National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

October 29, 2020

Reply to Attn of: Human Exploration and Operations Mission Directorate

Ms. Marlene Dortch, Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

SUBJECT: Report No. SAT-01501 Space Station Applications Accepted For Filing, AST & Science, LLC (SAT-PDR-20200413-00034)

Dear Ms. Dortch,

The National Aeronautics and Space Administration (NASA) submits this letter in response to the Federal Communications Commission's (FCC) Public Notice of October 2, 2020 Application for Fixed Satellite Service Mobile Satellite Service by AST & Science. With the increase in large constellation proposals to the FCC, NASA has concerns over the possibility of a significant increase in frequency of conjunction events. Consequently, NASA submits this letter during the public comment period for the purpose of providing a better understanding of NASA's concerns with respect to its assets on-orbit, to further mitigate the risks of collisions for the mutual benefit of all involved.

NASA has considerable assets in orbit. The applications referenced in the subject report and public notice outline operations of constellations of satellites in an orbit that have the potential to impact NASA operations and the safety of NASA assets. As such, NASA offers the following observations and recommendations:

The large constellation proposed by AST will, depending on definitions, either be collocated or placed just above the Earth Science Morning and Afternoon constellations, referred to here as the "A-Train." The A-Train is a group of ten NASA, USGS, and international partner (CNES, JAXA) missions that have a mean altitude of 705 km but have osculating altitudes between 690 and 740 km. Therefore, the AST constellation would be essentially collocated with the A-Train if the proposed orbit altitude is chosen. Additionally, this is an orbit regime that has a large debris object density (resulting from the Fengyun 1-C ASAT test and the Iridium 33-COSMOS 2251 collision) and therefore experiences frequent conjunctions with debris objects. Given these facts, the following substantial concerns are expressed regarding impact to the safety of NASA missions:

- The AST constellation contains extremely large satellites in a debris-rich orbital regime and will therefore experience a very large number of satellite conjunctions, certainly with debris objects and potentially with A-Train satellites themselves, both as part of the AST satellites' ascent/descent to on-orbit locations and during regular operations. Therefore:

  - It is imperative to the safety of the AST constellation and other assets in this regime that this constellation have a conjunction assessment (CA) and mitigation process of the same sophistication and risk aversion as the NASA satellites with which they will be collocated. NASA's Conjunction Assessment Risk Analysis (CARA) program performs the conjunction assessment service for these spacecraft and can provide more detailed information about the existing process.
  - A robust arrangement for direct contact and sharing of ephemerides and maneuver plans among NASA/USGS/partner and AST during routine operations is also imperative to prevent collisions and simultaneous maneuvers.
- The size and orbital regime of the satellites heighten the collision danger for any failed AST spacecraft, creating a threat to the A-Train and other considerable assets from resulting debris. A higher spacecraft reliability than that specified by the 2019 U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP), coupled with powered descents to move below the A-Train altitude at end-of-life (even if the spacecraft could passively comply with the 25-year disposal rule), would eliminate any lingering of large satellites incapable of active CA in the vicinity of the A-Train constellation, and thus their debris production risk.
- In light of both of these issues, AST should consider an orbit that lies below rather than above the A-Train constellation.

A more detailed technical discussion of these concerns is given below.

<u>Sophisticated CA Assessment/Mitigation and Information Exchange</u>
Historical experience with the A-Train constellation has shown that this particular region of space (~705 km altitude) tends to produce a large number of conjunctions between space objects, about 40% of which from the debris density arising from the Fengyun and Iridium-COSMOS events. NASA sees about 700 conjunctions per month across its LEO fleet, including the A-Train. Each CA screening, which occur every eight hours, generates a substantial number of proximity alerts per A-Train satellite; and at any given time there are several events per satellite requiring active examination and follow-up. Mitigation actions are typically executed when, at the decision point, the probability of collision (Pc) between the two objects exceeds 1E-04. The typical A-Train satellite might take two such mitigation actions per year, with maybe twenty such actions planned each year, but most waived off due to a drop in Pc before the mitigation action commitment point.

The proposed AST constellation increases the intensity of the CA situation in two ways. First, the AST constellation satellites are much larger than the A-Train satellites. A 900-square-meter antenna could require a circumscribing sphere of perhaps as much as a 30m radius, depending on antenna configuration, to represent the satellite size during close approach prediction screenings; this is called the "hard-body radius" and is the standard method of representing object size in the Pc calculation. The 30m value is considerably larger than that typically used for A-Train satellites, which ranges from ~3m to ~15m. Based on the results of a NASA CARA simulation tool, the number of mitigation actions required for a 30m hard-body radius (HBR) object in this orbit regime increases from ~2 to 6 per year—almost a tripling of what is observed presently. Second, the frequency of mitigation actions and associated planning efforts is of course multiplied by the number of spacecraft: for the completed constellation of 243 satellites, one can expect 1500 mitigation actions per year and perhaps 15,000 planning activities; this would equate to four maneuvers and forty active planning activities on any given day.

When two satellites with different owners/operators are collocated, any orbit change on the part of one of the satellites has to be coordinated with the other before execution to make sure that both satellites do not execute maneuvers that then cause the two satellites to collide. If the AST constellation and the A-Train constellation are in fact collocated, and if four CA risk mitigation maneuvers per day are executed by the AST constellation, the coordination with the A-Train satellites will be impossible through current means. An entirely new, mostly automated system for exchanging such information and taking cognizance of it in each satellite's flight dynamics support will be needed. Because many of the NASA/USGS/partner satellites are older and use legacy flight dynamics systems, the needed upgrade efforts to these systems would be considerable.

