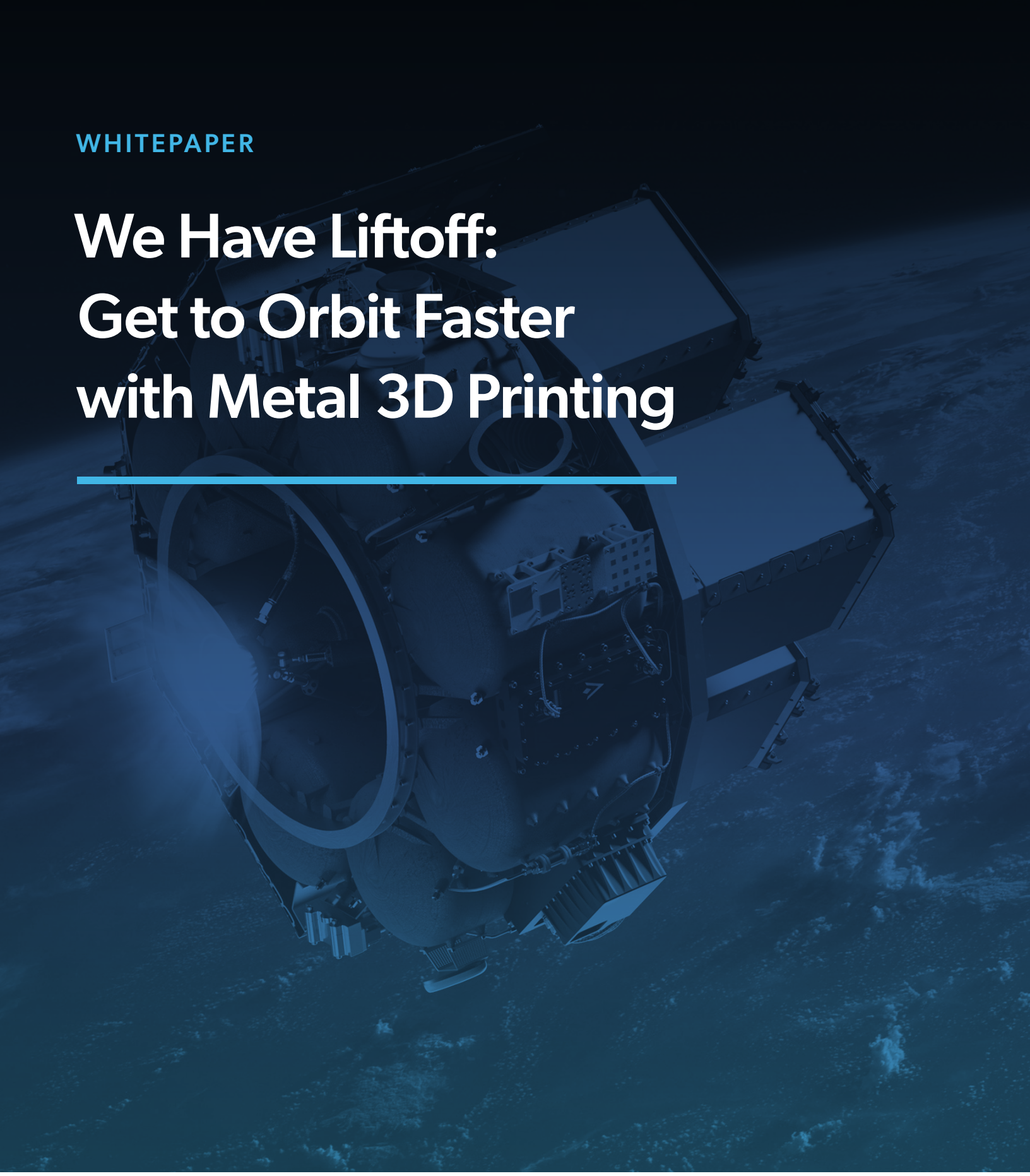
WHITEPAPER

We Have Liftoff: Get to Orbit Faster with Metal 3D Printing



VELO 3D

Velo3D.com

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Introduction

In the last five years, humanity has launched more objects into orbit than in the past three decades combined[1]. The increase in activity is the result of a booming space economy that has drawn massive interest from startups and innovation-driven organizations, resulting in a convergence of investment and ambition that is propelling the space industry to new heights.

