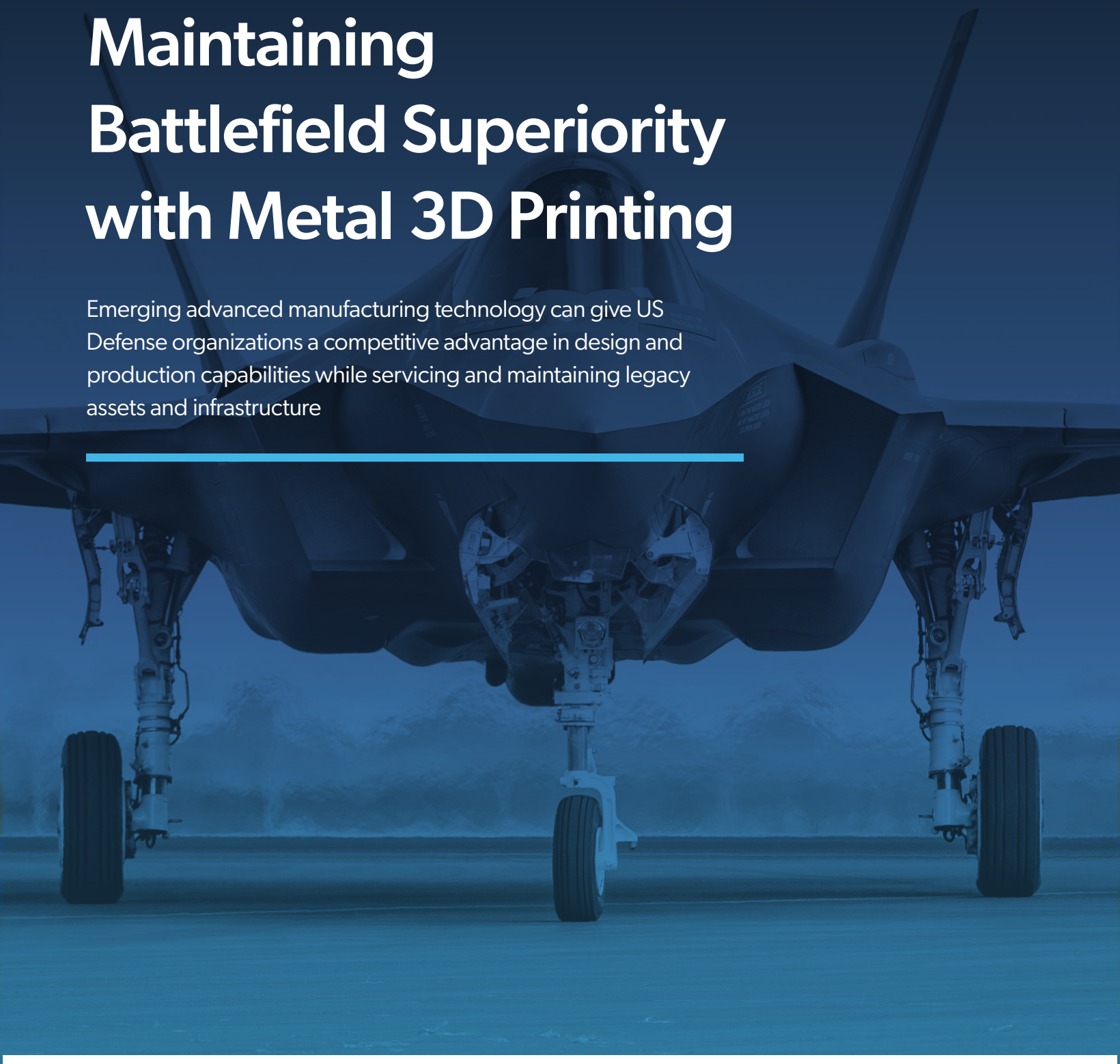
WHITEPAPER

Maintaining Battlefield Superiority with Metal 3D Printing

Emerging advanced manufacturing technology can give US Defense organizations a competitive advantage in design and production capabilities while servicing and maintaining legacy assets and infrastructure



VELO 3D

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Ensuring Warfighter Readiness With Advanced Metal AM

The US military has long been at the forefront of innovation. What has made our military so formidable is our commitment to and investment in technological advancement. What's more, innovations within our military have filtered out and impacted advancement in other fields from aviation to consumer electronics, which has helped build our economy to what it is today.

