VELO 3D

The Business Impact of a Support-Less Process for Metal Additive Manufacturing

by Todd Grimm

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Introduction

Additive manufacturing for metal parts has a constraint: the requirement for support structures to be added to parts and later removed. This adds steps throughout the workflow that negatively affect time, cost and quality.

When contemplating a workflow that excludes support structure creation and removal, most will focus on the reduction of time and the elimination of cost. These are real outcomes, but they undervalue the larger gains that can be realized by those that use metal additive manufacturing (AM).

These gains, hereafter called advantages, are the building blocks of a strong business case for support-less metal AM. To illustrate the advantages of support-less metal AM, six companies contributed their experiences, expectations, and insights. The contributors are:

- Hanwha Power Systems Americas Inc., a manufacturer of turbo compressors and innovative power generation systems
- Incodema3D, LLC, a contract manufacturer that specializes in AM
- Knust-Godwin, a full-service precision-machining company
- Interstellar Technologies, a provider of innovative, affordable and high performing propulsion and spacecraft solutions
- Protolabs, a digital manufacturing service provider specializing in both additive and subtractive manufacturing technologies
- Stratasys Direct Manufacturing, a provider of 3D printing and advanced manufacturing services for prototyping and contract manufacturing.

Support Structures

Presently, metal AM systems based on the laser powder bed fusion (LPBF) class of technology must address the challenge of support structures that are added to parts. David Bentley, senior manufacturing engineer for 3D printed metals at Protolabs, said, "Ninety-five percent of the parts that come through here are going to require supports." And Michael Corliss, VP–Technology for Knust–Godwin, noted that 60% to 70% of the parts they build have supports that then require CNC machining for removal.

95%

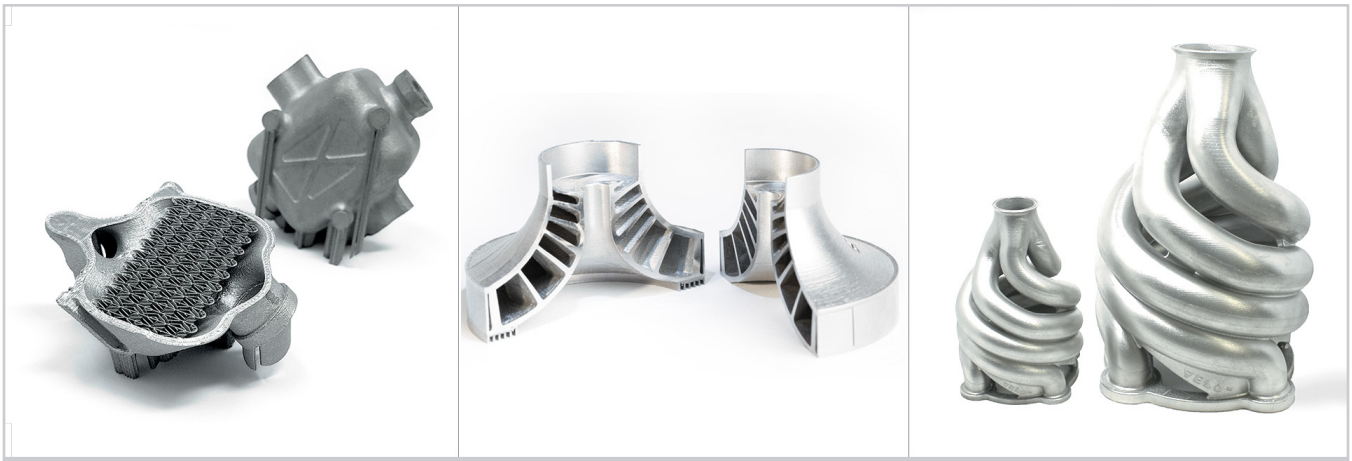
of parts built with metal additive requires support structures

- Proto Labs

Jeff Thornburg, president and CEO of Interstellar Technologies, said, "In general, if I have to send a part to a vendor to go through another process, there is the shipping time, the queue time, your actual value-added work time, and then the return and inspection time. That is typically several weeks." Insourcing this work does not decrease the lead time by much. Thornburg noted, "The only time gain is from avoiding transportation between Interstellar and its job shops."