What has traditionally been an almost insurmountable barrier to entry—and the sole province of governments, aerospace, and defense contractors—is now primarily being served by a small but growing cadre of companies building off the technical foundations of the original space industry, so much so that analysts believe the space industry could generate revenue of $1 trillion or more by 2040[2].

What is fueling this race to space? There are many factors: private investment and enterprise, modern software computing power, but perhaps the biggest driver to actually making these innovations lies in the unprecedented availability of modern metal additive manufacturing (AM) technology.

In this whitepaper, we explore the ways in which advanced metal AM technology enables innovation across the space sector. From improved part design to faster time-to-market, we share how Velo3D is helping today's most innovative and influential space companies:

- Reach orbit quickly
- Increase their return on investment
- Produce the parts they need in days
- Get to space in months instead of years

Velo3D offers large format printers and the right qualified materials for your missions to space.

[1]https://ourworldindata.org/grapher/yearly-number-of-objects-launched-into-outer-space?time=1987..2017&country=OWID_WRL~USA~RUS~CHN~GBR~JPN~FRA~IND~DEU~European+Space+Agency
[2]https://www.morganstanley.com/ideas/investing-in-space

Part I: Reduced time to market

The commercial space sector is at a critical point in its evolution. In the past three years the NewSpace industry has doubled, raising nearly $42 billion across more than 450 companies. This influx in funding has brought with it an influx in competition, with both entrepreneurs and innovators vying for investment capital and success.

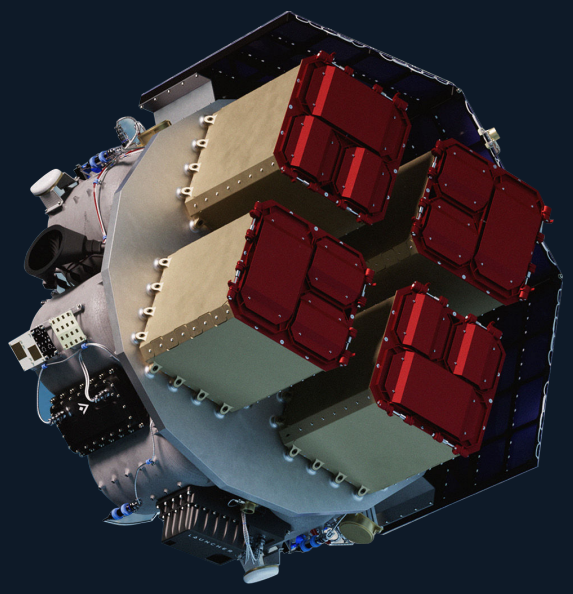
Today, metal AM solutions are helping space companies rapidly iterate and reduce production schedules. Velo3D's 3D printing solutions enable companies to rapidly design and produce metal components in just a few weeks, rather than months or even years. By using Velo3D technology, companies are seeing enhanced efficiency, with the ability to design, test, and manufacture with unprecedented speed.

Launcher Orbiter

Building off existing Ukrainian rocket IP, Launcher Space, which was acquired by Vast in February 2023, set out to design the highest performance engine in the small satellite launcher class with the largest thrust, lowest propellant consumption, and lowest cost-per-pound of thrust.

To reduce lead times for the turbopump and other critical components, Launcher opted to leverage the Velo3D fully integrated metal AM solution instead of conventional forms of manufacturing.

The company's original plan was to start in 2017 and reach revenue by 2027. But with the flexibility provided by the Velo3D platform, they were able to reach revenue faster than originally projected. The first Launcher flew on the Transporter-6 rideshare mission in January 2023 – five years after the company was founded.



