Virtual Research Presentation Conference

Additively Designed and Manufactured SmallSat Structures

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Program: Strategic Initiative

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Tutorial Introduction

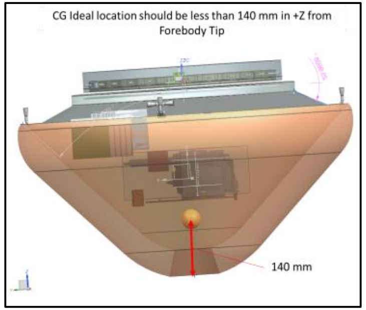
Abstract

The focus on the project is to demonstrate a methodology for creating multi-functional structures for small satellites (< 100 kg) which are enabled by the use of additive manufacturing. This effort is focused on the creation of a propellant tank, which can serve as primary structure, for the Cupid's Arrow reference mission.

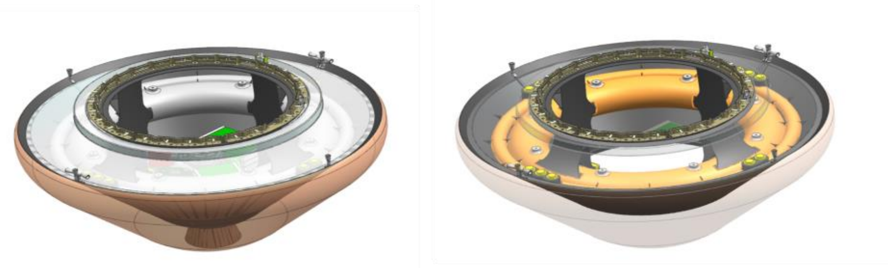
Problem Description

a) The goal of the effort is to demonstrate a design methodology to implement multi-functional structure with a flight-like development and qualification path for SmallSats, in order to advance the state-of-the-art and create highly efficient structures to enable the next generation of SmallSat missions to achieve planetary science objectives that are currently not obtainable. The reference mission for design purposes is Cupid's Arrow, a proposed Venutian atmospheric skimmer (above right). Additive manufacturing is the enabling technology allowing these advances to be made.

b) The current state-of-the-art is the use of separate elements for primary structure and for propellant tanks, resulting in significant lower mass and volumetric efficiency.



