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CONTROLLABILITY OF A SQUARE SOLAR SAIL WITH MOVABLE MEMBRANE TIPS

Abstract

Solar sails are propelled by momentum from solar radiation. Their unique advantage over other types of space vehicles is that they can operate without propellant. For a solar sail, the orientation of the spacecraft directly affects its thrust. Therefore, special care must be exercised when designing attitude control strategies for this class of space vehicles.

Conventional actuators are unsuitable for solar sails for several reasons documented by Wie [1]. For solar sail attitude control, one needs to generate an offset between the vehicle center of mass and its center of pressure, in order to produce the body torque needed for attitude control. One of such attitude control methods was recently proposed by Fu and Eke [2] for square sails. The method, which will be referred to in what follows as the movable wingtip method, works for any size solar sail, but is thought to be especially effective for large sails. A major advantage of this movable wingtip method over existing methods is that it is capable of producing control moment parallel to all three sail principal axes. A control algorithm based on this attitude control method can be found in [3].

The attitude control method proposed in [2] calls for eight controller inputs to a time-varying, nonlinear model of the system. In order to study other possible control arrangements that uses the movable wingtip method for attitude maneuver, the system's controllability must be well understood. In this study, we explore the controllability of a solar sail that uses the wingtip displacement attitude control methodology presented in [2]. First we present a full sail model built up from the single wing model described in [2]. Then we develop the nonlinear rigid body equations of motion for the sail-controller system. The controllability matrix is formed for this system and controllability is studied for various state variables over bounded domains. The implications of the results for reorientation maneuver planning are discussed.

[1] Wie, B., "Solar Sail Attitude Control and Dynamics, Part 2," Journal of Guidance, Control, and Dynamics, Vol. 27, No. 4, July 2004, pp. 536–544.

[2] Fu, B. and Eke, F.O. "Attitude Control Methodology for Large Solar Sails," Journal of Guidance, Control, and Dynamics, (Accepted for publication)

[3] Fu, B. and Eke, F.O. "A Reorientation Scheme for Large Solar Sails," Proceedings of the AAS/AIAA Astrodynamics Specialist Conference, Hiltonhead, NC, Aug. 2013.