Virtual Research Presentation Conference

InPACT (Integrated Propulsion Additive CubeSat Technology)

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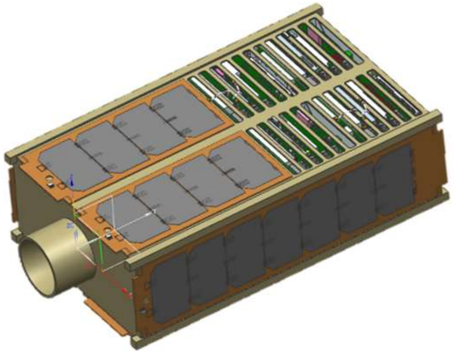
Program: Topical

Jet Propulsion Laboratory
California Institute of Technology

Assigned Presentation #RPC-271

InPACT (Integrated Propulsion Additive Cubesat Technology Introduction



- Technology development of additively manufactured Cubesat chassis with integrated propulsion components

Objective

- Design and Testing of a CubeSat Chassis with Integrated High Delta-V Propulsion Capability
- Characterize the design process for an integrated structure at a CubeSat scale
- Creating a reliable testing campaign to verify function and structural integrity

Benefits to JPL

- Short term impact in additive manufacturing design methodology and further knowledge in design and manufacturing of lattice structure and metallic foam
- Long term impact is the potential to implement low cost and standardized form factor that would allow launching of multiple different science missions to different objectives, including many science targets mentioned in the Decadal Survey, from Lunar Orbit to Near Earth Asteroids, and even Mars or Venus Orbit.

Budget:	FY 20: $220K FY 21: $220K

Problem Description

Context (Why this problem and why now)

- As additive manufacturing technology has been progressing quickly, the applications of additive manufacturing in a spacecraft system tended to be fairly localized, either in mass saving of a structure or utilization of internal geometry in thermal components.
- There has been difficulty in achieving this comprehensive application due to multiple barriers, from lack of necessary design tools and methodology, to unknown process of testing and validation of such spacecraft.

SOA (Comparison or advancement over current state-of-the-art)

- The proposed design is estimated to have delta-V capability in the order of 1000m/s, and the integrated components will include the propellant tank, the thrust nozzle, RCS nozzles, tubing, and mating features for valves and combustion chamber.
- That such propellant tank can be integrated into a CubeSat chassis, creating a new architecture that will allow for lower cost, interplanetary missions. The proposed tank design will save estimated 50% on schedule and cost compared to current standard metal tank production, and the proposed CubeSat design is estimated to have an increased delta-V capability compared to state-of-the-art (in the works of quantifying as we speak).
- Current high-pressure tank systems utilizing Composite Overwrapped Pressure Vessels (COPV) tend to have long lead-time, be expensive, and fixed to standard qualified shapes of cylindrical, spherical, or elliptical tanks. Integration of this tank to a small system like CubeSat is low in packaging efficiency as well.

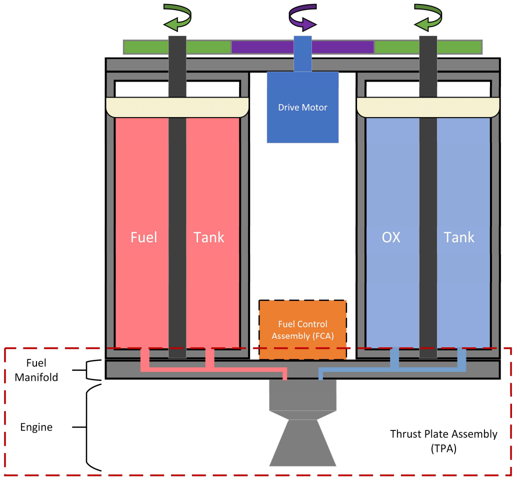
Relevance to NASA and JPL (Impact on current or future programs)

- Development of a small, propulsion capable, CubeSat architecture can give JPL the ability to conduct low cost science missions with significantly larger quantities of “spacecrafts”. **Utilizing additive manufacturing design, a high-delta V capable CubeSat can be designed, and create a platform for conducting missions outside Low Earth Orbit.** The low cost and standardized formfactor would allow launching of multiple different science missions to different objectives, including many science targets mentioned in the Decadal Survey, from Lunar Orbit to Near Earth Asteroids, and even Mars or Venus Orbit.

