WHITEPAPER

Overcoming Challenges to Scaling Metal AM Production:

An Engineer's Guide

VELO 3D

Velo3D.com

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The promise of metal additive manufacturing (AM) to completely transform how core parts are produced has largely been just that: a promise. The ability to 3D print parts has been deployed across countless industries, but limitations within conventional iterations of metal AM have relegated the technology to use primarily in prototyping or niche use cases.

As tech and industrial sectors have continued to evolve and innovate, their demands from manufacturing have grown. Global industries with complex logistics systems and parts supply chains require an agile solution that adapts to their needs. In short, now is the time for metal AM to rise to the challenge and offer a scalable manufacturing solution.

Fortunately, as those other industries—space, automotive, aerospace, aviation, oil and gas, and more—have continued to evolve, so too has metal AM. Issues in conventional AM systems that prevented the reliable, repeatable manufacture of parts have largely been addressed with progressive metal AM solutions like the one pioneered by Velo3D.

In this whitepaper, we'll discuss the advances that have taken place in metal AM to enable scalability through repeatability, including:

1. The importance of standardized parameters in printing
2. How a universal, persistent set of print instructions (referred to by Velo3D as a "Golden Print File") enables print consistency across a global network of printers year after year
3. Fleet-level calibration and its role in combating print variability
4. How a scalable metal AM solution can impact parts manufacturing, material qualification, and AM acceptance across countless industries
5. The role of post-processing to enable scalability

Section 1: Standardizing Print Parameters in Metal AM

Scaling metal AM for consistent production comes down to many factors. While it may not be difficult to successfully execute a print with a single printer at one facility, it's much more challenging to deliver that level of quality and repeatability on multiple printers operating at different locations.

Despite attempts by conventional metal AM suppliers to mitigate that variation through extensive "locked" or "fixed" process documentation (e.g., plate finishing method, powder quality requirements, laser parameters, gas flow speeds, etc.), the reality is if you are trying to print on machines from different makes, models and parameter sets, you are likely to get undesired differences across production parts.

The Challenges of Standardization

This lack of standardization inherent in legacy systems boils down to variation in the process from site to site or printer to printer. Challenges to standardization include the following:

- Print preparation software may vary from company to company
- Printers themselves can be calibrated differently from site to site and machine to machine
- Engineers may create feature-specific printing processes unique to their site or machines
- The resulting prints may cause even standardized materials to perform in different ways in the print process

In the end, space allowed for variance leaves room for inconsistency in the parts printed. This lack of a reliable, repeatable printing process in legacy metal AM systems degrades trust in metal AM as a manufacturing category and threatens its viability industry-wide.

Furthermore, it leaves each company operating within a silo. Rather than building off of a unified system, each company has to start from scratch with years of process development and millions of dollars of investment ahead of them.

Overcoming These Challenges

The end goal is to build a reliable, repeatable metal 3D printing process, and there are several key steps that need to be taken to get there.

The first step to reaching the goal of repeatability is to control the parameters throughout the entirety of the process to minimize variation and create a consistent set of instructions for the printers to execute.

Velo3D has been accelerating the mission for a repeatable process by building a fully integrated metal additive manufacturing solution that incorporates pre-print preparation software, printing hardware, and quality assurance software on one unified system.

This control of parameters begins in the design and print preparation phase. Velo3D's Flow print preparation software leverages a library of part "recipes"—meaning certain geometric features and other part characteristics that have proven successful in print—that can be easily applied to new designs.

With legacy metal AM systems, the design process is restrictive. This manifests in several different ways but it most often results in primitive design guidelines that require an engineer to compromise their design for the sake of manufacturability. In the Velo3D system, the pre-print software intelligently reviews the design and automatically applies the appropriate recipes to increase the likelihood of a successful print.

Within the printing phase, parameters need to be tightly controlled so every time that part is printed, it generates the same results. The Velo3D fully integrated metal AM solution achieves this by containing the parameters within the print file and not assigning them to a sliced file by the printer. Velo3D's Sapphire family of printers has an advantage over other systems because they operate exclusively from Flow print files. The integration of pre-print software and printing hardware works to minimize any variance throughout the process.

The second step towards repeatability is to ensure consistent execution of the print instructions through automated calibrations of the printers. Calibrations are critical to repeatability as they ensure the printer is following the proper instructions for each build before it begins. But even with the parameters of the design controlled and proven, that doesn't necessarily guarantee a successful print.

Imagine baking two frozen pizzas on two separate ovens of the same brand placed next to each other. The instructions say to bake both at 450 °F / 232 °C for 12 minutes, but perhaps only one oven can comfortably reach the desired temperature while the other cannot. Unfortunately, you would not know the variation that exists between each pizza until they were done baking. This is also true of metal AM parts printed on separate machines, where part variation often goes undetected until the print is complete, wasting time, money, and other resources.

