Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
KAROUSEL LLC	)	Call Sign: S2980
Application for Authority to Launch and Operate a Non-Geostationary Earth Orbit Satellite System in the Fixed Satellite Service	)	File No. SAT-LOA-20161115-00113

COMMENTS OF SPACE EXPLORATION TECHNOLOGIES CORP.

Space Exploration Technologies Corp. ("SpaceX") hereby comments on the application filed by Karousel LLC for authority to launch and operate a non-geostationary satellite orbit ("NGSO") system providing Fixed-Satellite Service ("FSS") in the Ku and Ka bands. The proposed Karousel system would consist of twelve satellites in highly elliptical orbits ("HEO"), with an operational altitude that varies from approximately 32,000 km to 40,000 km.[1] The Karousel system would use gateway and user downlink beams that, taking into account the significant spreading that would occur from Karousel's high operational altitudes, would result in very large spot sizes on the surface of the Earth and from the perspective of low-Earth orbit ("LEO") satellites. Many of these individual beams would be large enough to cover most or all of the continental United States.[2] The use of inflexible beams and very large spots, however,

[1] *See* Karousel LLC, *Schedule S*, IBFS File No. SAT-LOA-20161115-00113 (Apr. 2016).

[2] *See Application for Authority to Launch and Operate a Non-Geostationary Earth Orbit Satellite System in the Fixed Satellite Service*, IBFS File No. SAT-LOA-20161115-00113, Attachment 1 at 1-11

will result in poor spectral efficiency—*i.e.*, kilobits per second, per square kilometer, per MHz—for the Karousel system itself, and will also reduce the efficiency of all other NGSO systems in the band by increasing the frequency of in-line events.

In addition, due to Karousel's proposed operational altitude, Karousel's uplink beams are likely to cause significant interference to LEO satellites whenever a LEO satellite passes through a Karousel earth station's main beam or sidelobe. This would effectively prevent a LEO system with steerable beams (like SpaceX's) from working around the in-line event, forcing the default arrangement of band segmentation. The Commission should ensure that all system types under consideration in this processing round will be able to equitably share spectrum with one another while making efficient use of this scarce resource. If necessary, the Commission should impose license conditions to ensure that operators have the proper incentives to coordinate fairly and effectively with every other NGSO system.

I. LARGE BEAMS AND HIGH OPERATIONAL ALTITUDE REDUCE SPECTRAL EFFICIENCY

When the Commission adopted its current avoidance of in-line interference sharing regime, it anticipated that in-line events would be relatively infrequent.[3] However, due to Karousel's very large spot sizes, there will virtually always be at least one, and often more LEO satellites within Karousel's beam, greatly increasing the

(Nov. 15, 2016) ("Karousel Application"). Karousel also notes that these beams will be steerable. Steerable beams may theoretically increase flexibility and ease coexistence challenges. But it appears unlikely that this will be a viable strategy for Karousel's system with such large beams, and a limited number of satellites.

[3] *Establishment of Policies and Service Rules for the Non-Geostationary Satellite Orbit, Fixed Satellite Service in the Ka-Band*, Report and Order, 18 FCC Rcd. 14708, ¶ 19 (2003) ("*Ka-band NGSO Sharing Order*").

frequency of in-line events beyond what the Commission anticipated. In fact, in-line events involving three or more operators may not be uncommon.

Unfortunately, as SpaceX has previously explained,[4] large spot sizes—a function of both beamwidth and altitude—not only reduce an NGSO system's spectral efficiency by precluding intensive frequency reuse, they also limit the proposed system's ability to share spectrum with other NGSO/FSS constellations, increasing the likelihood of operations under the default mechanism of band segmentation. Large spots limit an operator's ability to provide satellite diversity, which would allow an operator to "avoid an in-line interference event by selecting another visible satellite within their system constellation (performing a hand-over process) whenever the current satellite approaches the in-line event with a satellite operating in another NGSO FSS system constellation."[5] But Karousel does not appear to provide any significant degree of satellite diversity.[6] This means that it has no way to limit the incidence of in-line events with the numerous satellites likely to fall within its beams at lower orbital altitudes, or those at higher altitudes seeking to serve users within Karousel's footprint. Other operators of more sophisticated systems will therefore be required to shoulder the burden of avoiding these in-line events, or the affected operators will be required to split the available spectrum, in the absence of another agreement.

