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AERODYNAMIC PERFORMANCE ENHANCEMENT STRATEGIES FOR PASSIVE TETHER-SAIL TRAJECTORY GUIDANCE SYSTEMS FOR EXTRA-TERRESTRIAL BALLOON SYSTEMS

Abstract

Extra-terrestrial balloon systems have been proposed as exploratory platforms for various planets for years. Most notably, this concept was validated by the Vega 1 and 2 aerostats which were used to explore the atmosphere of Venus. Such systems move with the winds at their designed float altitude obtaining in situ atmospheric measurements. Since the trajectory of the balloon is governed by the wind, the scientists operating these balloons have no way to control the path taken by the balloon. Thus, developing a trajectory control system for extra-terrestrial balloon systems is desirable. Recent developments in trajectory control systems using terrestrial balloons make it worth examining the potential for such systems for extra-terrestrial applications. Systems which rely on a propeller system to bias the balloon trajectory, altitude control systems to find favorable wind directions, and systems which utilize a suspended aerodynamic sail (commonly called a tether and sail system) to provide the desired control have all been pursued. This paper examines passive trajectory control systems, which have the advantage of low power consumption.

At the 67th and 68th IAC, a passive tether and sail system was presented and its system performance and trajectory control was discussed. Previous work on passive control systems have used a basic sail geometry without giving attention to improving the performance of the sail. There exist numerous aerodynamic performance enhancements, such as flaps and airfoils designed for specific Reynolds number regimes, which have the potential to increase the performance of a passive tether-sail balloon trajectory control system. The goal of implementing such enhancements is to produce the required guiding force while reducing the mass and size of the tether-sail control system.

This paper seeks to answer the fundamental question of what portion of a scientific balloon mass budget must be allocated for a tether-sail trajectory control system. First, a review of previous work and a system overview are presented. Second, a discussion of approximate Reynolds number regimes is presented along with a selection of appropriate airfoils for the atmospheres of Venus and Titan. Next, an aerodynamic analysis is outlined and integrated into the general system model. Fourth, the benefits of flaps and airfoil selection are demonstrated by comparing the control system masses of balloon systems for various control authority requirements. Finally, sample trajectories are shown to demonstrate the benefits of the proposed enhancements to passive tether-sail control systems for extra-terrestrial balloon exploration.