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April 13, 2022

VIA ELS

Marlene H. Dortch
Secretary
Federal Communications Commission
45 L Street, NE
Washington, DC 20554

Re: General Atomics
Response to FCC Questions, Ref No. 68373 (dated March 25, 2022)
ELS File No. 1064-EX-CN-2020

Dear Ms. Dortch:

General Atomics supplements its pending application and provides the attached response to the email inquiries from the Federal Communications Commission.[1]

Please feel free to contact the undersigned if you have any questions.

Very truly yours,

/s/Tony Lin

Tony Lin
Counsel to General Atomics

Attachment

[1] *See* Email from Doug Young, FCC, to Victor Gomez, General Atomics (March 25, 2022).

ATTACHMENT

General Atomics Responses to FCC Inquiries Regarding OTB-3 Mission

April 13, 2022

Provided below are responses to the FCC's email inquiries in the 1064-EX-CN-2020 application proceeding.[1] The FCC questions are reproduced below in bold.

> **1. Please provide greater detail concerning the factors that influenced orbit selection, and specifically address whether the applicant would accept a license that specified a maximum altitude that would ensure passive re-entry of the satellite within 25 years, regardless of whether the drag sail deploys.**

One of the payloads on the OTB-3 hosted payload mission is an ARGOS-4 sensor from the Center National d'Études Spatiales ("CNES") provided under an agreement with the U.S. Air Force Space and Missile Systems Center. To maximize the utility of the ARGOS-4 payload, it should be deployed in an orbit close to 850 km to provide a coverage that maximizes sensor data collection, reduces latency between data contacts, and works with other ARGOS satellites. A lower altitude would significantly reduce the amount of data collected by the ARGOS-4 payload and impair the value of the mission to the ARGOS-4 hosted payload customer.

The Rocket Lab Electron launch vehicle selected for the mission can deliver the OTB-3 satellite to a maximum altitude of 750 km. While this is below the optimal 850 km orbit, the parties negotiated 750 km as a compromise between the optimal 850 km orbit and launch costs.

The RADMON payload monitors ambient radiation for use in determining electronics susceptibility to single event upsets. To provide the best data for future General Atomics spacecraft missions, the RADMON payload would be optimally deployed between 750 km and 850 km. This consideration was also a factor in the negotiated 750 km deployment orbit.

General Atomics understood that a 750 km altitude would not provide passive reentry in 25 years, and so undertook adding a high reliability device, the drag sail, to actively deorbit the satellite within 25 years. The drag sail's reliability, which meets the NASA standard of 0.9 reliability,[2] is discussed in response to the FCC questions below.

GA filed its application in December 2020. At this stage, with a constructed spacecraft and finalized mission profile, any change to the deployment altitude significantly below 750 km, would materially frustrate the agreed upon OTB-3 mission objectives and impair the mission. For example, changing the target operational altitude would require revising the software, recalibrating equipment, and conducting additional testing for the new operational orbit, all of which would involve material time and expense. A maximum deployment altitude less than approximately 750 km is, therefore, not acceptable to General Atomics due to negative mission impact and redesign cost.

> **2. Please provide any additional supporting data or analysis concerning the reliability of the drag sail and systems that support its deployment. In particular, noting that the analysis provided in the most recent ODAR identifies only one component of the sail deployment mechanism for which a reliability figure is provided, and does not appear to factor into the reliability analysis the risk of small debris strikes or other component failures in the drag sail mechanism, please provide any additional supporting information that may be available. Please include in your analysis a discussion of possible failure**

[1] *See* Email from Doug Young, FCC, to Victor Gomez, General Atomics (March 25, 2022).

[2] *See* NASA-STD-8719.14C, Requirement 4.6-4, Reliability of Postmission Disposal Operations in Earth Orbit (Nov. 5, 2021).

modes such as mechanical failures either in structural components or through other failures that prevent completion of deployment functions.

