Editorial Corner

Opening Access to Space by Maximizing Utilization of 3D Printing in Launch Vehicle Design and Production

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The Aerospace industry is known for developing and adopting cutting edge technology to address the challenges involved in designing lightweight, high performance vehicles. While it is clear that design-based technologies helped to advance aerospace vehicle designs in their speed and payload carrying capacity, in many cases it was the manufacturing advances that enabled these evolving designs to be produced. Economic forces in the New Space industry are causing companies to think not only about the future of engineered products, but also ways to optimize the manufacturing process itself to consist of more broadly capable machines with less fixed tooling that can evolve with the production needs of tomorrow.

Beginning with its inception in 1981, additive manufacturing, commonly known as 3D printing, offered new possibilities when compared to traditional 'subtractive manufacturing', by enabling on-demand fabrication, unlocking new design capabilities, and permitting iteration at unparalleled speeds. While early 3D printer design was limited in its control of printing motion, printable material properties, and machine reliability, each year brings new breakthroughs in printing technology as companies remove boundaries by expanding the number and type of printable materials, and increasing fidelity of printed features, print envelope volume, and printing speed.

Thanks to decreases in price and improvements in ease of use, 3D printing has become more widespread as more organizations have access to the technology. In university environments, 3D printing affords students with cost effective and short lead time prototyping capabilities with broadened freedom in engineered designs. For example, many students become experienced in designing for near net shape elements and with more than one type of material now that this manufacturing capability is practically possible with low cost and duration projects.

As of 2015, Willamson [1] described the first utilization of 3D printing in space applications and referred to larger volume parts such as satellite fuel tanks, hoping that "perhaps printed rocket engines are closer than we think." A notable achievement around that same time was SpaceX's demonstration of 3D-printed SuperDraco engine chambers for their Crew Dragon escape system passing a firing test at full thrust in late 2013 [2]. As the methods of printing and number of printable materials expanded, the number of applications for this technology in the space industry grew as summarized by Sacco and Moon [3], where four years later metal additive manufacturing was widely recognized for use in propulsion systems in spacecraft and launch vehicles. With a wide variety of choices, designers may choose from a variety of metal additive manufacturing technologies, each with unique advantages and disadvantages. A comprehensive review of the technologies is recently provided by Cooke *et al.* [4]

Using Relativity Space's 3D printed launch vehicle (Figure 1) as an example full adoption of the 3D printing technology, the use of both large format wire arc additive manufacturing for primary structures and

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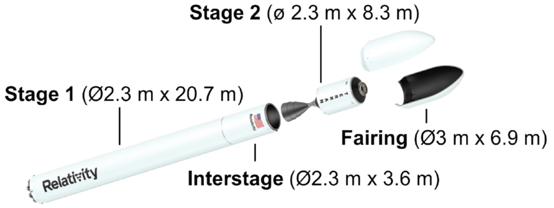

Figure 1: Relativity's Terran 1 launch vehicle design leverages 3D printing for all primary structures and nearly all propulsion components.

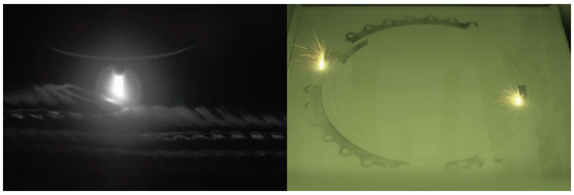

Figure 2: Deposition views of metal 3D prints: Stargate (left), Direct-to-metal Laser Sintering (DMLS) (right).

high fidelity direct-to-metal laser sintering (DMLS) printing of rocket engines takes the approach to an extreme where 90+% of the 9500 kg rocket dry mass is 3D printed (Figure 2). The novel architecture of Relativity's Stargate printers (Figure 3), combined with their custom aluminum wire chemistry and feed system allow for flight prints as large as 3.4 m diameter by 7.6 m height for a single print, making it currently the world's largest metal 3D printing system. Terran 1's payload fairing is printed as one monolithic structure and is expected to be one of the volumetrically largest prints in the world at 6.75 m tall by 3 m diameter at the time of production in early 2021. Similarly, their Aeon engines, which consist of gas generator, oxygen and methane turbopumps, and thrust chamber assembly (Figure 4) are almost entirely printed using DMLS powder bed printers (except for seals and other non-metallic components in the assembly) where 10 individual engines are included on each flight. Together, these large format and high temperature capable prints make up the Terran 1 launch vehicle, which stands over 35 m tall with 2.3 m diameter and is capable of delivering up to 1250 kg to Lower Earth Orbits [5]. Once in full production, simultaneous prints and streamlined integration due to simplified part count will be able to turn raw material into a flight ready vehicle in less than two months, significantly faster than the 1+ year long lead times typical for launch vehicles.