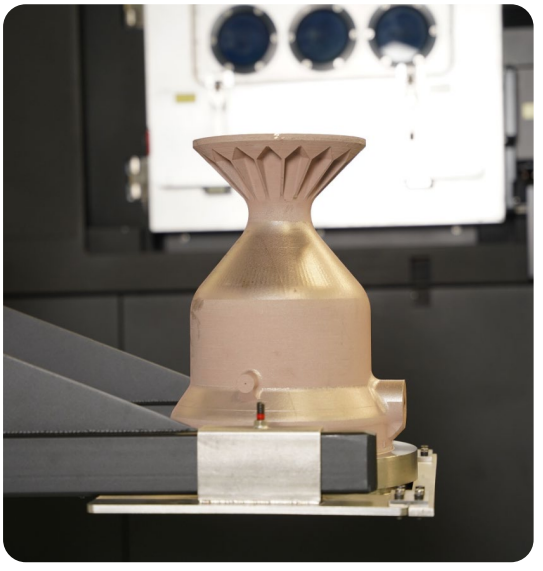
For defense organizations, each decade brings new unprecedented challenges. How the US responds to these challenges will be critical, and serves as a potent reminder of the need to accelerate our pace of innovation to maintain superiority, particularly in the field of hypersonics[1].

The defense sector needs to leverage every tool at their disposal to encourage military innovation, and metal additive manufacturing (AM) presents a unique opportunity to innovate in three key areas:

Increasing battlefield superiority: Metal AM provides advanced capabilities in designing and executing on the production of complex hypersonic components and can improve fuel burn, emissions, part lifecycles, and better material properties than casting.

Improved scalability and deployability: Create distributed supply chains based in the US (and abroad) that reduce the reliance on foreign manufacturing and without the need for specialist knowledge to operate.

Maintaining existing equipment: Advanced metal AM is not only a driver of innovation in net-new technologies, but a vital tool for the agile manufacturing of replacement, legacy parts; a necessary initiative as the tools and platforms our military currently relies on in the field look to be in service for the foreseeable future.



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.

[1] https://www.politico.com/news/2021/11/20/hypersonic-technology-us-behind-china-russia-523130

In this whitepaper we'll discuss how DoD organizations can leverage advanced metal AM to increase pace of innovation for warfighter technology and bolster legacy infrastructure with a distributed manufacturing supply chain.

As the geopolitical landscape becomes increasingly competitive, US defense needs to invest in the emerging technologies that will serve to maintain its leadership position against its adversaries.

As the defense sector looks to the future of warfighter readiness, advanced metal additive manufacturing can provide a crucial, secure platform for innovation in part design, performance, and durability that can preserve battlefield superiority.

How Metal AM Improves Part Performance

Within the advanced metal AM process, engineering teams are able to discover new avenues for efficiency and performance in key components of engine systems. Through advanced metal AM, hypersonic components can be consolidated and lightweighted, reducing overall unit weight and providing better speed without compromising performance. In arenas critical to the defense sector like unmanned aerospace, ballistics, and hypersonics, these lightweighting initiatives are all-important in keeping pace with competing military innovation.

Improved performance also means improved fuel burn and cost efficiency, further bolstering the business case for advanced metal AM-produced parts.

Microturbines, key components in unmanned aircraft used in defense applications, present a unique challenge for engineers: the units feature dozens of component parts that need to be expertly fabricated in complex internal structures, often requiring a combination of casting, five-axis machining, brazing and welding to produce a completed part. This process necessitates extensive lead times and presents a number of logistical hurdles.

