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3D ADEPT MAG

3D PRINTING

DOSSIER : HOW DOES AM TRANSFORM AIRCRAFT DESIGN AND PRODUCTION TODAY ?

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3D ADEPT MEDIA
All about Additive Manufacturing

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Table of Contents

Hello & Welcome

Current opportunities of AM for Aerospace & Space

The number of aerospace 3D printed parts flying today varies from one aerospace company to another and depends on several factors including the period when they start using AM. Boeing for instance, one of the key industrial players driving the advancement of AM, has already produced over 70 000 3D printed parts, compared to space company Maxar which has already sent over 2,500 additively manufactured parts on orbit, compared to Collins Aerospace, another relatively new entrant who has already produced over 75 production 3D printed parts and opened a $14 million Additive Manufacturing center last year.

When we look at these stats, it is clear that aerospace companies using AM have clearly understood the value proposition AM brings to lightweight parts, functional prototypes and tooling. It is also clear that they are willing to push the use of AM beyond prototyping, to focus on functional parts that can directly be used in an aircraft.

The thing is, with the current advancements in Additive Manufacturing processes, LPBF is no longer the only production candidate that can meet the production requirements of aerospace, space and defense parts.

This issue of 3D ADEPT Mag provides a picture of how AM transforms aircraft design and production. With stories from AM users and insights into related processes, it provides an avenue to explore the various possibilities currently available on the market.

Kety SINDZE
Managing Editor at 3D ADEPT Media
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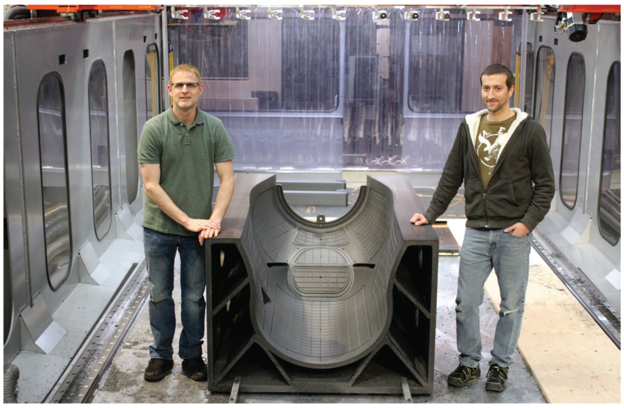
Editorial

Significant Cost Savings on Additive Tool

Partnership between Thermwood and General Atomics

The Details

Using a Thermwood LSAM 1020, the tool was printed from ABS (20% Carbon Fiber Filled) in 16 hours. The final part weighing 1,190 lbs was machined in 32 hours.



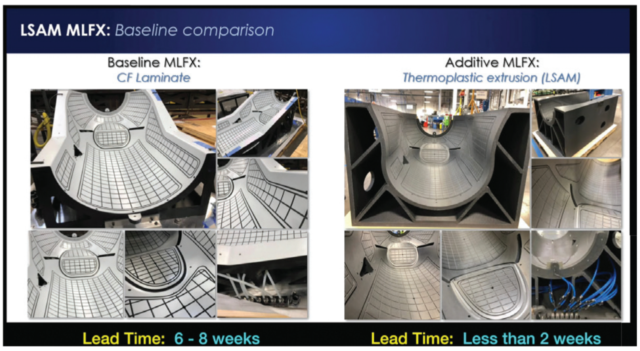
Cost Savings of around $50,000 vs traditional methods

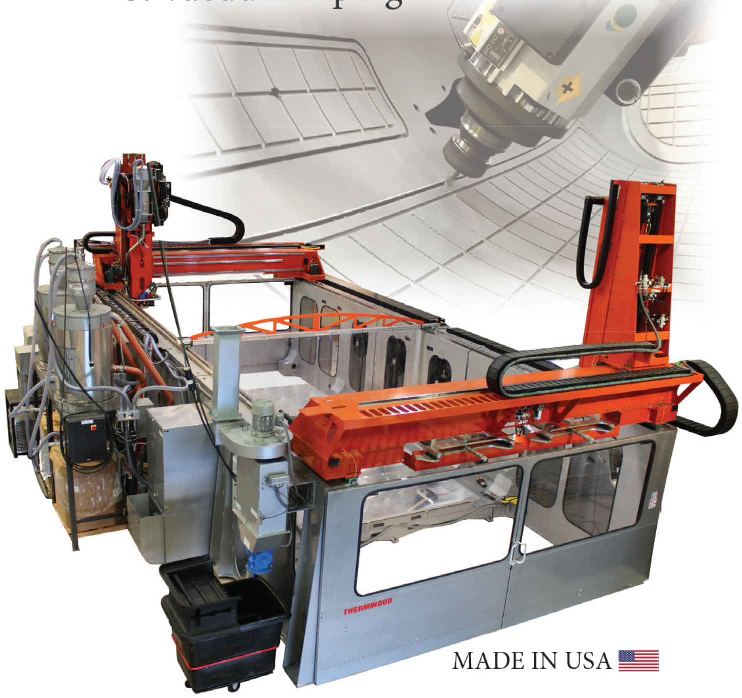
Total lead time for the part decreased from 6-8 weeks to less than 2 weeks by utilizing the powerful LSAM system.

The Results

- Cost Reduction: 2-3 times
- Faster Development: 3-4 times
- Production Capable Tool
- Vacuum Integrity
- Suitable for Large, Deep 3D Geometries, Backup Structures & Vacuum Piping

GENERAL ATOMICS AERONAUTICAL





Scan QR code to view a video of the LSAM and General Atomics process.

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Credit: GKN Aerospace

HOW DOES AM TRANSFORM AIRCRAFT DESIGN AND PRODUCTION TODAY ?

