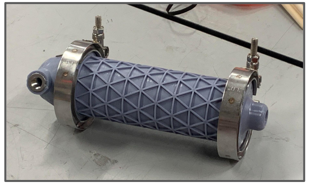
Exploring The Viability Of 3D Resin Printed Parts For Use In Liquid Rocket Engines

[1]Gavin Chung, [1]Rabih Chaar, [1]Ronaldo Valdivia, [2]Zoe Beckley, [2]Etsub Mechal, [2]James Fish, [2]Foroutan Rezazadeh, [2]Brayan Salazar, [2]Nicholas Nguyen, [2]Lucas Wiseman

Introduction

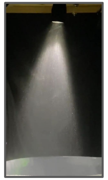
Rocket engine components have been traditionally manufactured using subtractive manufacturing methods out of metal or metal alloys. Recently, metal additive manufacturing has been desirable due to the simplified manufacturing process and the capability of manufacturing high complexity internal geometries in parts such as regenerative cooling channels, injector manifold elements, and turbopump assemblies. Both metal manufacturing methods are costly in both material and tool access.

Resin 3D printing is more accessible and less expensive than more traditional metal machining processes. The high resolution of common resin printers allows for complex parts to be printed with high precision and consistent tolerances. Additionally, the resin is resistive to melting, which allows for easily manufacturing one-time-use components that will be exposed to high temperature fluids, such as combustion gases.

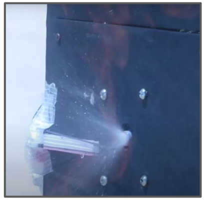


SPARK 1 (Student Propelled Aerospace Rocket Kickstart) is a 35 lbf thrust, 100 psi chamber pressure, ethanol/GOX and UNLV's first bi-propellant rocket engine that will have the thrust chamber assembly (TCA) entirely 3D printed out of resin, i including the combustion chamber, nozzle, and injector manifold. Additionally, the feed system will include 3D resin printed components, such as the cavitation venturi and the critical venturi.

Methods

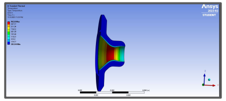


The injector underwent a series of cold-flow tests in order to determine the element geometry that yields the closest discharge coefficient, C_D, and most optimal atomization. Multiple designs were tested, including liquid and gas centered coaxial swirl, and liquid and gas centered coaxial shear, with water flowing through the ethanol inlet, and compressed air through the GOX inlet with a 30 psi pressure drop, ΔP. Mass flow rate, $\dot{m}$ was found by flowing the injector directly into a bucket for a set amount of time, which allowed C_D to be calculated. Atomization was



deduced by flowing the injector in a dark environment with a spotlight on the spray, slo-mo phone cameras were utilized to find the most atomized flow. Once the optimal injector design was established, the ignition was tested in conjunction with the arc-ignition system. The hot-fire test utilized ethanol and compressed air flowing through the injector at 30 psi ΔP with no combustion chamber in order to verify complete combustion of the propellants.

CFD and thermo-structural analyses were performed on various components to verify design before manufacturing.



The combustion chamber is interfaced to the injector manifold and nozzle by compression flanges and V-band clamps. The TCA was pressure tested using compressed air to verify internal combustion gases can be withstood. To limit the risks associated with pneumatic pressure testing, the TCA was tested underwater to dampen the energy of the shrapnel in the event aht CATO occurred. All other inlets were closed, and pressure was read from pressure gauges before the inlet, and at the air compressor.

The cavitation venturi was cold-flow tested using the same approach as the injector. With a 30 psi ΔP, water was flowed through the venturi into a bucket in order to determine the $\dot{m}$. C_D was also calculated and compared to literature. The cavitation venturi also underwent pressure testing similar to the TCA. The component was pressurized using compressed air.

Results

Injector C_D	
Theoretical	0.213
Experimental	0.212
Percent Diff.	0.47%

Cavitation Venturi ṁ (kg/s)	
Theoretical	0.028
Experimental	0.025
Percent Diff.	12.00%

Cavitation Venturi Max. Pressure (psi)	
Theoretical	~325
Experimental	135+

Combustion Chamber Max. Pressure (psi)	
Theoretical	~250
Experimental	~80

Discussion

In initial tests, C_D and $\dot{m}$ were much lower than theoretical calculations. After sizing adjustments accommodating the shrinkage in the 3D resin printed parts, consistent tolerances were able to be achieved and the recent tests yielded C_D and $\dot{m}$ were often times within 5% or less. In the case of the cavitation venturi, the difference was 12%, while not ideal, the small 0.685 mm radius throat is difficult to manufacture. Resin printing serves its advantage for purposes like these where small tolerances in internal geometries are difficult to manufacture using subtractive manufacturing, resin printing allows for easy manufacturing of small internal geometries. This is also apparent in the injector, where experimental C_D was within 0.5% of theoretical calculations despite the small internal volutes and coaxial element geometry.

The pressure tests yielded less ideal results. While small and thick components such as the cavitation and critical venturi were able to withstand the maximum pressure the air compressor was able to produce, the TCA failed at much lower pressures than the analyses predicted. More robust analysis is required to fully validate the internal pressure capabilities. The brittle resin requires considerably higher wall thicknesses in order to withstand pressures metal and metal alloys withstand consistently.

Conclusions

The high precision of the resin and low thermal conductivity allows for high complexity geometries to be manufactured to high accuracy with little worry for melting. This invites and enables creativity, innovation, and fast iteration in small scale liquid rocket engines. The low strength to weight ratio and high britillity means the component geometry has to be biased thick, which discourages flight weight engines to be manufactured out of resin, and increases inherent risk to personnel and nearby components when static fire testing. Overall, further research and development is required to fully explore the viability of utilizing 3D resin printed components in liquid rocket engines.

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