One of the major benefits of metal 3D printing is the ability to consolidate parts; a benefit California-based Sierra Turbines, Inc. found out firsthand. By engaging with Velo3D early in the design process, the team at Sierra was able to reimagine the production of their Mk1 microturbine. Through Velo3D's intuitive Flow pre-print software, the team was able to consolidate 61 discrete parts into a single unicore design without sacrificing quality or performance. The new-and-improved Mk1 saw 10x power density compared to incumbent parts, 40x more efficiency, and a performance of nearly 20x time between overhauls (TBO).

USING METAL AM TO IMPROVE CRITICAL PARTS

Metal 3D printing can have a transformative impact on a number of core parts. Some tried-and-true applications for metal AM have been:

Microturbines
Improved performance
Reduces weight
Consolidated assembly

Heat Exchangers
Thinner walls for improved heat transfer
Better surface finish for reduced pressure drop

Turbopumps
Reduced pressure drop
Lower print angles
No redesign for replacement parts

Part design innovation leveraging metal AM

One of the major advantages presented by advanced metal AM is the ability to produce parts beyond the scope of traditional forms of manufacturing such as welding or CNC machining, or legacy metal AM systems.

Through the integration of pre-print design software, the most advanced metal 3D printers in the industry, and in-situ quality assurance, engineers are able to design the critical parts they need, without making compromises to support the AM process (DfAM). By integrating all three of these components on one system, engineering teams can be confident that the parts they require will be printed as designed, and that the process will be repeatable.

Advanced metal AM unlocks the ability to produce parts with thin walls, complex internal channels, lattice structures and more, which can be transformational for key components in hypersonic systems including heat exchangers, microturbines, turbopumps and more.

The Ramjet engine was printed on a 1-meter-tall Sapphire XC 1MZ. It is pictured right next to it's counterpart, printed on a standard Sapphire printer. This display piece was made possible with funding through LIFT, the Detroit-based national manufacturing innovation institute, in partnership with the Department of Defense. This piece by Velo3D was developed in partnership with Lockheed Martin to demonstrate the industrial maturity of emerging in-situ process monitoring capability in the latest generation of laser powder-bed fusion additive manufacturing systems.

Emerging leaders in the field of hypersonic flight are turning to advanced metal AM to design, produce, and rapidly iterate on mission-critical components. Hermeus, an Atlanta-based company developing reusable hypersonic aircraft for defense and commercial applications, has invested in the Sapphire technology to dramatically reduce lead times on the production of core components for their Chimera engine.

According to Hermeus CTO Glenn Case, by leveraging metal AM, Hermeus strives to "increase performance, consolidate components, reduce weight of our aircraft, and minimize external dependencies'' in their first aircraft, Quarterhorse, an autonomous aircraft designed to reach Mach 4. With a proven concept, Hermeus intends to expand their hypersonic efforts to Darkhorse, a hypersonic UAS (uncrewed aerial system) designed for defense and intelligence customers, with the ultimate goal of delivering a manned commercial hypersonic aircraft, dubbed Halcyon, by 2029.

Advanced metal AM is also pioneering new, stronger alloys that continue to push the bounds of industry standards. In looking to future generations of military technology, defense organizations will need to deploy modern, validated materials that live up to the design and performance standards required of hypersonics and beyond.

By integrating quality assurance software into the printing process, Velo3D's advanced metal AM system creates layer-by-layer data that has been instrumental in the validation and industry-wide acceptance of next-generation alloys.

Some of the pioneering, aerospace-grade materials leveraged in advanced metal AM include

- Aluminum F357
- forAM® Haynes® 282®
- Copper GRCop-42
- Hastelloy® X
- Inconel® 625
- Inconel® 718
- M300 Tool Steel
- Scalmalloy
- Titanium 6Al-4V
- With many more being validated each year

Cut-in-half image of fuel-preheating ramjet used to power small vehicles in supersonic and hypersonic flight regimes.

Achieving Supply Chain Agility

Because operational needs can shift and escalate at a moments notice, advanced metal AM solutions provide unprecedented flexibility to take appropriate action by:

Creating a scalable manufacturing supply chain for US production and production at global military bases that achieves the same geometric accuracy and material properties as witnessed in US based development centers.