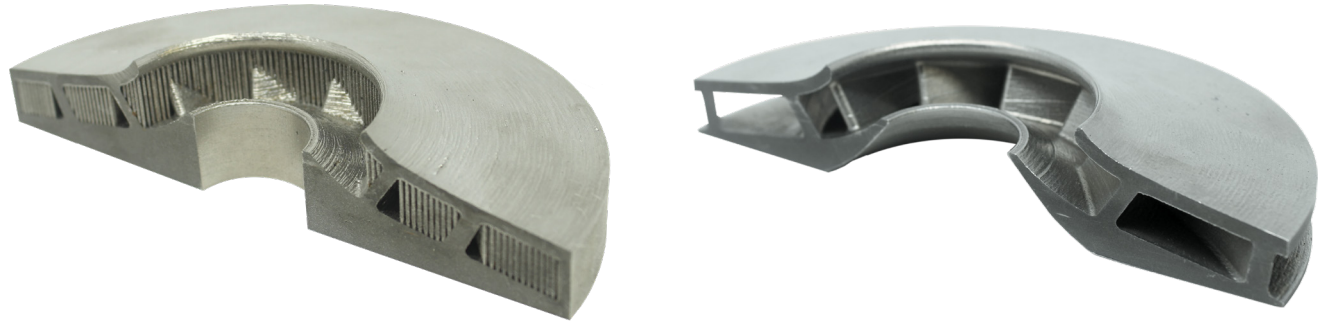
Although any metal AM part may require support structures, and therefore benefit from their elimination, the positive impact is greatest on parts with internal passageways or cavities. Bentley further clarified that the most problematic are, "Any parts with inlets, outlets, and manifold-like structures between these points of accessibility."

The most-cited example of support structures' impact on metal AM was shrouded impellers. Consisting of an impeller (a base with attached vanes) and a shroud (a top cap), the supports between the base and cap are very difficult to remove. It was noted that there has been a strong demand for shrouded impellers that has been difficult to satisfy because of the support structure challenge. Other examples of parts or part features commonly impacted by support structures are manifolds, heat exchangers, and conformal cooling channels.



Shrouded impellers, heat exchangers, and manifolds were the most cited examples that would be chief beneficiaries of a support-less process with metal AM.

Regardless of the complexity of the part design, support structures will require removal after the build, degrade surface finish, add time to the AM build, and consume material, which can be expensive. So, the benefits of eliminating supports are obvious in terms of time, cost and quality. However, the obvious benefits are secondary to the big business advantages that may be somewhat obscure.



Parts like impellers illustrate the challenge (and limitation) of printing with metal AM today. Impellers can't be economically printed without major modifications to the design to facilitate support structure removal. Velo3D's technology eliminates the need for support structures, thus creating a compelling business case for parts that were previously impossible to print.

Advantages of Support-Less Metal AM

The business advantages, those that deliver strong, compelling paybacks, build from the fundamental benefits in time, cost and quality. These advantages are numerous, and somewhat unique to each company. To initiate thinking in terms of the higher-level advantages, following are the outcomes described by the six contributors.