It is no secret that an aircraft is a complex system that involves a long list of interior and exterior components designed to maintain safety, meet certification standards, ensure functionality, and enhance comfort. Given the competitive and demanding requirements of such a large industry, production optimization and efficiency are continuously of paramount importance – hence the increasing push for manufacturing processes such as Additive Manufacturing (AM). Since the very first use of the technology in the 1989s, there has been an increasing shift in how aerospace parts are conceptualized, designed and produced. The article below aims to understand how the technology has evolved and how it's being adopted today by aerospace companies and part manufacturers.

As one of the first industries to adopt AM and given the number of growing applications achieved in the field, one can legitimately say aerospace has successfully integrated the technology into its production operations. If design and manufacturing are two different aspects of a part production; one cannot truly work without the other. They reinforce each other to generate the biggest impact and it's important to see how they evolve with the current advancements of the technologies.

Therefore, the article below ambitions to understand:

- The current state of design in aerospace parts production – and applications revealing the greatest impact of AM

- Which AM processes are transforming aircraft production the most and why?

- How far can AM be taken in the aerospace industry?

The current state of design in aerospace parts production

When you look at a **wing rib** for example – a structural part inside an aircraft that helps to carry some of the flight loads and maintain the smooth shape of the wing. With 2 metre long and 20 kg, this part has a complex shape that needs to be as light as possible to be the most functional. It used to be manufactured using machining in a single block of aluminum until engineers explored the AM route. With AM, they imagine a new design – a metal plate that is used as a base to build the part on. Where possible the part is designed so that the plate can be incorporated into the final part. Using WAAM, the AM part came out with a slightly wavy surface that still needs to be machined to deliver the final part.

This example shows that the right design must go hand-in-hand with the right production process. In aerospace, parts are complex and made up of intricate geometric structures. They form small parts that must fit together with other small parts. If the ability to produce several parts at once is one of the most cited benefits of "design for AM" – especially in the aerospace industry, one should note that the result of these designs often comes down to the use of the right design strategy.

The only thing, the design toolbox includes more and more complex techniques that require taking into account the **business case perspective** of the part being produced. Based on the example shared above, one can say "part consolidation" is one of the design techniques that is widely used in aerospace design to **help save weight and assembly costs**, while increasing the structural integrity of an AM part.

In general, *"AM design techniques and design strategies for aircrafts are being adopted differently in sectors like civil aviation, space, and ultralight aircraft vehicles in the context of urban air mobility and eVTOL.*

For ultralight aircraft vehicles, saving weight is, of course, a crucial element. AM supports this with proven design techniques like topology optimization, and all of AM's design opportunities are considered for components, including structural parts, and in different materials. AM is being utilized exhaustively for structural optimization and lightweighting. We see a similar situation for space applications. In both areas, making optimal use of the design space while

3D printed wing. ©GKN Aerospace

optimizing weight to functionality is essential. An interesting approach in this context is to switch to a lighter material or composite during the design exploration phase and compensate for its deviating material properties with geometric changes to the part design. In essence, AM is considered a valid manufacturing technology and is used as a complementary technology for a limited number of sophisticated solutions.

Looking at civil aviation the situation is different. Currently, the majority of the 3D-printed parts are not designed for AM. AM is ideal for sourcing low-criticality polymer parts for aircraft in civil aviation because parts can be printed off the virtual shelf, there's no waste, and no stock languishing in warehouses. However, existing designs are used and produced with AM, because it makes sense from a lead time or minimum order quantity point of view.

Nonetheless, AM offers a new approach to designing for aerospace by providing an economical alternative for damage-prone parts on planes. AM can provide tailored repair solutions for such parts, offering a path other than replacement and minimizing the time planes would otherwise be grounded.

This shows it's not always about finding the complex parts that require a complete redesign but the parts that make sense from a business case perspective. The right design approach is essential in this regard. Entirely redesigning a part is an investment, and the new design will require additional efforts to be accepted as a flying part. MROs and airlines are implementing Materialise's AM software to digitalize the production process and use the data available of thousands of builds from Materialise manufacturing to standardize designs and comply with safety regulations. Redesigning existing parts often doesn't have to rely on highly complex AM design technologies and only requires minor part changes. In civil aviation, safety is the primary concern, and the aerospace and AM industry must advance the standardization of 3D printing to raise its profile for civil aviation," **Erik de Zeeuw**, Market Manager Aerospace, Materialise explains.

Two other techniques that have also helped aerospace design evolve are **Generative Design** (GD) & **Topology Optimization** (TO). Not only have they been around the longest, they also show immediate benefits when it comes to show immediate benefits in terms of saving weight and increasing value when using AM.

AM processes that are transforming aircraft production the most – and applications revealing the greatest impact of AM

The number of aerospace parts flying today varies from one aerospace company to another and depends on several factors including the period when they start using the technology. Boeing for instance, one of the key industrial players driving the advancement of AM, has already produced over 70 000 3D printed parts, compared to space company Maxar which has already sent over 2,500 additively manufactured parts on orbit, compared to Collins Aerospace, another relatively new entrant who has already produced over 75 production 3D printed parts and opened a $14 million Additive Manufacturing center last year.

Credit: GKN Aerospace

When we look at these stats, it is clear that aerospace companies using AM have clearly understood the value proposition AM brings to lightweight parts, functional prototypes and tooling. It is also clear that they are willing to push the use of AM beyond prototyping, to focus on functional parts that can directly be used in an aircraft.

