Yes, You CAN Achieve the Parts You Want with Additive Manufacturing

What aerospace and defense industry professionals need to know about why advanced industrial metal AM is different and how it will bring bankable success to your 3D printed initiatives.

As a key stakeholder associated with the aerospace and/or defense industries, you've likely been aware for some time of the promise of metal additive manufacturing (AM, aka 3D printing): That performance-shattering, stronger, lighter, high-value parts made from heat-tolerant superalloys with innovative geometries—not achievable via any other method—are just a single print-run away!

If it all sounds too good to be true—unfortunately, for the most part, it has been. If you've spent any time exploring the possibilities of AM up to now, you've learned that it often falls short of expectations. Yes, you may have finally produced a 3D printed part that satisfies your needs, passes inspection, and maybe has even been certified for flight. But it's taken you much more development time and expense than anticipated. In addition, there's likely a lot of discarded metal in the recycle bin. The potential benefits of the technology seem so amazing, particularly given the huge competitive pressures involved in developing your category of products. Yet the failures you've experienced, and the risks they've exposed you to, are holding your organization back from moving forward with AM.

Along with all this comes the stress of working in industries where human life is at stake, be it in the air or on the ground in mission-critical situations. When safety-above-all-else is your mantra, the immense challenges of material and part certification have made you reluctant to push the envelope further.

Things are different now. A true shift in the evolution of AM has taken place: Advanced industrial metal AM is delivering both the exacting print quality and sky's-the-limit performance capabilities you've been searching for. Much more cost-effectively, too.

If you are new to 3D printing, your timing is perfect: you've lost no ground. If you're a battle-weary AM veteran, you're in luck: the issues that have held you back to date have been resolved: you can finally, intelligently, trust the evolved technology and succeed. In every case, you can now design and make what you want, not what other manufacturing methods—including all those previous-generation 3D printing systems—have limited you to.

This is not hyperbole, and in the following pages we will show you why.

What's still not working with most legacy AM systems

Most metal AM equipment—some of which you may have already tried—is bound by the notion that one needs to "Design for AM." The notion that you must adhere to the rules of DfAM to successfully 3D print something is based on the limits of current metal machines.

When creating designs that will be printable in most metal AM systems, you still have to consider how the part will sit within the build chamber. You need to be concerned about avoiding angled surfaces or overhangs that exceed the infamous "45-degree rule," which limits what can be printed without extensive support structures to prevent curling and warping. You have to restrict the diameter of any interior channels because those dimensions can't self-support and the structures themselves are closed to post-processing.

Next, when preparing a design for printing, you have to fine-tune the interface between the machine and your CAD model, defining the specific material and process parameters that will accurately guide the lasers to melt each layer of your part perfectly as it takes shape in the build chamber. Multiple test runs are not unusual; it's rare that your first, second or even third print run achieves full success.

As a final limitation of most metal AM systems, start-to-finish, mission-critical quality control—in the form of process-parameter definition, automated pre-print calibration, real-time build monitoring, re-calibration and reporting—is simply not available at a level that ensures the production of optimized finished parts the very first time.

A deeper dive, layer by layer

For a better understanding of what you should be asking of the AM system you choose to work with, it may be helpful to start with a quick refresher about how most current metal Laser-Powder Bed Fusion (LPBF) 3D printers function:

Dedicated software digitally "slices" the 3D CAD model of the part to be manufactured. Support structures are usually designed in during this step, and the part oriented to the build chamber based on its geometry and the presence of other parts.

The layer profiles and other operating parameters are entered in the 3D printer's computer to guide the laser(s) that will fuse the physical part inside the build chamber.

The floor of the build chamber contains a movable elevator platform, on which is mounted a metal build plate.

The recoater blade then pulls the next layer of fine metal powder across the build plate and the fusion process repeats. After each layer is complete, the elevator drops the build plate by a single-layer thickness, the recoater applies fresh powder across the surface, and the process continues until complete.

At the top of the chamber sit multiple lasers, powerful enough to melt (fuse, or sinter) the metal powder. A servo system drives the focused laser(s) along the path of the CAD design of the object, melting the powder in that shape.

