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IMPLEMENTATION OF ADDITIVE MANUFACTURING FOR THE DESIGN & DEVELOPMENT OF THE JESSIE & JAMES LIQUID ROCKET ENGINES

Abstract

The Liquid Propulsion Laboratory (LPL) presents the implementation and impact of additive manufacturing in the development of Jessie & James, a pair of 3D printed liquid rocket engines. The Jessie and James engines (J&J) were brought from conception to operation during the year of 2018 and represented the first time a university designed and manufactured a 3D printed rocket engine entirely on campus. The Liquid Propulsion Laboratory has recently adopted additive manufacturing as the primary method of developing rocket engines with the belief that this newfound process will increase design capabilities, improve iteration turnaround time, decrease development cost, and make an overall positive contribution to the laboratory's primary mission of workforce development. The purpose of the J&J project was to introduce the lab to additive manufacturing, quantify and validate initial beliefs, test the resources and manufacturing capabilities of the university, and to provide familiarity to designers and process engineers as the laboratory moves toward to more complex rocket engine designs in the near future. This paper steps through the technical approach on how to design and manufacture a liquid rocket engine, all while demonstrating how 3D printing can be implemented into the development cycle to increase the program's probability of success. Design considerations and printer parameters to arrive at a successful print are discussed. LPL has examined and implemented a post-print process workflow to ensure quality and reliable prints. The overall manufacturing process is discussed, including decisions made, roadblocks encountered, and future process improvements. The J&J injector is a prime example of the increased capabilities enabled with the new design space of additive manufacturing. This injector is of a similar size and performance as a previous LPL injector, manufactured subtractively. This allows LPL to compare cost, lead time, and performance. By utilizing additive manufacturing, LPL has been able to fabricate a rocket engine at a 45% cost reduction and in a third of time, when compared to subtractive manufacturing. The paper also provides examples of how the additive manufacturing approach can benefit student laboratories by overcoming rapid turnover rates, improving workforce development, and creating an infrastructure where continuous technical advancements can be achieved. The paper concludes with future work for the J&J project, considerations for different rocket engine designs, and provides overall feedback on the impact of implementing 3D printing into the liquid rocket engine development process.

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THE DEVELOPMENT PROCESS FOR A SINGLE-PART ADDITIVELY MANUFACTURED LIQUID ROCKET ENGINE INJECTOR WITH AS-PRINTED ORIFICES

Abstract

The Liquid Propulsion Laboratory (LPL) presents the research into utilizing additive manufacturing for the design, development, and production of liquid rocket engine injectors. The adoption of additive manufacturing gives engineers more flexibility to design unique geometries into a part that would be otherwise impossible to achieve with traditional subtractive methods. This capability is advantageous for liquid rocket engine injectors, which are typically complex and expensive to produce. LPL's Jessie & James injectors are interchangeable and feature shower head and like-doublet impinging injector element types for the oxidizer & fuel respectively. Utilizing Powder Bed Fusion Direct Metal Laser Sintering (DMLS), the injector consists of a single part and only requires post-machining for threaded ports and sealing surfaces. This enables rapid iteration during development and dramatically reduces the cost per unit, once in production. One of the current challenges with DMLS is the tendency for small features, such as channels and orifices, to shrink during the printing process. Due to the number of factors at play, the shrinkage phenomenon is not trivial to quantify. Diameter reductions of up to 40% have been observed in horizontal orifices with part feature diameters on the order of 0.02". This shrinkage tends to reduce as the diameter is increased and the angle with-respect-to vertical is decreased, becoming insignificant at diameters on the order of 0.08". Since injector stiffness scales with orifice diameter to the fourth power, it is desirable to reduce the uncertainty in orifice shrinkage. This relationship drives the tradeoff between the number of injector elements, which affects the degree of propellant mixing and atomization, and thus injector performance. Lack of shrinkage characterization that results in a diameter reduction of 40% would lead to a deviation from the desired injector stiffness by a factor of 7.7. For this reason, LPL introduces its method to empirically study and quantify the shrinkage experienced using an EOS M 290 DMLS printer for EOS MaragingSteel MS1 Steel & EOS NickelAlloy IN718 metal powders during the development of the Jessie & James injector. In addition, the Jessie & James injector incorporates a design feature that is aimed to increase operation time and reusability. This is done by printing in 10 injection elements positioned perpendicularly around the injector face circumference to direct fuel and thermally protect itself. The development of this film cooling technique looks promising thus far and the results of this additional study will be discussed at length.