Paper ID: 16510
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SPACE DEBRIS SYMPOSIUM (A6)
Modelling and Risk Analysis (2)

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STABILITY AND LIMIT CYCLE ANALYSIS OF DEBRIS REMOVAL

Abstract

The objective of this paper is to examine the behavior of the space debris population in response to the rate and effectiveness of debris removal and the characteristics of different species of debris. There is a considerable body of research in such problems in dynamical systems such as time dependent multi-compound chemical reactions and in population dynamics. Passive debris is the "prey" and active debris removal systems are the major "predators." However, the debris population is diverse. Some classes of debris can extinguish other classes or diminish its own class, such as large objects colliding with other large objects. Some classes are increased, static, or extinguished by different kinds of collisions. For example, collision of two very small particles might be elastic, creating no new particles. One can express the problem in terms of different classes of predators and prey according to a set of classical parameters: prey growth rate, prey density dependence, a conversion efficiency, the predators' attack rate, the predators' handling time, predator death rate, and competition among predators. The last element might be different organizations competing for removing debris in order to gain salvage rights or other rewards. The generalized governing equations were developed independently by Lokta and Volterra in the early 20th century. Constraining specific parameters yields subcases that are well known, such as Malthus (analogous to Kessler Syndrome equations), Verhulst or Logistics Equations (applied by Pardini and others), and more esoteric expressions of population dynamics. These are generally nonlinear equations. Except for Malthus, which is unconditionally unstable, all exhibit a variety of behaviors that might be stable or unstable and which can exhibit limit cycles to which all solutions for varying initial conditions converge in time. The asymptotes of the linearized equations near equilibrium points are called isoclines, and their intersections imply the eventual equilibrium between prey and predators. Note that the predators are not only the active debris removal systems. This is a unique approach to guiding the nature, frequency, and duration of debris removal missions. One may infer that the Kessler Syndrome is not inevitable. There are unconditionally stable solutions; however, these may lead to unacceptably high debris populations. The outcome depends on how debris removal is executed and distinguishing among different classes of debris, not all of which are prey.