Ultra-fine metal powder is deposited on the build plate and smoothed to a very thin layer by a recoater blade.

This is a simple explanation of what is actually an extremely complex process. And while the quality of parts that come out of most current AM systems has continued to improve in recent years, your own experience will tell you that significant challenges to achieving finished, highest-quality results remain.

The Problem: Where legacy AM systems fall short of what aerospace needs

Most legacy systems do not provide a fully inert environment, frequently resulting in less-than-perfect results.

The purity of the atmosphere that surrounds the burgeoning workpiece during the printing process is critical. The injection of inert gases such as argon into the build chamber eliminates oxygen to reduce embrittlement and other undesirable metallurgical conditions. This phenomenon is especially true with titanium and similarly reactive metals (alloys the aircraft industry prefers for their high strength-to-weight ratio), where oxygen and hydrogen can create higher porosity levels in parts. Legacy systems do a less-than-stellar job at atmosphere regulation, some still allowing a surprisingly large percentage of oxygen and humidity to remain present during a build, which results in less-than-perfect results showing up in the part.

Modulating inert gas flow to keep up with the soot that can accompany the lasing process is another challenge for legacy systems. Because they don't optimally manage ventilation and flow of build-chamber gases during a build, any soot that's produced during lasering, when not evacuated quickly enough, can actually interfere with energy delivered to the powder bed. Results can be inconsistent. A solution that some legacy systems use is to pause the build process at the end of the layer to allow for the soot to clear; however, this dramatically impacts print speed.

Most legacy systems don't monitor or capture usable metrics.

While some current systems claim to offer in-situ monitoring to detect some of these issues, in most cases this is mass data produced in a fashion that is not usable nor actionable. Imperfections can only be identified visually or through scanning after a print run is complete.

The recoater blade can also be an Achilles heel for many current metal AM systems.

That's because as the part being printed overheats, protrusions occur, and when the protrusion reaches the height of the recoater (typically 20 to 40 microns), the rigid blade collides with the part and crashes the build.

Operators of many legacy systems remain locked into an expensive, time-consuming build-break-rebuild cycle.

Because most systems can't optimize build parameters for a specific part in advance, it often takes multiple builds to fine-tune a design and achieve final quality.

The Solution: Stacking it up right with advanced AM

Metal AM equipment with the highest level of parameter definition, production mechanics, automated controls and in-process metrology technology—what we will henceforth call **advanced industrial metal AM**—provides a full-stack solution that mitigates many of the design and manufacturing concerns just discussed.

It starts even before the first print, knowing that, with an advanced industrial metal AM system available, *you really **can** manufacture almost anything your designers can imagine*. The key is quality control. As the build angle decreases, the process window to print parts decreases as well.

Because the process control is so precise in these machines, the need to design-in support structures is greatly reduced and often eliminated. This not only increases design freedom but reduces secondary machining and finishing costs. There's no necessity for your innovation to be restricted by DfAM considerations with these advanced machines: opportunities to realize the benefits of **part consolidation** expand exponentially because you can print whatever novel geometry you need to boost turbine performance, increase surface area for better thermal cooling, or pack more power into a smaller, lighter flying machine.

The non-contact recoater arm in an advanced AM system eliminates any issues with protruding surfaces during a build that cause recoater clashes. Since recoater clashes are the leading cause of failed build, this is a game-changer—dramatically better for yield than any other type of AM out there.

Perhaps most important, the extreme process controls built into advanced industrial metal AM systems simply make better parts, faster, with the metallurgical and structural integrity demanded by aerospace and other mission-critical applications. When 3D printed in the most advanced systems, metal alloys can come out as 99.9% dense material—versus around 95% for castings.

Successful 3D printing depends on a robust workflow, starting with the software used to prepare parts for printing. Because the process begins with a CAD file, interoperability with systems that perform topology optimization and generative design is key. By working with CAD files directly, STL files are avoided, and do not need to be tracked. Additionally, the STL translation issues are avoided completely. The print-preparation interface utilizes the intelligence of the CAD file to make edges and surfaces easily selectable. This dramatically decreases the amount of time engineers spend preparing a file.

