National Aeronautics and Space Administration

Additively Manufactured High Delta-V Capable CubeSat for Low Cost, Interplanetary Multi-mission Architecture

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Program: FY21 R&TD Topics **Strategic Focus Area: Additive Manufacturing, Multifunctional Systems**

Objectives

The objective of this proposal was to design, build and test a high delta-v capable CubeSat that outperformed current state of the art and reduced risked, schedule and costs to the missions. The CubeSat utilized an emerging disruptive technology, known as additive manufacturing (AM), to explore non-intuitive / non-conventional CubeSat architectures that resulted in increased volume efficiency, fuel and oxidizer volume and delta-v.

The quantitative objectives are to show 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 400% delta-V capability compared to state-of-the-art.

Background

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. However, the full potential of additive manufacturing can only be fully realized when it is applied at a full spacecraft scale. In creating an integrated, multifunctional spacecraft structure, the remarkable savings in cost, mass, and schedule can be achieved with additive manufacturing.

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. By developing a small-scale spacecraft with low complexity that has integrated function, such as propulsion capability, the necessary design tools, printing process, and testing methodologies can be identified, and developed. We have selected CubeSat architecture as a suitable candidate to explore this development strategy.

CubeSat missions enable low cost, space access and valuable science return without heavy engineering costs due to the intrinsic form factor and ability to accommodate standard payloads.

Approach and Results

The milestones at the beginning of FY21, inherited from original PI, included: design and printing of metallic foam integrated lattice structure tank units, burst testing, material and fracture property testing, surface characterization, surface post processing experimentation, design of integrated CubeSat chassis accepted by independent peer review, analysis of printed chassis, printing of the integrated Cubesat structure, design of a water flow testbed, random vibe testing, post random vibe CT scan and water flow testing of the proposed architecture and propulsion system. However, after evaluating the objectives, and inherited design, the system architecture completely changed from the original idea and the research had a new direction. Moving forward, the following milestones were removed: burst testing, random vibe testing and post random vibe CT scan. In addition, the water flow testing of the proposed architecture and propulsion system was not able to happen due to an unforeseen manufacturing issue related to the tanks that physically did not allow for assembly.

The original concept consisted of a high pressure blow down bi-prop system. The selected architecture consisted of a low-pressure square piston driven design with cuboid tanks to increase volume efficiency and decrease dead space within the design. This abrupt change in architecture came about because of unforeseen issues with the metallic foam integrated lattice structure tank. The main issues pertained to manufacturability and undesirable expulsion efficiency. The idea was to print porous material into the tanks to act as a PMD; however, initial manufacturing studies suggested that it would be impossible to remove the powder and that chemically etching the porous material would have difficult quality controls. One more thing to note, feature size of internal lattice of the tank plays critical role in capillary action / expulsion efficiency of the tanks. The findings suggested that the idea of metallic foam integrated lattice structure tank is in theory possible; however, the engineering design problem associated with this idea is not trivial and could result in its own R&TD.

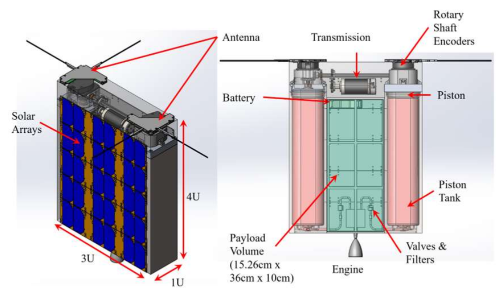
The approach to achieve the remaining objectives involved working milestones in parallel. Material and fracture property testing, surface post-processing experimentation and initial propellant compatibility assessment of AM Ti-6Al-4V occurred in parallel. On the architecture side, the team began by performing research on both current and past NASA and commercially available CubeSats. Which included architecture, prop system, fuel type, fuel volume, initial acceleration, delta-v etc… From there, the team identified downfalls to all mono prop and bi-prop systems, that were assessed, and brainstormed an architecture that relied heavily upon additive manufacturing technologies to provide a solution that outperformed state of the art. The team worked with JPL TeamX individuals and scientists, reviewed the solar system road map and selected a Mars-Phobos mission.

In conclusion, the resulting architecture and prop system first order models suggested that it could be capable of producing 1000 m/s when in the 12U configuration (4x3x1). Best of all, the architecture / prop system is vertically scalable which results in a predicable delta-v performance band that can be tailored for specific missions.

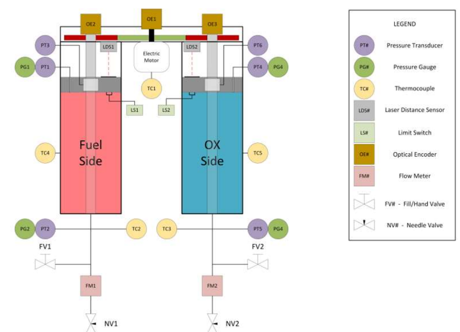
Significance/Benefits to JPL and NASA

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.

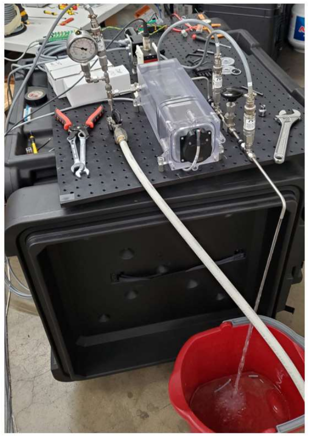
Key technology improvements that will enable this is understanding design and production of lattice structure, topology optimization of pressure vessels, advanced engineering design approaches utilizing mathematical stress/displacement field to drive the placement of material, to create non-standard shaped cuboid tanks. Finally, understanding and development of design tools for creating such integrated structure, and creating a reliable testing campaign to verify function and structural integrity, would be a critical development for this and future additively manufactured integrated spacecraft design.



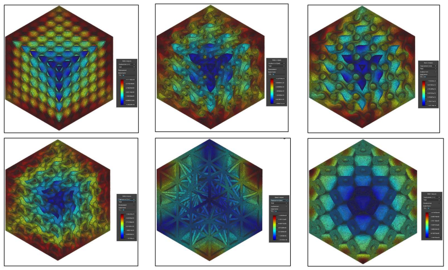
Additively manufactured laser powder bed fusion Ti-6Al-4V topology optimized tank



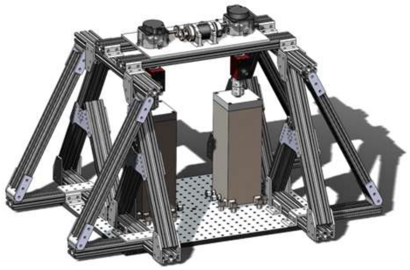
Flight like design nomenclature and propulsion stand P&ID



Waterflow testing of SLA rapid prototyped design for functionality testing and proof of concept



Triply periodic minimal surface & lattice filled cuboid pressure vessel von mises stress contour plots



Metal waterflow testbed design

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