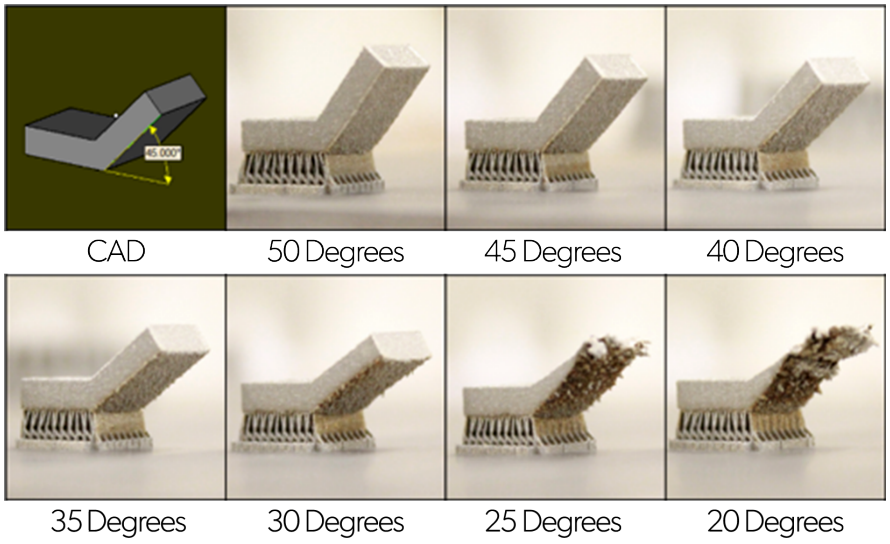
Unshackled Designs

For many years, AM has been positioned as a technology that unleashes freedom of design. Yet, while true for the printing process, this dream has been shackled by the constraints imposed when secondary operations are considered. The most-cited secondary operation that imposes these design constraints is support structure removal.

> "With support-free building, we can provide a much easier one-to-one transition from conventional manufacturing while still reaping the benefits of additive processes."

The inability, or difficulty, to remove supports from a part that leverages design freedoms in a way that impedes access by machine tools or hand tools will limit the design possibilities that AM promises. When this challenge is eradicated, design liberties are plentiful. Andrew Carter, senior manufacturing engineer at Stratasys Direct Manufacturing, said, "We may never get 100% true freedom of design in laser-based metal powder bed fusion, but this support-less process is completely widening the span of applications."

For his shrouded impellers, Chad Robertson, senior engineer at Hanwha Power Systems America, said, "Additive give us the capability to control some features that traditional cannot; features like the fillets where the impeller meets the shroud." Without AM, the shroud is brazed or electron-beam welded to the impeller. However, when supports lie between the impeller and shroud, the removal process limits his ability to benefit from the additional control offered by AM.



Designing for Additive Manufacturing requires all angles less than 45 degrees to have support structures. As the angle decreases, the features downward-facing surface becomes rougher and eventually the part will fail if the angle is reduced too far. Source: Proto Labs

Elimination of support structures also unshackles metal AM for parts that have been designed for traditional manufacturing processes. Features that are ideal for machining, molding, or casting can dictate support structures for metal AM. Carter said, "3D printing companies need to basically prove a cost benefit, performance benefit, or lead time savings for using additive manufacturing, and with support-

free building, we can provide a much easier one-to-one transition from conventional manufacturing while still reaping the benefits of additive processes."

By working on projects designed for conventional manufacturing rather than those that require design for additive manufacturing (DfAM) principles, Carter believes, "We can reduce or eliminate the barriers to adoption of AM for many OEMs."

Scott Volk, former Chief Technology Officer for Incodema3D, had similar thoughts. He said, "Now we don't have to push as hard. We can allow for some of the things customers have already designed. We don't have to push back as much and cause them to go back and redesign them."

Repeatability and Reliability

An outcome of support elimination is that scrap rates are dramatically reduced. With lower scrap rates, companies realize advantages that include improvements in resource utilization, throughput, efficiency, cost of goods sold, and lead time. Expanding on these, the customer (internal or external) has higher satisfaction, higher confidence, and improved results.

"With the AM machine making support-free parts with better surface finishes, it's repeatable. When you're doing it with humans, it's never consistent; you don't get the repeatability."

According to Stratasys Direct, support structures can be the root cause of production concerns. Carter said, "Designs requiring disadvantageous support structures can introduce problems during the manufacturing process. Poorly conceived support structure strategies can cause build interruptions, build failures, or poor part quality so we work very hard to ensure proper support placement"

There are software tools that automatically create support structures, although Carter noted that the results are not build-ready. Instead, a manual review is required, and adjustments are frequently needed. Essentially, the software provides a starting point, and an experienced AM professional then applies knowledge from past experiences to optimize the resulting supports to maximize process efficiency and minimize the possibility of failure. Carter said, "We leveraged the automatic support generation to help set the base. But every support structure needs to be reviewed by an operator." He continued, "It's still very much tribal knowledge, and if support structures do need to be changed, that adds time to the project."