Even if the AST constellation placement is such that direct colocation does not occur, a sophisticated CA system for AST would be needed to ensure that this substantial constellation of large satellites to avoid a considerable debris-generating collision that will rain debris down on the A-Train constellation and potentially render its orbit regime unnavigable. Constituent activities of such a CA system include but are not limited to the following:

- Production and public release of accurate predicted ephemerides, with realistic state covariances, for all constellation spacecraft at least daily (but more helpfully several times per day), seven days per week;
- Arranging for screening of these ephemerides against a comprehensive satellite catalogue (such as that maintained by USSPACECOM) at least daily (but more helpfully several times per day), seven days per week;
- Processing all of the screening results to identify potential (Pc > 1E-07) and actual (Pc > 1E-04) high-risk conjunctions;
- Executing maneuver planning for conjunctions likely to be high-risk at the maneuver commitment point, which includes choosing a maneuver that will remediate the main conjunction (without introducing any new conjunctions of concern), generating an ephemeris that contains this maneuver, and submitting the maneuver ephemeris for explicit screening against a comprehensive satellite/debris catalogue; and
- At the maneuver commitment point, rendering a decision on the mitigation action (generally choosing such an action if the Pc remains above 1E-04) and, if appropriate, executing the maneuver.

Failed Spacecraft

Spacecraft that fail on-orbit above the A-Train present a worrisome debris-production potentiality. Failed or "dead" satellites cannot perform active collision avoidance, so they are at greatly increased risk for collision with debris objects. The NASA Orbital Debris Program Office's DAS tool estimates, using the ORDEM debris model, the likelihood of collision in a specified orbital corridor between an object of a stated size and a large debris object (> 10cm). DAS runs executed for a single proposed AST satellite in a 720km circular orbit, a ten-year on-orbit presence, and inclinations ranging from 0 to 50 degrees produced collision risk numbers from 1.3% to 1.6%. These numbers are by comparative standards extremely high— both the ODMSP (Objective 3-1) and the NASA internal requirement have a threshold of 0.1%, more than an order of magnitude smaller. With a constellation of satellites, there is of course a risk of multiple satellites failing. One must therefore compute the total cumulative risk of collision using the below equation to understand the overall risk to the space environment:

$$P_{cum} = 1 - \prod_{i=1}^{n}(1 - P_i)$$

How many AST satellites might fail on orbit? The initial launch of a recent large constellation realized something on the order of a 4% failure rate; with more recent launches, the rate has retreated to 1%. For bounding numbers, one could choose a 1% failure rate of 3 satellites (1% rounds up to 3) for the entire constellation and a 4% rate of 10 satellites. Overall, this would produce bounding values for the aggregate risk of a catastrophic collision with a failed satellite of 3.8% and 14.9%. Given that the present practice is to mitigate conjunctions with a probability of collision greater than 1E-04 (one in 10,000) and that the ODMSP and NASA upper-bound lifetime requirement for collision with a large object is 1E-03 (one in 1,000), the risk values presented here (between 1 in 25 and 1 in 7) are unacceptably large in such proximity to a pre-existing constellation and in an orbit regime in which the debris from any such collision would persist for longer than the 25-year disposal requirement. Evidence of an extremely small expected satellite failure rate—far smaller than has ever been observed historically with a new spacecraft type—would be required to render this proposed orbital placement viable. In short, failed satellites that cannot perform CA pose a major concern; and given the size of these particular satellites, failure rates in the range of what have been observed with recent large constellation efforts would present an unacceptably high risk of a catastrophic debris-producing collision (~4% to 15%, as remarked above).

It is also noteworthy that the ODMSP also establishes additional standard practices on the required post-mission disposal (PMD) reliability for large constellations. First, the PMD reliability should be at a level greater than 0.9 with a goal of 0.99 or better. Second, the reliability threshold should be established based on mass, collision probability, orbital location, and other relevant parameters. AST should work with the FCC to conduct a detailed analysis to identify and achieve the necessary PMD reliability for the proposed constellation to mitigate potential negative effects from the constellation to the environment.

Reconsideration of Proposed Orbit

Given the considerations above, especially that of the implications of spacecraft failures that the debris generation threat that they would present, NASA recommends AST consider alternative orbit regimes for this constellation, perhaps notably below the A-Train constellation, in order to allow for a more manageable safety-of-flight situation for a constellation of such large satellites.

Evaluation Data

NASA performed this evaluation with only a few days' notice and with a very limited amount of information about the proposed spacecraft and constellation configurations. Further information and details from the proposer beyond what was available in the public filing could modify these findings and possibly alleviate certain concerns. NASA is available to engage with the proposer to reevaluate these findings if additional information and details are available.

Although these observations and recommendations are made with respect to the subject report and filings, they can be generally applied to other large constellations, and NASA is supportive of the creation of "best practices" focused on such programs. Should you have any questions, do not hesitate to contact me at (321) 607-2286 or samantha.fonder@nasa.gov.

Sincerely,

Samantha Fonder
NASA Representative to the Commercial Space Transportation Interagency Group
Human Exploration and Operations Mission Directorate, Launch Services Office