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COUPLED ROTO-TRANSLATIONAL MOTION OF THE HELIOGYRO APPLIED TO EARTH-MARS CYCLERS

Abstract

Solar sailing is a flight-proven low-thrust propulsion technology. Scheduled missions, including NASA's Near-Earth Asteroid (NEA) Scout, will further highlight the technology's maturity and its potential for innovative scientific missions. All previous solar-sail missions employed a solar-sail system design consisting of four triangular sail quadrants supported by deployable booms. As an alternative to such a fixed and flat sail-system design, this paper investigates the dynamics of the heliogyro.

The heliogyro is a helicopter-like sail design that utilizes a set of long slender blades which are deployed and flattened by spin-induced tension and whose orientations can be individually controlled. The main advantages of such a design are the easier stowage and deployment and potentially lower structural mass. Moreover, the individual blade orientation allows higher authority on the forces and moments produced by the sail, but at the same time complicates the heliogyro dynamics.

The heliogyro's translational and rotational motions are strongly coupled, with non-trivial relationships between the control inputs and the forces and moments produced by the sail. Research on the heliogyro's dynamics is scarce, often contains several limiting assumptions and either investigates the translation or rotational motion. The purpose of this paper is to investigate - for the first time - the coupled roto-translational motion of the heliogyro. As tantalizing application, the paper analyzes the heliogyro's performance for Earth-to-Mars stopover cycler trajectories, which could aid the exploration of Mars by providing recurrent propellent-less logistics links between Earth and Mars.

Two numerical models to describe the heliogyro coupled roto-translational dynamics are derived; a simplified and full-fidelity model, where the simplified model only considers the translational and spin-axis motion, averaging forces and moments over the heliogyro's spinning rotation. The validity of the simplified model is subsequently proven in the context of interplanetary trajectories. To design time-optimal heliogyro Earth-to-Mars stopover cycler trajectories, a multiple shooting algorithm is employed and the feasibility of the concept is demonstrated. The performance of the resulting trajectories is expressed in terms of sail technology required to complete the cycler within a set number of synodic Earth-Mars periods. This performance is then compared to that of a traditional fixed and flat sail-system design, highlighting the advantages of the heliogyro.

The results of this paper will expand on the limited existing research about the dynamics of the heliogyro, presenting a novel model for the coupled roto-translational dynamics, and proving the potential of interplanetary heliogyro Earth-to-Mars cyclers.