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DEBRIS SHAPE APPROXIMATION USING BALLISTIC COEFFICIENT ESTIMATION

Abstract

The space debris resulting from collision and explosion events are irregularly shaped in most cases, with unknown dimensions and masses. The physical characteristics of the debris are not well known, and any information that can be deduced will improve our knowledge of fragmentation modeling, individual object identification, and orbit lifetime studies. This paper will describe a debris shape approximation technique that includes orbit determination and shape characterization processes and provides insight on the physical characteristics of orbit debris resulting from the Cosmos-Iridium collision in 2009.

The forensic analysis developed here uses two-line element (TLE) data to estimate the ballistic coefficient of an individual object in low Earth orbit over one year or longer. The ballistic coefficient of the debris is estimated over short time arcs throughout the year, providing a time-varying metric to evaluate the cross-sectional area, given that the mass of an individual debris item is almost certainly constant.

A trend appears in the variation of estimated ballistic coefficients that is attributed to weekly or longer changes in orientation with respect to the velocity direction. This trend appears to be above the noise of the orbit determination errors and not correlated with atmosphere flux over the same time period. By evaluating the observed cross-sectional area over time, a distribution emerges that is used to determine shape characteristics. For example, a sphere has a distribution that shows a sharp Gaussian peak because its cross-sectional area does not change over time. However, a tumbling cylinder produces a distinct exponential-like distribution due to its changing cross-sectional area.

To test this hypothesis, the cross-sections of objects of known shape and mass, such as spheres, rocket bodies, and CubeSats, were estimated to acquire a control data set. The cross-sectional areas of these objects were then simulated over thousands of random orientations to produce a distribution and compared against the observed cross-sectional area distribution. Comparison between the observed and simulated cross-sectional areas of the control group showed statistically significant correlation. With the hypothesis confirmed, it becomes possible to assert that the shape characteristics of unknown orbit debris can be approximated from the distribution of its time-varying cross-sectional area. This process was carried out for the debris from the Cosmos-Iridium collision to extract their shape characteristics.