

ABSTRACT

Solar Sails: Modeling, Estimation, and Trajectory Control

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There has been great interest in developing solar sail technology and missions by several international space agencies in recent years. However, at present there is no consensus on how one can mathematically model forces and moments acting on a solar sail. Traditional analytical models and finite element methods are not feasible for integration into a precise navigation system.

This dissertation takes a step toward resolving this issue by developing tools and concepts that can be integrated into a precise solar sail navigation system. These steps are the derivation of a generalized sail model, a linear estimation method for estimating and predicting forces and moments acting on a solar sail, and a new trajectory control methodology for tracking a nominal trajectory when the sail performance exceeds the nominal design performance.

The main contributions of this dissertation follow. First, the generalized sail model (GSM) is defined to analytically describe the forces and moments acting on a

solar sail of arbitrary shape. The GSM is derived by performing an integration, of all the differential forces and moments acting on the sail, over the sail surface. Next, the GSM is applied to several examples to illustrate the use of the GSM's analytic equations. These examples allow comparisons of forces and moments generated by different solar sails, the computation of force derivatives, and the application of the model to orbital mechanics problems. Since it is difficult to model the sail geometry based on ground measurements, errors in the sail model are expected once the sail is deployed in space. Due to this difficulty, a least-squares estimation method for the force and moment coefficients of the GSM is derived. For realistic implementation of a sail trajectory, the deployed sail must have an excess thrust capacity. We develop and implement a control methodology for flying a nominal mission profile with such an excess capacity. Control laws for maintaining a flat, ideal solar sail orbiting an equilibrium point of the circular restricted three-body problem and tracking neighboring halo orbits are provided. The control laws are tested under several conditions including solar sail surface degradation.