During the slicing process, there is a generous library of process parameters specifically tailored to the high-performance materials being used, saving much pre-build development effort and reducing reliance on external vendors. Having *a single, optimized print file that produces the same results on one of these advanced machines—anywhere in the world*— dramatically simplifies your PLM universe with improved traceability and enhanced supply chain flexibility on a global scale.

During a build, advanced AM systems' finely tune control of the tiny meltpool zone of molten metal that forms around the laser beam—and precise, ongoing modulation of laser energy during critical parts of the build—lead to enhanced print accuracy, better surface finish, and enhanced mechanical properties and performance in the finished workpiece. These machines fill in the core (the center of the workpiece) faster than anything else out there. *Production times (and cost) for the most complex high-performance parts drop from weeks to days.*

Gas ventilation in an advanced system goes far beyond what most legacy ones provide. The latest systems evacuate the build chamber of any accompanying soot much more quickly than previous ones. This, in turn, enables laser fusion to continue at a more rapid pace, particularly in two-or-more-laser systems. There's also no waiting time needed for occluding vapors to evaporate.

As parts are taking shape, an advanced system collects process and quality metrics for reporting and documentation purposes. Control charts of critical parameters during the build help avoid problems downstream, as does 3D topographical mapping of the print bed. And comprehensive machine performance data allows technicians to fine-tune build parameters and continuously improve manufacturing processes.

From all this you'll see how it becomes clear that the software and workflow aspect of any 3D printing technology is nearly as critical to success as its electromechanical capabilities—and *only the most advanced systems deliver the complete full-stack package you need for success with AM.*

Taking to the skies

Assuming all the above features are in place, what **benefits** can you, as an aerospace, defense, or other highly exacting industry team leader expect **from an advanced industrial metal 3D printing system** like that just described? Here are a few examples of some notable success stories:

- San Jose, California-based **Sierra Turbines** Inc. is a startup firm with plans to remake the microturbine industry. The company has developed a 3D printed turbine in the Hastelloy® X superalloy for use in unmanned aerial vehicles (UAVs) and auxiliary power units (APUs), one that promises to increase the time between overhaul from 40 or so hours to more than 1000, with less noise, weight, and cost. The key is a consolidated "unicore" construction that reduces part count by 60 pieces and increases power density ten-fold.

- **KW Micro Power Inc.** of Opa Locka, Florida has a similar microgenerator success story. The compressor diffuser dubbed the "spaceship" is a Ti-6Al-4V titanium disc roughly 10" in diameter and 4" high. Using topology optimization and metal AM, this innovative firm was able to print a part that many said was unmanufacturable due to its complex labyrinth of exhaust channels. Again, the 3D printed design is a model of part consolidation and performance, cutting weight nearly in half and operating temperatures by one-third.

- **Honeywell Aerospace,** a leading user of Additive Manufacturing (AM) technologies with extensive knowledge across various platforms and applications, has selected an advanced AM system for qualification at its Phoenix, Arizona facility as a viable manufacturing platform for 3D print production of aircraft components. The system was selected for its unique capabilities for building highly complex geometries without the requirement of support structures. The qualification process is focused on INCONEL®, a nickel-based super alloy well suited for extreme temperatures.

Here are some examples from other critical industries: **Hanwha Power Systems** has achieved "huge geometric freedom" in the design and 3D printing of nickel-based turbomachinery parts. **Mohawk Innovative Technology** enjoyed a cost savings of 250% over traditional methods on a recent solar energy project. **Duncan Machine Products** invested in metal AM to produce oil and gas components, as did **Knust-Godwin,** both established firms with long histories in machining and other conventional manufacturing processes.

How advanced AM delivers

These manufacturers share a common trait. They're all customers and/or partners of VELO3D, the developers of Sapphire® and Sapphire® XC Metal AM systems, Flow™ print preparation and Assure™ quality assurance software—the company with first bragging rights to the development of SupportFree metal printing.