From a technology perspective, materials associated with aerospace parts are both **metallic and polymer**, depending on the criticality of the part. If polymer materials can be used across different AM processes, their selection still depends on how much they can achieve lightweight requirements with high strength in order to reduce emissions, save fuel, and adhere to the safety requirements. That's the reason why, **SLA** and **FDM** will remain ideal production candidates for producing prototypes. In the same vein, although SLS 3D printing, and LFAM can be used to produce respectively components like air ducts, and other forms of aerospace tooling, an increasing focus remains on the **use of metal 3D printing technologies** to achieve production parts.

With over **18 different metal AM processes** known to date, **laser-based powder bed fusion** technologies remain the most widely used AM processes. New metal 3D printing technologies continue to pop up on the market every day, and they come with great expectations in terms of cost reduction and production time. Furthermore, since the development of new technologies is faster than the applications they can enable – this makes it difficult to assess the maturity of other metal AM processes that are transforming aircraft production today.

GKN Aerospace, a multi-technology tier 1 aerospace supplier relies on an AM technology that involves layer-by-layer construction using metal wire or powder fused together with lasers. **Large-scale laser metal deposition with wire** (LMD-w) enables the production of complex and lightweight structures. These structures optimize the overall performance of aircraft components, contributing significantly to weight reduction, fuel efficiency, and the ability to create intricate geometries that were previously challenging with traditional manufacturing methods.

SMART Demo rotor produced by GKN Aerospace for Northrop Grumman Corporation (NGC). Credit: GKN Aerospace.

According to **Sébastien Aknouche**, Responsible for Material Solutions at GKN Aerospace in Sweden, today when we look at aircraft engines especially, no what AM process one leverages, to appreciate the impact of the technology on aircraft production, one must be able to identify in the short term, the following transformation factors:

- *The lead-time of demand – design – make – deliver. It is probably down to 5%, maybe even less, of the traditional approach for a new demand.*
- *There are fewer steps in the process than the traditional manufacturing of aircraft parts.*
- *AM allows us to utilize the already limited global availability of super alloys significantly more efficiently. We may produce 2 to 10 times as many engines with the same amount of metal. This again reduces the amount of waste material (carvings).*
- *Through AM, the lead time for industrialized production is just a fraction of traditional productions lead-time, where any change in demand may take over 2 years to meet.*
- *AM allows for rapid changes in demand and a much more flexible supply situation. This will allow for much smaller inventory and unlock a huge amount of cash currently tied to inventory.*
- *AM allows for less cost to the customer through higher flexibility of supply, less cash tied to inventory, higher security of supply with less under-absorption and much faster process from new product to industrialized process.*
- *Any AM production process provides for a significant and positive environmental factor. The CO2 emission is substantially less through less energy-demanding processes and less shipping, and the utilization of our global resources is significantly more effective.*

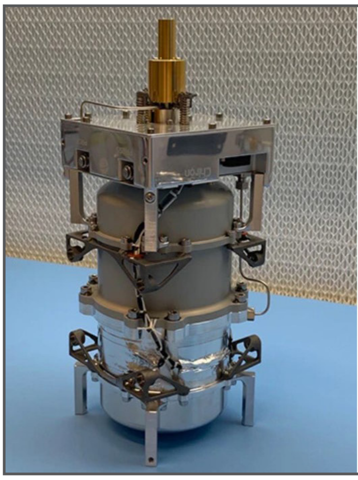
That being said, aircraft parts must undergo a certification process to be deemed suitable for flight operations. These certifications may come from **FAA, EASA, IASA** depending on the region where the part will be used. The paradox is, although metal AM technologies are the processes that drive the most the growth of AM in aerospace, the validation process for any metal component remains quite long. This may take 7 to 10 years compared to plastic 3D-printed parts.

When asked if there are lessons one can learn and replicate from plastic 3D printed parts to advance the use of metal 3D printed parts, Aknouche said these lessons could be *"adopting a more iterative testing approach, leveraging simulation tools for virtual testing, and establishing standardized testing protocols. By incorporating these practices, the aerospace industry can potentially reduce the validation timeline for metal components, ensuring safety and compliance without compromising efficiency."*

Nevertheless, the applications revealing the greatest impact of AM remain those complex, lightweight components such as engine components. *"These parts benefit from the design freedom offered by AM processes, resulting in improved performance, fuel efficiency, and reduced environmental impact. Moreover, the ability to consolidate multiple components into a single, intricately designed AM part contributes to overall weight reduction and increased aircraft efficiency,"* GKN Aerospace expert adds.

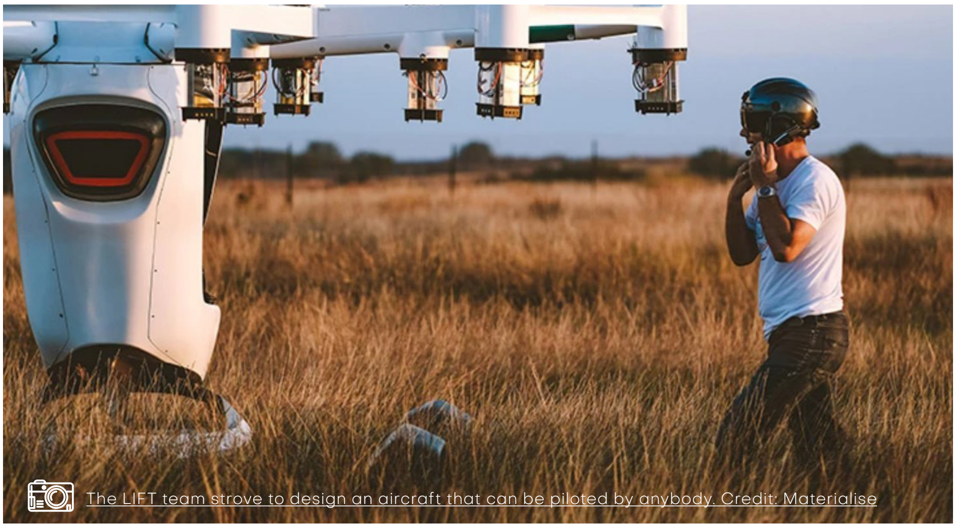
Outside of the metal AM segment, **Erik de Zeeuw** notes that *"low-criticality polymer parts or parts prone to breakage in and around the aircraft are perhaps where AM stands out the most in terms of impact. One such example is the* ***cabin decompression panel on the Boeing B737****. The latches and pins on the panel tend to break frequently. Stirling Dynamics worked with Materialise to design a reinforced panel that had the same functionality but was stronger and less likely to break than the original part.*