There are three failure modes. One failure mode is if the Frangibolt does not release the sail at the end-of-mission. The calculated reliability of the Frangibolt is 0.99999, as stated in the ODAR.[3]

A second failure mode is if the drag sail has a mechanical failure while deploying. Attached as Exhibit 1 is additional information provided by the drag sail vendor, MMA Design LLC ("MMA"), regarding the reliability the dragNET system, including de-orbit and related pantograph flight heritage. Specifically, slide 6 of Exhibit 1 shows the calculated deployment reliability expectations for the mechanical components of the drag sail system (0.99994), which excludes consideration of the Frangibolt reliability (0.99999).[4] The mechanical reliability values were computed based on the techniques and formulas specified by the Naval Surface Warfare Center Carderock Division, Handbook of Reliability Prediction Procedures for Mechanical Equipment, NSWC-07 Rev. C (September 28, 2007).[5]

Finally, a third possible failure mode is if, as a result of collision with space objects of sufficient size during the mission lifetime, the sail or any other critical post-mission disposal equipment is damaged during the life of the mission, preventing post-mission use. The critical components are identified in Table 4 of the ODAR, and the combined probability of a collision regarding any of those components is 0.00734.[6]

All considered, the overall reliability of the satellite surviving until the end of the five-year mission lifetime and the drag sail successfully deploying is **0.91318**, which exceeds 0.90, the NASA-specified reliability measure. The drag sail reliability is calculated as follows:

0.99999 *(Frangibolt release)* multiplied by **0.99266** *(survival of critical post-mission disposal components)* multiplied by **0.99994** *(mechanical deployment of drag sail)* multiplied by **0.92** *(spacecraft reliability)*.

As discussed in the ODAR, a successfully deployed drag sail will deorbit OTB-3 in 17.1 years from an initial orbit of 750 km, consistent with orbital debris requirements.[7]

Please address the durability of the sail material, both during deployment and in the longer term due to exposure to the space environment. Useful information would include whether there any other sails with the same or comparable materials that have been deployed for periods comparable to those planned for this device.

Discussion of similar sail structures is provided in the response to the question below.

The LEO space environment has two elements of exposure that can cause degradation: Micro Meteorites and Orbital Debris (MMOD), and Atomic Oxygen (AO). MMOD can degrade a membrane by penetrating it, and AO can degrade materials. The membrane contains rip stop and porosity features that provide resistance to damage by MMOD. Using standard NASA models for MMOD effects and the membrane characteristics, MMA analyzed the effects and determined that the membrane will survive 25 years in the LEO orbit regime from 750 km and below.

The drag sail membrane is coated with a specified thickness of atomic oxygen-resistant material, which

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[3] *See* General Atomics, Orbital Debris Assessment Report, File No. 1064-EX-CN-2020, at 24 (filed April 5, 2021) ("ODAR").
[4] Greyed out cells in the table on slide 6 indicate that the respective mechanical part type is inapplicable.
[5] *See* Naval Surface Warfare Center Carderock Division, Handbook of Reliability Prediction Procedures for Mechanical Equipment, NSWC-07 Rev. C (September 28, 2007).
[6] *See* ODAR at 18. The collision probability provided above rounds up the 0.0073 number stated in Table 4 of the ODAR, in order to provide a more accurate and conservative assessment.
[7] *See* ODAR at 24.

has extensive industry flight heritage, including the four missions identified below.[8] MMA selected a coating from NASA approved materials, and determined the AO fluence survivability using the measured coating thickness and NASA design data in chapter 8 of NASA publication Space Environmental Effects on Spacecraft: LEO Materials Selection Guide, Contractor report 4461, 1995. The analysis using the NASA guide determined that the AO protection is resistant to a total AO fluence of more than 2e22 cm^{-2}.[9]

Although the satellite will de-orbit in 17.1 years, General Atomics separately analyzed what the total AO fluence would be if the satellite drifted down from 750 km over 25 years to be conservative. The total AO fluence for this profile is calculated to be 1.77e20 cm^{-2}, using the SPENVIS 4.6.10.3386 software based on the NRLMSISE (Navel Research Laboratories) atmospheric model. The margin of over 2 orders of magnitude of AO fluence shows that AO degradation of 25 years will be negligible, and the sail will survive exposure to the space environment during its expected lifetime.