The competition seen in today's burgeoning commercial space industry is such that it's simply not enough to dream; organizations must be able to design, test, and iterate on their designs and outpace the competition. 20 years ago, the barriers to entry to the space industry were insurmountable without astronomical amounts of capital. As technological advances in telecommunications, software, data analytics, and more have lowered those barriers, more entrepreneurs with a vision have entered this competitive field. One of the ways advanced metal AM helped tear down those barriers and galvanize investment is by reducing the capital requirements to get started.

While many conventional additive manufacturing systems require the purchase of a system, installation, and expensive upkeep to utilize their technology, Velo3D provides customer with a more flexible approach to adoption. Customers can purchase a system and produce parts in house, or they can utilize Velo3D's network of contract manufactures. This dual approach means customers can ramp in-house production when ready or lean on a growing network of metal AM specialists to provide additional scale as needed.

The path to consistent parts production

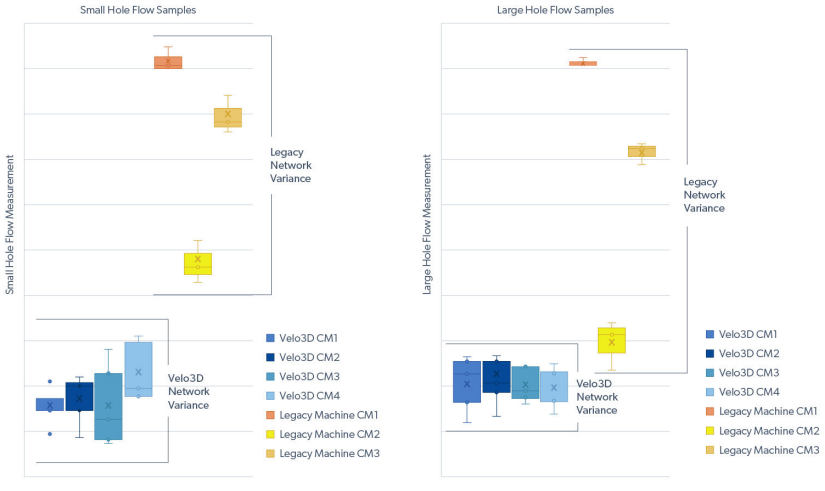
The path to consistency starts with Velo3D's fully integrated metal AM solution. This consists of the Sapphire family of printers, Flow pre-print software, and Assure software, which provides layer-by-layer quality control.

Flow's seamless integration with Sapphire printers results in pre-validated build instructions. These conformal instructions, combined with Sapphire's automated calibration routines, mean that exported "Golden" print files (*.veloPrint) can be used to manufacture parts with consistent geometric accuracy, surface finish, and material properties from any Sapphire printer worldwide. Leverage a digital inventory where qualified parts have a persistent, unmodifiable, secure, digital print file that can be transmitted to a Velo3D-enabled global print facility and recreated to match original specifications.

Building a scalable solution

When it comes to being successful in the commercial space industry – speed matters but so does the ability to scale. In the highly competitive space field, companies are focused on velocity; metal AM can support those efforts by bringing design concepts to full production far faster than traditional manufacturing processes.

Site to Site Variability of Printed Holes



Velo3D site to site variability

Legacy AM site to site variability

The above data is from a high-performance space launch and hypersonics propulsion provider. The organization's combustion geometry is highly sensitive to dimensional and surface finish variation, which in turn affects part and system performance. Current supply chain (single laser) AM machines produce inconsistent results outside of acceptable limits. This caused the organization to trial the Velo3D fully integrated metal AM solution and its "Golden" Print File capability to successfully produce consistent results within a single machine across multiple machine S/N vendors. As a result of its successful trials, the customer is moving its entire AM supply chain to Velo3D technology for scalability, consistency, and security.

Again, this is where Velo3D's fully integrated solution can be revolutionary for upstart space companies. The integration of design software, printing hardware, and quality assurance software means that once a part has been successfully designed and sliced within Velo3D's integrated Flow print preparation software, engineers are left with what is known as a "Golden" Print file.

