Characterizing the Orbital Debris Environment Using Satellite Perturbation Anomaly Data

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The untracked orbital debris environment has been described as one of the most serious risks to satellite survivability in high-traffic low-Earth orbits, where acute satellite population growth is taking place. The 2018 National Space Policy Directive 3 calls for “advancing the science and technology of critical space situational awareness (SSA) inputs such as observational data and models necessary to improve SSA capabilities […] in particular in coverage regions with limited sensor availability and sensitivity in detection of small debris (and) updating debris mitigation guidelines, standards, and policies to mitigate the operational effects of orbital debris.” This policy was formulated at a time when the presence of satellites in low Earth orbit is expected to grow as much as a factor of 10 on the next decade. Prior to launch, all USG agencies (DoD, NASA, NOAA, etc.) that operate satellites in low Earth orbit currently have requirements for assessing risks to satellite (from loss of control, or from loss of ability to dispose of the satellite at the end of mission) due to impacts from small debris (< 1cm). The accuracy of these risk assessments depends on the accuracy of orbital debris environment predictions.

NASA studies show that orbital debris in the 1mm to 3mm size regime cannot be directly measured above 400 km altitude, but can be expected to cause serious or catastrophic damage to spacecraft in low Earth orbits. Furthermore, current NASA orbital debris environment models and spacecraft assessment techniques at altitudes above 400 km may over-predict the number or mass of satellite impacts and failures by factors on the order of 5 (failures) to 10 (impacts). Clearly, better orbital debris environment data is needed at these altitudes to accurately predict number of impacts and failures as the use of LEO space expands. Continued over-prediction of debris impacts can be expected to lead to satellite overdesign, heavier satellites and higher launch costs.

This paper outlines a technique for calculating the size of small, untrackable orbital debris particles impacting satellites based on observed small changes (1 to 20 meters) in satellite mean altitude for three satellite size regimes (microsats, minisats, and smallsats). These vertical satellite movement anomalies can directly feed improvements to NASA’s orbital debris model (ORDEM 3.0), a basis for required satellite risk assessments.

The paper also presents a variety of techniques for determining the magnitude of vertical movement of satellites from 1 to 20 m (associated with debris hits of 1 to 4mm, depending on satellite design). Some of the most promising include monitoring a satellite’s GPS position, and detecting loss of communication crosslinks with its neighboring satellites in a constellation. Internal spacecraft anomalies (failures) that might accompany a rapid change in orbital position, if reported, would also improve confidence in current orbital debris models.

A major goal of Space Policy Directive 3 is to make improvements in data collection and data processing to better track and predict locations of satellites and debris. To best address the potential risk of orbital debris, anomaly data (including unexpected satellite movements) and other satellite information needs to be shared in a common framework so that debris models, particularly the ORDEM model, can be improved. Creating a transparent, simple process of submitting anomaly data to a Department of Commerce (DoC) data repository could be sufficient to motivate satellite operators to take responsibility for fostering a safe space environment. However, if the good-will approach is not enough, requirements could be adopted into the space regulatory environment. U.S. owners and operators could be incentivized to provide anomaly data. FCC, FAA, and NOAA could extend their debris mitigation plans in the licensing applications to require owners or operators to provide anomaly data to the DoC data repository.