VELO3D has achieved a level of advanced AM beyond any other current system, with roots that are unique in comparison with any other 3D printer manufacturer. As an engineer working in the semiconductor industry, VELO3D founder and CEO Benny Buller learned early on the importance of comprehensive process management and quality control. He and his team applied that same mindset to the design and manufacture of a new generation of advanced industrial laser powder bed fusion (LPBF) metal printers.

Designed from the ground up, every Sapphire® system comes with technology that's founded on strict environmental control of the build chamber, automated in-process metrology, precision meltpool monitoring, and advanced powder management. Coupled with built-in software that supports interoperability with modern CAD systems, production parameters second to none, and end-to-end process-flow controls, these features explain why this relative newcomer to the AM industry has quickly become the leading supplier of full-stack advanced metal 3D printing solutions.

As you well know, aerospace and defense manufacturers face a slew of regulatory, cost, and operational hurdles, all while producing some of the most complex parts imaginable in equally challenging materials. While advanced industrial metal AM can't solve all of these challenges, the genuine value it brings to manufacturing in your industry is now substantial—and achievable.

The case for aerospace

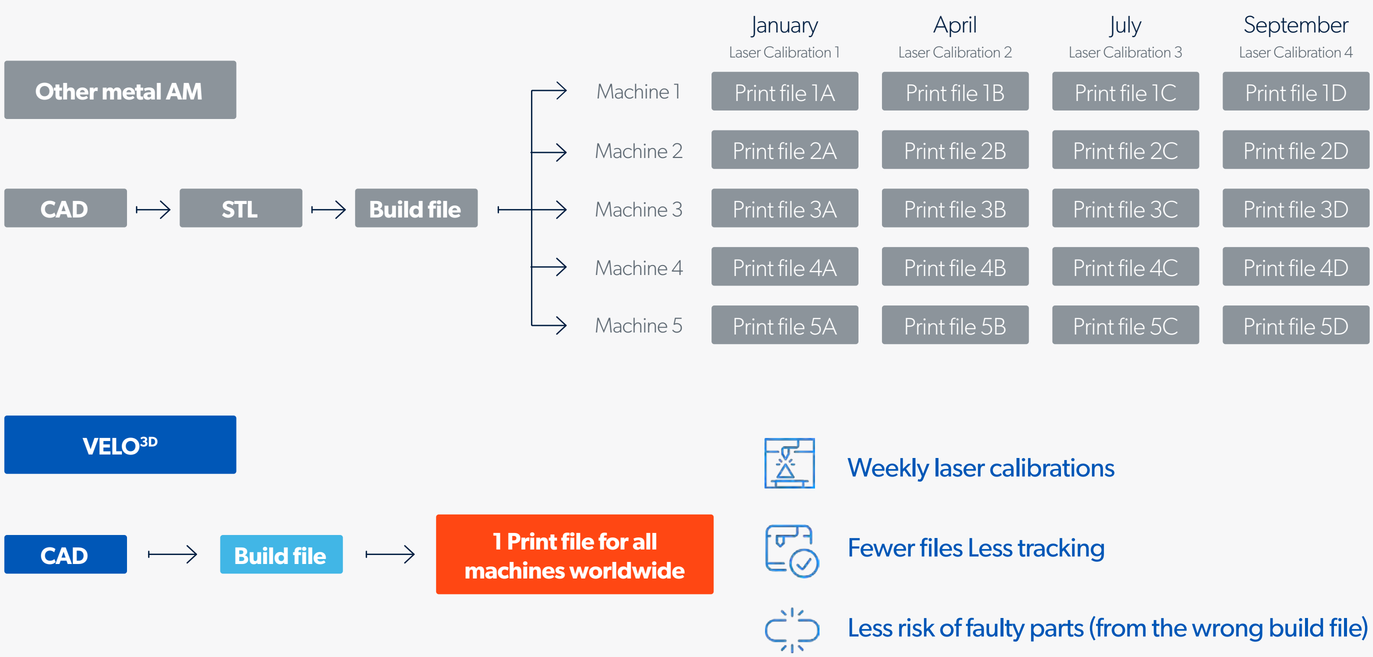
Consider design freedom. As Honeywell, KW Micro Power, Sierra Turbines, and countless other design and manufacturing companies have discovered, metal AM has opened doors that would have otherwise stayed firmly shut. It gave them the ability to generate the thin walls and internal passageways needed to quickly and effectively dissipate heat while the surrounding geometry remained strong enough for the most demanding applications. Doing so required a 3D model, the VELO3D manufacturing solution, and just enough Inconel®, Hastelloy® X, or titanium powder to build the part. That's it.

