Low-Thrust Trajectory Design

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Abstract. This research aims to develop autonomous methods for designing low- thrust interplanetary trajectories. The low thrust produced by electric propulsion systems is challenging to mission designers compared to high-thrust systems as low-thrust must be modelled as continuous. Optimisation of these trajectories requires a non-intuitive initial guess. This research is developing methods of performing global searches using an optimiser without the need to provide an initial guess.

Trajectory design for satellites using electric propulsion systems is challenging because these systems are capable only of producing low thrust. For high thrust systems, thrusting is done over a very short period of time so can be approximated as instantaneous. The motion of the spacecraft relative to a central body can be modelled using two- or three-body dynamics, with thrusting modelled as an instantaneous change in velocity and mass. No such approximation can be made for low thrust systems; thrusting must instead be included in the equations of motion. This is because in low thrust systems a much longer burn – hours or days – is required to manoeuvre. The more complex equations of motion make optimisation difficult because the additional terms take longer to compute, and because they introduce parameters to control thrust. Optimisation requires the mission designer to make an initial guess as a starting point. The additional control parameters are non-intuitive and so very hard to guess for. In the preliminary stage of trajectory design, a wide problem space must be searched to find candidate trajectories. Due to the complications of low thrust, it is desirable to find a method for preliminary design and optimisation with as little input from the mission designer as possible.

Research here is focused on doing so for interplanetary cases. The Sims-Flanagan transcription [1] provides a starting point for a model to find interplanetary low thrust trajectories. It approximates continuous thrust as a series of instantaneous impulses, thereby removing thrusting from the equations of motion so making the process much simpler. The trajectory is divided into segments. Thrusting, along with any perturbations due to the gravity of other bodies, atmospheric drag, etc., are applied at the centre of each segment, and otherwise the motion of the spacecraft can be propagated using a two-body model. This method of modelling trajectories is called the multiple gravity-assist low-thrust (MGALT) model [2]. Combined with the optimisation algorithm monotonic basic hopping (MBH) [3], this can perform a low fidelity global search for low-thrust interplanetary trajectories. Work at the University of Auckland will develop this model to function at a higher fidelity to find interplanetary trajectories. So far this has included creating a way of using the method to escape the Earth and reach Venus, starting from a launch on a lunar rideshare. This work will be presented at the AAS/AIAA Astrodynamics Specialist Conference in August [4].

REFERENCES

[1] Jon A. Sims and Steve N. Flanagan. Preliminary Design of Low-Thrust Interplanetary Missions. In *AAS/AIAA Astrodynamics Specialist Conference*, Girdwood, AK, USA, August 1999.

[2] Donald H. Ellison, Bruce A. Conway, Jacob A. Englander, and Martin T. Ozimek. Application and Analysis of Bounded-Impulse Trajectory Models with Analytic Gradients. *J. Guid. Control Dyn.*, 41(7), 2018.

[3] Jacob A. Englander and Arnold C. Englander. Tuning Monotonic Basin Hopping. *International Symposium on Space Flight Dynamics* 2014, 24:1–33, 2014.

[4] Darcey R. Graham, Jacob A. Englander, Nicholas J. Rattenbury, and John E. Cater. Low-Thrust Transfer to Interplanetary Trajectories from Lunar Trajectories with Rideshare. In *AAS/AIAA Astrodynamics Specialist Conference*, Lake Tahoe, CA, USA, August 2020