Furthermore, large spot sizes increase the number of in-line events that a Karousel satellite is likely to experience with other systems, increases the duration of those in-line

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4 Comments of Space Exploration Technologies Corp. at 12-14, 15-17, IBFS File No. SAT-LOI-20160428-00041 (Aug. 15, 2016).

5 *Ka-band NGSO Sharing Order* ¶ 44.

6 *See* Karousel Application at 29 (illustrating the configuration of operational satellites in the Karousel system).

events, and increases the odds that a given satellite will experience in-line events with multiple operators at one time. Instead of a fleeting event, an in-line event with a Karousel satellite will last a significant period of time, during which affected satellites will remain in either a band-splitting or other spectrally inefficient coordination regime. For other systems with inflexible beams and large spot sizes, each individual satellite may experience long-duration in-line events with Karousel satellites. In systems with larger numbers of satellites and smaller spots, each satellite may only be briefly affected, but a number of satellites may be affected simultaneously. In either case, other operators must shoulder the burden of long periods of in-line coexistence with Karousel's satellites, due to its inflexible system design. This will significantly reduce the spectrum available to the Karousel system itself, and will further reduce the spectrum available to other systems, especially in cases of in-line events with more than one operator, unless those other operators take on the burden of finding ways to mitigate the impact of in-line events.

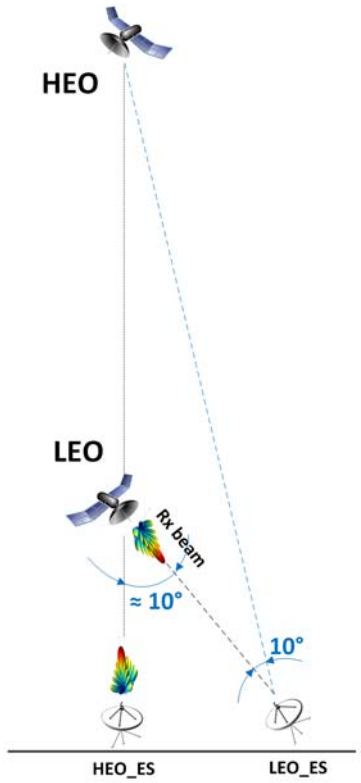
II. HIGHLY-ELLIPTICAL ORBIT SYSTEMS MAY CAUSE INTERFERENCE TO ANY LEO SATELLITE WITHIN OR NEAR THEIR BEAMS, EVEN WITHOUT AN IN-LINE EVENT

The Karousel system, and other systems with high operational altitudes, are likely to cause interference to LEO systems due to the very high power of these systems' earth station uplink beams. For example, in order to communicate with satellites at altitudes of 40,000 km, Karousel's uplink beams will transmit at power levels as much as 40 dB higher than SpaceX's. This means that they will also be approximately 40 dB stronger than SpaceX's desired uplink signal as its satellite crosses through the Karousel uplink beam, and much stronger even in the uplink sidelobes. With such an extreme power

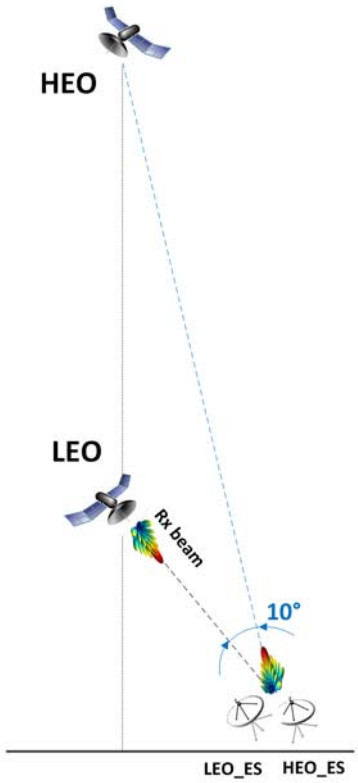
disparity, the Karousel uplink beam would likely degrade any LEO satellite's ability to receive any uplink signal in the affected band from *any* location on the Earth, whether or not it is near the transmitting Karousel earth station. This would essentially prevent a LEO satellite with steerable beams from using that steering capability to avoid an in-line event, forcing both operators to default to band segmentation.