Methodology

Formulation, theory or experiment description

- The idea is to pack as much usable fuel onboard the cubesat into as small of a package as possible.
- Use of current state of the art small components also helps to reduce overall system dry mass. In the past these components (tanks, valves, sensors) were individual items that needed to be plumbed into a system. The theory now is to try and additively manufacture them (tanks) or provide spaces for them (sensors, valves) in AM designs.
- The experiment is designed to develop several modular, additively manufactured products in order to maximize propellant load, minimize residual losses, and integrate fuel system components.
  - Propellant Tank(s)
  - Fuel Control Assembly (FCA) [control valves and sensors]
  - Thrust Plate Assembly (TA) [fuel manifold and engine]



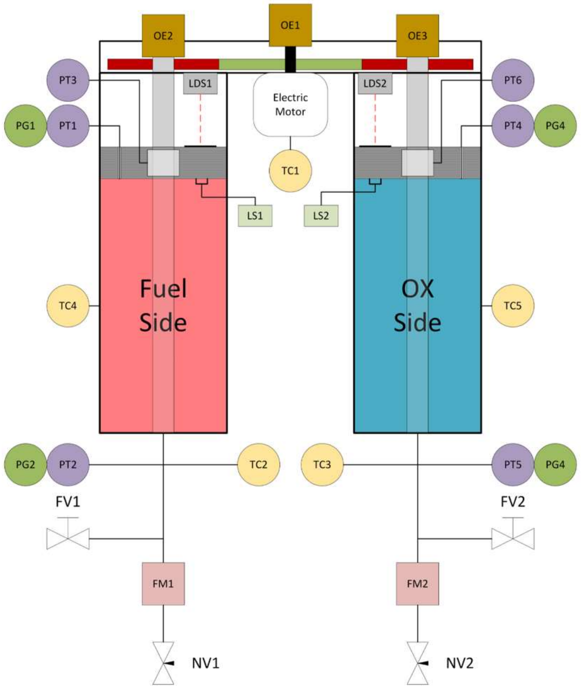
Innovation and advancement

- By designing a modular propellant tank to fit within existing cubesat form factors (1U, 2U, 3U) we achieve higher propellant loads and a better volumetric/packing efficiency compared to traditional style (Spherical, Cylindrical, Ellipsoidal) tanks in the same cubesat form factor.
- By taking advantage of newer, smaller scale components (valves, sensors) we can design smaller, more compact FCAs and TPAs to fit inside established cubesat frames while simultaneously making fluid pathways more efficient with less propellant residuals trapped inside fuel lines. Which means that more of the propellant get to the engine for more DV capability.

Proposed Process Instrumentation Diagram

Notes

- Pressure transducers & gauges on the piston and downstream of the tank to verify no abnormal pressure excursions during operation.
- Pressure transducer measuring the effectiveness of the hydraulic thread sealing technique (spiral fluid passageway sensor)
- Limit switches to prevent excess runout.
- Optical rotary encoders for piston and motor shaft position information
- Laser diode distance sensors for alternative piston travel distance (works in combination with the optical rotary encoders for accurate positional information).
- Needle valves for precision fluid control (variable flow rates in order to test various speeds which correlate to different thrust levels)
- Flow meters to verify the piston speeds meet desired thruster performance mass flow rates.



LEGEND

PT#	Pressure Transducer
PG#	Pressure Gauge
TC#	Thermocouple
LDS#	Laser Distance Sensor
LS#	Limit Switch
OE#	Optical Encoder
FM#	Flow Meter
⋈	FV# - Fill/Hand Valve
⋈	NV# - Needle Valve

Results

Accomplishments

- Machine parameter study has been completed.
- Coupon testing of lattice unit and metallic foam was completed.
- Design and printing of lattice structure tank test unit was completed.
- Diamond triply periodic minimal surface lattice filled cuboid tank analysis was completed.
- Expulsion efficiency assessment was completed.
- Propellant compatibility assessment has began baselining additively manufacturing Ti-6Al-4V laser powder bed fusion coupons baselining Masten’s proprietary hypergaulic bipropellant blend MXP-351.
- Tensile and fracture property coupons were printed and tested giving us tensile design allowables and mode I fracture properties.

Significance

- The parameters allows printing of components with satisfactory surface finish.
- Design and printing of the lattice unit, lattice structure tank, and metallic foam increased confidence in that manufacturability was possible.
- Diamond triply periodic minimal surface lattice filled cuboid tanks can significantly outperform traditionally manufactured pressurized tanks on the pressure-volume-weight performance metric due to the ability to hold extremely high pressures while staying lightweight.
- The expulsion efficiency of the triply periodic minimal surface filled cuboid propellant tank lead to a complete overhaul of the CubeSat architecture.
- Monomethyl Hydrazine and Nitrogen tetroxide was ruled out due to hazardous concerns and replaced with Masten’s green hypergaulic bipropellant.
- Tensile and fracture properties open many doors pertaining to the design and testing of components made from the Ti-6Al-4V laser powder bed fusion process.

Next steps

- Design and test a propellant tank capable of fitting within the cubesat form factor.
- Design, Additively manufacture and test complex flow paths for the FCA and TPA for the cubesat in order to show full flow characteristics while minimizing both mass and residual propellant space.
- Incorporation into a Type II Class D CubeSat NASA Science Mission.
- Flight qualification environmental testing, including acoustics testing, thermal testing, and a full propulsion test, should follow the completion of this proposal in order to qualify the internal propulsion component.

