Supplement to Orbital Debris Assessment Report

Provided below are the responses of Hiber, Inc. ("Hiber") to questions from the International Bureau regarding the company's orbital debris assessment report ("ODAR").

1. *Please provide the inputs/assumptions that were used in your orbital calculation software.*

The first TLEs derived for Hiber-1 and Hiber-2 are presented below. They're used to baseline the initial parameters of the satellites.

```
HIBER-1

1 43744U 18096AB  18334.16184889  .00016808  00000-0  64911-3 0  9997
2 43744  97.4873  39.1532 0018371 328.7415 122.9043 15.26180788   147


HIBER-2

1 43774U 18099S   18339.89354746  .00000485  00000-0  49943-4 0  9992
2 43774  97.7736  49.0247 0011038 250.1788 109.8235 14.94763969   316
```

A. STELA

Hiber entered the following technical and orbital parameters into the STELA software program to produce its Orbital Debris Assessment Report:

A.1 Orbital evolution from launch to end of year 3, the nominal end-of-mission life

Parameter	Hiber 1	Hiber 2	Hiber 3-24
Satellite mass	7.5 kg	7.5 kg	5 kg
Reflecting area	0.2315 m2	0.2315 m2	0.17025 m2
Reflectivity coefficient	1.5	1.5	1.5
Drag area	0.03405 m2	0.03405 m2	0.0658 m2
Drag coefficient	2.2	2.2	2.2
Atmospheric model	NRLMSISE-00	NRLMSISE-00	NRLMSISE-00
Solar activity	Variable	Variable	Variable
Date	11/29/2018	12/03/2018	10/01/2019
Perigee	481.767 km	582.559 km	600 km
Apogee	506.991 km	597.926 km	600 km
Inclination	97.4873°	97.7736°	97.8°
RAAN	39.1532°	49.0247°	280°
Argument of perigee	328.7415°	250.1788°	0°
Mean anomaly	122.9043°	109.8235°	0°

A.2 Orbital evolution from end of year 3 to atmospheric reentry

Parameter	Hiber 1	Hiber 2	Hiber 3-24
Satellite mass	7.5 kg	7.5 kg	5 kg
Reflecting area	0.2315 m2	0.2315 m2	0.17025 m2
Reflectivity coefficient	1.5	1.5	1.5
Drag area	0.1142 m2	0.1142 m2	0.0781 m2
Drag coefficient	2.2	2.2	2.2
Atmospheric model	NRLMSISE-00	NRLMSISE-00	NRLMSISE-00
Solar activity	Variable	Variable	Variable
Date	11/29/2021	12/03/2021	10/01/2022
Perigee	457.39 km	575.83 km	577.34 km
Apogee	505.62 km	599.25 km	584.38 km
Inclination	97.40°	97.69°	97.8°
RAAN	47.67°	44.37°	281.74°
Argument of perigee	67.06°	191.28°	145.89°
Mean anomaly	0°	0°	0°

B. DRAMA

Hiber entered the following technical and orbital parameters into the DRAMA software program to produce its ODAR:

	Parameter	Hiber-1	Hiber-2	Hiber 3-24
Time	Launch date	11/29/18	12/03/18	10/01/19
	Lifetime	3.89 years	10.4 years	11.66 years
	Equivalent radius	0.2335 m	0.2335 m	0.1931 m
Year 0	Semi-major axis (km)	6872.38	6968.24	6978
	Eccentricity (mean value)	0.002735	0.0023	0.001225
	Inclination (°)	97.49	97.77	97.8
	RAAN (°)	39.15	49.02	280
	Arg. of perigee (°)	328.74	250.18	0
Year 1	Semi-major axis (km)	6871.08	6967.98	6977.12
	Eccentricity	0.002675	0.002275	0.001245
	Inclination (°)	97.46	97.75	97.8
	RAAN (°)	42.89	48.68	279.84
	Arg. of perigee (°)	100.66	116.88	117.23
Year 2	Semi-major axis (km)	6869.15	6967.59	6972.96
	Eccentricity	0.00265	0.002275	0.00126
	Inclination (°)	97.43	97.72	97.8
	RAAN (°)	45.50	47.11	280.02
	Arg. of perigee (°)	253.77	26.70	55.76
Loss of satellite control				
Year 3	Semi-major axis (km)	6859.51	6965.54	6958.86
	Eccentricity	0.00247	0.002235	0.001275
	Inclination (°)	97.40	97.69	97.8
	RAAN (°)	47.67	44.37	281.74

