Extended Abstract

for the
AAS/AIAA Astrodynamics Specialist Conference
August 3-7, 2003
Big Sky, Montana

A Simple Control Law for Low-Thrust Orbit Transfers

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Abstract

A method is presented by which to determine both a thrust direction and when to apply thrust to effect specified changes in any of the orbit elements except for true anomaly, which is assumed free. The central body is assumed to be a point mass, and the initial and final orbits are assumed closed. Thrust, when on, is of a constant value, and specific impulse is constant. The resulting thrust-profile is not optimal, but is based firstly on the optimal thrust directions for changing each of the orbit elements and secondly on the desired changes in the orbit elements. The control law has few input parameters, but can still capture the complexity of a wide variety of orbit transfers.

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Introduction

With the aim of providing both simple approximations to, and good initial guesses for, propellant-optimal, low-thrust orbit transfers which involve specified changes in all orbit elements except true anomaly, we develop a control law which has but few input parameters yet captures the complexity of a wide variety of orbit transfers. As an approximation, this control law provides mission designers with rapid estimates of propellant requirements and times of flight, as well as the trade-offs between the two. In providing initial guesses for optimisation, the control law would be particularly useful for the case where large numbers of revolutions are required. Both continuous and intermittent thrusting is permitted for the transfer, but no constraints are placed on when thrusting can occur. When non-zero, the thrust is assumed to be constant, and the specific impulse is similarly constant. The central body is modelled as a point mass, and the initial and final orbits are assumed closed. No perturbing forces are considered. The control law builds on the ideas of Kluever[1], and Gefert and Hack[2], who "blend" the instantaneously optimal thrust directions for changing each of the orbit elements. We present in this paper a new technique for blending these thrust directions and determining where on the transfer coasting should occur.

Methodology and Preliminary Results

Four guiding principles are used in the control law. The first is one of "effectivity." When thrusting is deemed insufficiently effective, thrust is turned off. For example, if we are to change the semimajor axis, without regard for the other elements, the most effective place to do so is at periapsis. As the spacecraft proceeds on the transfer orbit, thrust is discontinued if the effectivity of thrust drops below some specified cut-off level when compared with the effectivity at the osculating periapsis. For changing other orbit elements, similar cut-off effectivities are set for the orbit elements in question. The second principle is one of overshooting. It may be beneficial to change an orbit element beyond its target value in order to make it easier to perform required changes in other orbit elements. An obvious example is that of changing inclination and semimajor axis concurrently. For large enough inclination changes, less propellant is required overall if the orbit is first enlarged, the inclination change performed at this enlarged orbit, and finally the orbit reduced to the desired size. Similar trade-offs occur with some of the other orbit elements. The control law includes logic for determining when overshooting should occur, based on the changes needed in the elements and the rates of change achievable for these elements on the osculating orbit. The third principle, employed towards the end of the transfer, is one of thrusting so that each of the elements has an equal "time-to-go" to its target value. The fourth principle is simply one of determining a thrust direction when the previous three principles would call for conflicting thrust directions. Associated with these principles are a small number of parameters which control how exactly the principles are implemented.

Two sample orbit transfers effected by means of the control law are shown in Figs. 1 and 2. High thrust-to-weight ratios are used simply for illustrative purposes so that successive revolutions of the transfer are sufficiently far apart to be visible at the scale of the figures. The first and last revolutions of the transfer are shown with a thicker line. The transfer

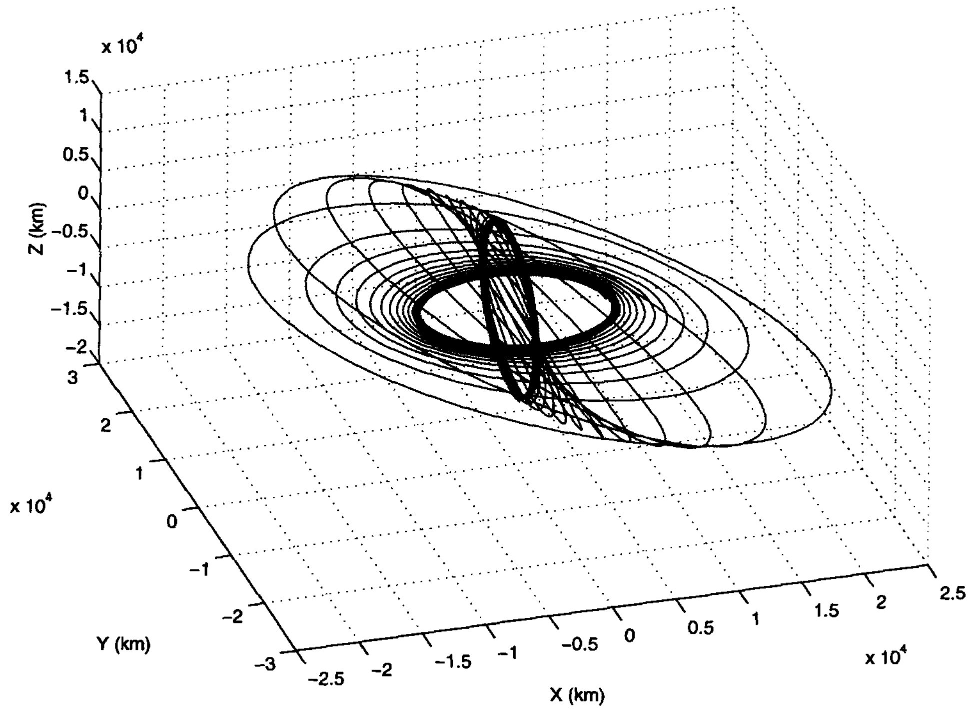

Figure 1: Low-thrust orbit transfer with 90° plane-change from an initially circular orbit, and with 1.35-fold increase in semimajor axis.