References

[1] O'Hara, Ryan P. “Rapid Production Methods for Next Generation Satellite Designs Enabled through Implicit Design and Additive Manufacturing.” Ntopology

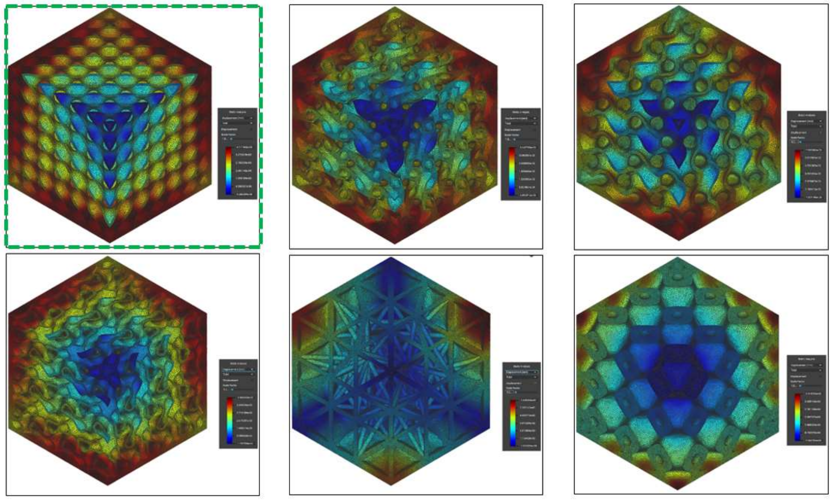
Backup

Triply Periodic Minimal Surface Lattice Filled Cuboid Pressure Vessel

Notes

- Triply periodic minimal surface (TPMS) lattice filled Cuboid pressure vessel performance assessment through design of experiments
- Performance metric, PVW = [(Pressure @ Burst) * (Fuel Volume)]/(Weight)
- Diamond TPMS lattice significantly out performed all other volumetric lattice types and TPMS types. In addition, the diamond TPMS lattice doubled the expected PVW metric for traditionally manufactured pressure vessels for flight applications.
- Triply periodic minimal surface (TPMS) lattice filled Cuboid pressure vessels are very promising for high pressure applications where 98% - 100% expulsion efficiency is not required.

Diamond TPMS



Predicted Performance (first order modeling)

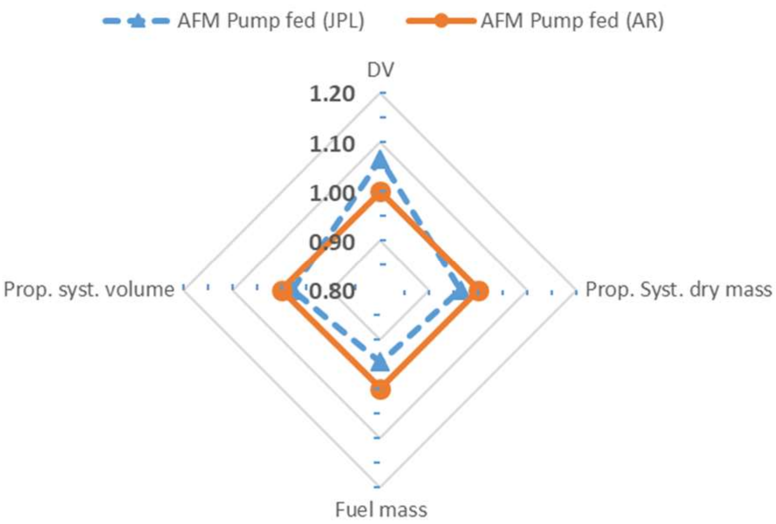


Figure 1. Modeled performance of an ADM pump fed AFM system vs Aerojet predictions. Normalized by the Aerojet MPS system performance.

