Benson, Conor J. (Ph.D., Department of Aerospace Engineering Sciences)

Solar Torque and Dissipation Dynamics for Tumbling Bodies: Theory and Observations

Thesis directed by Prof. Daniel Scheeres

Reflection and thermal re-emission of solar radiation can influence the rotational dynamics of small bodies via the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect. The YORP effect plays a primary role in the dynamical evolution of small asteroids. Modeling and observations indicate that many defunct high-altitude earth-orbiting satellites are also driven by the YORP effect. However, no comprehensive YORP studies for defunct satellites in general rotation have been conducted. Better understanding of defunct satellite spin state evolution would improve solar radiation pressure modeling for orbit prediction and facilitate active debris removal and satellite servicing which require accurate target attitude information. This work explores the long-term general (uniform and tumbling) rotational dynamics of defunct satellites subject to the YORP effect, internal energy dissipation, and gravity gradient torques through dynamical modeling and observation analysis. Focus is placed on the well-documented and dynamically interesting GOES 8-12 geosynchronous satellites. Full dynamics models are developed which illustrate rich, previously undocumented behavior including tumbling cycles, sun-tracking precession, tumbling period resonances, and asymptotically stable tumbling states/limit cycles. Using osculating rotational elements, the relevant perturbations are then analytically and numerically averaged over the satellite's general rotation, defined by Jacobi elliptic functions. These new tumbling-averaged models capture and explain the full dynamics behavior and reduce computation times by several orders of magnitude. The tumbling-averaged models facilitate broad exploration and classification of small body spin state evolution. Techniques for extracting spin state information from tumbling satellite light curve and Doppler radar observations are then developed. Analysis of GOES 8-12 observations from 2014 - 2020 reveals diverse, evolving spin states and clear consistencies with dynamical theory. The averaged models are then applied to box-wing satellites and meter-sized asteroids.