Notional design of Cupid's Arrow with C_g noted



Conceptual design of toroidal additively manufactured tanks to tailor C_g

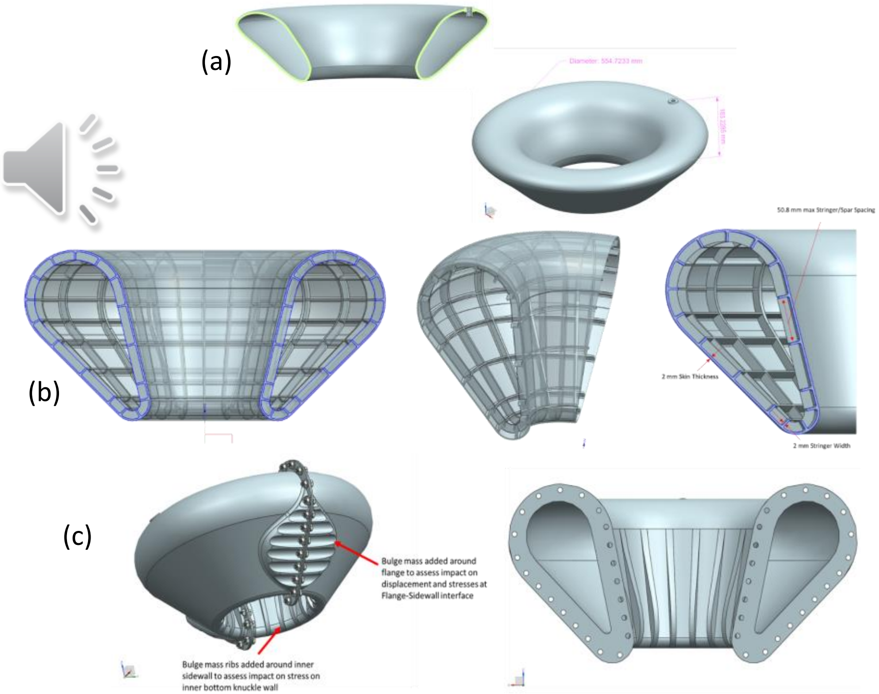
Methodology

ID	Concept	Mass	Cost	Aerodynamics	Mechanical Simplicity	Accomodation to Payload Changes	TOTAL SCORE
		0.1	0.1	0.3	0.2	0.3	1
1	Multiple Cylindrical Tanks (CM)	3	3	3	3	3	3
2	Conformal Kidney Bean Tank (AM)	3	3	4	3	4	3.6
3	Spherical Tank (CM)	3	3	2	5	2	2.8
4	Toroidal Tank (AM)	3	3	3	4	3	3.2

Trade study ranking methodology

a) The approach taken was to perform a trade study against various conventional configurations (e.g. single large spherical tank, multiple cylindrical tanks, advanced additive architectures) to downselect, which resulted in the choice of a conformal, pseudo-toroidal design. The design was then propagated, with input from structures and manufacturing, to create a final architecture.

b) The approach taken evolved from a simple thin-walled structure (a) through multiple iterations looking at concepts such as integral stiffeners (b) and finally to a constant cross-section, fabricated in two pieces with structural bulges to minimize gapping/distortion during testing (c). The final design iteration was a compromise based upon the current machine size limitation and includes structural mounts.



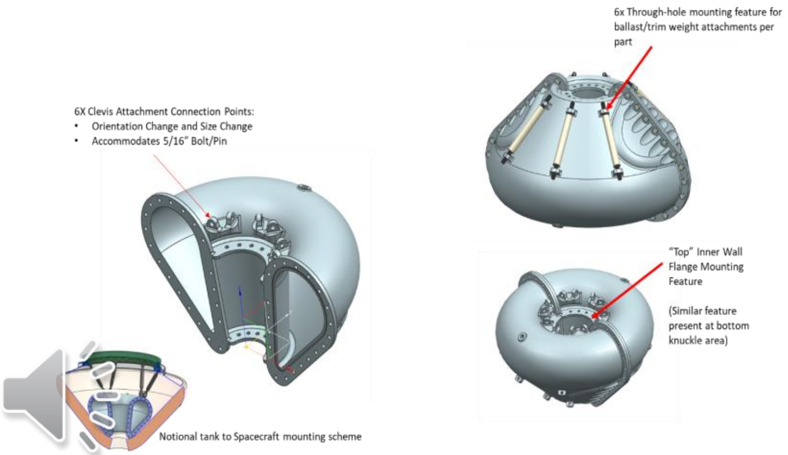
Results

a) Development of HRL 7A77 properties was conducted on two separate laser powder bed fusion machines at Volunteer Aerospace (Knoxville, TN), resulting in properties 25 – 30% better than the incumbent AlSi10Mg. Significant effort and iterations were performed to improve the strength, achieve full density and improve the elongation of the material.

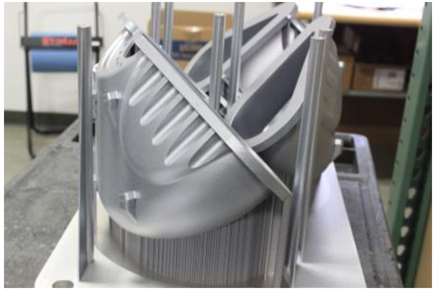
b) The tank design was finalized for printing, including structural elements such as primary structure clevis fittings, instrument attachment features and Cg tailoring elements, creating a viable, multi-functional structure.