Volk added that tall supports, those that rise two or three inches can be problematic, especially when the support structure originates from a part surface that lies below the supported feature. He said, "In laser powder bed fusion, one of the issues we have is supports that build from the part to the part. They tend to fall apart, and that is a build failure."

Another aspect that decreases repeatability is inconsistencies that arise from manual removal operations. Corliss said, "With the AM machine making support-free parts with better surface finishes, it's repeatable. When you're doing it with humans, it's never consistent; you don't get the repeatability." Carter concurred, "Using support-free building reduces the human element so it increases our reproducibility. The support removal is such a manual process and it is very, very hard to control."

Productivity and Process Gains

By eliminating resource demands related to support structures, productivity improves, which allows a company to do more without adding personnel or equipment. The companies that provided their insights mentioned gains in engineering, manufacturing engineering, and sales.

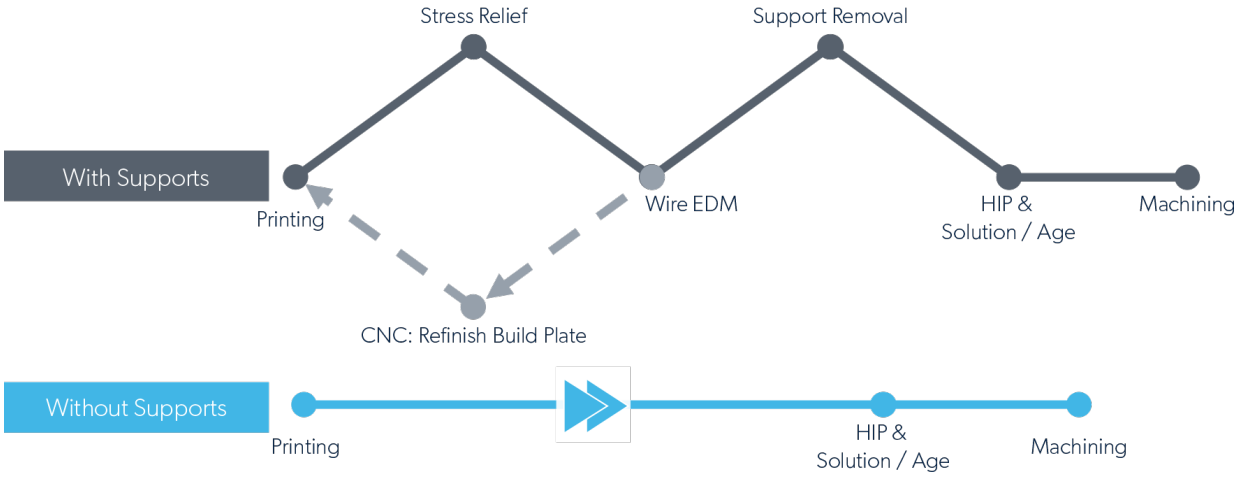
Corliss said, "It is going to help the engineering side tremendously. We'd have less work to do because we can print it as-is. We don't have to worry about how we are going to manufacture, remove supports, or fixture a part."

