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OPTIMAL ATTITUDE PATH PLANNING ALONG TORQUE EQUILIBRIUM POINTS USING AERODYNAMIC DATABASE FOR DEORBITING LARGE DEBRIS BY SMALL SATELLITES

Abstract

The problems posed by orbital debris tend to become more severe in line with the increasing amount of space debris. This study sought a solution focusing on small satellites to capture and remove large debris cost-effectively. However, it is difficult for a small satellite to apply conventional deorbiting strategies by using only chemical propulsion due to strict limitations on the amount of fuel. This study used a hybrid strategy of deorbit that (1) employs electric propulsion to descend from high altitudes where atmospheric density is low and (2) actively utilizes orbital disturbances at low altitudes acting on the large debris attached to a small satellite and with considerable atmospheric drag.

Atmospheric drag is typically considered a primary disturbing force in low Earth orbit, and attitude and orbit state become co-dependent through drag. Previous work proposed a torque equilibrium attitude (TEA) that depends on orbital altitude to minimize attitude disturbance torques during rapid deorbit. A TEA around an equilibrium (balance) point in attitude dynamics and affected by aerodynamic and gravity gradient torques. Previous work[1] presented aerodynamic torque calculations performed under several assumptions, such as using a cylindrical spacecraft model with a constant center of pressure.

The challenge to TEA utility is that the derivation is complicated by the complex geometry, of the solar array paddle (SAP), for example. It is impractical to incorporate the aerodynamic calculations of computational fluid dynamics (CFD) or molecular fluid analysis (MFA) into the GNC simulation loop due to computational costs. Further, in this system, the center of wind pressure varies considerably depending on the SAP angle, so it is necessary to determine the equilibrium attitude according to the SAP rotation angle and the altitude with only a small number of calculations.

This study first develops an MFA-based aerodynamic database (ADDB) by calculating the aerodynamic torque for each altitude and SAP rotations according to the attitude angle from the ground speed coordinate. This database was implemented in the GNC simulator to enable analysis using a rigorous aerodynamic model at a low computational cost. This way, the determined optimal TEA path plan minimizes the magnitude of disturbance torque, depending on the sun's direction and orbit altitude, which determine the SAP rotation angle.

[1] Sasaki, T., et al, Acta Astronautica, 193 (2022) 667–678.