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TRAJECTORY CONTROL FOR A SOLAR SAIL SPACECRAFT IN AN OFFSET LUNAR ORBIT

Abstract

Almost twenty years ago, Robert Forward proposed and patented the idea of a Statite, a satellite equipped with a solar sail that uses solar radiation pressure to counteract gravity and hover statically above a planet's pole. Shortly thereafter, Colin McInnes presented equilibrium surfaces in the circular restricted Sun-Earth system contained these hover points and that these surfaces form the basis for orbits that are offset from the central body. Recently, there has been new attention focused on solar sails in the Earth-Moon system, specifically, with the generation of viable orbits in this dynamically complicated regime. Promising numerical techniques have been employed to generate viable trajectories. States and pre-defined control histories resulting from these numerical approaches can be used to initiate explicit integration schemes with tight tolerances to verify the solution from the new numerical techniques. Almost universally, solutions from high-accuracy collocation schemes perform better in this test than solutions from lower-accuracy finite difference methods.

The solutions from these low-accuracy schemes can, however, be used as initial guesses for the higher-accuracy schemes. They can also be used as initial guesses in shooting methods, a more common strategy for solving boundary value problems, but usually these schemes require specific insight into the system dynamics for a successful outcome. The availability of a low-accuracy solution can substitute for that insight when the expected behavior of the system is unknown.

Any solution is only as good as the model used to generate it, especially when the trajectory is dynamically unstable, certainly the case when it is an orbit purposefully offset from the Moon. Perturbations from un-modeled bodies, variations in the solar flux, mis-modeling of the sail and bus properties, etc. all will move the spacecraft off the reference trajectory and potentially into an unrecoverable or dangerous regime. Therefore, a control to the reference is required in addition when designing an offset solar sail trajectory.

This paper examines strategies for a control strategy to the reference trajectory. A simple tracker is developed to explore the ideal three-axis accelerations required to target the nominal trajectory. An open loop controller, based on shooting methods employed along arc segments, is then used to correct the sail attitude profile, thus re-targeting the spacecraft to the reference trajectory. Since the sail attitude only controls two degrees of freedom, a small change to the sail reflectivity can supply a third control component; this option is also examined.