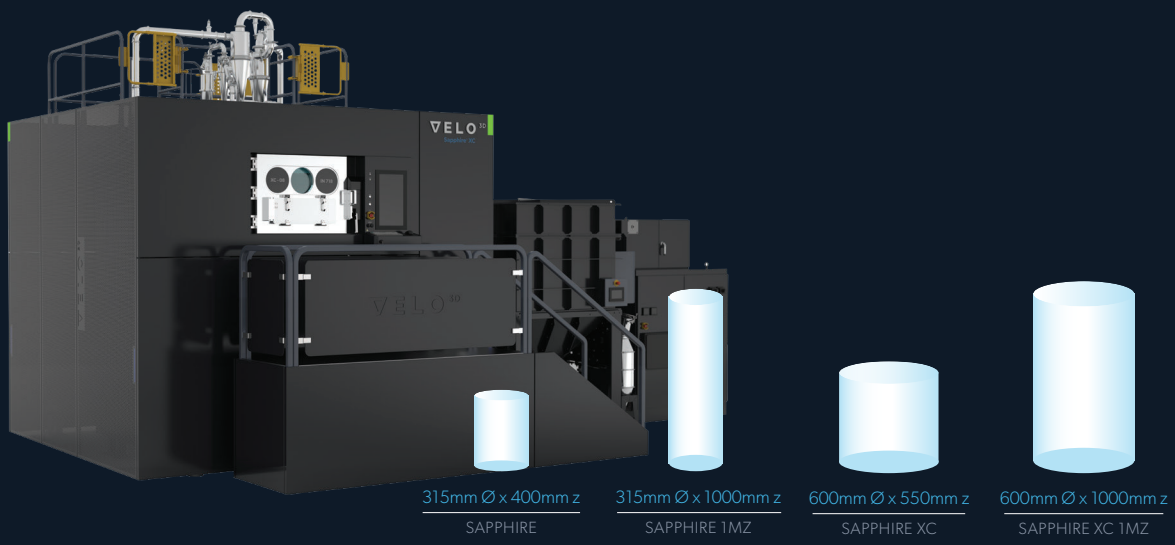
The "Golden" Print file is important because it's what entails the proprietary print settings that can be used to repeatedly print a part, as needed, on any Velo3D Sapphire printer, anywhere in the world.

What this means is that if a company is relying on a network of CMs, or if they're choosing to handle production in-house, if they're printing on a Velo machine, they can expect the same geometric accuracy and material properties on every subsequent print. This consistent repeatability means that replacement parts can be produced on-demand, or that large runs of parts can be scaled with an unprecedented level of agility.

This transition to large-scale production is further aided at Velo3D through an expansive and ever-growing network of global contract manufacturers in addition to the introduction of high-volume Sapphire printers capable of producing multiple parts on larger build plates or smaller runs of larger parts.

A Spotlight on the Sapphire XC 1MZ

Many conventional metal AM systems struggle with volume, and as a result have typically been relegated to the role of prototyping. With a cylindrical 600 mm diameter x 1000 mm z-height build volume, the Sapphire XC 1MZ is the largest printer available from a leading laser powder bed fusion (LPBF) supplier on the market today, and truly brings metal AM into its next evolution. With a capacity for building larger parts and larger runs of parts, the Sapphire XC 1MZ offers a powerful, scalable path to manufacturing.



Part II: Improved geometric freedom for maximum performance

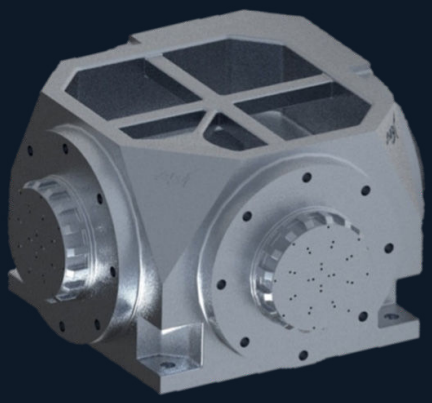
One of the major stumbling blocks with conventional metal AM systems has been the need to redesign parts in ways that reduce their performance. These changes force engineers to compromise on the functionality they require for optimal performance in service of manufacturability.