These low-criticality parts are not just the bread and butter of AM for aerospace. They also provide the data required to work on high-criticality parts. This data is being used by aerospace companies today to ensure repeatability in their manufacturing processes."



More than 25 of Bradford Space's water-powered comet propulsion systems are currently in orbit. Copyright Bradford Space. Shared by Materialise.

How further can AM be taken in the aerospace industry?



The LIFT team strove to design an aircraft that can be piloted by anybody. Credit: Materialise

Based on our conversations with experts invited to share insights into this topic, one would like to keep in mind three main areas of interest: **new designs, aircraft structural components, and the buy-to-fly ratio.**

When we look at design, the most important transformation factor that will help propel the adoption of AM in aerospace is **new designs**. According to **Aknouche**, *"new designs of jet engines, for example, will make them lighter and more effective and thus save CO2 emissions every minute the airplane flies. "Even though we have been able to design and calculate the advantages of a future vision of new engines, we have not been able to realize them until metal-based AM was introduced,"* **he outlines**.

As far as aircraft structural components are concerned, we have seen examples of 3D printed parts whose design is the perfect replica of the same part previously produced through machining. One of the challenges we often see is that, sometimes, the complete redesign of the part to achieve the well-known advantages of AM makes it complicated or "impossible" to achieve a part with intricate 3D-printed forms that could be certified. Indeed, given its stringent regulatory requirements, it's easier for the aerospace industry to certify a part design and maintain that design throughout the entire lifespan of the aircraft. Add the problem of quality assurance, you reach another level of complexity to demystify. For this reason, despite the potential of AM for structural parts, we might need to wait a bit longer, for new parts, with new designs for new aircrafts to pop up before saying we've reached a new level of maturation of the technology.

"AM and Materialise haven't rushed to tackle the high-criticality metal structural components market. Part of that is due to the strict safety regulations that are necessary in the aerospace industry, but some of it has to do with the readiness of the 3D printing technology itself. However, with Materialise's track record of providing low-criticality polymer parts, the data now available through our work, and the investments by major aerospace companies such as GKN, AM is being considered for structural aircraft components. The winglet of the Aviation Alice aircraft designed by GKN is just one example of work in this space. In parallel, Materialise and other partners are working to create a path to qualify the process of producing metal AM parts. The group consisting of aerospace and AM experts will provide a whitepaper as a first effort to author an SAE Aerospace Recommended Practice for using in-situ process monitoring to validate an AM process. Such efforts will drive the technological readiness of AM and motivate more aerospace companies to consider AM for high-criticality parts in airlines", de Zeeuw comments.

As for the buy-to-fly ratio, GKN Aerospace's expert confirmed "improved buy-to-fly ratio" could be a key transformation factor in the industry in the long run: *"the weight ratio between a substrate and a completed part) will enable us to utilize available metal even more efficiently with even less waste. Indeed, there is a reduced waste of material the more the AM process becomes efficient, and the more the "buy-to-fly" ratio moves closer to 1,0."*

"There is probably no clear border to where we

Expleo's Flight-Ready Spare Parts produced in collaboration with Materialise. Credit: Materialise *may end up, but we will not be able to make parts with no material, but maybe parts with a "buy to fly ratio close to 1,0", and will not have lead-times down to zero, but very short, and the production will probably not have zero emission, but very little. The question is more how close to that ideal stage will we get? The answer to that one will have to follow the development to find out"*, he concludes.

Obviously, other areas of interest could have been mentioned. In the end, let us not forget that the way AM advances, depends on the player that is making use of it.

Editor's notes

GKN Aerospace and Materialise are collaborating on several projects to address certification and additive production of functional and flight-critical aerostructures. However, none of the companies was aware the other one was participating in this dossier.

GKN Aerospace has been invited to share insights into this topic as its expertise lies in leveraging AM to optimize aircraft design and production processes. The company said its latest project involves the development of advanced AM techniques for critical structural components, showcasing the profound impact on both design flexibility and manufacturing efficiency. By integrating AM into our workflow, we have achieved notable advancements in weight reduction, part consolidation, and overall system performance.

As for Materialise, it has now fully matured its aftermarket offering for low-criticality cabin parts. Over the last 10 years, they have gained an enormous data lake proving the consistency of the technology, process, material, and machines we operate. Although we certified the process some five years ago, getting printed parts on an existing aircraft is not as easy as it may sound given the strict requirements of the industry. The company continues to collaborate with aerospace companies to advance key areas of improvement in the aerospace industry. Apart from GKN Aerospace, one of its recent partnerships was signed with Stirling Dynamics.