	Arg. of perigee (°)	67.06	191.28	145.89
Year 4	Semi-major axis (km)		6946.06	6933.50
	Eccentricity		0.001945	0.001295
	Inclination (°)		97.65	97.79
	RAAN (°)		42.00	287.05
	Arg. of perigee (°)		85.51	96.37
Year 5	Semi-major axis (km)		6917.13	6904.31
	Eccentricity		0.0016	0.00128
	Inclination (°)		97.62	97.77
	RAAN (°)		42.36	296.90
	Arg. of perigee (°)		317.56	60.48
Year 6	Semi-major axis (km)		6883.53	6881.04
	Eccentricity		0.00126	0.00127
	Inclination (°)		97.58	97.74
	RAAN (°)		46.89	310.47
	Arg. of perigee (°)		98.74	101.94
Year 7	Semi-major axis (km)		6853.40	6863.02
	Eccentricity		0.001215	0.001255
	Inclination (°)		97.55	97.70
	RAAN (°)		55.78	326.37
	Arg. of perigee (°)		114.42	79.40
Year 8	Semi-major axis (km)		6823.98	6849.88
	Eccentricity		0.00123	0.001255
	Inclination (°)		97.54	97.67
	RAAN (°)		69.12	343.46
	Arg. of perigee (°)		73.97	89.91
Year 9	Semi-major axis (km)		6792.77	6838.36
	Eccentricity		0.001205	0.0012525
	Inclination (°)		97.54	97.65
	RAAN (°)		87.80	1.42
	Arg. of perigee (°)		112.58	108.79
Year 10	Semi-major axis (km)		6734.91	6824.57
	Eccentricity		0.001105	0.00124
	Inclination (°)		97.56	97.65
	RAAN (°)		114.96	21.21
	Arg. of perigee (°)		96.85	75.82
Year 11	Semi-major axis (km)			6795.99
	Eccentricity			0.001165
	Inclination (°)			97.67
	RAAN (°)			45.25
	Arg. of perigee (°)			99.69

2. *Specifically, please provide the area-to-mass of the satellites (1&2) as they are during their operational lifetimes.*

During the lifetime of the satellites, the cross-sectional area and area-to-mass of each of the satellites during nominal operations are 0.03405 m2 and 4.54 x 10-3 m2/kg, respectively.

3. *Please provide EOL configurations for each satellite, to include detailed physical orientation.*

The satellites have a nominal three-year operational lifetime. At end-of-life ("EOL"), the satellites will be put into safe mode: all the systems will be shut down, except for the on-board computer ("OBC"), telemetry, tracking and command ("TT&C"), electrical power subsystem ("EPS") and attitude determination and control subsystem ("ADCS"). The satellites will be rotated to place the solar panels in the Ram facing direction. This will result in a cross-sectional area of 0.2315 m2 and an area-to-mass ratio of 0.0309 m2/kg. This orientation will be maintained as long as the systems are working.

However, some subsystems might not be working at EOL, and it may not be possible to control the satellite's attitude. Accordingly, for purpose of this ODAR, Hiber has assumed a worst-case scenario and assumed that the satellite will begin tumbling immediately at the end of the nominal three-year operational lifetime.

In that situation, the satellite would spin around each of the three axes. Therefore, we can assume that each face of the satellite will be RAM facing at some point. The average cross-sectional area and area-to-mass ratio for the three faces is 0.1142 m2 and 0.0152 m2/kg, respectively. These average values were used to calculate orbital decay.

