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MULTIPLE-SHOOTING CONTINUATION OF SUN-ASSISTED LUNAR TRANSFERS FROM THE PLANAR BICIRCULAR TO THE EPHEMERIS MODEL

Abstract

A sun-assisted lunar transfer (SALT), also known as a weak stability boundary transfer or ballistic lunar transfer, is a low-energy transfer to the Moon when a spacecraft departs from a low Earth orbit to a distance far beyond the lunar orbit, undergoes the influence of the solar gravity field, and then heads toward the Moon to be captured ballistically. This type of transfer is characterized by the propellant efficiency and wider launch windows compared to conventional high-energy fast transfers to the Moon. The flight along a SALT trajectory typically takes several months, but requires 200-300 m/s less delta-v. Such a benefit makes SALT trajectories an attractive option both for the efficient cargo payload delivery to the circumlunar space (in particular, to the prospective crewed lunar orbital station) and for lunar missions of small spacecraft with very limited propellant resources.

Previously, the authors presented several geometrical and analytical tools for the systematic design of SALT trajectories in the planar bicircular restricted four-body problem (PBCR4BP). This model is the simplest one that captures the main geometrical and energy properties of sun-assisted trajectories. Therefore, it can be used for the initial guess trajectory design. The aim of the current research is to study the problem of adapting SALT trajectories from the PBCR4BP to the realistic ephemeris model and specific boundary conditions. The standard tool of trajectory adaptation to a more complex dynamical model is the multiple shooting technique (MST). The resulting system of nonlinear equations is usually solved by some gradient-based method. However, the evaluation of the gradients in the ephemeris model is cumbersome and leads to slow or even poor convergence when using a planar SALT trajectory as an initial guess. Two complementary strategies are proposed to overcome these difficulties. First, the non-gradient modification of the multiple shooting technique is considered. Several approaches of solving the MST system of nonlinear equations are analyzed that do not involve the gradient computation. Second, the discrete continuation in a scalar parameter is exploited to gradually change the dynamical model from the PBCR4BP to the ephemeris one. The convergence characteristics (the percentage of convergence, the algorithm runtime) of the modified MST are compared with those of the standard MST over the set of SALT trajectories with different times of flight. The effect of the continuation step size on the adaptation procedure convergence is explored.