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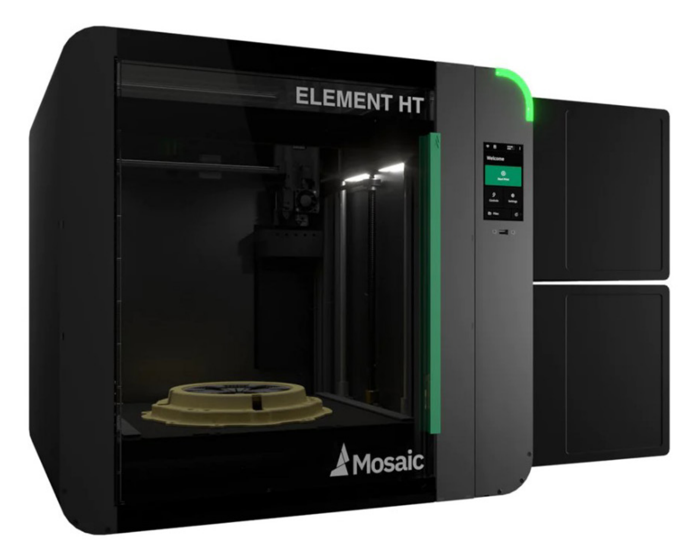
The "fall and rise" of desktop 3D printing

3D printing may have started with desktop 3D printers but the current demand for more industrial applications is raising a lot of debates on the future growth of this specific segment. Interestingly, despite their DIY roots, the desktop 3D printing market that has almost always been associated with FFF 3D printing has expanded to encompass resin 3D printers which have found their niche in industries like jewelry. But is it enough to drive the growth of this segment? As the industry strives for the industrialization of AM, it's fair to reassess the importance and current place of desktop 3D printing in this journey.



Desktop 3D printer Element HT - Credit: Mosaic Mfg

First and foremost, desktop 3D printers are machines that are sold for less than $ 5,000 and that can easily stand on a desktop office. Obviously, this price varies from one OEM to another as the market is also filled with desktop 3D printers that cost more than $ 5,000. It all comes down to the capabilities of each 3D printer.

The problem with desktop 3D printing is that not only was it behind the media hype of the 2010s – when the technology was trying to carve out a legitimate place in the market, but this hype generated unrealistic expectations regarding its true potential at the time. As time went by, most of the analyses made on 3D printing were made with those expectations as a basis.

Eventually, with the increasing focus on industrial 3D printing, desktop 3D printing has been unconsciously relegated to the status of "a consumer or educational technology." Yet, today, according to CONTEXT's latest report, "entry-level printers remain the hottest segment" of the market.

CONTEXT is a market intelligence and analysis firm that tracks global 3D Printer shipments quarterly. The company has seen the ENTRY-LEVEL category (consisting of printers selling for $ 2,500 and below) see the most consistent growth with shipments in Q3-23 up +9% from the prior year.

Before **Chris Connery**, VP of Global Analysis and Research, explains this context, I would like to emphasize that being labeled "a consumer or educational technology" is not pejorative – especially when one realizes that the ENTRY-LEVEL 3D printer segment represents the 2nd largest market with 28% of the global system revenues coming from the sale of products in this price-call over the trailing-twelve-months.

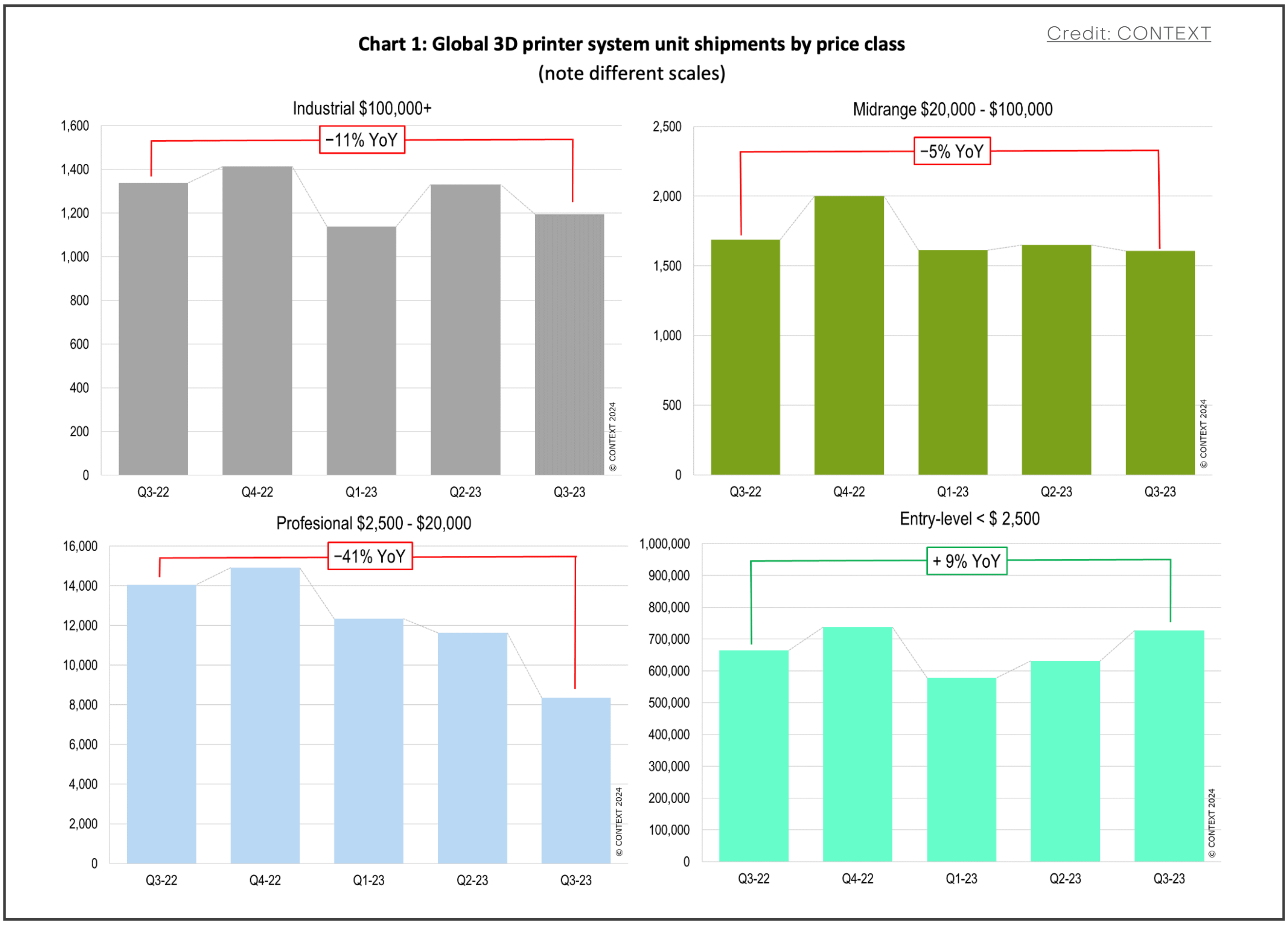
"While most of the industry headlines rightly surround happenings in the industrial price class (which accounted for 53% of the global system revenues in the TTM), the low-end 3D Printers are not just toys for consumers with this segment representing an important gateway for many to learn and understand various 3D Printing concepts," Connery outlines.