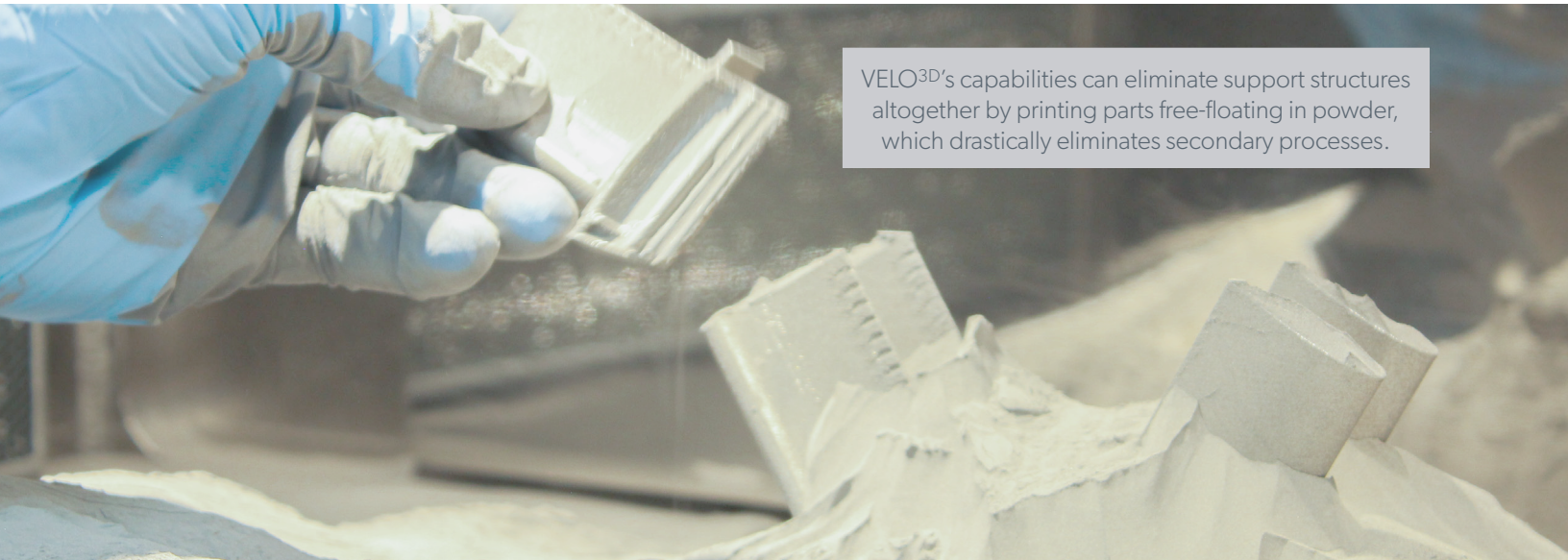
Carter also cited productivity gains in the sales cycle that come from the ability to accept orders for parts that do not require redesigns. He said, "A big advantage is that we can reduce the sales cycle for a part because we're seeing less back-and forth in the applications development process." When supports aren't part of the equation, "We can reduce the time to give customer quotes and provide them a part closer to their initial design," he said.

Business Expansion

When seeking to expand into new markets or gain new customers within an existing market, having a competitive advantage is key. For Knust-Godwin, the competitive advantage lies in lower prices and faster delivery that are possible when eliminating support removal.

Eliminate post-processing steps completely





VELO3D's capabilities can eliminate support structures altogether by printing parts free-floating in powder, which drastically eliminates secondary processes.

Support structure elimination is a component of Knust-Godwin's business growth plans. Corliss said, "If I can provide my customers with a lower cost and faster throughput, that is key." He noted that support removal and resurfacing often are not bench operations (hand working parts), rather they require machine tools to get the job done. Considering the cost of CNCs and the skill level of the operators, the added expense for a metal AM part can be significant. Additionally, when considering the time to prepare a CNC job and do the work, the impact on deliveries is substantial.

Corliss added, "Improved throughput is a key to our success because the more you get out the door, the more you can bring in." Freeing up CNC operations from support removal activities creates more sellable capacity without additional capital expenditures. And this fuels business expansion in both new and old markets.

Carter confirmed that throughput is critical to AM. Although speed is often positioned as a key benefit of AM, it is also an Achilles' heel. He said, "When we look at the price of the part, the majority of the cost is the build time alone. Any improvement in throughput helps offset that part cost. Therefore, if the actual machine time is dedicated to building the part and not support structures, we have a more efficient process and less material is consumed as waste."

More AM Opportunities

When opportunity knocks but a company cannot accommodate the needs, the business suffers a loss of ongoing income. For those serving internal customers, the inability to meet their needs translates to a reduction in the number of occurrences where AM can contribute to the company's success. An advantage of support-less metal AM is that more opportunities can be successfully addressed because fewer are turned away as impractical applications.

