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IAF SPACE PROPULSION SYMPOSIUM (C4)
New Missions Enabled by New Propulsion Technology and Systems (9)

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SOLAR SAIL-BASED DEEP SPACE TRANSFERS USING V-INFINITY LEVERAGING MANEUVERS

Abstract

Orbital transfers in the Solar System usually require a large initial hyperbolic excess velocity relative to the Earth to be provided by the launch vehicle, thus affecting the total mission cost and the payload capability. An interesting technique to increase such a velocity is usually referred to as V-infinity leveraging (ViL) maneuver, and it consists of a heliocentric trajectory that is designed to re-encounter the Earth with an increased relative velocity. The effectiveness of ViL maneuvers has been discussed in the literature for spacecraft equipped with either high-thrust or low-thrust propulsion systems. However, the propellant saving can be further enhanced using innovative propellantless propulsion systems, such as solar sails, which provide a continuous acceleration without consuming propellant.

Solar sails are thin reflective membranes which exploit the solar radiation pressure to propel a spacecraft. These devices could enable the design of mission concepts that would be unfeasible with conventional propulsion systems and are particularly fit for rendezvous missions with inner planets or even asteroids, as it is proved by the planned NEA Scout mission. In fact, the study of minor bodies of the Solar System is of great importance for scientific purposes and planetary defence. However, asteroids usually track heliocentric orbits with peculiar orbital parameters, so a rendezvous may require a considerable amount of propellant, making solar sails a valid alternative to conventional thrusters.

The aim of this work is to provide a preliminary investigation of solar sail-based deep space trajectories towards target bodies of the Solar System composed of a ViL maneuver followed by an Earth flyby and a transfer phase. The spacecraft is assumed to be subjected to Sun's gravity and solar radiation pressure only as soon as it exits Earth's sphere of influence. The optimal sail steering law for the ViL maneuver is obtained as a function of the given flight time and initial excess velocity, with the aim of maximizing the excess velocity at Earth re-encounter. The latter provides the initial condition of the transfer phase after the Earth flyby, which is analyzed to find minimum-time trajectories to rendezvous with the target. Both optimizations are performed using an indirect approach. An updated optical model is used to describe the thrust generated by the solar sail, and the sail performance parameter is assumed to be consistent with current technology level.

The manuscript is organized as follows. First, the mathematical model of the problem is thoroughly presented. Then, the two optimization algorithms are discussed. Finally, this procedure is applied to some scenarios of interest, and the results are compared with those available in the literature.