Particularly in space where parts require high levels of geometric complexity – regenerative cooled thrust chambers with intricate internal channels and rocket injectors with complex internal structures, for example – these redesigns, specifically around channel geometry and thin walls, cause inefficiencies and lower final performance. However, not all systems face the same limitations.

Aerojet Rocketdyne

Aerojet Rocketdyne and advanced modeling company nTopology collaborated to create lighter, smaller RCS systems using advanced metal additive manufacturing. Traditional manufacturing methods, such as casting, brazing, and welding, could not achieve the required complexity of the internal channels. Conventional metal additive manufacturing systems also struggled with the part's delicate lattice features, which are used to increase stiffness.

Aerojet Rocketdyne was able to have the part printed with minimal supports and without tilting the part relative to the build plate—a common technique used in traditional additive manufacturing processes—by using Velo3D metal AM technology. This resulted in a print that accurately produced the fully optimized new design and eliminated significant amounts of post-processing.



Titanium RCS injector block printed on a Velo3D Sapphire metal AM printer.

In addition, Velo3D successfully printed the part using Titanium 6Al-4V, a notoriously hard and brittle material, with its advanced processing steps capable of minimizing thermal stresses. The resulting RCS thruster is one-fifth the mass and one-half the size of the incumbent part while retaining all the original functionality. The new part also boasts a cost one-third of the conventionally manufactured version. The final part contains far fewer components, which makes it easier to assemble and is expected to have a lower risk of failure in operation.

The advanced metal AM system pioneered by Velo3D enables engineers to focus on what they do best and not waste time with parameter development. The integration of Flow pre-print software and Sapphire printers means that any design, no matter how complex, can be executed without compromise. This level of design freedom encourages engineers to build the parts they require without having to scale back their original design to support manufacturability.

Today's most effective additive manufacturing solutions allow engineers to realize their designs without compromising their original design intent. Manufacturing high-pressure tanks, turbines, and heat exchangers—and others part that feature intricate geometries and internal channels— is now possible.

Velo3D's fully integrated metal AM solution caters to design freedom and part performance. The solution utilizes an extended range of controlled parameter sets that provide specific instructions for skin and contour printing for many advanced features found in the most aggressive designs. For example, conventional metal AM rules require the addition of supports for overhangs less than 45 degrees to the build plate. This results in numerous problematic supports that may be difficult or impossible to remove without compromising the performance of the part.

Rather than a parameter set that is blind to the specific geometric features of a part, Velo3D software intelligently applies the optimal process, such as parts with internal supports, thin walls that may interfere with recoating, or thick sections that may deform due to the accumulation of stress.

Part III: Investing in materials that drive innovation

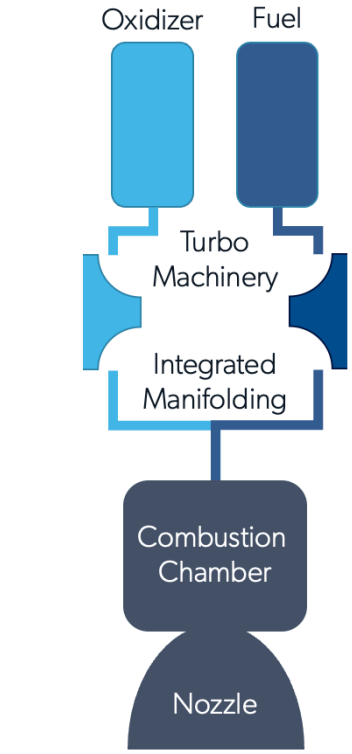
The most ambitious space projects are only as good as the materials utilized to fuel those ambitions. Even the most complex, optimized designs can only take a project so far; the levels of heat and pressure that come with space flight present some of the most challenging conditions for any engineer.

At Velo3D, our work in material development is not only transforming how individual companies leverage our metal AM solution, but is working to build broader industry-wide acceptability for AM technology.

