Cygnus NG-16 Debris Assessment Report

Purpose

This memorandum is an attachment to the Northrop Grumman Systems Corporation (NGSC) FCC experimental radio license application for the Cygnus NG-16 spacecraft.

Scope

This memorandum provides a technical analysis in support of the FCC Office of Engineering and Technology (OET) e-File system application. The data is provided to satisfy § 5.64 Requirements in support of the following application:

Description	Number
FCC File Number	0875-EX-ST-2021

Mission Overview

NGSC, through its affiliate, Orbital Sciences LLC, will launch and operate the Cygnus NG-16 spacecraft as part of the NASA Commercial Resupply Services 2 (CRS2) program. The launch vehicle will be an Antares out of Pad 0A at Wallops Flight Facility. The Cygnus mission will include launch, orbit-raising maneuvers, approach to and berthing with the International Space Station (ISS), un-berthing and departure from the ISS, orbit maneuvering, and destructive reentry into the Earth's atmosphere.

Analysis

1 47 C.F.R. § 5.64 (B)

Requirement

Except where the satellite system has already been authorized by the FCC, applicants for an experimental authorization involving a satellite system must submit a description of the design and operational strategies the satellite system will use to mitigate orbital debris, including the following information:

Note

Orbital Sciences Corporation has previously prepared and submitted to NASA, pursuant to contractual requirements, a "Cygnus Reentry Analysis for NG-12+ Missions" (6472-ER6106).

1.1 § 5.64 (b) (1)

Requirement

A statement that the space station operator has assessed and limited the amount of debris released in a planned manner during normal operations, and has assessed and limited the probability of the space station becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal;

Assessment

No planned explosions or intentional collisions are performed for Cygnus.

The Cygnus has a Probability of No Penetrations (PnP) of 0.9996 from Micrometeoroids and Orbital Debris (MMOD) while berthed to the ISS for up to 90 days. Cygnus will arrive at the ISS generally within 3 days of launch and de-orbits approximately 50 days after departing the ISS. Any increase in MMOD risk (beyond that calculated for the ISS berthed phase) will be negligible given that: (a) the time period on-orbit before and after visiting the ISS is very short; and (b) although the berthed Cygnus receives limited shadowing of the incoming MMOD flux by the ISS, this does not have a significant effect on MMOD PnP, compared to free flight, since the Cygnus sensitive surfaces remain exposed to the flux.

For the Cygnus vehicle itself, there is no planned object or debris release from Cygnus during the mission, with exception of cubesats or so-called microsats. For the NG-16 mission, Cygnus will deploy a number of cubesats following departure from ISS. The external SEOPS SlingShot cubesat deployer will be installed by NASA Astronauts while the spacecraft is berthed to the ISS. The exact number of cubesats will be provided to the FCC when it becomes available. The deployer, with integrated cubesats, is provided to Orbital Sciences Corporation by NASA and SEOPS. The cubesats' release point will be approximately 45 km above the ISS. The Cygnus orbit will be circular at the time of the deployments. Cubesat regulatory requirements including reentry debris assessment are the responsibility of the cubesat owner(s) and the respective providers, and are not covered in this document.

1.2 § 5.64 (b) (2)

Requirement

A statement that the space station operator has assessed and limited the probability of accidental explosions during and after completion of mission operations. This statement must include a demonstration that debris generation will not result from the conversion of energy sources on board the spacecraft into energy that fragments the spacecraft. Energy sources include chemical, pressure, and kinetic energy. This demonstration shall address whether stored energy will be removed at the spacecraft's end of life, by depleting residual fuel and leaving all fuel line valves open, venting any pressurized system, leaving all batteries in a permanent discharge state, and removing any remaining source of stored energy, or through other equivalent procedures specifically disclosed in the application;

Assessment

Because the Cygnus spacecraft operates in the vicinity of the ISS, Orbital Sciences Corporation follows a stringent set of safety requirements. As a fundamental design requirement, Cygnus is two-fault tolerant to catastrophic hazards, including accidental explosions that could endanger the ISS and its crew. Fault tolerance has been verified through detailed Orbital Sciences Corporation FMEA and hazard assessments, and has been accepted by the NASA ISS Safety Review Panel (SRP) for previous Cygnus missions.

The only identified possible cause of an on-orbit explosion of the Cygnus propulsion subsystem is overpressure of the fuel and oxidizer tanks due to failure of a pressure regulator. The expected probability of a resulting explosion event during Cygnus on-orbit operations is 0.0003, which meets NASA quantitative criteria for limiting the risk of accidental explosions.

The Cygnus planned reentry is performed at the end of the Cygnus mission, and into the South Pacific in an uninhabited area. In light of the planned destructive reentry, additional measures for removal of stored energy are not necessary to achieve the goal of preventing on-orbit debris generation.

1.3 § 5.64 (b)(3)

Requirement

A statement that the space station operator has assessed and limited the probability of the space station becoming a source of debris by collisions with large debris or other operational space stations. Where a space station will be launched into a low-Earth orbit that is identical, or very similar, to an orbit used by other space stations, the statement must include an analysis of the potential risk of collision and a description of what measures the space station operator plans to take to avoid in-orbit collisions. If the space station operator is relying on coordination with another system, the statement shall indicate what steps have been taken to contact, and ascertain the likelihood of successful coordination of physical operations with, the other system. The statement must disclose the accuracy - if any - with which orbital parameters of non-geostationary satellite orbit space stations will be maintained, including apogee, perigee, inclination, and the right ascension of the ascending node(s). In the event that a system is not able to maintain orbital tolerances, i.e., it lacks a propulsion system for orbital maintenance, a statement disclosing that fact shall be included in the debris mitigation disclosure. Such systems shall also indicate the anticipated evolution over time of the orbit of the proposed satellite or satellites. Where a space station operator requests the assignment of a geostationary-Earth orbit location, it shall assess whether there are any known satellites located at, or reasonably expected to be located at, the requested orbital location, or assigned in the vicinity of that location, such that the station keeping volumes of the respective satellites might overlap. If so, the statement shall identify those parties and describe the measures that will be taken to prevent collisions;

Assessment

During free-flight operations, conjunction screening before and after Cygnus phasing Delta-V burns is performed by NASA (with support from JSPOC). Phasing burns are adjusted if a conjunction is noted to clear the conjunction.