Speaking of the reasons why these entry-level printers remain the hottest segment, he continues:

"On a trailing twelve-month's basis (Q4-22 to Q3-23) compared to a year-ago (Q4-21 to Q3-22) shipment growth was even stronger with +12% more printers shipped globally. While this side of the market continues to see gains by market share, leaders like Creality, Anycubic and Elegoo (with Creality holding a particularly strong market-share lead), upstarts like Bambu Lab have really taken the market by storm and helped to grow this market. While in the past, products at the low end were assumed to be just for consumers, research shows that companies like Bambu Lab have seen strong growth in non-consumer markets. For this reason, CONTEXT has recently moved away from classifying such products as "PERSONAL" 3D Printers (or "Desktop" or "Consumer") printers to rename this low-end as "ENTRY-LEVEL" to help highlight the increasing sales of these products in more professional markets. To better highlight this trend, shipments in the price-class CONTEXT calls PROFESSIONAL (which consist of printers in the $ 2,500 to $ 20,000 price-range) have seen a -27% drop on a TTM (trailing-twelve-months) basis showing the cannibalization of PROFESSIONAL products by

lower-priced ENTRY-LEVEL printers. Key to this growth in the ENTRY-LEVEL category (and decline in the PROFESSIONAL category) has been global inflation which has pushed price points up, causing buyers to seek lower-price alternatives. The introduction of more feature-rich "professional" type products at lower prices in this ENTRY-LEVEL category has seemingly been well received and allowed buyers to comfortably shift demand from higher-priced PROFESSIONAL products to lower-priced ENTRY-LEVEL products without feeling that they have sacrificed functionality or quality."

Credit: CONTEXT

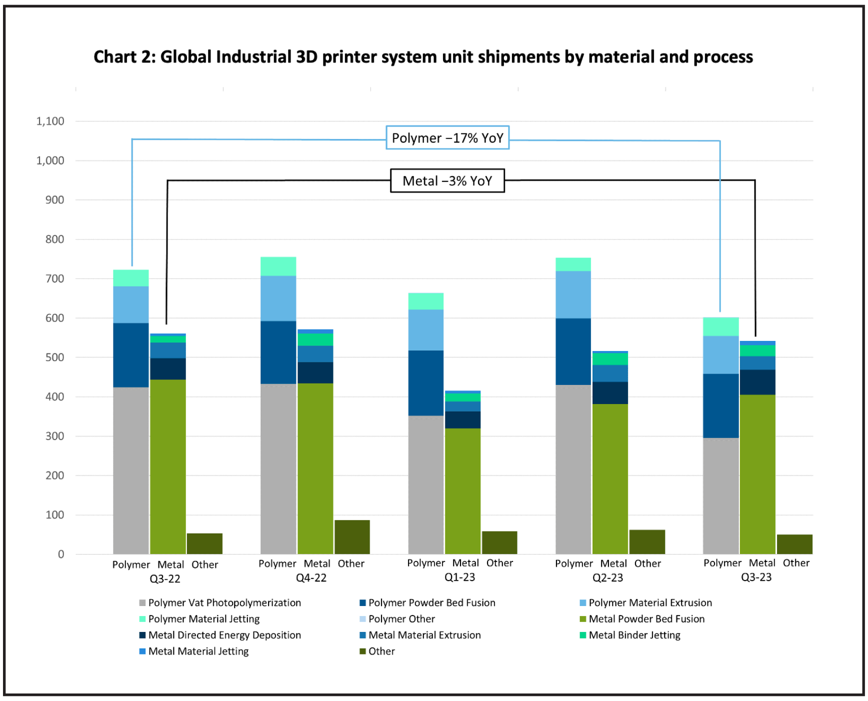


I hear what Connery is explaining about those entry-level 3D printers and I can't help but think that somehow, these brands that have the strongest market share (Creality, Anycubic and Elegoo) have been victims of their reputation – that is "designed for consumers and makers". I still remember how a Creality employee told me two years ago that he sold about 200 Creality 3D printers to a big aerospace company but nobody would ever know about that. The fact is, it's fancier to say that a multinational conglomerate buys 3 industrial 3D printers rather than 200 Creality desktop machines.