Thankfully, Velo3D Sapphire printers present some of the tightest parameter controls in the industry, including advanced systems of:

- Laser calibration
- Metrology sensors
- Inert environmental controls
- Non-contact recoater calibration

Controlling these parameters work to remove inconsistencies and volatilities inherent in metal AM. Meanwhile, standardizing the environmental and mechanical conditions of the printers helps to ensure repeatability in design.

The third step is to consistently measure the print layer by layer ensuring that each part prints with an identical fingerprint to the original. It's great when a part has been printed successfully, but it's not instructive for future success without proof through data.

The Velo3D system integrates Assure Quality Control Software that delivers extensive reports on every aspect of the printing process. This data provides benchmark validation that future prints can be measured against to determine repeatability. Rather than each print being a onetime process, it can be measured against the exact same parts printed. This level of validation is built into the Velo3D solution to provide trust that each print was executed within the same parameters with the same outcome as past prints.

Assure – Quality Control Software

Factory Monitoring

- Real-time machine fleet tracking
- Live build progress monitoring

Printer Health

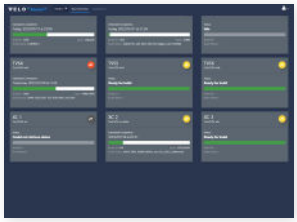
- Automated system calibration

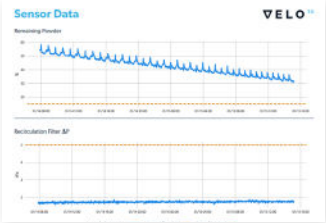
In-process monitoring

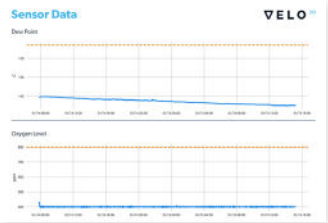
- Optical health
- Powder bed quality
- Build chamber environment

Build report

- Build information summary
- Tool and build data documentation

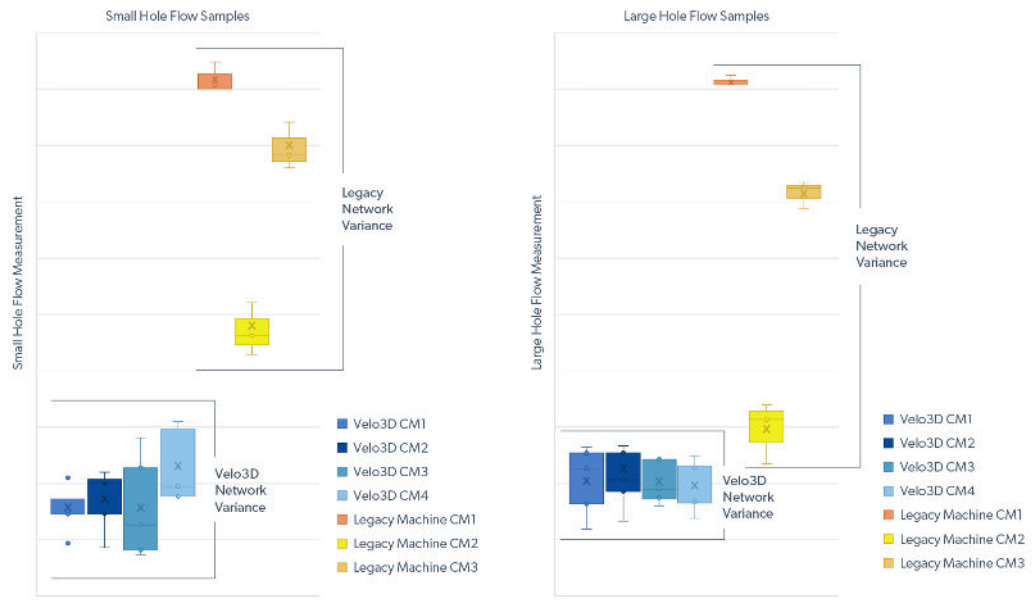






Because the printing process is beginning from a standardized, uniformly calibrated point, the benchmark results are more trustworthy than they would be on a conventional system with variable parameter sets across multiple printers or sites.

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.

Two choke valves optimized with IMI Critical DRAG™ technology. The parts were 3D printed using a Velo3D Sapphire system.

