HWG | HARRIS, WILTSHIRE & GRANNIS LLP

4 August 2020

Via IBFS

Mr. Jose P. Albuquerque
Chief, Satellite Division, International Bureau
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Swarm Technologies, Inc.; IBFS File Nos. SAT-MOD-20200501-00040 and SAT-AMD-20200504-00041; Call Sign: S3041

Dear Mr. Albuquerque:

Swarm Technologies, Inc. ("Swarm") hereby responds to your July 21, 2020 letter[1] requesting information about its pending application to modify the authorization for its non-voice, non-geostationary-orbit mobile-satellite service system in the 137–138 MHz and 148–150.05 MHz frequency bands[2] and the amendment filed thereto.[3]

Question 1. Please provide the specific impulse of the spacecraft's propulsion system.

Response: The propulsion system is a dual mode cold gas and electric propulsion system.[4] The cold gas system has a specific impulse of up to 50 seconds. The electric propulsion system has a specific impulse of up to 450 seconds.

---

[1] *See* Letter from Jose P. Albuquerque, Chief, Satellite Division, International Bureau, FCC, to Shiva Goel, Harris, Wiltshire & Grannis, LLP, Counsel to Swarm Technologies, Inc., IBFS File Nos. SAT-MOD-20200501-00040 & SAT-AMD-20200504-00041, Call Sign S3041 (Jul. 21, 2020).

[2] *See* Swarm Technologies, Inc., *Application to Modify the Authorization for the Swarm NGSO Satellite System*, IBFS File No. SAT-MOD-20200501-00040 (filed May 1, 2020) ("Modification Application"); *see also Application of Swarm Technologies, Inc.*, Memorandum Opinion, Order and Authorization, 34 FCC Rcd. 9469 (Int'l Bur. Oct. 17, 2019).

[3] *See* Swarm Technologies, Inc., *Amendment to Application to Modify the Authorization for the Swarm NGSO Satellite System*, IBFS File No. SAT-AMD-20200504-00041 (filed May 4, 2020) ("Amendment").

[4] Modification Application, Narrative Exhibit at 4-5; Amendment, Narrative Exhibit at 18.

Question 2. What is the number of expected conjunctions requiring a maneuver, per spacecraft, over the course of its orbital lifetime?

Response: Swarm assumes that each 1/4U satellite will require a maximum of 5 maneuvers per year on average over its orbital lifetime, though it expects that the number of actionable maneuvers will be closer to 1 per year on average. With a worst-case lifetime of 7.9 years,[5] and assuming a worst-case of 5 required maneuvers per year on average, fewer than 40 maneuvers are anticipated over the lifetime of each satellite.

These values were estimated from the observed frequency of Conjunction Data Messages ("CDMs") received from Combined Space Operations Center ("CSpOC") for Swarm's nine experimental satellites since 2018. These satellites orbit at altitudes ranging from 420 and 580 km, spanning a similar altitude range to Swarm's future commercial satellites.

Historically, Swarm has received fewer than 5 unique event alerts per year, per satellite. However, only 6% of these notifications have met typical actionable thresholds of a collision probability ("Pc") greater than 1e-4 or a miss distance of less than 100 meters. Additionally, the Pc value reported in these CDMs is calculated conservatively, because CSpOC models the Swarm satellites with a 5-meter exclusion volume radius, which is several times larger than the actual size of the satellite plus its antennas when fully deployed. This means that, in computing the Pc, CSpOC will treat an encounter as a collision if the secondary object's surface passes within 5 meters of the Swarm satellite, even if the objects would not actually collide in the modeled scenario. A refined Pc value based on true spacecraft geometry would typically be much lower, particularly during conjunctions with small satellites.

Notably, in scenarios where the secondary object is also a maneuverable spacecraft, Swarm will coordinate with the other operator to mutually determine if a maneuver is necessary and to ensure any potential maneuvers are planned cooperatively.

Question 3. What is the propellant budgeting for the force required per such conjunction to clear the risk? Is there enough propellant to cover the estimated number of required maneuvers over the lifetime of the spacecraft? If not, are there any additional capabilities or plans to further reduce collision risk?

Response: The encounter geometry and covariance data associated with each predicted conjunction are unique and refined over time with updated tracking measurements. Operationally, Swarm would compute an optimal maneuver for each event, with the goal of reducing collision probability to an acceptable value using a minimal impulse.

---

[5] Amendment, Narrative Exhibit at 8.