Credit: Mosaic Manufacturing

To avoid such generalization and labels related to desktop 3D printing, Connery seems to recommend one should rather categorize those 3D printers by price-classes:

"Often times people reference the "consumer goods" segment as a key end-market for 3D Printing/Additive Manufacturing but indeed it gets a bit confusing when painting the "3D Printing" market as one, cohesive market. For example, there are printers which costs millions of dollars and sit on factory floors, down to desktop variety products which cost a few-hundred dollars and are often used by general consumers typically in the home. To help compartmentalize various solutions and end-markets, CONTEXT compartmentalizes printer hardware by price-classes which it calls ENTRY-LEVEL (for printers under $ 2,500), PROFESSIONAL (those ranging in price from $ 2,500 to $ 20,000), MIDRANGE ($ 20K - $ 100K) and INDUSTRIAL ($ 100K+). Beyond this high-level price-class distinction, printers can be further segmented by printer type (such as polymer resin-based VAT Photopolymerization printers or polymer Material Extrusion printers or even laser-based metal Powder Bed Fusion printers in the INDUSTRIAL price-class), different materials which various printers can handle (such as Polymers, Metals, Ceramics, Composites, Bio, etc.), end-markets in which these printers are used (such as Aerospace, Medical, Hobby, etc) and even the principle use of these printers (used for prototyping, for single end-part production, for mass-customization, for volume production, etc.) Often when people reference the "consumer goods segment" of the 3D Printing market, they mean the use of industrial machines in the mass production of consumer goods. Today already, industrial 3D printers are used for manufacturing of certain consumer goods like the mid-soles of running shoes (a consumer good). Others are experimenting with using 3D Printers to mass-produce jewelry or even parts for mobile phones and smartwatches. Another way that people sometimes reference "consumer goods" when talking about 3D Printing, however, is the in-home use of ENTRY-LEVEL printers for general consumers to make products for themselves. For its tracking, CONTEXT classifies the end-markets for ENTRY-LEVEL 3D printer usage either by those unique to the consumer market including: Hobby/DIY, Gadget, Household and Scale Model or by their principal use including: DIY, Toys&Games, Hobby/Household and Fan Art. The growing trend being seen however is the use of these products for more industrial and professional end-markets including: Automotive, Medical & Healthcare, Dental, Aerospace & Aviation, Jewelry, Education, R&D, Art & Architecture, Energy, Oil & Gas and Movie Props. Some areas for the biggest growth in ENTRY-LEVEL printer shipments have been in Dental (from resin-based printers) and in Automotive, Medical & Healthcare, Aerospace & Aviation and Jewelry markets all of which considered professional (versus consumer)."



So, the communication purpose and the labels left aside, what can truly justify an investment in several desktop 3D printers for one's business rather than one industrial 3D printing machine?

We need to recognize something: current desktop 3D printing solutions have overcome the limitations of earlier machines, and now provide strong reliability and versatility. The hardware, software, and materials have been enhanced to offer a hassle-free user experience.

That being said, for **Mitch Debora**, CEO of Mosaic Manufacturing, a Canada-based 3D printer manufacturer, *"the reason businesses are choosing to invest in several professional level printers over a single industrial system is all about scale and cost control. The demand for additive manufacturing is increasing significantly within businesses in product development and manufacturing. They understand that multiple printers running in parallel will significantly outperform a single industrial printer in both throughput and part cost. There is a case to be made for $ 100k+ industrial printers in niche applications* *where a specific feature set is required but for the most part, investing in 5 x $ 10k capable professional printing systems will put a business in a much better position. We see this all the time at Mosaic where businesses will sell off their legacy industrial printers and replace them with several of our ELEMENT HT multi-material and high temperature printers."*

Array 3D printers. Credit: Mosaic Mfg

Taking the example of their Element and Array 3D printers, he explains the reasons that may lead one company to invest in the Element solution rather than the Array: *"At Mosaic, we offer a desktop printer called Element as well as an automated production system run by robotics called Array. Typically a business that has demand for 5+ printers will purchase an Array since the robotics free's up their employees time to work on value generating work rather than spending time operating the printers 24/7. Businesses see a very quick ROI on Array by freeing up the staff's time thanks to the robotics in Array. Businesses who invest in Element typically do so either because they don't have the capacity requirements that Array offers or because they are looking to validate a business case before investing in a fleet of Arrays. It is common for us to see a customer buy an Element and then upgrade to an Array or to buy an Array and then to upgrade to 5 Arrays – the modularity of these building blocks makes it effortless for companies to incrementally grow capacity with their business."*

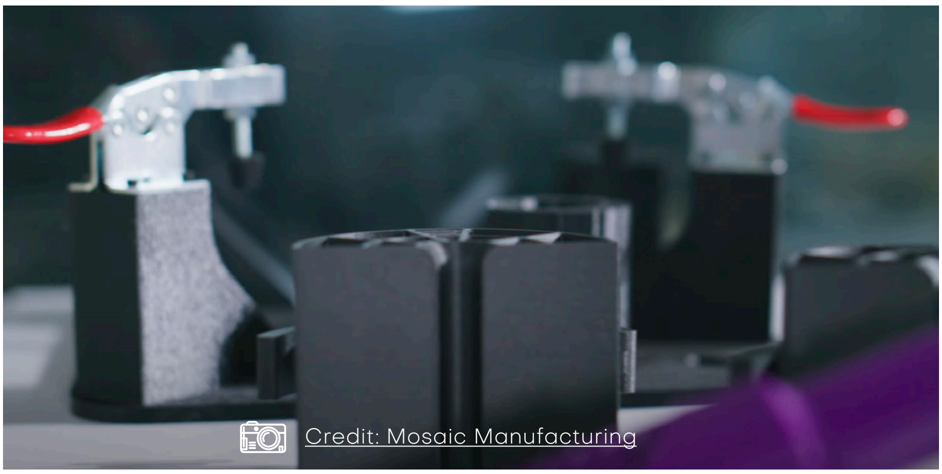
Debora's explanation highlights the current possibilities of desktop 3D printing – possibilities that show how it can be a great addition to a workshop because it seems to make the capabilities of high engineering possible in a safe, easy-to-use bundle that can enable savings while delivering ROI.