Provided below are minor corrections to the ODAR to reflect more precise technical and orbital parameters. The corrected text are underlined and in bold. Additionally, Figures 2 and 3 should replace the respective figures in the ODAR.

<u>Section 3.1</u>

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 <u>**481.8**</u> km, apogee at <u>**507.0**</u> km and a 97.5° inclination. Hiber-2 was launched into an orbit with a perigee at <u>**582.6**</u> km, apogee at <u>**597.9**</u> km and inclination at 97.8°.

<u>Section 3.2</u>

Total spacecraft mass at launch, including all propellants and fluids: <u>**7.5**</u> kg

Dry mass of spacecraft at launch, excluding solid rocket motor propellants: <u>**7.5**</u> kg

<u>Section 3.5</u>

Collision probability	Hiber-1	Hiber-2	Hiber 3-24
Year 0-1	**0.1908 x 10-4**	**0.3183 x 10-4**	**0.3117 x 10-4**
Year 1-2	**0.2001 x 10-4**	**0.3632 x 10-4**	**0.3464 x 10-4**
Year 2-3	**0.2378 x 10-4**	**0.3122 x 10-4**	**0.3604 x 10-4**
Year 3-4	**0.1912 x 10-4**	**0.3164 x 10-4**	**0.2445 x 10-4**
Year 4-5		**0.2256 x 10-4**	**0.2287 x 10-4**
Year 5-6		**0.2191 x 10-4**	**0.1968 x 10-4**
Year 6-7		**0.2510 x 10-4**	**0.2481 x 10-4**
Year 7-8		**0.1606 x 10-4**	**0.1926 x 10-4**
Year 8-9		**0.1081 x 10-4**	**0.1571 x 10-4**
Year 9-10		**0.6721 x 10-5**	**0.1381 x 10-4**
Year 10-11		**0.3676 x 10-6**	**0.1152 x 10-4**
Year 11-12			**0.6951 x 10-5**
Total	**0.8199 x 10-4**	**2.3454 x 10-4**	**2.60911 x 10-4**

Table 5: Annual collision probabilities

The total collision probability for both Hiber-1 and Hibert-2 is **3.1653 x 10-4**, which is under the 0.001 threshold.

When considering the 24 satellite system the total collision probability becomes **6.0566 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.

Section 3.6

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 that it will take Hiber-1 **0.89** years and Hiber-2 **7.4** years to reenter the atmosphere**, after a 3-year nominal mission 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 2 and 3.