Materials to support space exploration

From liftoff to beyond the reaches of our atmosphere, space flight demands a wide array of materials that demonstrate a range of properties. Velo3D has been investing in material development crucial to the space sector for years, and now boasts a roster that addresses many of the requirements of the industry. These materials include:

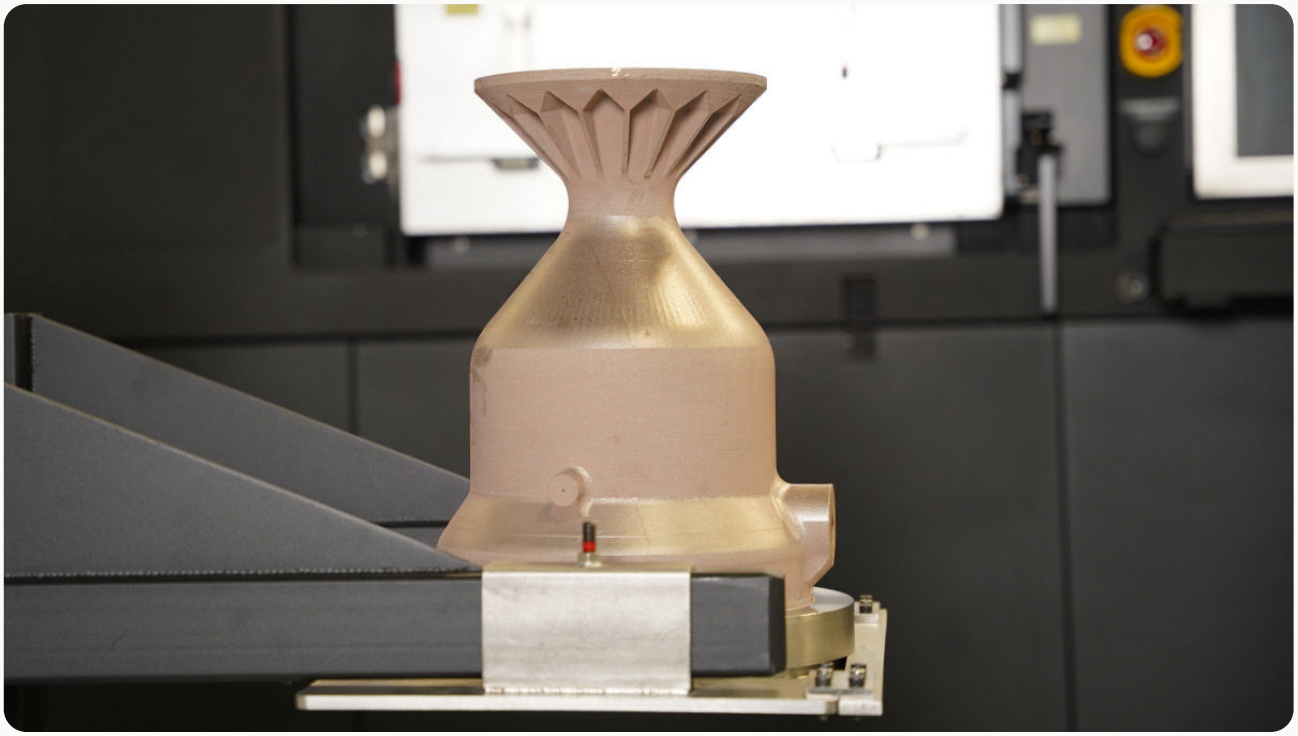
- Copper GRCop-42
- Copper C18150
- Inconel® 718
- Inconel® 625
- Haynes® 214® (UNS N07214)
- forAM® Haynes® 282®
- Titanium Ti-6Al-4V
- Aluminum F357
- Aluminum Aheadd® CP1
- Custom Alloys



Simplified rocket schematic showing the major sections of a rocket engine.

Additionally, Velo3D is constantly introducing more materials at the request of our space partners. The Velo3D team is available to work with you and your organization to qualify additional materials as needed.

Every material that your rocket engine needs, all available on a 600 ø mm x 1,000 ø mm z-height platform.



Regeneratively-cooled rocket thruster printed in GRCop-42. The thruster is a development unit that will demonstrate the first ever flight of large liquid modular aerospike rocket engine and gather crucial operational and performance data in a relevant sub-orbital trajectory. The part--which went through DfAM but was unable to print on a conventional metal AM system-- was printed on its first attempt using a Velo3D Sapphire.