Orbital Sciences Corporation has assessed and limited the probability of unintended contact with the ISS. Cygnus's approach to the ISS is closely coordinated between ISS operations staff and Orbital Sciences Corporation operations staff. The approach involves successive maneuvers of Cygnus to a series of way-points below ISS, with well-developed contingency plans for aborting the approach if that should become necessary. Each maneuver is designed and verified to be fail-safe, i.e., any failure will leave Cygnus in a trajectory that does not intersect with the ISS. Once Cygnus is in the immediate vicinity of the ISS, the ISS crew grapples the Cygnus spacecraft and berths it to ISS. Cygnus Flight Software, including new upgrades, is tested and accepted prior to each mission with the NASA customer, including this phase of flight. The flight software is built on previous mission testing and on-orbit experience, going back to the Cygnus Demonstration mission.

When the spacecraft is berthed to the ISS, it will be part of the ISS conjunction assessment and collision avoidance maneuver process.

Post departure from ISS, Cygnus will perform additional mission operations prior to de-orbit, specifically in support of secondary mission objectives sponsored by NASA. These objectives include a SEOPS SlingShot cubesat deployer, the Prototype Infrared Payload (PIRPL) experiment, and the KREPE Reentry Experiment. These operations will be completed within 50 days of ISS departure. After completion of the secondary mission objectives, the Cygnus spacecraft will be de-orbited, approximately 50 days after departure from ISS.

1.4 5.64 (b) (4)

Requirement

A statement detailing the post-mission disposal plans for the space station at end of life, including the quantity of fuel - if any - that will be reserved for post-mission disposal maneuvers. For geostationary-Earth orbit space stations, the statement shall disclose the altitude selected for a post-mission disposal orbit and the calculations that are used in deriving the disposal altitude. The statement shall also include a casualty risk assessment if planned post-mission disposal involves atmospheric re-entry of the space station. An assessment shall include a statement as to the likelihood that portions of the spacecraft will survive re-entry and reach the surface of the Earth, and the probability of human casualty as a result.

Assessment

A controlled reentry is performed by Cygnus. The Cygnus spacecraft is single failure tolerant to conducting the controlled reentry operations. In addition, Orbital Sciences Corporation will reserve sufficient fuel for reentry operations.

The declared reentry zone for Cygnus controlled reentry is defined by the following boundary coordinates:

500000 S 1300000 W (50.0°S, 130.0°W)

303000 S 1300000 W (30.5°S, 130.0°W)

303000 S 1600000 W (30.5°S, 160.0°W)

500000 S 1600000 W (50.0°S, 160.0°W)

The closest inhabited area to this reentry zone is the French Polynesian island of Rapa, which is located at 27.6° S, 144.6° W. Its population is approximately 500, and its distance from the northern reentry zone boundary (at 30.5° S) is approximately 410 km. The closest highly

populated city is Papeete, French Polynesia, with an urban population of approximately 130,000, and located approximately 1800 km north of the reentry zone boundary.

Monte Carlo analysis of possible trajectories and dispersions shows the predicted debris area provides very large margin against possible debris impacts outside of the declared reentry zone.

Cygnus will have a controlled reentry that will occur over an unpopulated ocean area. Given compliance with the reentry trajectory constraints defined above, the population density beneath the trajectory is extremely small and assumed to be 0.

For any uncontrolled reentry resulting from a combination of Cygnus vehicle anomalies, the Casualty risk is calculated as:

$$E_C = (1\text{-}Ps) \times \left(\sum A_{ci} \times D_{pi}\right)$$

where $\left(\sum A_{ci} \times D_{pi}\right)$ = the Human Risk factor described in 6472-ER6106, Table 7.3-1; and Ps = Cygnus probability of mission success

Based on the Reliability Analysis prepared for the Enhanced Cygnus missions and documented in 6472-ER61101, mission probability of success is predicted as 0.9451 for a 110-day total (90 days berthed) mission duration. For purposes of the reentry calculation, however, a separate calculation is performed to include only those Cygnus functions required to successfully perform the reentry. De-orbit and reentry is controlled from the ground and, therefore, the Orbital Sciences Corporation MMC-D ground station is also included in the calculation. Based on these assumptions, the predicted probability of success for a successful reentry is 0.9937.

The calculation of casualty risk is then:

$$E_c = (1 - 0.9937) \times (9.1E\text{-}4) = 5.75E\text{-}6$$

For each Cygnus mission, Orbital Sciences Corporation provides advance notifications to the appropriate regulatory agencies which in turn issue advisories for air traffic (NOTAMs) and sea traffic (NOTMARs) in the affected area. These agencies include:

- For NOTAM postings: New Zealand Civil Aviation Authority (CAA) and Direccion General de Aeronautica Civil de Chile (DGAC)
- For NOTMAR postings: US National Geospatial-Intelligence Agency (NGA)