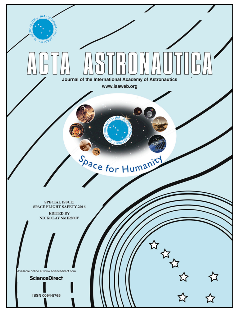
Accepted Manuscript



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PII: S0094-5765(17)31251-1

DOI: 10.1016/j.actaastro.2018.06.007

Reference: AA 6925

To appear in: *Acta Astronautica*

Received Date: 6 September 2017

Revised Date: 8 May 2018

Accepted Date: 3 June 2018

Please cite this article as: M. Gomez Jenkins, D. Krejci, P. Lozano, CubeSat constellation management using Ionic Liquid Electrospray Propulsion, *Acta Astronautica* (2018), doi: 10.1016/j.actaastro.2018.06.007.

CubeSat Constellation Management using Ionic Liquid Electrospray Propulsion

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Abstract

The Space Propulsion Laboratory (SPL) of the Massachusetts Institute of Technology (MIT) is developing the Ion Electrospray Propulsion System (iEPS), designed to address a current need in CubeSat technology: miniaturized electric thrusters. These could be used for different applications, ranging from attitude control to interplanetary flights. In this work, performed together with the Space Systems Laboratory of the Costa Rica Institute of Technology (SETEC Lab), we explore a case study in which the iEPS is used for constellation management in Low Earth Orbit (LEO) when integrated in a 3U CubeSat. We analyze how a 180^o separation in the Right Ascension of the Ascending Node (RAAN) between two CubeSats (SatA and SatB) starting in the same orbit can be achieved by modifying one of the spacecraft's orbital altitude, resulting in a difference in their rate of nodal precession (defined as the drift rate) due to the $J2$ effect, and therefore a difference in their relative RAAN. The method consists of SatB increasing its semi-major axis, drifting in a higher orbit with a lower drift rate, and returning to the original semi-major axis once the desired difference in RAAN in achieved relative to the other spacecraft. SatA will stay in its original orbit, using its thruster to compensate for orbital energy loss due to atmospheric drag, therefore demonstrating another application of iEPS for constellation management. Three different simulations were studied, defined as the minimum time trajectory, minimum propellant trajectory and a hybrid trajectory, consisting of reaching a higher altitude orbit, but actively changing the RAAN using the propulsion system instead of drifting. It was observed that the difference in this orbital element could be achieved using 85 g of propellant in as little as 164 days for the minimum time trajectory. The same difference could also be achieved using only 44 g of propellant in 245 days for the minimum propellant trajectory. Furthermore, the results of the hybrid trajectory showed that the goal could be achieved in 161 days, but using 158 g of propellant mass, demonstrating the benefit of using a drift orbit. The results proved the feasibility of implementing iEPS for constellation management using 3U CubeSats in LEO.

Keywords: CubeSats, electric propulsion, trajectory optimization, constellation management

1. Introduction

Just as cellular phones have experienced miniaturization over the past decades, so have satellites. A milestone in the proliferation of nanosatellites was marked by the introduction of the CubeSat standard, created by Jordi Puig-Suari and Robert Twiggs in 1999 [1]. The original CubeSat was designed to have a mass of approximately 1 kg and a volume of 1000 cm^3, placing it in the nanosatellite category. An advantage of this standard was the reduction of development time and cost by standardization, allowing developers to execute space missions at a low-cost compared to other existing technologies. Twiggs and Puig-Suari originally envisioned CubeSats for universities, giving graduate students the opportunity to design, build and fly their spacecraft in a period of a few years. However, the standard was soon not only used by universities but also by private companies, space agencies, emerging nations, high schools and other entities, therefore democratizing access to space. CubeSats have been popularized over the last years, resulting in more than 400 CubeSats launched from 2000 to 2015 [2]. They have been used for different applications such as Earth observation, astronomy and technology demonstration, but most of them still lack several features to be competitive with larger spacecraft.

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