shown in Fig. 1 involves a 90° plane-change from an initially circular orbit, together with a 1.35-fold increase in semimajor axis. Clearly seen are the much larger intermediate orbits where most of the plane change occurs. The transfer shown in Fig. 2 is coplanar, with an increase in eccentricity from 0.2 to 0.7 and a 3.25-fold increase in semimajor axis. Thrusting occurs only around periapsis, where it is most effective to change semimajor axis. There is no thrusting around apoapsis because even though that would be most effective in increasing eccentricity, such thrust would reduce the semimajor axis, contrary to the desired increase.

References

[1] Kluever, C. A., "Simple Guidance Scheme for Low-Thrust Orbit Transfers," *J. Guidance, Control, and Dynamics,* Vol.21, No.6, Nov. 1998, pp.1015–1017.

[2] Gefert, L. P. and Hack, K. J., "Low-Thrust Control Law Development for Transfer from Low Earth Orbits to High Energy Elliptical Parking Orbits," AAS/AIAA Astrodynamics Specialist Conference, AAS Paper 99-410, Girdwood, Alaska, Aug. 1999.

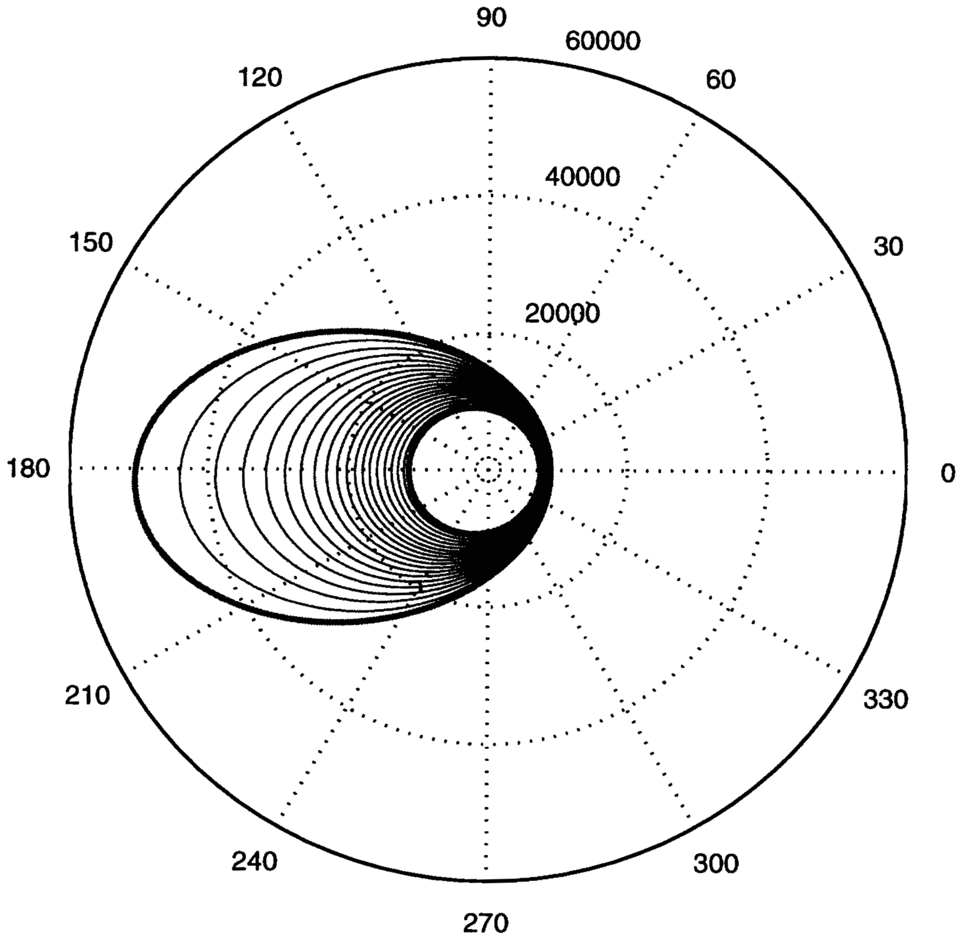

Figure 2: Polar plot of a low-thrust orbit transfer with eccentricity changing from 0.2 to 0.7 and semimajor axis increasing by a factor of 3.25. Polar angles in degrees and radius in normalised units.