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Low-Thrust Many-Revolution Trajectory Optimization

Thesis directed by Professor Daniel J. Scheeres

This dissertation presents a method for optimizing the trajectories of spacecraft that use low-thrust propulsion to maneuver through high counts of orbital revolutions. The proposed method is to discretize the trajectory and control schedule with respect to an orbit anomaly and perform the optimization with differential dynamic programming (DDP). The change of variable from time to orbit anomaly is accomplished by a Sundman transformation to the spacecraft equations of motion.

Sundman transformations to each of the true, mean and eccentric anomalies are leveraged for fuel-optimal geocentric transfers up to 2000 revolutions. The approach is shown to be amenable to the inclusion of perturbations in the dynamic model, specifically aspherical gravity and third-body perturbations, and is improved upon through the use of modified equinoctial elements. An assessment of computational performance shows the importance of parallelization but that a single, multi-core processor is effective. The computational efficiency facilitates the generation of fuel versus time of flight trade-offs within a matter of hours.

Many-revolution trajectories are characteristic of orbit transfers accomplished by solar electric propulsion about planetary bodies. Methods for modeling the effect of solar eclipses on the power available to the spacecraft and constraining eclipse durations are also presented. The logistic sunlight fraction is introduced as a coefficient that scales the computed power available by the fraction of sunlight available. The logistic sunlight fraction and Sundman-transformed DDP are used to analyze transfers from low-Earth orbit to geostationary orbit. The analysis includes a systematic approach to estimating the Pareto front of fuel versus time of flight.

In addition to addressing many-revolution trajectories, this dissertation advances the utility of DDP in the three-body problem. Fuel-optimal transfers are presented in the Earth-Moon circular restricted three-body problem between distant retrograde orbits, between Lyapunov orbits and between Halo orbits. Those include mechanisms for varying the time of flight and the insertion point onto a target orbit. A multi-phase DDP approach enables initial guesses to be constructed from discontinuous trajectory segments. DDP is shown to leverage the system dynamics to find a heteroclinic connection between Lyapunov orbits, which is facilitated by the multi-phase approach.