Design and Testing of a 3D-Printed Attitude Control Thruster for an Interplanetary 6U CubeSat

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Outline

- Background
- Design
- Testing
- Future Work
Background – BioSentinel

- NASA Ames Interplanetary 6U Cubesat
- Planned launch on EM-1
- Biological experiment to study deep space radiation damage
- 18 month mission in heliocentric orbit
- Thruster needed for attitude control
Background – Cold Gas Propulsion

- Propulsion systems that release propellant under pressure to create thrust
- No combustion or electromagnetic acceleration
- Systems are relatively simple and low cost, but also low specific impulse
- Well suited for attitude control
Design – Requirements

- Thruster will be used for detumble and reaction wheel desaturation
- Must produce at least 40 mN from each nozzle
- Total impulse of 36 N-s for 18 month mission
Design – Overview

- Majority of structure is a single piece of 3D printed material
- Metal interfaces are used to connect valves and sensors
- Seven nozzles used to provide 3 DOF attitude control
- Fits as an endcap onto BioSentinel
Design – Printed Structure

- Structure made of a single piece of printed material
- Accura Bluestone, ceramic-like qualities
- Structure includes pipes, nozzles, propellant tanks and mounting points
Most propellant stored in the main tank as saturated mixture
- Main tank stores 230 grams
- Propellant is expanded into the plenum as a vapor alone before firing
- Nozzles cannot ingest liquid
Design – Interior Geometry

- Main Tank
- Plenum
- Manifold Attachment Points
- Nozzles
Design – Piping and Nozzles

- Pipes printed directly into the structure
- Fewer pressure seals means fewer potential leaks
Design – Control

- Fluid flow controlled by 8 miniature solenoid valves
- Split between 2 manifolds, each with a PCB
- Main tank and plenum have pressure and temperature sensors
- Onboard microcontroller communicates with CDH, controls valve timings, and refills the plenum
Design – Propellant

- R-236fa, a commercially available refrigerant
- Non-toxic, non-flammable
- Low storage pressure (<100 psi at 50 C)
- Safety qualified for ISS on a previous thruster
- Not the best propellant ($\gamma = 1.069$)
- High liquid density offsets this
Engineering unit built and tested in spring and summer of 2016 at Georgia Tech

Tests conducted in high vacuum chamber on a torsional pendulum thrust stand

Thruster fired ~4,900 times
Testing – Thrust Stand

- Thruster pulses ~3-10ms
- Stand period ~10s
- Highly underdamped torsional pendulum
- Flex pivots allow the arm to swing when the thruster is fired
- LVDT records stand deflection
Testing – Thrust Stand

Axis of Rotation

Counterweights

LVDT

Thruster
Testing – Performance

- Single nozzle at 24 C
- Thrust:
  - 51 ± 4 mN
- Specific Impulse:
  - 31.7 ± 1.7 s
- Min. Impulse:
  - 198 ± 14 µN-s
- Agreement between nozzles within margin of error
Future Work and Conclusions

- Mid-summer test campaign at Glenn Research Center
- Results are only preliminary, but agree with GT results
- Second test campaign at GT, longer firing times
- Flight unit will be built and delivered in 2017
Thank You For Your Attention