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SOLAR-SAIL CONTROL LAWS FOR PERTURBED EARTH-BOUND TRAJECTORIES

Abstract

Solar sailing is a spacecraft propulsion method relying solely on solar radiation pressure to provide thrust and is therefore propellantless by nature. Combined with ongoing technical developments, solar sailing represents a practical and promising propulsion system particularly suited for heliocentric flight regimes. Nevertheless, considering the current technology readiness level, near-term sailcraft missions will remain Earth-bound and are thus subject to perturbations absent or negligible in heliocentric flight, including the effect of eclipses, non-spherical gravity and aerodynamic drag. The magnitude of these perturbations can be comparable to, or even exceed that of solar radiation pressure. These perturbations therefore play a crucial role in the dynamics of solar sails in close proximity of the Earth and should be investigated to ensure the controllability of future Earth-bound solar-sail missions.

This paper analyzes these perturbed solar-sail dynamics and, in particular, the effects of the above-mentioned perturbations on the sailcraft controllability by including the gravitational and aerodynamic perturbations in Gauss' planetary equations. From this formulation, steering laws can be derived to optimally change individual, or a combination of orbital elements. These newly derived steering laws form an extension to the laws found by McInnes for unperturbed solar-sail Earth-bound motion. By accounting for the perturbations in the derivation of the steering laws, their effect can be exploited by the sailcraft to achieve orbits otherwise unreachable.

The improved maneuverability will be quantified based on the established increase (or — if desired — decrease) of the targeted orbital element. A range of different starting orbits will be considered to characterize how the perturbations affect the solar-sail maneuvering capabilities in different orbital regimes. As demonstration of the real need for this investigation, NASA's Advanced Composite Solar Sail System (ACS3) mission will be considered as real-case scenario. This mission is scheduled for launch in late 2021 or early 2022 and may benefit from the steering laws derived in this paper to proof the maneuverability of solar sails in Earth orbit.