> "Support-free metal AM frees us up to use the geometry we'd like to use rather than being pushed into using a design that compromises the aerodynamics in order to make an AM-friendly part"

With elimination of support structures, Carter said, "We're now seeing applications that we couldn't address earlier." Bentley elaborated, "We have seen a sizeable list of parts that we would have

required design modifications to properly produce the geometries and get the right surface finish, and the customer ultimately didn't order the parts."

Both companies cited shrouded impellers as a prime example of what support-free metal AM makes possible. Carter said, "We've been approached for as long as I can remember, and I've been with the company for eight years now, to make shrouded impellers, They have been the holy grail, if you will, but they were difficult, if not impossible, to manufacture with previous equipment." He continued, "Our ability to produce support-less parts allows us to aggressively attack that market. That's what we saw right off the bat as the driving application. Hanwha is a great example of that. They came to us a few years ago, and due to technology limitations, the project couldn't move forward. Today, we've been working with them to produce incredibly advanced parts on the Velo Sapphire."

Incodema3D also referenced shrouded impellers. Volk said, "It does open up other markets for us. For example, shrouded impellers become a doable market." He noted that Incodema3D has built shrouded impellers in the past, but there were issues with support removal. He cited one example, "We did this with a customer who's in power generation, but it didn't turn out well. I mean we were able to do the product, but the amount of money it took to make it…it just wasn't feasible."

Beyond shrouded impellers, Carter further expanded by saying, "We've seen significant growth in projects for manifolds, conformal cooling, and nozzles and chambers for rocket propulsion--all because of support structure elimination and increased design freedom."

Optimal Performance

To accommodate or avoid support structures, design modifications may be necessary when using a 'traditional" LPBF process. However, these alterations may also impact the performance of the part. When supports become unnecessary at the process level, the new-found design freedoms allow ideal configurations that in turn yield optimal part performance.

Hanwha Power Systems, which is driving innovation in supercritical CO2 engines, has experienced the limitations of supported metal AM parts firsthand. Robertson said, "The parts that we are interested in for AM are generally pretty tricky parts to print on a standard AM machines just due to the support structure. What we have been working on the most are shrouded impellers, and that inherently has a lot of overhung features."

Robertson said, "Support-free metal AM frees us up to use the geometry we'd like to use rather than being pushed into using a design that compromises the aerodynamics in order to make an AM-friendly part."

Volk has seen a similar scenario with heat exchangers. He noted innovative designs that dramatically increase the surface area where heat exchange occurs but where too challenging for the metal AM processes. He said, "It opens up new possibilities to increase heat exchanger performance and efficiency."

Fuel Innovation

Perhaps the greatest advantage is innovation, which differentiates the innovator from all others. The benefit of support-less metal AM promotes innovation by removing barriers that constrain designs, processes, and business models. Interstellar's Thornburg said, "One of the things that my team and I

have been very attracted to is anything in the industry that provides more speed, more forward velocity, and faster innovation."

In Interstellar's view, support structures and the need to remove them, are an impediment to its mission of innovation in propulsion systems. By simply avoiding the removal procedures, its innovation is accelerated. Thornburg said, "The key to unlocking faster schedules and faster innovation is the ability to shrink the post-processing time down."

As discussed previously, shorter lead times are a benefit of support-less metal AM. The advantage that originates from that benefit that Thornburg relishes is faster realization of innovative concepts. "We are focused very much on innovation at Interstellar. So, I'm very keen on getting those prototype parts in the test facility and getting them tested in a system as fast as possible."

Another innovation-related advantage is creation without limitations. He said, "Instead of working around a limitation, I think it frees you up to be more creative and innovative. You're taking that time that would be spent to design around a limitation and applying it to creativity, which then leads to even better designed performance."

Considering support-less metal AM as its own innovation, he concluded, "That type of innovation is key to really fulfilling the promise of additive manufacturing."