Figure 3: Relativity's Large Format Metal Stargate 3D Printing System producing a Terran 1 first stage tank section.

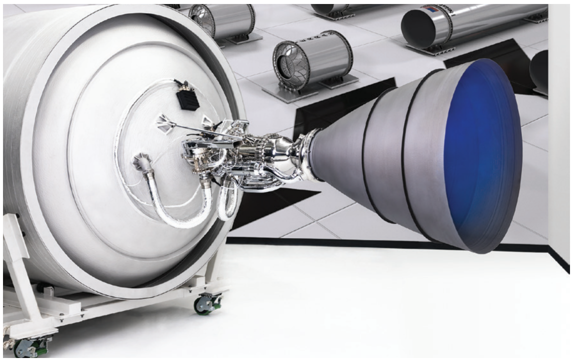

Figure 4: Terran 1's Aeon DMLS-printed engine assembly attached to the Stargate-printed aluminum Terran 1 second stage tank.

To streamline production operations, each Stargate printer includes realtime in situ monitoring, inspection, and post-processing capabilities, which are coupled with the print head and act per deposited layer rather than post-print. Identifying flaws in situ avoids the costs of scrapping entire prints, and reduces the number of potential repairs. Visual, aural, and thermal sensors enable closed-loop control and in-process inspection to mitigate flaw formation. Computer vision and machine learning bring state-of-the-art control techniques to a highly nonlinear, highly coupled process. Relativity, along with other members of the space industry contingent, are leveraging lessons learned from 3D printing development to standards for new applications through participation in ASTM International's F42 Committee on Additive Manufacturing's sub-committee "Spaceflight" [6].

By vertically integrating on its 3D printing technology, Relativity transitions much of the complexity of hardware manufacturing into software controlled realms that can be scaled more efficiently than manual operations. Benefiting from being able to print structural features integrally, Relativity's 3D printed launch vehicle assembly consists of roughly 100 times fewer parts than a traditional launch vehicle, meaning a significant reduction in supply chain complexity, assembly time and labor involved once the print is finished. Relying on a small number of broadly capable machines allows for smaller capital investment, smaller manufacturing facility footprint, and implementation of a wider variety of designs than would be possible using fixed tooling for traditional manufacturing.

Historically, access to space has been constrained by the availability of launch and the high cost associated with launch services. SpaceX changed the paradigm by developing a more efficient organization, launch vehicle design, and operationally reusable concept which brought the cost of launch down by a factor of 20 in comparison to historical offerings [7]. As the launch provider supply base proliferates, there are more launch options but prices of capacity are not getting cheaper unless providers implement new technology or further segment their offerings to smaller increments of total capacity. By optimizing launch vehicle design and production around 3D printing, the flexibility of the vehicle design, lead time, and cost of launch can be optimized to offer not just a lower cost per kilogram, but also solve for a wide variety of satellite program needs whether that be rapid response, custom payload adapters, or mission-unique fairing designs. Unlike traditional manufacturing where much of the investment surrounding a particular design is in the tooling required to create that design, a single 3D printer with the right capabilities can manufacture a wide variety of product designs, thereby becoming a critical part of the chain in evolvable design and production.

In order to unlock further adoption and widespread use, continued 3D printing research is critical for expanding the number and type of printable materials, diversifying the capability of printed material properties, increasing print volumes, and enhancing print precision. With each improvement, 3D printing becomes a more robust design and production tool for engineers to consider across all applications on this planet and beyond.

References

[1] M. Williamson, "Building a rocket? Press 'P' for print... [3D printing space exploration 3D]," *Engineering & Technology*, vol. 10, no. 2, pp. 40–43, 2015.

[2] E. Howell, "SpaceX taking 3D printing to the final frontier," 2014. [Online]. Available: https://www.space.com/26899-spacex-3d-printing-rocket-engines.html

[3] E. Sacco and S. K. Moon, "Additive manufacturing for space: Status and promises," *The International Journal of Advanced Manufacturing Technology*, vol. 105, pp. 4123–4146, 2019.

[4] S. Cooke, K. Ahmadi, S. Willerth, and R. Herring, "Metal additive manufacturing: Technology, metallurgy and modelling," *Journal of Manufacturing Processes*, vol. 57, pp. 978–1003, 2020.

[5] Relativity Space, "Terran 1 Technical Specifications," 2020. [Online]. Available: https://www.relativityspace.com/terran

[6] ASTM International, "Subcommittee F42.07.02 on Spaceflight," 2020. [Online]. Available: https://www.astm.org/COMMIT/SUBCOMMIT/F420702.htm

[7] H. W. Jones, "The recent large reduction in space launch cost," in *Proceedings of International Conference on Environmental Systems*, 2018, pp. 1–10.

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