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Abstract: Navigation performance of the BioSentinel Deep Space CubeSat Mission

The BioSentinel mission was recently launched aboard the SLS launch vehicle (LV) as part of the Artemis-1 campaign. The BioSentinel navigation team successfully tracked and guided the spacecraft through a lunar gravity assist to its destination Earth-trailing heliocentric orbit. This 6U CubeSat carries live yeast cells to analyze the effects of radiation at large distances from Earth, becoming the first biological payload in Deep Space. Prelaunch activities included mission design updates, orbit determination rehearsals and the development of a tracking schedule in coordination with the Artemis-1 payload office and the Deep Space Network (DSN). An important influence on the trajectories of Artemis I secondaries was the uncertainty associated with deployment from the Interim Cryogenic Propulsion System (ICPS), the upper stage of the SLS LV. The ICPS was rotating at a rate of 1 rpm; there was also an uncertainty in the spin axis attitude, which translated into an unknown clock angle of deployment. The variability in this angle and magnitude of deployment implied the existence of a non-negligible risk of a lunar impact, which was evaluated for various potential launch dates. We present the results of Monte Carlo analyses and compute the pertinent maneuvers to avoid it. In addition, we present a comparison with the actual deployment once the mission launched by reconstructing our trajectory with tracking data.

On November 16th 2022 BioSentinel successfully deployed from ICPS and the navigation team started to receive 2-way Doppler and Sequential Ranging data from the DSN. We processed early data to try to obtain a first ephemeris using Initial Orbit Determination (IOD) methods such as the least squares. Soon after deployment, the spacecraft was tumbling and entered safe mode, creating a period where the tracking data were sparse. The mission team recovered the spacecraft and after four tracking passes, we solved for a first ephemeris that was sent to the DSN for better tracking of the spacecraft. After propagating this first ephemeris solution, we determined that we avoided impact with a margin of a few hundred km from the lunar surface. More tracking data over the next few days (from DSN as well as ESA antennas) allowed for a more refined orbit solution predicting a periselene altitude of 406 km and a lunar eclipse lasting 36.5 minutes. Therefore, BioSentinel operators aborted any correction maneuvers. This periselene altitude also gave us the necessary energy to achieve a heliocentric orbit. The next challenge was due to the necessary adjustments in our orbit determination method due to the large energy boost resulting from the lunar flyby. After a series of tracking passes we were able to get a nominal solution that resulted into a stable trajectory.

This paper discusses in detail the navigation performance using the X-band IRIS transponder, as well as the challenges and lessons learned prior to and during this deep space, CubeSat mission.