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LOW-THRUST MICROSPACECRAFT DELIVERY TO A LUNAR ORBIT AFTER THE LAUNCH TO GTO OR MEO

Abstract

In recent years, the number of small spacecraft projects for deep space exploration is growing. The fundamental reason behind this trend is the substantially increased endurance of electronic commercial off-the-shelf components and actuators for micro- and nanosatellites. Along with the traditionally mentioned advantages of cheapness and production simplicity, it opens the road for small spacecraft and their formations to deep-space missions, both technology-testing and science. The main obstacle on this road is the delivery issue: any small spacecraft has to wait for a piggyback launch, which happens very rarely even for the nearest destination—the Moon. Moreover, due to the usual inflexibility and/or unpredictability of piggyback launch parameters, the deep-space mission design appears to be challenging. In this research, we perform a feasibility study on delivering a microspacecraft to a low lunar orbit by its own propulsion system. In order to avoid the unacceptably large fuel expenditure, a low-thrust engine with a high specific impulse is only considered. Two launch options are commercially available on a regular basis: the launch from Kourou into a standard geostationary transfer orbit (GTO) and the launch from Baikonur or one of Chinese launch pads into an inclined medium Earth orbit (MEO). Both options are assessed from the viewpoint of radiation dose accumulated when repeatedly crossing the Van Allen belts. The mass penalty is calculated based on the required thickness of aluminum shielding provided by ESA's SPENVIS online interface. The MEO launch is proved to be much more efficient due to the high inclination which minimizes the total time spent in the most hostile near-equatorial zone. An extensive search for optimal spiral trajectories performed across different launch dates reveals the dependence of transfer performance characteristics (delta-v, time of flight) on the initial geometrical configuration of the Earth-Moon system. The effect of including one or several resonant encounters with the Moon followed by lunar ballistic capture is analyzed. The final leg of a transfer trajectory when the spacecraft spirals down to the target low lunar orbit is obtained by integrating backward in time and then patched with the near-Earth trajectory leg in the L1 point region. Upon calculating the whole trajectory in the circular restricted three-body problem model, it is numerically adapted to the ephemeris model. The study uses two parameters to specify a spacecraft and its thruster: the initial thrust-to-weight ratio and the specific impulse. Several combinations of their values typical for micro- and nanospacecraft are considered, which covers the vast range of possible future missions.