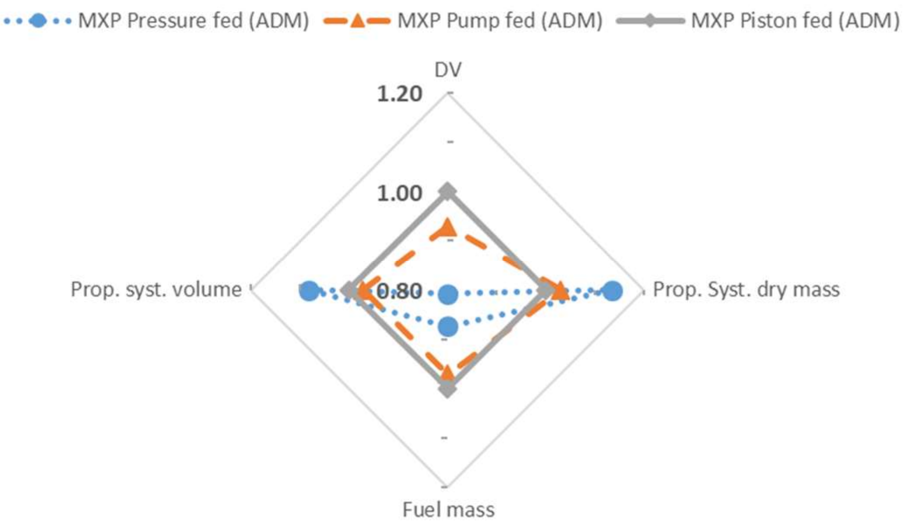


Figure 2. Relative performance of three ADM MXP systems (pressure, pump, and piston fed), normalized by the piston tank system performance.

Material/Fracture Property Coupon Printing & Testing Plan

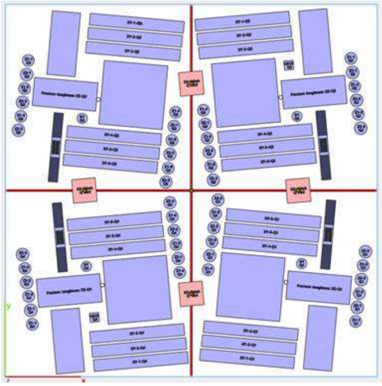
Material property test coupons

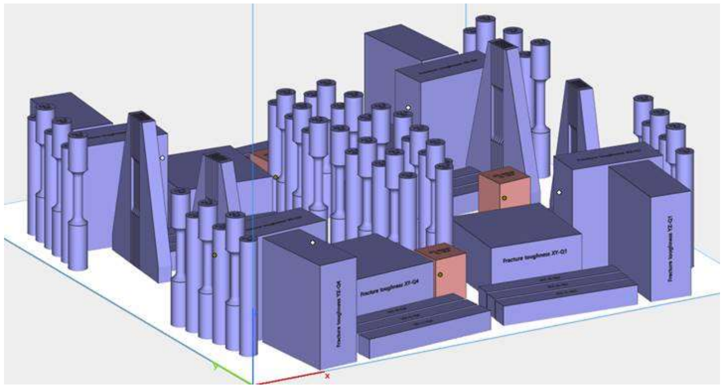
- Fracture toughness J1C coupons
- Tensile coupons
- Micro specimens

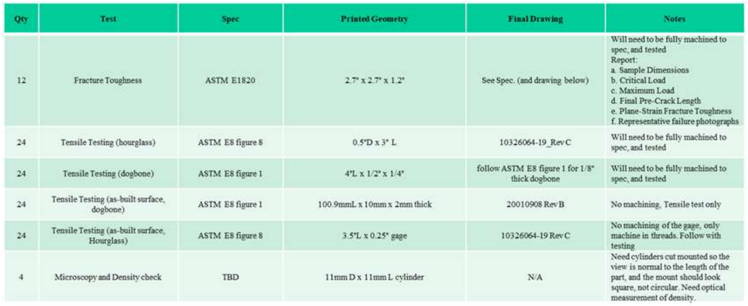
Material property and fracture toughness testing

- Tensile, Yield, Elongation, Reduction in Area-Hourglass, Fracture Toughness J1C
- Microstructural evaluation

3D Material/Fracture Property Coupons Build Layout







Qty	Test	Spec	Printed Geometry	Final Drawing	Notes
12	Fracture Toughness	ASTM E1820	2.7" x 2.7" x 1.2"	See Spec. (and drawing below)	Will need to be fully machined to spec, and tested Report: a. Sample Dimensions b. Critical Load c. Maximum Load d. Final Pre-Crack Length e. Plane-Strain Fracture Toughness f. Representative failure photographs
24	Tensile Testing (hourglass)	ASTM E8 figure 8	0.5"D x 3" L	10326064-19_Rev C	Will need to be fully machined to spec, and tested
24	Tensile Testing (dogbone)	ASTM E8 figure 1	4"L x 1/2" x 1/4"	follow ASTM E8 figure 1 for 1/8" thick dogbone	Will need to be fully machined to spec, and tested
24	Tensile Testing (as-built surface, dogbone)	ASTM E8 figure 1	100.9mmL x 10mm x 2mm thick	20010908 Rev B	No machining, Tensile test only
24	Tensile Testing (as-built surface, Hourglass)	ASTM E8 figure 8	3.5"L x 0.25" gage	10326064-19 Rev C	No machining of the gage, only machine in threads. Follow with testing
4	Microscopy and Density check	TBD	11mm D x 11mm L cylinder	N/A	Need cylinders cut mounted so the view is normal to the length of the part, and the mount should look square, not circular. Need optical measurement of density.