Understanding long-term orbital debris population dynamics

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ABSTRACT

A commonly held misconception about 3D evolutionary models is that they enable accurate forecasts of the orbital debris population. Given the uncertainty accompanying our knowledge of the future state of key parameters, such as solar activity and launch traffic, it is not reasonable to use these models to make such forecasts. Instead, their primary purpose is to aid our efforts to anticipate significant events and trends in the population of orbital debris, and to understand in detail the likely influence of new space systems or debris mitigation measures. In recent years, for example, evolutionary models have been used to investigate the effectiveness of post-mission disposal for spacecraft and rocket bodies crossing the Low Earth Orbit (LEO) region. This work supported the development of the Inter-Agency Space Debris Coordination Committee (IADC) guideline for post-mission disposal in LEO, commonly referred to as the “25-year rule”. Most recently, evolutionary models have been used to address concerns related to the deployment of large constellations of satellites, again supporting the development of IADC recommendations for these space systems. This type of detailed investigation is not possible for other classes of computer model, such as “Particles-in-a-box”, but the typical complexity of these fully 3D evolutionary models tends to preclude their use for analyses over periods longer than one or two centuries. This is an important limitation because many spacecraft and rocket bodies in LEO have orbital lifetimes much longer than this. For instance, some derelict spacecraft at altitudes higher than 750 km are estimated to have orbital lifetimes greater than 250 years. Consequently, we lack a true understanding of the future trends engendered by our space activities; an understanding that relates to concerns about the long-term sustainable use of space for all future generations.

A simple systems model, analogous to the “Particles-in-a-box” method, which encapsulates the fundamental behavior of the orbital debris population, will demonstrate three basic outcomes: near-exponential growth, exponential decay or dynamic equilibrium. If this systems model is correct then linear growth of the orbital debris population (i.e. growth at a constant rate) is not a true long-term trend, as it is not one of the three possible outcomes. Nevertheless, this is what is observed in the results of many evolutionary models when they are used to simulate the effects of the widespread adoption of the IADC debris mitigation guidelines, or the effects of no future launch activity. Either the systems model is too simplistic, or the apparent linear growth of the debris population is actually near-exponential growth, but at a slow rate. To answer this question, the Debris Analysis and Monitoring Architecture to the Geosynchronous Environment (DAMAGE) evolutionary model was used to perform ultra-long projections of the future debris population > 10 cm in LEO under a variety of future launch and debris mitigation conditions. The projections extended 1000 years into the future from a 1 February 2018 start date and were aimed at improving our understanding of the long-term trends in the population of orbital debris.

The DAMAGE results showed that the linear growth rate observed for the first 200 years of the projection period was transient and became non-linear as the projection continued, even with the ongoing and widespread adoption of debris mitigation measures. Nonetheless, the shift to near-exponential growth was slow under these conditions. When debris mitigation measures were not as widely implemented, or when the orbital distribution of newly launched spacecraft was more random, the onset of near-exponential growth was more rapid and obvious. Under these conditions, the debris population tended to evolve in the manner predicted by the simple systems model. Further, it was apparent that debris accumulated more readily in the long-term at altitudes between 1200 km and 1500 km, even when recent launch activity was repeated. This observation challenges the previous results of the DAMAGE model, and others, which have shown a rapid build-up of debris at altitudes between 600 km and 900 km over the next 200 years, but are in line with predictions made by Kessler and colleagues. This finding is noteworthy, in part, because of plans to deploy large constellations of satellites close to this region. Overall, these results indicate that additional measures to mitigate the effects of orbital debris are likely to be needed, and particular emphasis should be placed on measures that protect the 1200-1500 km region in LEO.