Unlocking the "Golden Print File"

Once a part has been successfully designed and sliced within Velo3D's Flow print-preparation software, engineers are left with what's known as a "Golden Print File." What the golden print file entails is a set of proprietary print settings that can be used to repeatedly print a part, as needed, on any Velo3D Sapphire printer, anywhere in the world.

The Golden Velo3D Print File – Flexible Scalability

Revolutionary single print file enables same output on any Velo3D Sapphire printer, anywhere in the world

Instant scalability through CM or internal network

Enabled by Velo3D's unique calibration

Through the integration of pre-print software and hardware within the Velo3D solution, engineers can unlock a distributed system of manufacturing. Rather than being trapped into one centralized manufacturing hub capable of printing one part, parts can be printed on demand wherever Sapphire printers are in operation. That be in-house or it can be across Velo3D's trusted partner network of contract manufacturers.

Section 2: The Importance of Fleet-Level Calibration in Scaling Metal AM

Beginning with the Golden Print File, engineers are left with a proven set of instructions that can theoretically be printed on any Velo3D Sapphire printer anywhere in the world. Achieving that repeatability across multiple printers and multiple sites, however, requires special considerations.

Tightly controlled parameters mean teams can achieve repeatability and consistency, but that doesn't necessarily mean that the process is scalable. To ensure scalability, the same process needs to be repeated with minimal variance across multiple print sites within an organization or a network of contract manufacturers (CMs). In legacy metal AM systems, a successful print may work at one location, but discrepancies in printers may mean one set of instructions is limited to one machine or site.

Standardization is hard to ensure on an individual printer. For a CM operating multiple legacy metal AM printers, each printer may have its own set of parameters that are slightly different from the machine next to it. And when you consider that challenge on an entire fleet of printers worldwide, it seems nearly impossible to address. It's the main reason why metal AM faces such an uphill battle in scaling.

At Velo3D, our calibration is done at the fleet level, meaning all the printers in the field that are assigned for a specific material and build are calibrated to achieve the same result.

A Sapphire printer in California assigned to print a choke valve in Inconel 718 will be calibrated the same as a printer in Australia with the same parameters and can be expected to replicate the same geometric accuracy, surface finish, and material properties.

Velo3D Sapphire printers have an integrated tool health checklist that analyzes several factors calibrated to the specifications of the build. Ensuring that the printer is calibrated in accordance with the rest of the fleet is a quick, automated process that doesn't require any specialized tools or field technicians.

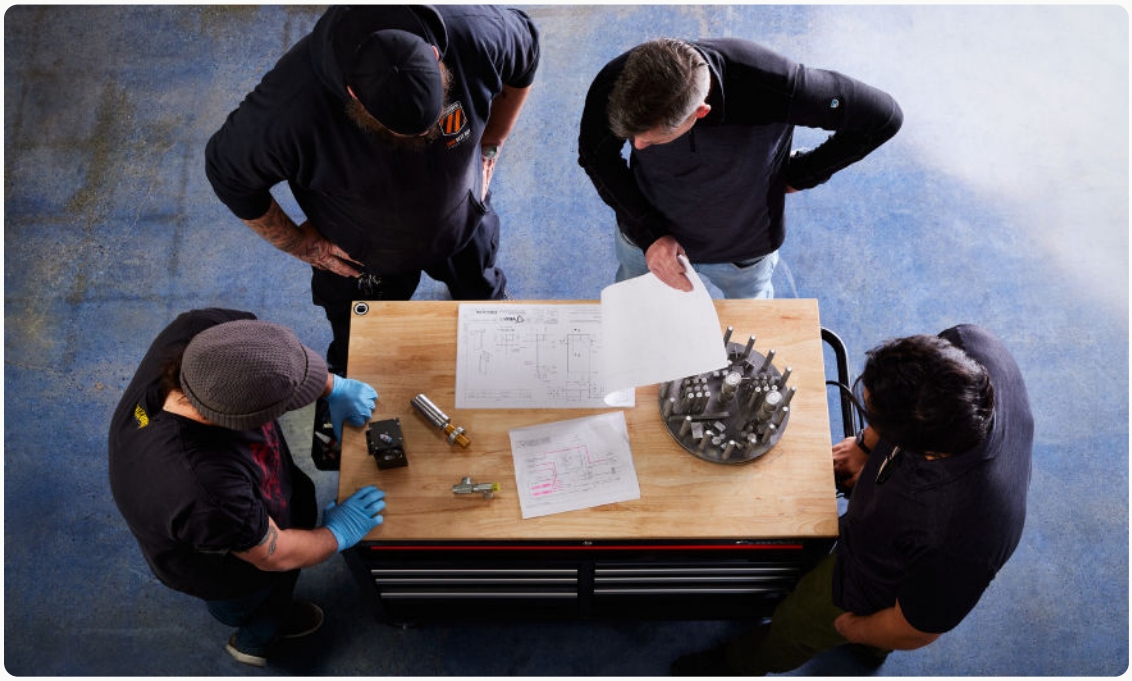
The focus of fleet-level calibration centers around laser alignment; one of the hardest variables to make consistent and the bane of legacy metal AM systems that work, as Velo3D does, in laser powder-bed fusion (LPBF) printing.

