Aerodynamic Stabilization with a Drag-makeup Propulsion Unit for Very Low Earth Orbit

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Introduction

Power constraints, large RF free-space path losses, and system complexity prevent many researchers from fielding novel sensing hardware aboard nanosatellite missions. Access to lower orbits would decrease downlink losses, improve optical sensor performance, and ensure natural de-orbit for inoperable payloads. Conventional propulsion technologies are capable of providing thrust required to maintain a low orbit, but increase system complexity and draw power away from sensors. The United States Naval Academy has developed the Water Vapor Independent Satellite Propulsion system (WISP) to maintain orbits as low as 250km. This system utilizes an aqueous methyl alcohol propellant that passively evaporates across a phase separation boundary, requiring no electrical power during steady state operation. Theoretical calculations show that this system of 1U volume (10 x 10 x 10cm) is capable of providing sufficient thrust to maintain 250km orbit for 3U satellite for approximately 30 days.

System Architecture & CONOPS

WISP is composed of five main components: (1) a liquid propellant reservoir, (2) a passive phase separator, (3) a gas expansion chamber, (4) converging-diverging micronozzle, and (5) four deployable attitude stabilization surfaces. WISP’s modular design and shelf-stable propellant allow for safe handling and storage followed by rapid integration to meet mission time constraints. After reaching the desired orbital altitude, attitude stabilizers deploy to detumble the spacecraft. Once a stable attitude is achieved, the thruster is activated, initiating propellant flow through passive phase separation. After propellant is exhausted, drag forces acting on the spacecraft cause natural deorbit.

Performance Analysis

Expansion Ratio

Maximum expansion ratio was determined by the stagnation temperature relation, applied to prevent an exit temperature lower than the propellant freezing point, as shown in Figure 4. In addition, the aerodynamic surfaces (“5” in Figure 1) will also be acting as a heater for the propellant, transferring heat into the system with max absorptivity and min emissivity. Thrust & Runtime

To maintain orbit, a thrust equal to atmospheric drag must be generated. According to mean atmospheric density at 250 km for a circular orbit, a 3U spacecraft with drag coefficient of 2.2 would experience approximately 125μN of drag. Theoretical calculations yielded a thrust coefficient of 1.49, characteristic velocity of 516 m/s, and mass flow of 0.213 m/s. By dividing propellant reserve by steady state mass flow, a runtime of 42.1 days was calculated (Figure 5).

Conclusion

Designed to provide thrust for nanosatellites meeting the CubeSat standard, WISP offers researchers the opportunity to collect data from the space environment without needing to design and integrate a custom bus, power management system, or communications hardware. Instead, scientific instruments can be installed directly into a universal bus system providing propulsion and attitude stabilization until natural deorbit at the end of the mission. This architecture would allow much greater numbers of researchers and institutions to contribute earth science data without adding to the volume of debris currently in orbit. This capability is contained within a 1U bolt-on architecture that allows for streamlined integration and use by members of the scientific community who lack dedicated satellite build capability. The thruster is scalable depending on the amount or propellant desired, and a system that fits within a 1U volume (10 x 10 x 10 cm) can extend the mission life of a 3U CubeSat to approximately 30 days.

One thing to note is that the nozzle performance was estimated using ideal rocket equations. At the scale of the nozzle throat area for the current design, the Reynolds number is low enough that the continuous flow assumption would start to introduce large errors. Previous researches by others have shown that the error is within 20% of the ideal values at this range of Reynolds number. Actual manufacturing and testing of the nozzle is planned to verify the theoretical performance.