Paper ID: 70746
oral
student

20th IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Interactive Presentations - 20th IAA SYMPOSIUM ON SPACE DEBRIS (IPB)

Author: Ms. Celina Pasiecznik
Massachusetts Institute of Technology (MIT), United States, cpasiecz@mit.edu

Dr. Andrea D'Ambrosio
Massachusetts Institute of Technology (MIT), United States, andreada@mit.edu
Mr. Daniel Jang
Massachusetts Institute of Technology (MIT), United States, djang@mit.edu
Prof. RICHARD LINARES
Massachusetts Institute of Technology (MIT), United States, linaresr@mit.edu

A DYNAMICAL SYSTEMS ANALYSIS OF THE EFFECTS OF LAUNCH RATE DISTRIBUTION ON THE STABILITY OF A SOURCE-SINK ORBITAL DEBRIS MODEL

Abstract

Future launches are projected to significantly increase both the number of active satellites and aggregate collision risk in Low Earth Orbit. Ensuring the long-term sustainability of the space environment demands an accurate model to understand and predict the effect of launch rate distribution as a major driver of the evolution of the LEO orbital population. In this paper, a dynamical systems theory approach is used to analyze the effect of launch rate distribution on the stability of the number of objects in LEO. A multi-shell, multi-species source-sink model of the LEO orbital environment is developed in which a set of Partial Differential Equations are used instead of a set of ordinary differential equations commonly used in the literature. This system of PDEs expresses the rate of change of the number of objects as a function of the launch rate distribution. The three species included in the model are active satellites, derelict satellites, and lethal debris. Each shell is modelled by a system of three equations, representing each species, that are coupled through coefficients related to atmospheric drag, collision rate, mean satellite lifetime, post-mission disposal probability, and active debris removal rate. The major sink in the model is atmospheric drag, whereas the only source apart from collision fragments is the launch rate, making it the critical manageable factor impacting the orbital capacity.

Analytical solutions of the system of PDEs are computed, and an analysis of the Lyapunov stability of the equilibrium points is conducted for numerous launch rate distributions. The stability of the equilibrium points is used to test the sensitivity of the environment to run-away debris growth, known as Kessler syndrome, that occurs at the instability threshold. The impact of mega-constellations on orbital capacity in LEO is analyzed. Various bounding cases are studied from low launch rates (business as usual) to high launch rates, wherein all the mega-constellation proposals filed with the International Telecommunication Union and Federal Communications Commission are launched. The PDE source-sink model is compared to other models in the literature including MISSD, DAMAGE, and FADE. The theoretical model is supported by numerical simulations considering the launch rate distribution based on future launch data taken from ESA's MASTER database. The results will help to better understand the orbital capacity of LEO and the stability of the space environment, as well as provide improved guidelines on future launch plans to avoid detrimental congestion of LEO.