NASA Guided Material Characterization Program

As we've discussed, one of the major challenges with conventional metal AM systems is a lack of repeatability. With inconsistent calibrations from machine to machine, it's never certain that the same part will print from machine to machine. This inconsistency isn't just tied to consistent part geometry but extends to material properties, too.

The result of this inconsistency has meant that standards for material properties can be difficult to codify. In an industry like space—and particularly manned space flight—that requires intense oversight and regulation, this lack of accepted standards has impeded metal AM's ability to gain a foothold.

The integrated AM solution offered by Velo3D is important on multiple levels; for individual companies, the integration of pre-print, printing hardware and quality assurance software means scalability and consistency, but for the industry at large it means a repeatable baseline of material standards that can be used to validate parts for regulatory purposes.

The integration of Assure quality assurance software provides in-situ, layer-by-layer validation data on every part in every print.

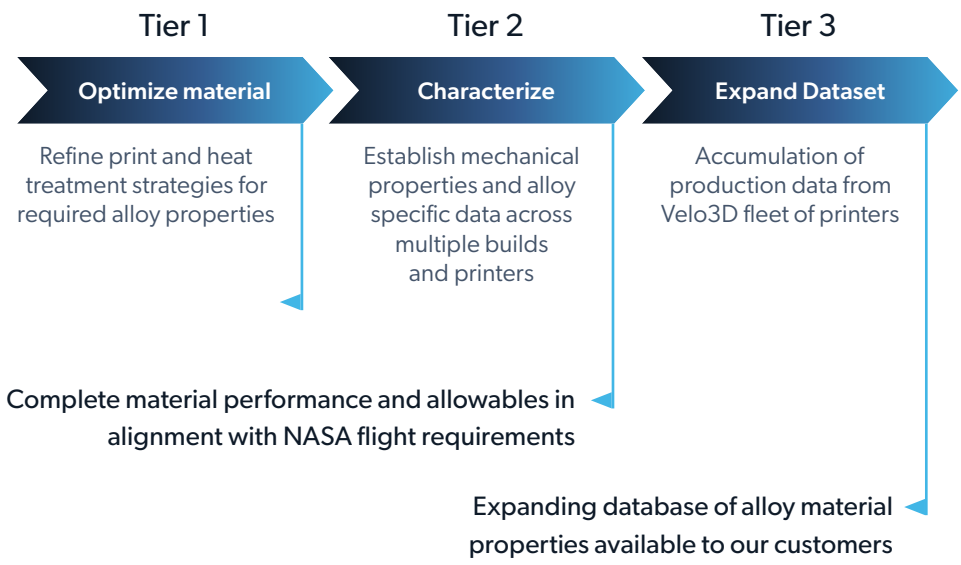
Consistent manufacturing results in repeatable material properties. With Velo3D's fleet-level controlled parameters and system calibrations, we have started collecting significant amounts of material property data. This has enabled us to start a **NASA-guided program for materials characterization.**

While this groundwork is tailored to manned space flight, many industries look to this program as the standard to ensure that their parts perform as designed.

By working to set qualification standards for space-ready materials, Velo3D is not only offering our partners the most reliable metal AM solution, we're laying the groundwork for wider acceptability of metal AM in not only manned space flight, but aerospace and aviation as well.

Material characterization is an exhaustive process, and demands an AM system capable of not only repeatability across two machines at a single site, but an entire fleet of printers, all with consistent calibration. Within that system, material characterization takes a three-step process:

Material Characterization Path



Summary: The technology to meet the moment

In an era of rapidly advancing space innovation, leaders in the industry require a manufacturing solution capable of rising to those ambitions. The brand of advanced metal AM on display in Velo3D's integrated solution provides the design freedom for engineers to achieve the parts they need without compromise, the consistency and repeatability required to scale production, and the data-backed validation capable of building wider acceptance of metal additive manufacturing.

Get in touch with the expert engineering team at Velo3D today to see how advanced metal additive manufacturing can transform your operations.

Without Compromise

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