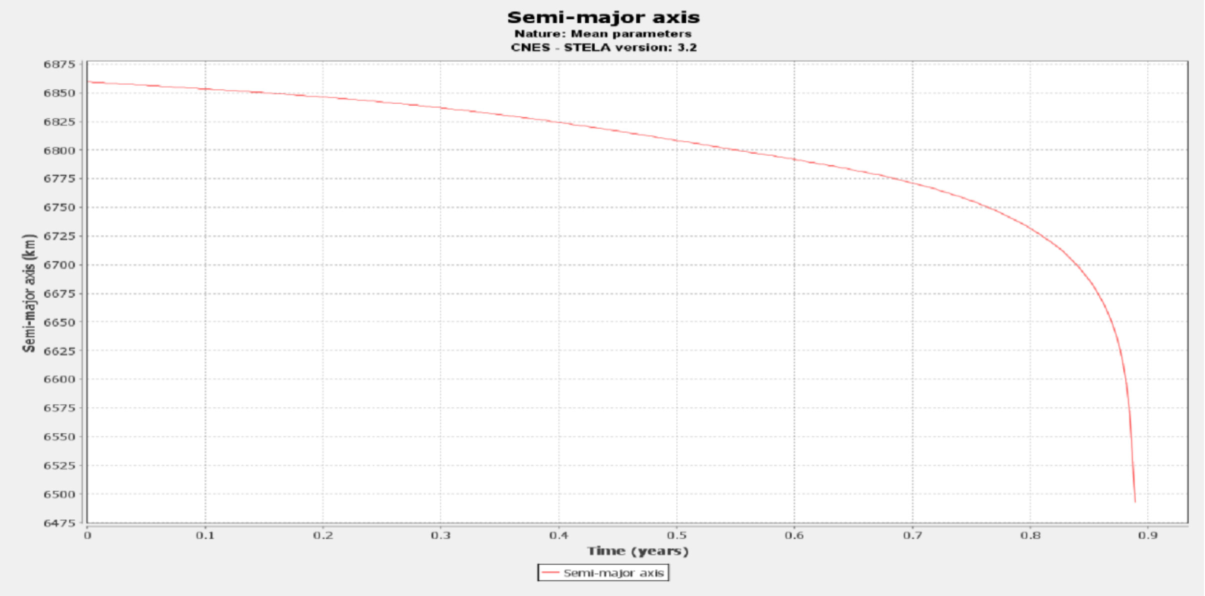

Figure 2: Hiber-1 altitude evolution

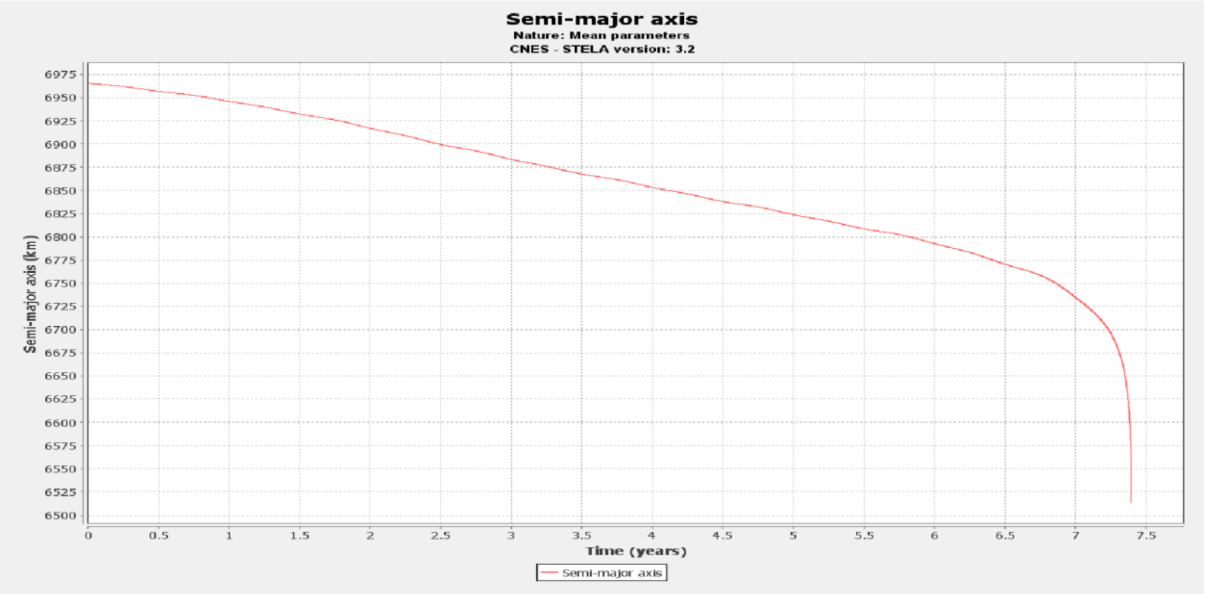

Figure 3: Hiber-2 altitude evolution

Calculation of the area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected: **See the response to Question 3 above**.

Technical Certification

I, Maarten Engelen, hereby certify that I am the technically qualified person responsible for the preparation of the engineering information contained in the foregoing supplement to the orbital debris assessment report of Hiber, Inc. I have either prepared or reviewed the engineering information submitted in the supplement, and it is complete and accurate to the best of my knowledge and belief.

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Maarten Engelen
Program Executive/Project Manager
Hiber, Inc.

Dated: March 15, 2019