> **Please provide any updates concerning the deployment of the sail on the STP-3 satellite. Noting also the reference to the ORS-3 Minotaur, please address similarities/dissimilarities between the Minotaur and OTB-3 missions. What altitude did the Minotaur upper stage deploy the sail from? Are the area-to-mass characteristics of the spacecraft comparable? How do the sizes of the sails themselves compare between this spacecraft and the Minotaur upper stage? What was the expected lifetime of the Minotaur prior to dragsail deployment and what was the resulting decrease in orbital lifetime due to the dragsail?**

The dragNET system or related sail technology has been used on the following three missions: ORS-3 Minotaur upper stage, FalconSat-7 photon sieve, and R3D2 antenna system. The dragNET system is pending deployment on a fourth mission, involving the STPSat-3 satellite.

The same drag sail system used for OTB-3 (in terms of sail size and material components) was used to successfully de-orbit the ORS-3 Minotaur 1 Upper Stage from an altitude of 500 km and within a 2-year timeframe.[10]

Both the FalconSat-7 and R3D2 missions provide flight heritage for the MMA-designed pantographs and demonstrate the mechanical reliability of those components. The FalconSat-7 mission involved the deployment of a 200 mm diameter photon sieve membrane using an MMA-designed three pantograph system.[11] The R3D2 mission involved the deployment of a 2.25-meter antenna system using an MMA-designed eight pantograph system.[12]

The same drag sail system used for OTB-3 (in terms of sail size and material components) was installed on the STPSat-3 satellite, which launched on the above-referenced ORS-3 Minotaur rocket. The STPSat-3 satellite operates at a 450-km orbit, and the sail has not yet been deployed, as General Atomics previously stated.[13]

General Atomics has no additional information responsive to the other FCC questions identified above.

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[8] For commercial and other reasons, the other missions for which the coating was used cannot be publicly disclosed. General Atomics has no additional information on the specific coating materials.

[9] When MMA prepared its drag sail design, the applied coating thickness was based on an erosion analysis for a deorbit exposure starting from 900 km over 13 years with an erosion margin of 1.5.

[10] *See* NASA, State-of-the-Art of Small Spacecraft Technology, Deorbit Systems, *available at* https://www.nasa.gov/smallsat-institute/sst-soa/deorbit-systems.

[11] *See* ESA eoPortal, Satellite Missions, FalconSat-7, *available at* https://directory.eoportal.org/web/eoportal/satellite-missions/f/falconsat-7.

[12] *See* ESA eoPortal, Satellite Missions, R3D2, *available at* https://directory.eoportal.org/web/eoportal/satellite-missions/r/r3d2.

[13] *See* Letter from Tony Lin, Counsel to General Atomics, to Marlene Dortch, Secretary, FCC (Jan. 12, 2022).

3. Please state the design life of the spacecraft, and whether the information given in the ODAR for bus reliability is for a specific design life.

The design life of OTB-3 is 5 years, and the reliability specified is based on that design life. As stated in the ODAR, the bus reliability is based on the SSTL-150 ESPA system.[14] Anecdotally, SSTL spacecraft have not had a mission failure on-orbit in over 15 years and has never had a mission failure with this class of satellite.[15]

4. Please indicate whether, either by contractual terms or by operation of federal regulations on acquisition, General Atomics believes it would be indemnified by one or more of its customers for any damage resulting from debris surviving atmospheric re-entry.

General Atomics is not aware of any express contractual terms under the relevant agreements with its hosted payload customer that would require the customer to indemnify General Atomics in the event there was damage resulting from any OTB-3-related debris surviving atmospheric re-entry.