Most of those parts took just a day or two to build, an act accomplished in a largely automated fashion. It wasn't the months of waiting for a machine shop to tool up, program CNC equipment, and machine dozens of pieces that must then be brazed, welded, or bolted together. That's what your industry has long been accustomed to; now imagine how this new manufacturing paradigm can change your expectations. Granted, parts made with metal AM can still require some secondary machining to remove any support structures and finish critical surfaces. The Sapphire® printing process is not wholly exempt from this requirement, but thanks to its greatly reduced support-structure requirements, and ability to print horizontal holes and flat surfaces with little to no curling or distortion, such secondary finishing processes are minimal. And because the precision laser and recoater controls produce surfaces that are demonstrably smoother right out of the build chamber, time spent in post-processing is significantly reduced. Due to the rigid process controls that make all of this possible, any concerns you may have had in the past about voids and metallurgical integrity common with most 3D printers are eliminated.

The path to certification by the FAA and other governing bodies is of obvious interest to those in your industry. VELO3D is a member of the MMPDS committee that is expected to release the first materials certification guidelines for the additive manufacturing (AM) of 3D printed parts with Inconel® 718, a high-strength, high-temperature alloy commonly used in the aerospace industry. Once Inconel® gets its MMPDS clearance, the development of data curves for aluminum and titanium will follow.

Until now, flight-certified AM products have been the purview of those major OEMs and MRO providers who've had the time and money to develop their own internal specs and allowables. The slow evolution of earlier 3D printing capabilities has certainly contributed to halting progress in this area. Now that advanced industrial AM can produce metal parts that match the exacting specifications of newly certified materials, OEMs and MRO providers of all sizes can, with full confidence, take advantage of the many benefits AM offers the industry.

Enterprise-wide scalability



These arguments apply to MRO providers as well. Here, suppliers have two choices for castings: maintain an inventory of replacement parts that might never be used, or tell aircraft owners they must wait months to have them made, most likely at a premium price due to the cost of tooling up for a single-piece or very low-volume order.

Access to a 3D printer or service bureau relieves MRO providers of both these unpleasant situations. Replacement parts can now be turned around quickly. And in the likely event that a decades-old component has no drawing available, reverse-engineering via an inexpensive scanner is easily accomplished, the resulting CAD file ready for 3D printing.

The bigger picture

The quality of 3D printed parts now available when you work with the most advanced AM systems will have far-reaching effects throughout your industry's supply chain. The robust library of process parameters, together with a high-value list of VELO3D-machine-certified metal powders, means that parts printed on the Sapphire® printer in Los Angeles will be exactly like those printed in Quebec, Dallas, or Seoul. So not only does the abbreviated lead-time and ability to print complex assemblies in a single-piece shorten the supply chain considerably, it has also made it far more flexible—and above all, scalable. It's quite simply a great way to make parts, wherever you are located.

Adding it all up

Advanced industrial metal AM technology has at last reached the point where it reliably delivers on the promise of unprecedented design freedom, shorter lead times, reduced development and production costs, and highest-quality, fully-functional end-use parts for aerospace and defense. Manufacturers in pursuit of these goals now have access to a system with an end-to-end technology stack that encompasses the entire 3D printing workflow. And equipment with the process controls and monitoring systems needed to assure the level of part quality that aerospace and defense designers, engineers and manufacturers have been searching for.

We like to say that we're not here to sell you a 3D printer. We're here to sell you on the technology itself, which you can access through the ever-growing global network of contract manufacturers or service bureaus that carry VELO3D AM systems. We want to help you solve your most difficult engineering problems so you can realize your most ambitious dreams for improving performance in your industry.

Headquarters
511 Division Street
Campbell CA 95008

To learn more visit:
www.velo3d.com
info@velo3d.com