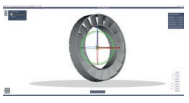
Leverage a digital inventory where qualified parts have a persistent, unmodifiable, secure, digital print file that can be transmitted to a Velo3D enabled global print facility and recreated matching original specifications.

Through the integration of software and printing hardware with automated, fleet-level calibration, defense organizations can be confident in the repeatable production of key components in near-theater operations.

Where advanced metal AM systems—like the one pioneered by Velo3D—diverge from traditional AM technologies is repeatability. Velo3D metal AM provides a true path to part consistency through automated calibration, tightly controlled parameters, and in-situ quality assurance software, engineers can have the confidence in knowing the parts they print will uphold the same standard of quality time and again.

Path to Consistency

01



Consistent instructions through controlled parameter sets

- Extended range of **controlled parameter** sets that specify instructions for skin and contour printing for many advanced features found in the most aggressive part designs.
- Provide **user-selectable core recipes** as well as **skin/contour overrides** that give users the control they need to produce parts but also create consistent material conformal to a growing, established allowables dataset.

02

Consistent ready state of the printer

- **System calibrations:** Automated, in-situ, calibrations that can be run directly by the user from the system GUI with no added equipment in a runtime environment.
- **Service records:** Calibration results displayed real time and tracked over the lifetime of the system for future reference.

03

Consistent execution during the print

- **Layer-by-layer:** Layer-by-layer validation of lasers, atmosphere, and powder bed helps to create the highest quality parts in the AM industry.
- **Accurate lasers:** Each layer, verify and adjust (if necessary) any multi-laser calibration to ensure accurate performance.
- **Effective gas flow:** Throughout the print, the monitor O^2 and humidity.
- **Planar powder bed:** Leverage a 3D topography camera (structured light scanner) to validate the powder bed health and planarity of the powder bed prior to and after the lasing of each layer.
- **Protrusion checks:** Check for parts that may be protruding from the powder bed due to excessive stress or other issues

Supporting Legacy Infrastructure

Building a distributed supply chain to support legacy military infrastructure

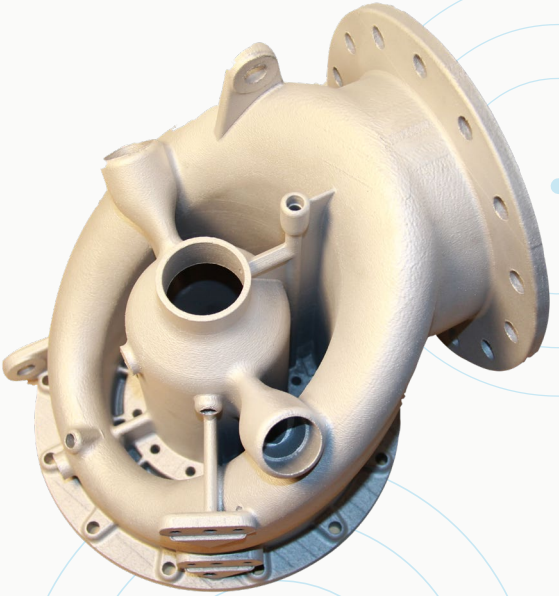
Looking to the future and keeping pace with competing world powers is obviously a key driver for our defense sector, but that doesn't solve the immediate concerns of servicing legacy assets and infrastructure that may not be updated in the foreseeable future.

Advanced metal AM supports the most difficult maintenance and sustainment challenges by providing a reliable source of parts to extend the life of existing assets and respond to shifting maintenance and sustainment challenges with speed and precision.

With advanced metal AM solutions like the one pioneered by Velo3D, US defense organizations can print parts without the need to redesign for AM including parts with thin walls, round holes, and other complex internal geometries.

Establishing advanced metal AM manufacturing helps maintain battlefield advantage by creating an on-demand replacement part manufacturing system that limits reliance on foreign parts production and requires less specialized labor to operate.

This distributed supply chain also works to extend the lifecycle of mission-critical components whether they were initially designed for metal AM or traditional manufacturing technologies.