Incorrect alignment can cause mechanical defects, porosity, and poor surface roughness, and can also lead to build failures. By deploying pre-build alignment procedures, as well as in-situ process monitoring that tracks laser alignment at each layer of the build, Sapphire printers can ensure the most repeatable calibration.

All the tools of the Velo3D fully integrated metal AM solution are designed to work in concert with one another to ensure repeatability across all printers no matter where they are in the world. Scaling that process can be achieved in multiple ways.

Ways to Scale Additive Manufacturing

- **Add additional printers** to the fleet. In legacy systems, more printers don't necessarily mean larger print capacity because there was no prospect of consistency. In the Velo3D system, there is.
- **Choose a printer with a larger capacity**. Another unique aspect of the Velo3D system is that every printer, no matter its volume capacity, can be calibrated at the fleet level with other printers. Expanding the volume of print by opting for a larger build plate with the Sapphire XC can help scale an operation even faster.



Section 3: Pedigree Data and Broader AM Acceptance

The key to maintaining consistency and having predictable outcomes with respect to materials comes down to data. By amassing vast quantities of data and closely tracking every aspect of a print across the entirety of printers in the field, Velo3D has built, and continues to build, standards to which materials will perform in the print process.

Having predictable material qualification standards is incredibly valuable for companies to weigh in their material consideration process, but it also has wider implications to how industries view metal AM as a viable manufacturing option.

By submitting data from factory acceptance tests, site acceptance tests, and periodic checks to third-party verification entities, Velo3D has managed to be at the forefront of crafting industry material qualification standards that has set metal AM on the path to regulatory acceptance in multiple industries including energy and aviation.

While many metal AM companies will focus on setting their standards internally, the work Velo3D is doing is public, designed to build broader acceptance of metal AM as a repeatable, scalable manufacturing process.

Orbiter propellant tank: Titanium pressure vessel printed in Ti-6Al4V shown as printed still attached to the build plate. Printed as a single piece, engineers can quickly have a fully functional assembly that is lighter, stronger, and reduces the risk for leaks.

Section 4: The Role Post-Processing Plays in Scalability

The initial chemistry (of the metal powder), printing parameter selection, machine calibration, and post-processing are the most critical elements in determining final material properties. Maintaining consistency throughout each of these phases is essential to creating a repeatable process with predictable material outcomes. As we've discussed, the synergy of print preparation software, printing hardware, and quality assurance and process monitoring software is vital in producing a repeatable manufacturing process. But what happens after the part is printed?

Post Processing Steps

Post-processing is the final phase of manufacturing before teams are left with a completed part. This phase impacts the quality of printed parts in several ways, including (but not limited to):

- Powder removal
- Electrical discharge machining (EDM) from the build plate
- Heat treatments
- Post machining
- Surface finishing

Building scalability in metal AM system means creating predictable outcomes at every point in the manufacturing process. Every post-processing treatment invites a new avenue for unpredictability.

While Velo3D doesn't handle these post-processing steps within the fully integrated system, by understanding and quantifying every aspect of the input material, the print process, and the post-processing specifications, it reduces variance in recommended processes and creates a predictable baseline. The more we know, and the more we can quantify, the better we are able to forecast how a part will perform throughout each phase of production.

Predictability means repeatability, and repeatability means scalability.

What a Scalable Metal AM Solution Means for All Industries

Addressing the longstanding issues of repeatability and consistency in metal AM has been Velo3D's mission since our inception. Through our fully integrated solution, we've shifted the possibilities and expectations for AM as a truly scalable manufacturing option. The implications of this decentralized system of parts manufacturing are monumental for industries, with benefits including:

Benefits of Decentralized Manufacturing

- Drastically reduced lead times for parts
- Lower costs for part warehousing
- Reduced logistical burdens to get parts to remote operations
- Uniformity in part quality across disparate sites

Velo3D's standardization and control over nearly every aspect of the printing process from design through production works to ensure predictable results for finalized parts, crucially backed by data. In the end, this work not only benefits our partners, but it establishes metal AM as a viable manufacturing process worthy of regulatory and industry acceptance.

To learn more about scaling your metal AM operations, reach out to the experts at Velo3D today.

Without Compromise

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