With respect to indemnification requirements under the Federal Acquisition Regulation ("FAR"), the Anti-Deficiency Act, 31 U.S.C. § 1341, generally prohibits the Government from incurring obligations or expending funds in advance of or in excess of sufficient appropriations from Congress. Thus, as a general rule, when entering into contracts, the Government cannot agree to indemnify contractors. This general rule is expressly reflected in several provisions in General Atomics' government contracts with its hosted payload customer.

In limited circumstances, there may be exceptions to this general rule where appropriate authority has been granted (*see, e.g.*, FAR Part 50 – Extraordinary Contractual Actions and the safety act). General Atomics is not aware of any applicable exceptions in this case.

[14] *See* ODAR at 26.
[15] *See id*. (stating that SSTL has a long heritage of successful missions with 49 spacecraft launched to date with over 500 years collectively on orbit).

EXHIBIT 1

MMA DragNET De-Orbit and related Pantograph Flight Heritage

Update 12APR2022

DragNET

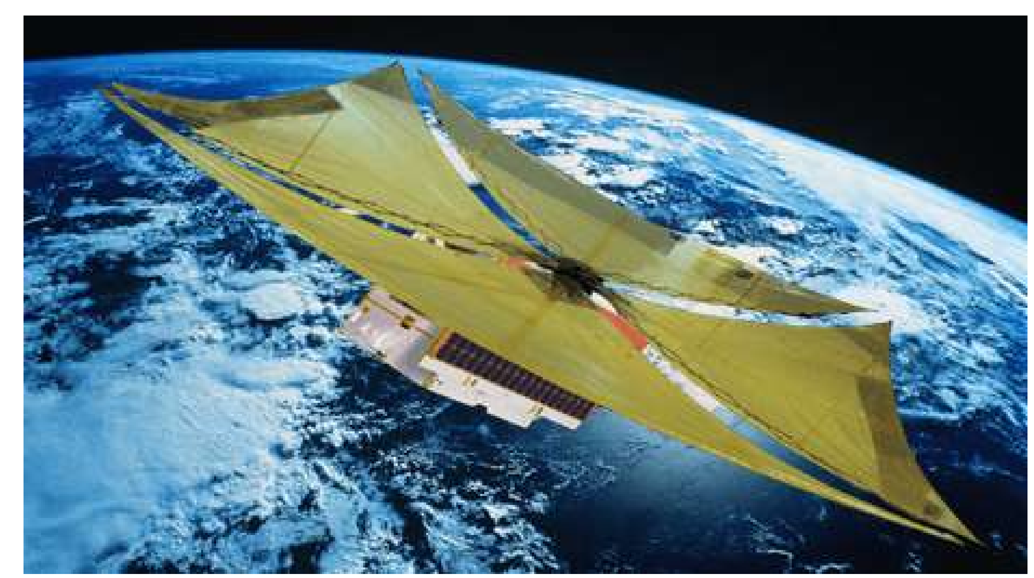
2 systems launched 11/19/13

ORS-3 Minotaur Upper Stage

- Successfully Deployed
- Successfully de-orbited
- 4 pantograph segments

STPSat-3

- Successfully Launched
- Pending Deployment
- 4 pantograph segments

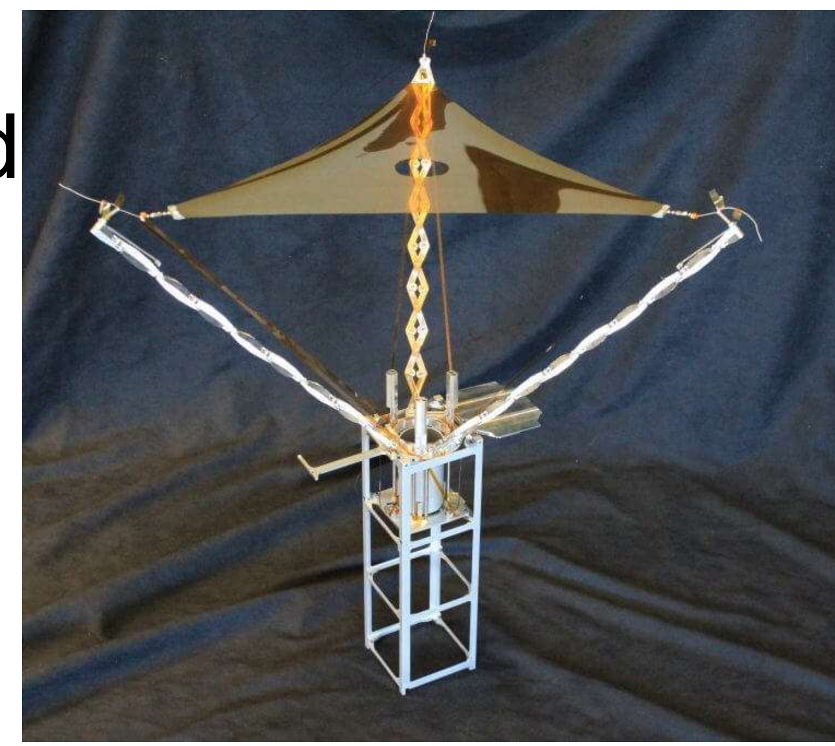


FalconSat-7

Photon Sieve with Pantograph Deployment launched 6/25/19

Satellite Successfully Deployed

- 3 pantograph segments



R3D2

1 Antenna system launched 3/28/19

Antenna deployment confirmed

- Pantograph Successfully Operated
- 8 pantograph segments

AO Protection