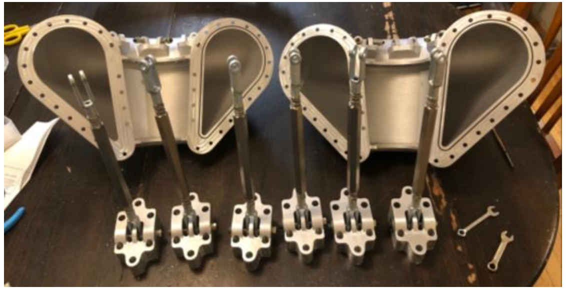
c) The project demonstrated that the primary goals (25% reduction in mass, cost, and schedule, plus a 15% reduction in volume) were achievable directly or through the next, single-piece iteration. The design principles used followed flight processes and were tied to high-fidelity analysis.

d) Pressure and vibration testing occurred too late for inclusion in this work, but the follow-on work in FY21 will focus on a single-piece design that can be accommodated in existing machines, as well as capturing dynamic materials data.



FY20 Final design iteration showing all critical features



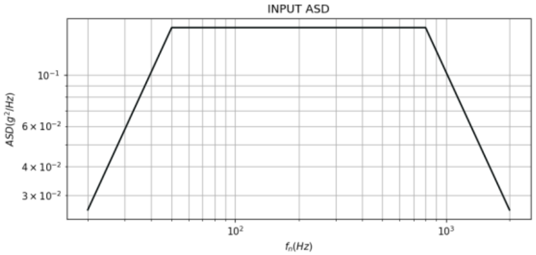


Left: as-built hardware on the build plate
Right: As-processed hardware awaiting assembly (note: bipods and bipod mounts are conventional materials; lightweighting planned for Year 2 or 3)

Results (cont.)

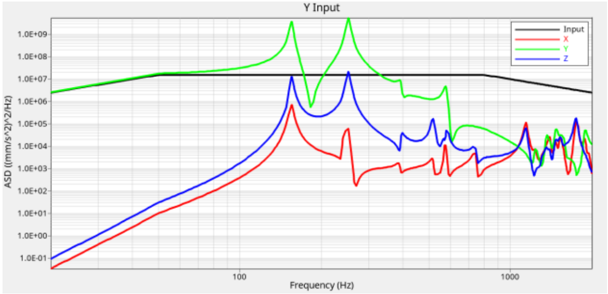
a) Testing parameters per GSFC GEVS-STD-7000 shown at right. These loads are derived for smallsat or payload systems with an undefined launch vehicle and primary satellite structure, per typical JPL best practices.

b) Full structural analysis was performed with high fidelity on each individual component, resulting in a detailed understanding of behaviors. This resulted in de-rating certain aspects of the testing due to conventional parts (e.g. bipods, bipod feet), as well as de-rating due to the first article being produced from AlSi10Mg. Significant improvements will be incorporated into FY21 with the use of both a single-piece architecture and the use of the higher strength HRL 7A77, which was not available to meet the schedule for FY20.



Freq (Hz)	ASD (g^2/Hz)
20	0.026
50	0.160
800	0.160
2000	0.026
grms	14.1

Planned dynamic loads per best practice



Response limiting methodology for testing

Publications, References, Acknowledgements

Publications will be prepared for submission in FY21.

The ADAMSS team would like to thank a variety of individuals for their contributions to our work: Ms. Maxine Beeman for assisting with structural analysis, Dr. Theresa Juarez for materials testing and propellant tank knowledge, Mr. Gary Wang for detailed insight into structural analysis and requirements, as well as very beneficial input into vibration testing parameters, Mr. John Baker and Dr. Christophe Sotin for architectural commentary and insight into the Cupid's Arrow reference mission, and Mr. Timothy O'Donnell for his unflagging support of this project.

Assembled hardware, with Mr. Michael Schein (3551), being prepared for testing at Experior (Oxnard, CA)