Heliogyro Solar Sail Structural Dynamics, Control, and Experimentation

Daniel Guerrant and Dr. Dale Lawrence
University of Colorado, Department of Aerospace Engineering Sciences, 429 UCB, Boulder, CO, 80309-0429, USA
daniel.guerrant@colorado.edu and dale.lawrence@colorado.edu

Dr. W. Keats Wilkie
NASA Langley Research Center, 4B West Taylor Street, Mail Stop 230, Hampton, Virginia, 23681-2199, USA
william.k.wilkie@nasa.gov

The heliogyro is a high-performance, spinning solar sail architecture that uses long reflective membrane strips to produce thrust from solar radiation pressure. The heliogyro's membrane "blades" spin about a central hub and are stiffened by centrifugal forces only, making the design exceedingly lightweight. Blades are also stowed and deployed from rolls; avoiding deployment, packaging, and scalability problems associated with traditional square-rigged or spinning-disk solar sail designs. Analogous to a helicopter, changing the cyclic and collective blade pitch creates attitude control torques. Ground demonstration of a heliogyro is impossible; however, recent advances in microsatellite technologies and rideshare opportunities make a small-scale heliogyro technology flight demonstration potentially feasible. The heliogyro demonstrator concept HELIOS presented herein has a characteristic acceleration target of 0.5 mm/s^2 at one AU. This is high enough to facilitate a variety of compelling science and exploration missions. Furthermore, this work addresses the primary concern with heliogyros: the structural dynamics of controlling their long, thin blades with extremely small bending stiffness and damping. A finite element model of blade twist dynamics is presented along with a pitch control law that incorporates realistic phase loss. This controller damps blade pitch maneuvers in 3.2 minutes, well within HELIOS mission requirements. Finally, the results of a vacuum chamber ground test are discussed. This test determined the frequency response of a hanging blade in order to validate the finite element model and estimate the material damping. The model agreed extremely well with experiment and had less than 12% difference for the first four structural mode frequencies. Furthermore, the material damping results were much higher than expected. The first five modes saw damping ratios above 1%, and as high as 17%. Additionally, several blade test articles were constructed to gain insight into the relative importance of transverse battens, edge reinforcing, and residual manufacturing stress in keeping the blade as flat as possible. It was found that residual manufacturing stress in the 2.5μm sail material will lead to undesirable curling, but a random stress distribution from crumpling the blade material significantly improves flatness with minimal penalties in reflectivity and mass. These results are very encouraging, and alleviate the most significant concerns hampering heliogyro development.