Collision Risk Assessment for Derelict Objects in Low-Earth Orbit

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Collisions between rocket bodies and non-operational satellites are the most significant source of debris-generating risk in Low-Earth Orbit (LEO), as they represent the bulk of the uncontrollable mass and orbit in congested regions. A collision between two of these massive objects, or even between one of these objects and a piece of smaller debris, could significantly increase the collision risk for operational satellites. Clusters of hundreds of derelict rocket bodies and satellites exist above 750 km, with a combined mass of over 1000 tons. While most of these large objects were put into orbit in the 1980s and 90s, upper stages continue to be left in orbit, and defunct satellites add to the uncontrolled mass in the region. The low-drag environment ensures that these objects will remain in orbit for centuries without intervention from robotic de-orbiting missions.

A first step in addressing this problem is characterizing the risk. In this paper, we study the two clusters of approximately 200 objects orbiting at roughly 775 km and 850 km. These clusters are comprised of predominantly paired Russian rocket bodies and satellites, but also include newer massive satellites such as Envisat. We focus on close conjunctions between objects in the clusters, rather than conjunctions with smaller pieces of debris. LeoLabs performs automated full-catalog conjunction screening using high-precision ephemerides, a first-of-its-kind service.

We present several case studies analyzing close conjunctions of less than 100 meters between objects in these clusters. Using LeoLabs' high-precision orbital solutions on these objects in the days leading up to the time of closest approach (TCA), we analyze trends in the orbital solutions, miss distances, and probability of collision for several events in order to evaluate the consistency of the solutions and predictions. We compare results to analyses performed with two-line element sets (TLEs) issued by the US Air Force's Combined Space Operations Center (CSpOC), along with CSpOC high-precision special perturbation (SP) ephemeris.

We perform a statistical analysis of conjunction events for objects in these clusters and summarize (a) the consistency of the LeoLabs predictions in the days leading up TCA, (b) the consistency between the CSpOC-based solutions and the LeoLabs solutions, and (c) the relationship between miss distance and probability of collision for these events. Finally, we summarize the overall risk of the populations and potential strategies for risk reduction. This analysis portrays one use case of how new commercial radar systems can be applied to provide responsive insights useful for management of the debris population.