High strength aluminum manifold integrates multiple internal channels into one single part.

What repeatability means for defense organizations is a scalable solution. Leveraging advanced metal AM, low-rate initial production volumes can be scaled out to full production for deployment in the field, further reducing the reliance on foreign supply chains.

Advanced metal 3D printing has had a wide-ranging impact across the supply chains of a number of industries, seeing particular success with those that operate in remote theaters like military and defense or harsh environments like oil & gas.

IMI Critical, a world leader in flow control solutions, was tapped by a major oil & gas operator to validate the viability of metal AM to reduce lead times on critical components, particularly choke valve cages, to service operations in difficult-to-reach environments. After partnering with Velo3D in the design of their improved choke valve cage, IMI was left with what's known as a "Golden" Print File: a set of universal printing instructions that can be easily produced on any Velo3D Sapphire printer, anywhere in the world.

Flow Control Element (Choke Valve) for major O&G operator field conditions. Meets API20S quality documentation requirements.

Through the "Golden" Print File, IMI was able to work with Velo3D's global network of contract manufacturers, successfully printing the same design in six different locations around the world. The resulting parts were of identical quality and performance, and demonstrated both a drastic reduction in lead time to produce core parts, but also the ability for production to be scaled as needed.

A Secure, US-Based Solution

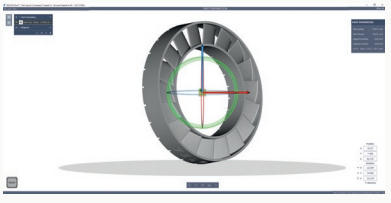
- Velo3D is a US-based solution – both developed and produced in the US – that's compliant with Buy American Act requirements
- Capable of working with export-controlled data and operating in classified environments with data segregation routes to different servers based on need
- Tap into a secure, trusted network of contract manufacturers in the US and abroad
- Trusted by leaders in military and defense

ADDMAN ENGINEERING
AEROJET ROCKETDYNE
HARTECH GROUP
BETTER TECHNOLOGY A BETTER EXPERIENCE
HERMEUS
Honeywell
KNUST-GODWIN
LOCKHEED MARTIN
PRATT & WHITNEY DEPENDABLE ENGINES
GO BEYOND

Unlocking the Potential of Advanced Metal AM

In these challenging times, it's never been more important for our defense sector to explore the innovative manufacturing solutions that will define the decades to come. Velo3D is at the forefront of that innovation, pioneering an integrated advanced metal AM system that combines pre-print design, some of the most advanced printing hardware in the world, and in-situ quality assurance, all unified on one intelligent system. The Velo3D solution is built for repeatability and scalability without compromising design complexity or function.

The Velo3D Fully Integrated Metal AM Solution for Global Readiness



Flow
Print Preparation Software

Sapphire
Metal AM Family of Printers

Assure
Quality Validation

UNDERLYING INTELLIGENT FUSION MANUFACTURING PROCESS

By leveraging advanced metal AM, defense organizations can spearhead the advancement of critical part design that will drive our military into the future, and create more agile supply chains to reduce the logistical burdens of servicing legacy assets.

The Velo3D Difference

Velo3D is the industry-leader in advanced metal additive manufacturing. Our team of engineers is skilled in addressing the challenges the defense industry faces, and specializes in designing the solutions needed to maintain our military advantage around the globe. Here's what our consultation process looks like:

Design Consultation

If you are working in propulsion, heat exchange, energy generation, or any application where flow of a fluid or transfer of heat is critical to system performance, we would like to talk with you about the application.

CONCEPT REVIEW

- Designated team
- Define schedule
- Technical review
- Short list initial parts
- Define success metrics
- Start Impact document

EVALUATION

- Print modeling
- Success metrics review
- Select part candidates
- Print POC parts
- Validation of parts
- In-situ testing

CAPACITY PLAN

- Plan production briefing
- Intro to CM network
- Down select CMs
- Volume agreement
- Ready for production
- Begin volume production

Reach out to our team to learn more

Without Compromise

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