To illustrate this point, consider two in-line scenarios involving the NGSO systems proposed by Karousel and SpaceX. As depicted below, in Scenario 1, the SpaceX LEO satellite is in the main beam of the Karousel earth station uplink to a Karousel HEO satellite.[7] In Scenario 2, the SpaceX and Karousel earth stations are essentially collocated while their satellites have an apparent angular separation of 10 degrees.

[7] Note that, given the extreme difference between the operating altitudes of the two systems, the separation angle between HEO_ES and LEO_ES from the LEO satellite perspective is essentially the same as the angle between HEO and LEO from the LEO_ES perspective.



Scenario 1



Scenario 2

Using operational parameters from the SpaceX and Karousel applications, we can determine the impact (measured as ΔT/T) of these in-line events.

For example, Table 1 below sets forth the analysis of the impact that the Ku-band uplink beams from a Karousel gateway earth station would have on SpaceX in Scenario 1, yielding ΔT/T of 778,990%, assuming 10 degrees of angular separation.[8]. A similar analysis applies for interference from Karousel user terminals, with ΔT/T of 508%. As this analysis demonstrates, both Karousel user terminals and gateway uplinks could cause

[8] For purposes of this analysis, SpaceX used a representative frequency (14.5 GHz) and representative orbital altitude for its system (1,110 km), and EIRP values for Karousel earth stations taken from the table on page 47 of its application. I/N is calculated using this equation (where k = Boltzmann constant):

$$\frac{I}{N} = EIRP - 10\log(4\pi d^2) - 10\log\left(\frac{4\pi}{\lambda^2}\right) + \frac{G}{T} - 10\log(k)$$

a dramatic increase in noise temperature relative to the desired signal at the Ku-band receive antenna on SpaceX satellites.

SpaceX SAT Rx antenna gain at nadir [dB]	37.00	
SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*see SpaceX FCC filing*
SpaceX SAT Rx antenna G/T at 10º [dB/K]	-20.20	*32-25log(φ) at 10° separation*
Karousel ES EIRP [dBW/200MHz]	90.10	*13m gateway, per Karousel*
Karousel ES EIRP [dBW/Hz]	7.09	
I/N [dB]	**38.92**	
ΔT/T [%]	**778,990%**	

Table 1. Impact of 13-Meter Karousel Gateway Earth Station in Scenario 1

SpaceX SAT Rx antenna gain at nadir [dB]	37.00	
SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*per SpaceX FCC filing*
SpaceX SAT Rx antenna G/T at 10º [dB/K]	-20.20	*32-25log(φ) at 10° separation*
Karousel ES EIRP [dBW/1.25MHz]	36.20	*75cm User Terminal, per Karousel*
Karousel ES EIRP [dBW/Hz]	-24.77	
I/N [dB]	**7.06**	
ΔT/T [%]	**508%**	

Table 2. Impact of Karousel User Terminals in Scenario 1

In both cases, interference is so strong that it would prevent the SpaceX satellite from using its steerable beams to service other users (outside the area subject to the in-line event) using frequencies shared with Karousel, and thus essentially prevents SpaceX from using the frequency anywhere during the in-line event.

An analysis of Scenario 2 yields similar results, although here it is the sidelobes of the Karousel earth station[9] that interfere with the main beam of the SpaceX earth station's uplink transmissions. Tables 3 and 4 below show the increase in noise temperature expected in the SpaceX uplink due to operations of a Karousel gateway and

[9] For this analysis, SpaceX determined off-axis gain of Karousel earth stations using the formula 32-25log(ϕ) from Recommendation ITU-R S.465-6, *available at* https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.465-6-201001-I!!PDF-E.pdf.

user terminal, respectively, when the separation angle between a SpaceX satellite and a Karousel satellite is 10 degrees from the earth station's point of view.

SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*see SpaceX FCC filing*
Karousel ES Diameter D [m]	13.00	*Gateway, per Karousel FCC filing*
Karousel ES Gmax [dB]	64.00	*per Karousel*
Karousel ES Gain @ 10º [dB]	7.00	*32-25log(φ), per Rec. ITU-R S.465-6*
Karousel ES rejection @ 10º [dB]	57.00	
Karousel ES EIRP @ 10º [dBW/40kHz]	-3.89	
Karousel ES EIRP @ 10º [dBW/Hz]	-49.91	
I/N [dB]	**11.92**	
ΔT/T [%]	**1,554%**	

Table 3. Impact of Karousel Gateway Earth Station in Scenario 2

SpaceX SAT Rx antenna G/T at nadir [dB/K]	9.80	*see SpaceX FCC filing*
Karousel ES Diameter D [m]	0.75	*UT, per Karousel FCC filing*
Karousel ES Gmax [dB]	39.3	*per Karousel*
Karousel ES Gain @ 10º [dB]	7.00	*32-25log(φ), per Rec. ITU-R S.465-6*
Karousel ES rejection @ 10º [dB]	32.3	
Karousel ES EIRP @ 10º [dBW/40kHz]	-11.05	
Karousel ES EIRP @ 10º [dBW/Hz]	-57.07	
I/N [dB]	**4.76**	
ΔT/T [%]	**299%**	

Table 3. Impact of Karousel User Terminal in Scenario 2

As these tables demonstrate, the high EIRP of the Karousel earth stations will make equitable sharing of spectrum with a LEO system difficult or impossible. In Scenario 1, interference is so strong that it would prevent the SpaceX satellite from using its steerable beams to service other users (even outside the area subject to the in-line event) using spectrum shared with Karousel, and thus essentially prevents SpaceX from using those frequencies anywhere during the in-line event. In Scenario 2, because SpaceX will experience an unacceptable level of interference without a separation angle much larger than 10 degrees, the operators would have to expand the in-line event zone which would negatively impact spectral efficiency and usable capacity for both systems.

The Commission's definition of "in-line interference event" already contemplates this possibility, defining such an event as one where satellites in two or more systems are aligned "with an operating Earth station of **one** of these networks."[10] Thus, under the Commission's rules, and in the absence of another coordination agreement, Karousel would be required to split the spectrum with the LEO system when one of its satellites and a LEO satellite were aligned with a transmitting Karousel earth station. Band splitting in this situation, however, will be especially burdensome and inefficient, as it could require the LEO system to refrain from using a portion of the spectrum, *even when communicating with earth stations outside the area subject to the in-line event.*

Without effective coordination, this pervasive HEO-to-LEO interference will significantly reduce the overall utility of NGSO operations throughout the band. The Commission is currently considering whether to adopt default limits for EIRP density of NGSO uplink transmissions in order to facilitate spectrum sharing among systems,[11] and SpaceX believes that such limits will be critical to equitable spectrum sharing among non-homogeneous NGSO systems. At a minimum, any grant of Karousel's application should be conditioned upon compliance with the outcome of that rulemaking proceeding. The Commission should also consider whether it would be appropriate to impose additional conditions to address this potential interference and enhance the potential for efficient spectrum sharing.

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[10] 47 C.F.R. § 25.261(b) (emphasis added).

[11] *See Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters*, 31 FCC Rcd. 13651, ¶¶ 28-31 (2016).

III. CONCLUSION

As a practical matter, systems with very large, inflexible beams shift the burden of effective and efficient spectrum sharing onto other operators. They require other operators to shoulder either the burden of designing a highly flexible system that can ameliorate in-line events, as SpaceX has done, or the burden of inefficiently splitting spectrum during a large portion of its satellites' time on orbit. High-altitude systems such as Karousel's compound these challenges by posing an asymmetric interference risk to lower-altitude operators whenever they pass through the main beam or sidelobe of a Karousel uplink transmission. The Commission should carefully consider whether the public interest would be served by authorizing systems that are only workable if other, more adaptable systems take a disproportionate burden of sharing, as the compromises required would reduce the overall capacity available to serve consumers

Respectfully submitted,

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June 26, 2017

ENGINEERING CERTIFICATION

The undersigned hereby certifies to the Federal Communications Commission as follows:

(i) I am the technically qualified person responsible for the engineering information contained in the foregoing Comments,

(ii) I am familiar with Part 25 of the Commission's Rules, and

(iii) I have either prepared or reviewed the engineering information contained in the foregoing Comments, and it is complete and accurate to the best of my knowledge and belief.

Signed:

/s/ Mihai Albulet

Mihai Albulet, PhD
Principal RF Engineer
SPACE EXPLORATION TECHNOLOGIES CORP.

June 26, 2017

Date

CERTIFICATE OF SERVICE

I hereby certify that, on this 26th day of June, 2017, a copy of the foregoing Comments was served by First Class mail upon:

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