Arcturus Space Debris Mitigation Plan

Issue date: June 2, 2021
Version Number: 2.0

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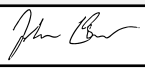
J. Bowen	Arcturus Program Manager		06 / 02 / 2021

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Contents:

Introduction

This document describes the space debris mitigation measures that Astranis Bermuda Ltd. ("Astranis Bermuda") shall implement with respect to the Arcturus satellite to be operated at the 163° West Longitude (W.L.) orbit location.

The Arcturus satellite is designed and manufactured by Astranis Space Technologies Corp. ("Astranis") using its proprietary MicroGEO bus. The Astranis satellite design leverages flight heritage hardware, utilizes architectures and design practices common to geostationary orbit ("GSO") spacecraft, and is consistent with traditional GSO spacecraft standards, such as SMC-S-016. The satellite is three-axis stabilized, uses monopropellant chemical propulsion for north-south station-keeping, and uses a xenon Hall thruster for east-west station-keeping.

The Arcturus satellite is scheduled to launch as a secondary payload on a SpaceX Falcon Heavy rocket and commence service in early 2022.

Astranis Bermuda is aware of the Federal Communication Commission's ("Commission") adopted but not-yet-effective rules related to orbital debris mitigation. As described below, the Arcturus satellite complies with both the existing and not-yet-effective rules, and Astranis will seek to comply with other rules which the Commission may adopt in the future.

Related Documents

1. Air Force Space Command Space and Missile Systems Center Standard, Test Requirements for Launch, Upper-Stage, and Space Vehicles, SMC-S-016 (September 5, 2014)
2. FCC, Orbital Debris Mitigation Standard Practices, FCC 04-130 (June 21, 2004)
3. FCC, Orbital Debris Mitigation Report and Order, FCC 18-313 (Apr. 24, 2020)
4. ITU-R Recommendation S.1003-2, Environmental Protection of the Geostationary Orbit (2010)
5. NASA Safety Standard, Guidelines and Assessment Procedures for Limiting Orbital Debris, NSS 1740.14 (August 1995)

Arcturus Operations

Astranis Bermuda will operate the satellite to control and limit the amount of debris released during normal operations, and has assessed and limited the probability of the satellite becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal to be less than 0.01 (1 in 100), as calculated using the NASA Debris Assessment Software. In addition, fault-tolerant components are spatially separated from each other and housings for electronic components contain significant shielding to further limit the effects of meteoroids.

Astranis has further assessed and limited the probability of the space station(s) becoming a source of debris by collisions with large debris or other operational space stations and has determined this of such collisions with the Arcturus satellite to be negligible.

The Arcturus satellite design does not create any debris during normal operations. A safe operational configuration of the satellite system is ensured due to the hardware design and operational procedures. The Arcturus satellite incorporates significant redundancy in the context of on-station operations and end-of-life disposal.

The Arcturus satellite will be controlled within its station-keeping box (163° W.L. +/- 0.05°) by standard routine periodic orbit correction maneuvers. Astranis Bermuda has reviewed the station-keeping volume that overlaps with the Arcturus satellite and determined that there are no spacecraft that will overlap with the station-keeping volume. Physical coordination of Arcturus satellite operations will be performed during orbit raise, graveyard transfer, and other appropriate circumstances.

Astranis has designed the Arcturus satellite to limit the probability of accidental break-up both during and after the completion of mission operations. All systems that may potentially experience such an event (i.e., propulsion hardware and batteries) utilize components that both have significant flight heritage and are designed with significant margins, thereby ensuring that energy sources onboard the satellite are contained, controlled during an event, and will not convert system components into fragments. Operating conditions in the satellites' batteries and tanks will be monitored by telemetry.

The Arcturus satellite is designed such that high levels of thruster activity and orbit perturbation do not result when foreseeable onboard events occur.

As described below, at end-of-life and after the Arcturus satellite has been raised to graveyard orbit, energy sources will be rendered inactive by venting remaining propellant (via opening all valves) and by leaving the batteries in a permanent state of discharge. Considering its design safety margins, the probability of accidental explosion of the Arcturus satellite is negligible.

The Arcturus satellite will operate from its nominal 163° W.L. orbit location and is fully trackable by existing ground stations and via radio ranging.

Arcturus End-of-Life Disposal

The post-mission, end-of-life disposal activities for the Arcturus satellite are as follows:

1. The orbit altitude of the satellite will be raised by 350 km to ensure that the Arcturus satellite will not re-enter the GSO protected region (GSO altitude +/- 200 km) in the long term. To ensure sufficient margin, a mass of 0.4 kg of xenon propellant has been allocated and reserved to carry out the post-mission disposal maneuver. This equates to

20 m/s of delta-v, or enough delta-v to raise the orbit roughly 500 km. The Commission will be informed of any material change to the above quantity of propellant.

The minimum perigee altitude to avoid re-entering the GSO protected region can be computed using the IADC formula applied to this satellite:

Delta_H (km) = 235 + 1000 * C_R * (A/m) where

- 235 accounts for the 200 km GEO protected region and 35 km for gravitational perturbations
- C_R is the solar radiation pressure coefficient
  - C_R = 2 in the most conservative case
- A/m is the aspect area (m^2) to dry mass (kg) ratio
  - A/m = 11.18/271.4 = 0.041 for Arcturus

Therefore, a conservative Delta_H for Arcturus is calculated as follows:
  - Delta_H = 235 + 1000 * 2 * 0.041 = 317

The planned 350 km above GSO altitude (along with additional fuel margin) is sufficient to satisfy the 317 km requirement. Astranis Bermuda will monitor the remaining propellant to ensure that sufficient fuel remains in the tanks to reach the GSO + 350 km minimum perigee.

2. The satellite tracking, telemetry, and control operations are planned to avoid interference and will be coordinated with potentially affected satellite networks.

3. As part of the end-of-life activities, energy sources on the Arcturus satellite will be rendered inactive such that debris generation will not result from the conversion or dissipation of energy sources onboard the satellite. For the Arcturus satellite, this involves the following:
   a. Discharge the batteries and isolate them from the solar arrays to prevent further electrical energy storage.
   b. Switch off the reaction wheels.
   c. Deplete and vent the propellant tanks, to the extent possible, which allows depressurizing during passivation operations and results in only negligible residuals remaining in the tanks.
      i. Xenon in the electric propulsion system, which is contained in two tanks, will be vented and proportional flow control valve-based pressure regulation allows nearly complete evacuation (as compared to mechanical regulator). Additionally, the pressure relief valve prevents catastrophic failure regardless of venting.

ii. During end-of-life deorbiting, the monopropellant is nearly entirely consumed via depletion burns. Small residuals of less than 1 kg may remain in propellant lines and would be contained by normally closed dual-seat solenoid valves after system passivation.

iii. Monopropellant pressurant (helium) remains in diaphragm tank at low pressure. The tank has a total capacity of 91L, containing 0.1 kg of helium, which has a pressure of ~5 bar at the expected disposal temperature of -50 C.

The monopropellant tank has a burst pressure of 49.3 bar and the xenon tanks have a burst pressure of 772.4 bar. All tanks are validated against MIL-STD-1522A.

The Arcturus satellite contains no pyrotechnic systems to passivate.

Notifications

Astranis Bermuda undertakes to provide the relevant bodies as required (UNCOPUOS, UK Space Agency, FCC, ITU, etc.) with all appropriate notifications as required by law or regulations, including but not limited to those concerning initial entry of service, locations, relocations, inclined orbit operations, and disposal operations.