- The membranes are coated with a specified thickness of AO-resist material
- Coating has extensive industry flight heritage
- Applied coating thickness was based on an erosion analysis for a deorbit exposure starting from 900km over 13 years with an erosion margin of 1.5
- Coating adhesion and thickness were verified

Mechanical Reliability Analysis

Deployment Reliability Results table

		LMSC/D520737D Rev C		NSWC-07 Rev C																		
Description	**Qty (N)**	**Base Failure Rate (λb)**	π_E	C_E	C_G	C_{DW}	C_N	C_Y	C_L	C_K	C_{CS}	C_{DC}	C_R	C_M	C_t	C_D	C_f	C_{NW}	C_S	C_F	**Part Failure Rate λp**	**N * λp**
Spring, Torsion	1	14.296	0.5	1.040		0.715	21.952	0.556	0.204		0.100	0.195	1.000	1.000							0.258	0.258
Axle	52	9.539	0.5																	0.678	3.231	168.032
Axle	52	9.539	0.5																	0.678	3.231	168.032
Spring, Torsion	26	14.296	0.5	1.040		0.044	1.588	0.556	0.031		0.100	99.897	1.000	1.000							0.089	2.304
Spring, Torsion	26	14.296	0.5	1.040		0.044	1.588	0.556	0.031		0.100	99.897	1.000	1.000							0.089	2.304
Axle	16	9.539	0.5																	0.678	3.231	51.702
Spring, Wave	1	1.100	0.5	1.040				0.741			0.100		1.000	1.000	0.033	191.103	0.066	2.778			0.049	0.049
Spring, Torsion	16	14.296	0.5	0.980		0.009	1.588	0.586	0.050		0.100	150.662	1.000	1.000							0.046	0.742
Washer, Belleville	1	1.221	0.5	0.980				0.586			0.100		1.000	1.000	3.512	191.103	0.389		1.158		10.613	10.613
Spring, Helical Compression	1	9.980	0.5	0.980	0.670	0.007	2.744	0.586	0.227	0.724	0.100	199.205	1.000	1.000							0.115	0.115
																					Total Failure Rate (FPMH)=	404.152

Total Failure Rate (FPMH)	404.152
Total Deployment duration (seconds)	500
Deployment Reliability	**0.99994**

$$e^{-\lambda t}$$