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BI-OBJECTIVE OPTIMIZATION OF A MULTIPLE-TARGET ACTIVE DEBRIS REMOVAL MISSION

Abstract

The increasing number of space debris in Low-Earth Orbit (LEO) raises the question of future Active Debris Removal (ADR) operations. Typical ADR scenarios rely on an Orbital Transfer Vehicle (OTV) using one of the two following disposal strategies: the first one consists in attaching a deorbiting kit, such as a solid rocket booster, to the debris after rendezvous; with the second one, the OTV captures the debris and moves it to a low-perigee disposal orbit. For multiple-target ADR scenarios, the design of such a mission is very complex, as it involves two optimization levels: one for the space debris sequence, and a second one for the "elementary" orbit transfer strategy from a released debris to the next one in the sequence. This problem can be seen as a Time-Dependant Traveling Salesman Problem (TDTSP) with two objective functions to minimize: the total mission duration and the total propellant consumption.
In order to efficiently solve this problem, ONERA has designed, under CNES contract, TOPAS (Tool for Optimal Planning of ADR Sequence), a tool that implements a Branch & Bound method developed in previous work together with a dedicated algorithm for optimizing the "elementary" orbit transfer. A single run of this tool yields an estimation of the Pareto front of the problem, which exhibits the trade-off between mission duration and propellant consumption. We first detail our solution to cope with the combinatorial explosion of complex ADR scenarios with 10 debris. The key point of this approach is to define the orbit transfer strategy through a small set of parameters, allowing an acceptable compromise between the quality of the optimum solution and the calculation cost. Then we present optimization results obtained for various 10 debris removal scenarios involving a 15-ton OTV, using either the *deorbiting kit* or the *disposal orbit* strategy.
We show that the advantage of one strategy upon the other depends on the propellant margin, the maximum duration allowed for the mission and the orbit inclination domain. For high inclination orbits near 98 deg, the *disposal orbit* strategy is more appropriate for short duration missions, while the *deorbiting kit* strategy ensures a better propellant margin. Conversely, for lower inclination orbits near 65 deg, the *deorbiting kit* strategy appears to be the only possible with a 10 debris set. We eventually explain the consistency of these results with regards to astrodynamics.