Conclusion

The advantages of eliminating support structures from the metal AM workflow are numerous and extensive. The business case for Knust-Godwin is business expansion. For Protolabs, Incodema3D, and Stratasys Direct Manufacturing, the big win is in expanding the addressable market for metal AM parts. Meanwhile, Hanwha Power Systems gains performance, and Interstellar Technologies fuels innovation.

"With a support-less process, we can provide a much easier one-to-one transition from conventional manufacturing while still reaping the benefits of AM. "

Andrew Carter,
Sr. Manufacturing Engineer

stratasys DIRECT MANUFACTURING

"There are big, high value parts that can only be produced with Sapphire."

David Bentley,
Sr. Manufacturing Engineer

PROTOLABS Manufacturing. Accelerated.

"Support-less parts have a better surface finish and is repeatable. Reducing the human element increases reproducibility."

Mike Corliss,
VP of Technology

KNUST-GODWIN

Each company could build justifications based on time and cost reductions, but that is imprudent. Focusing on the smaller benefits ignores the powerful motivators that can drive businesses to act, to change, and to innovate. Both the benefits and the advantages improve the bottom line, but the advantages do so in a much more powerful way.

The advantages are numerous and extensive, so much so that this report is incomplete; just a glimpse at the potential. Additionally, the advantages that are meaningful to individual companies are unique, driven by their business conditions, goals and desires. Capitalize on support-less metal AM by discovering the unique advantages that will drive your business forward.

Contributors

We deeply appreciate the six companies that shared their insights and experiences.

Hanwha Power Systems Americas Inc.; Chad Robertson, Senior Engineer

Hanwha Power Systems (formerly Hanwha Techwin) is one of the fastest growing companies in the turbo machinery industry. As a total energy solution provider, Hanwha Power Systems is expanding the business globally, pursuing its world-leading technology and commitment to quality. Based in South Korea, it has offices in China, Italy, Russia, UAE, and the U.S. Hanwha Power Systems mainly produces turbo compressors and develops innovative power generation system such as sCO2 (Supercritical CO2) engines. Hanwha Power Systems Americas is the U.S. corporation, based in Houston, Texas, that has R&D and sales functions. www.hanwhapowersystems.com

Incodema3D, LLC; Scott Volk, former Chief Technology Officer (and now leads Innovation and Strategy at Keselowski Advanced Manufacturing)

Incodema3D, a division of the Incodema Group family of companies, specializes in contract additive manufacturing. The vision of Incodema3D is to create a serial production contract manufacturing operation, leveraging its proven knowledge and skills developed over decades in the advanced manufacturing industry. Incodema3D offers a range of additive production machines from multiple vendors and offers a breadth of materials to accommodate demands from a variety of key markets. www.incodema3d.com

Interstellar Technologies; Jeff Thornburg, President and CEO

Interstellar is a small, veteran-owned business focused on providing innovations in design and manufacturing for propulsion and space systems. With over 113 years of experience in aerospace and mechanical engineering for advanced space systems, the Interstellar team has previously worked several high-profile government and commercial space programs that have included the SpaceX Falcon 9 launch vehicle, the SpaceX Dragon capsule, and NASA's Space Shuttle. In addition, the Interstellar team has experience stemming from over ten rocket engine development and flight programs, including the Space Shuttle Main Engine, Air Force Integrated Powerhead Demonstrator (IPD) engine, NASA J-2X engine, SpaceX Merlin engine, SpaceX Raptor engine, SpaceX Draco and SuperDraco, NASA Additive Manufacturing Demonstrator Engine, and the PGA Engine program. www.interstellartechnologies.space