As a simplified, conservative value, Swarm has budgeted 0.1 m/s of delta-velocity ("delta-V") for each maneuver. When applied along the velocity vector, a maneuver changes the satellite's orbital period sufficiently to create over 1 km of relative displacement within 1 hour. Historically, actionable conjunctions have had nominal miss distances well below 1 km, and at least 1 day of advance notice. In general, an appropriately directed 0.1 m/s maneuver conducted at least 1 hour in advance would be capable of clearing a conjunction. In practice, even smaller maneuvers are typically feasible.

In cold gas mode, each maneuver has a measured thrust of 6 mN (0.006 Newtons), and the 1/4U spacecraft has a total delta-V budget of 30 m/s. If the thruster is not used for de-orbit, this equates to the ability to perform 300 collision avoidance maneuvers with a budget of 0.1 m/s per maneuver. This represents a 7.5x safety factor over the assumed maximum of 40 lifetime conjunction maneuvers, and an even higher safety factor relative to the expected number of actionable maneuvers.

In electric propulsion mode, each maneuver has an expected thrust of 1 mN (0.001 Newtons), and the 1/4U spacecraft has a total delta-V budget of 240 m/s. If the thruster is not used for de-orbit, this equates to the ability to perform 2400 collision avoidance maneuvers with a budget of 0.1 m/s per maneuver. This represents a 60x safety factor over the assumed maximum of 40 lifetime conjunction maneuvers. The margin relative to the expected number of actionable maneuvers is, again, significantly larger.

In addition to propulsive maneuvers, Swarm's 1/4U satellites can use differential drag to produce meaningful amounts of in-track separation without propellant. The efficacy of differential drag maneuvers is coupled to altitude and solar activity, with much more rapid maneuvers possible at low altitudes and during elevated solar activity. Under worst-case conditions (minimum solar activity, maximum 585 km altitude), a differential drag maneuver can still produce 700 meters of separation after 72 hours. Under mean solar activity, this improves to more than 10 km of separation in 72 hours (achieving over 1 km of separation during the first 24 hours). In most scenarios, enough time is available after receiving a conjunction notice for a suitable differential drag maneuver to be performed in lieu of propulsion.

Question 4. Please address whether the propellant system proposed is sufficiently capable to reduce conjunction risk. Include in your answer a discussion of the criteria, such as probability of collision that will be applied in triggering a maneuver, the extent to which the system is capable of substantially reducing that risk, any criteria used to determine whether a reduction is substantial, and an indication of the amount of time required prior to the forecasted conjunction when a maneuver must be initiated in order to meaningfully reduce risk.

Response: Swarm's analysis with the National Aeronautics and Space Administration's (NASA) Debris Assessment Software version 3.0 indicates that Swarm's proposed constellation meets lifetime collision probability requirements without the addition of active maneuverability.[6] The addition of the proposed propulsion system, combined with existing differential drag capabilities, reduces residual conjunction risk even further.

In the notional concept of operations ("ConOps"), upon receiving notification of a potentially actionable conjunction (including, but not necessarily limited to, an event with Pc exceeding 1e-4), Swarm would first establish whether the secondary object is cooperative and maneuverable. If so, Swarm would attempt to contact the operator to determine a mutually acceptable maneuvering strategy. If not, Swarm would plan a maneuver by default. If lead time is insufficient to attempt a differential drag maneuver, Swarm will compute and schedule a propulsive maneuver with a fundamental goal of modifying the forecast conjunction geometry to reduce Pc below 1e-6. Swarm will coordinate the maneuver plan with CSpOC and LeoLabs, and, if feasible, allow time for post-maneuver orbit determination to verify the expected Pc reduction. Depending on the orbit and available tracking assets, this may require 2 to 6 hours and would allow the satellite to perform a backup maneuver if necessary.

The proposed propulsion system is more than sufficient to support the conjunction risk mitigation strategy described in the ConOps. As discussed in Swarm's response to Question 3, a 0.1 m/s propulsive avoidance maneuver can be feasibly conducted within an hour of a forecast conjunction and still effectively eliminate the conjunction risk by substantially displacing the satellite from the location of the conjunction. However, as noted above, maneuvers would typically be planned at least several hours prior to the conjunction to allow for verification of success.

---

[6] *Id.* at 19-23; Modification Application, Narrative Exhibit at 9.

Please do not hesitate to contact me if you have any additional questions.

Sincerely,

Shiva Goel
Counsel to Swarm Technologies, Inc.