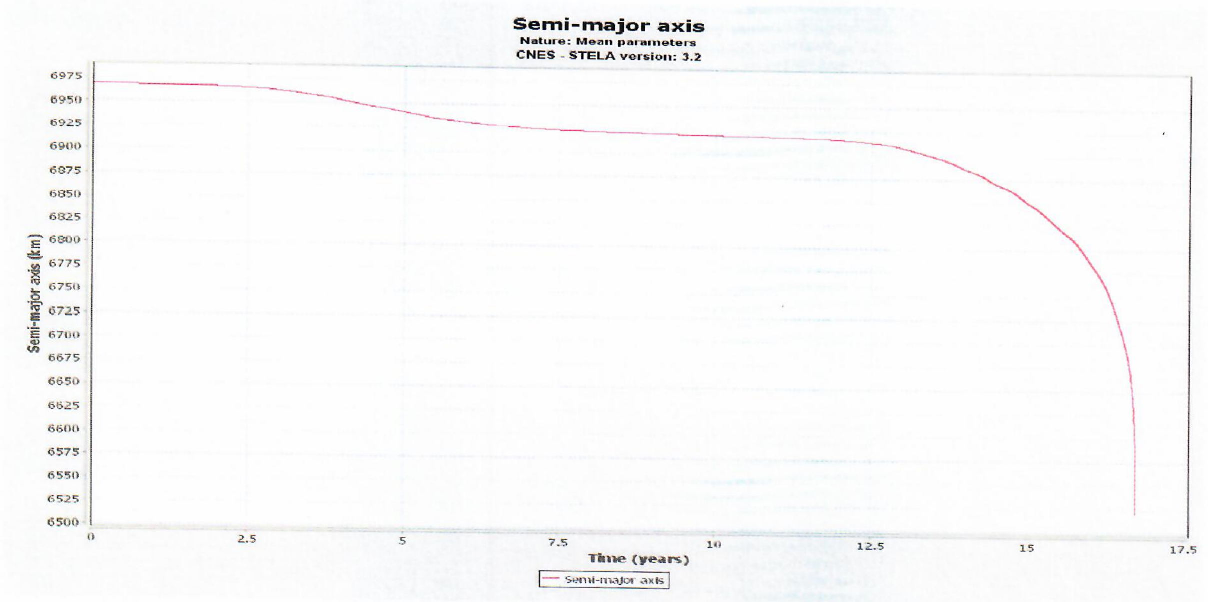

Figure 3: Hiber-2 altitude evolution

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

- **Plan for any spacecraft maneuvers required to accomplish postmission disposal:** N/A

- **Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:** The mass of the satellite will be 7.23 kg at the end of life. At the end of life, the satellite will no longer be controlled and will automatically align its longest axis with nadir. This means the cross-sectional area will be either 0.03405 m^2 or 0.0681 m^2, depending on which side is oriented with the velocity axis. As a result, the area to mass ratio will vary between 4.71 x 10^{-3} m^2/kg and 9.42 x 10^{-3} m^2/kg.

- **If appropriate, preliminary plan for spacecraft controlled reentry:** N/A

- **Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-4**

Requirement 4.6-1 : Disposal for space structures passing through LEO: Compliant. The satellites will reenter the atmosphere within 25 years.

Requirement 4.6-2 : Disposal for space structure near GEO: N/A

Requirement 4.6-3 : Disposal for space structures between LEO and GEO: N/A

Requirement 4.6-4 : Reliability of post-mission disposal operations in earth orbit: Because the disposal operation is natural and will happen automatically, it is entirely reliable.

3.7 *Assessment of Spacecraft Reentry Hazards*

- **Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle, if the atmospheric reentry option is selected**

Group	Name	Quantity	Material	Shape	Mass (kg)	Diam / width (m)	Length (m)	Height (m)
EPS	PCCM + PDM	1	FR4 (fiberglass)	Box	0.429	0.100	0.100	0.050
	BM	3	Li-ion	Box	0.220	0.100	0.100	0.033
	depSPA s	2	GaAs	Box	0.279	0.100	0.3405	0.00015
	depSPA l	2	GaAs	Plate	0.557	0.200	0.3405	0.00015
CDHS	iOBC	1	FR4	Box	0.096	0.100	0.100	0.014
PDHS	PDHU	1	FR4	Box	0.099	0.100	0.100	0.014
	TXS-2	1	FR4	Box	0.068	0.090	0.096	0.033
	S-Patch	1	Ceramic	Cylinder	0.420	0.084	x	0.0148
TTC	TRXVU	1	FR4	Box	0.077	0.090	0.096	0.015
	ANTs + cover plate	1	Aluminum	Box	0.204	0.098	0.098	0.007
AOCS	RW	3	Brass	Box	0.153	0.046	0.046	0.0315
	ADCS Board	1	FR4	Box	0.278	0.090	0.096	0.075
	STR	1	FR4	Box	0.067	0.035	0.050	0.100
	CSS	10	FR4	Box	0.015	0.001	0.003	0.001
	FSS	2	FR4	Box	0.08	0.09	0.096	0.01
	MTM	1	FR4	Box	0.015	0.03	0.03	0.005
	MTM (red)	1	FR4	Box	0.071	0.03	0.03	0.1
Payload	HCT	1	NiTinol	Cylinder	0.290	0.100	0.100	0.330
	BEE	1	FR4 RO4350	Box	0.500	0.100	0.100	0.100
	GPS ant	1	Ceramic	Box	0.040	0.035	0.035	0.0055
MECH	Structure	1	Aluminum 6061	Box	1.155	0.100	0.200	0.3405
MISC	IGIS	1	FR4	Box	0.105	0.100	0.100	0.01
	Harness	1	Copper	Box	0.500	0.100	0.100	0.006

Table 6 : Description of spacecraft components

Location: All components are inside the spacecraft, except for the antennas, solar arrays, sun sensors, and magnetometers.

- **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:** Using ESA's DRAMA software, Hiber concludes that the ceramic S-Band and GPS antennas are expected to survive re-entry. The probability that both fragments reach ground is 93.041%. The probability that at least one fragment reaches the ground is 99.875%. The estimated casualty cross section area is 0.8024 m2 and the estimated mass at ground impact is 0.415 kg.

- **Calculation of probability of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination (compliance with requirement 4.7-1):** Using ESA's DRAMA software, the probability of human casualty is 9.3378×10^{-6}. The casualty probability is compliant with requirement 4.7-1, which requires a probability lower than 1/10 000.

3.8 *Assessment of Spacecraft Hazardous Materials*

- **Summary of the hazardous materials contained on the spacecraft:**

Chemical and commercial name of the material	**Description of how it is a hazard to humans**	**Estimated state, quantity, activity, pressure at launch**	**Estimated state, quantity, pressure on orbit**	**Estimated state, quantity, pressure at EOM**	**Estimated state, quantity, pressure at end of passivation**	**Estimated state, quantity, pressure to survive reentry**
Li-ion battery cell Panasonic NCR18650A	Toxic gases released when exploding	Solid 0.66 kg	Solid 0.66 kg	Solid 0.66 kg	Solid 0.66 kg	None

Table 7: Hazardous materials found on spacecraft

3.9 *Assessment for Tether Missions*

There are no tether systems in the mission.