Knust-Godwin; Michael Corliss, VP - Technology

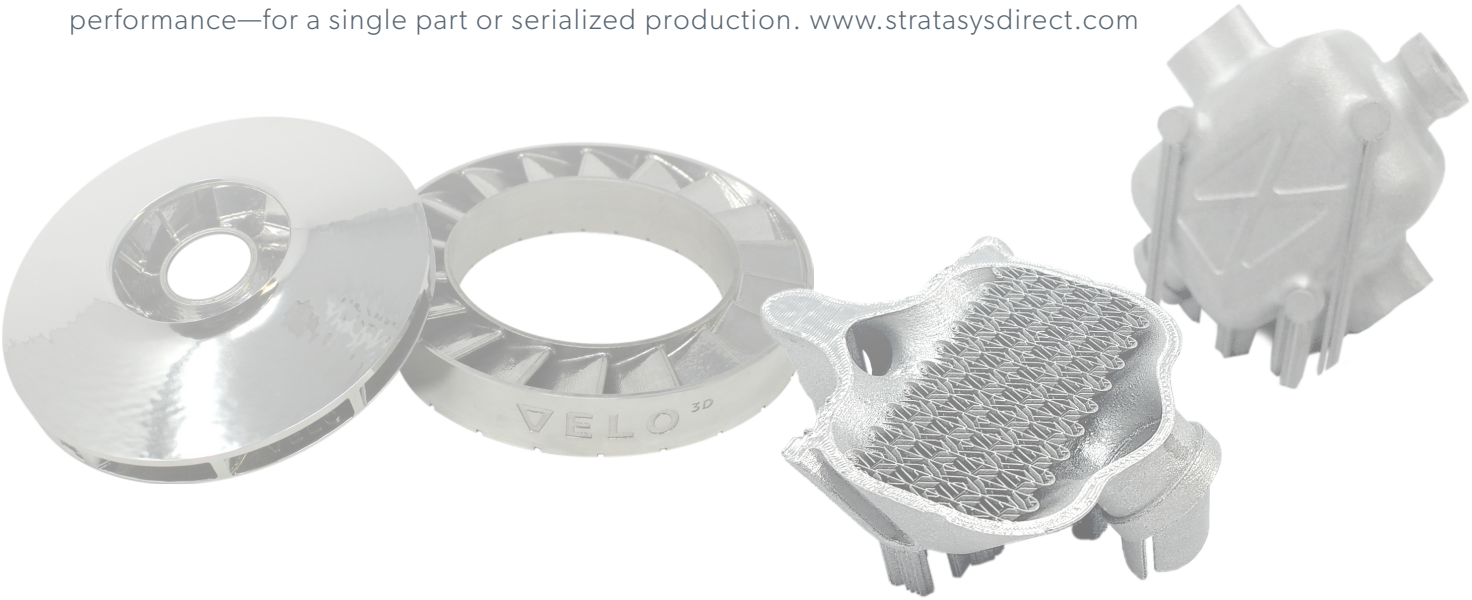
Knust-Godwin has been providing high-quality, precision production machining services for over a combined 100 years to companies throughout the world. It specializes in CNC turning and CNC milling with significant experience in the oil and gas, geophysical/seismic, semiconductor, and medical industries. Knust-Godwin is more than just a machine shop; it is part of the manufacturing solution. From a concept, to engineering, to prototype, to production runs, it provides a place to go for all machining needs. Its commitment to quality produces high-precision part components as well as complicated turn-key assemblies. www.kgsbo.com

Protolabs; David Bentley, senior manufacturing engineer for 3D printed metals

Protolabs is the world's fastest digital manufacturing source for rapid prototyping and on-demand production. The technology-enabled company produces custom parts in as fast as one day with automated 3D printing, CNC machining, sheet metal fabrication, and injection molding processes. Its digital approach to manufacturing enables accelerated time to market, reduces development and production costs, and minimizes risk throughout the product life cycle. www.protolabs.com

Stratasys Direct Manufacturing; Andrew Carter, senior manufacturing engineer

With 20 million parts shipped, Stratasys Direct Manufacturing is the leading provider of 3D printing and advanced manufacturing services utilizing a broad range of additive and conventional technologies. It leverages nearly 30 years of 3D printing, design and engineering experience to ensure project success at each stage of product development, from prototypes to production runs. Serving companies of all sizes, from start-ups to established global brands, it pioneers development of cutting-edge methods, materials and processes that optimize and enhance additive and conventional manufacturing's capabilities, redefining what's possible to help customers transform performance—for a single part or serialized production. www.stratasysdirect.com



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