PDC2023
Vienna, Austria

Space Mission & Campaign Design

Comprehensive Mission Design Architecture Trade Study for Planetary Defense Missions

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Keywords: *planetary defense, mission design, trajectory optimization, systems optimization*

ABSTRACT

Planetary Defense (PD) missions are characterized by a variety of mission objectives and complicated by a high degree of variability in the orbit of the hazardous body, the warning time before collision, and the time of collision. Moreover, these high-level, driving characteristics are tightly coupled to mission architecture variables such as the launch vehicle (LV), spacecraft propulsion system, launch and arrival date, deflection date, and payload mass. While most interplanetary missions are designed on a mission-by-mission basis, a comprehensive mapping of mission performance (i.e., solution space) to mission design variables (i.e., design space) for both reconnaissance and deflection PD missions would enable the following:

1. Allow for advance development of ready-to-build hardware designs for most PD mission categories (e.g., reconnaissance or deflection)
2. Catalyze development of new enabling technologies for PD missions
3. Inform cost decisions for different PD problem types
4. Reduce or eliminate the preliminary design phase of a PD mission

A full mapping of the PD architecture trade space is challenging, however. The variability in the orbits of hazardous bodies and the timing from observation to collision dictate consideration of many simulated bodies when taking a holistic design approach. A catalog of 27,000 simulated orbits has been developed as representative of the hazardous body population. This large number of bodies in combination with an expansive mission design trade space of both integer (e.g.,

gravity assist sequence) and gridded continuous variables (e.g., launch date) comprise a design space of over 2.7x10^13 unique trajectory optimization problems. Allowing for two minutes of computational time to optimize each trajectory problem would then demand the age of the universe (13.7 billion years) to fully map the design to solution space assuming a single processor.

To address the computational difficulty posed by a full PD architecture trade, a multi-step approach is developed in this work. First, a pool of hazardous bodies is down selected by categorizing the full population of bodies through k-means clustering with consideration for both orbit and mission performance characteristics. Next, PD mission design categories such as a rendezvous deflection with solar electric propulsion or a flyby reconnaissance mission with high-thrust chemical propulsion are defined. Each design category can be formulated as a many-objective optimization problem with clearly defined objectives, constraints, and independent variables composed of both spacecraft systems and trajectory parameters. This optimal control problem is then solved stochastically in the third step by applying a hybrid scheme in which a genetic algorithm capable of solving many objectives simultaneously is applied as a wrapper around a gradient-based innerloop. This hybrid formulation enables efficient design space sampling for the coupled systems-trajectory problem for each body and each PD design category.

Ultimately, the poster will outline a tractable strategy to trade PD mission architectures given an inherently expansive design space. The resulting mapping aids decision makers in determining what missions and spacecraft would be applicable to a wide array of hazardous objects and will inform how to best invest in future technology for critical PD missions.

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