How might the desktop 3D printing market evolve this year?

I am more optimistic about desktop 3D printing and how it can be deployed across industries to achieve various manufacturing purposes. Bear with me, I am not saying desktop 3D printers could match the performance of industrial machines. Industrial 3D printers will always lead the way in some industrial settings, but there is a legitimate place today for desktop 3D printing in such settings as well.

"I don't see it as a rise and fall of desktop printers so much as I see it as the ride of desktop printers alongside the rise of industrial printing systems," Mosaic Mfg CEO reacts when asked if it was a "rise and fall" situation.

"At times it can seem like the desktop segment is falling but I think this is an illusion and is more a symptom of industrial systems outpacing desktop systems at that moment. Both segments are growing at a healthy pace year over year and are complementary. For example, it is common that industrial applications are inspired by teams who had access to desktop printers (at home or at work) and connected the dots between challenges in their business and the capabilities of additive manufacturing. The more capable and accessible that hobby grade desktop systems at the low end of the market become, the larger the funnel of technical people there will be who will inspire the next 100 killer applications for additive manufacturing. This year I expect desktop printers to become more capable in material properties, throughput, and user experience," he concludes.


Credit: Mosaic Manufacturing

THE USE OF HIP FOR CRITICAL 3D PRINTED PARTS : INTRODUCTION AND APPLICATIONS

Hot isostatic pressing (HIP) is a process used to reduce porosity and increase density in powders, cast and sintered parts in a furnace at high pressure (100-200 MPa) and at temperatures from 900 to 1250°C (1652°F to 2282°F). To guarantee material properties in demanding environments, the process has been a key part of upstream production processes such as casting, MIM, and over recent years, Additive Manufacturing (AM). In AM especially, the process has proved its efficiency in removing defects and improving the mechanical properties of materials for critical 3D printed components. The dossier below aims to understand how and where exactly HIP can influence the AM process to make the most of it.

This dossier is part of our series of "post-processing" articles, which aim to demystify each post-processing task that can be used at the end of the additive production. Remember that **post-processing** is an umbrella term that covers a variety of stages that 3D-printed parts have to undergo before being used for their final purpose. Needless to say, the use of each post-processing task depends on several factors including the AM process and materials used as well as the ultimate goal to achieve for a given 3D printed part.

HIP is considered a type of heat treatment solution that can be applied to parts manufactured via both AM and traditional manufacturing processes. As a reminder, in a previous dossier, we discussed heat treatment for AM parts. In this feature, we will focus on helping AM users understand:

- The differences in the use of HIP for casting, MIM and AM

- How this process is being performed for 3D-printed parts especially

- The decisions that may lead to the use of HIP

The differences in the use of HIP for casting, MIM and AM

Although HIP is mostly associated with metallic parts, it should be noted that it can also be used to reduce porosity and increase density in ceramics, polymers, and composite

Courtesy of Aalberts surface technologies

materials. While metals and ceramics are the most-widely used materials with HIP, **Greg Lane**, Key Account Manager at **Aalberts surface technologies**, notes that Fe-, Ni-, and Ti-base (super-) alloys are some of the typical metals that can be treated via HIP, along with Aluminum (AlSi10Mg and A357), Cu, SS , Tool Steels, Co alloys, MCrAlY. For this reason, in this article, most examples and insights will be given taking into account metal 3D printed parts.

Speaking of how porosity and defects occur, **Greg Lane** said: *"Porosity is generated during solidification in investment castings and AM as well as during sintering. A remaining pore is always a weak spot and can serve as a possible crack initiation site, thus, limiting the lifetime of a part. Even a small network of pores within a part makes crack initiation and propagation very easy, especially when subjected to cyclic loading."*

If the goal of HIP remains the same – **enhance material properties and remove defects** – regardless of the manufacturing process used, there are a few considerations that are specific to casting, Metal Injection Molding (MIM), or Additive Manufacturing (AM).

The HIP task in casting aims to mainly address porosity issues while with MIM, it helps to improve the density of the final product. As far as AM is concerned, HIP helps to meet issues related to defects and pores raised during the manufacturing process.

As you can see, HIP is not a "one-size-fits-all" solution. Understanding how it works is important to assess the specific considerations related to metal 3D printed parts.

How this process is being performed for 3D-printed parts especially

In general, the HIP process happens in a pressure vessel inside a hot furnace. Parts are placed inside the chamber, which is then heated up, filled with an inert gas like argon to make it pressurized, and kept at this temperature for a specific time. The heat and pressure are evenly applied to the part to remove any holes. Sometimes, rapid cooling with pressure is also used as a quick cooling bath. The whole process can take 8 to 12 hours or longer.

HIP can be leveraged with parts produced via almost all metal AM processes. In his list of the most used processes, **Lane** counts **Laser Beam Powder Bed Fusion (PBF-LB), Electron Beam Powder Bed Fusion (PBF-EB), Wire Arc Additive Manufacturing (WAAM), as well as Binder Jetting.**

As far as HIP for 3D printed parts is concerned, Lane first recalls that most of the commercial HIP treatments applied to AM parts are the same as for cast parts, but are not optimized. *"However, the nature of the AM process is quite different in comparison to the aforementioned manufacturing routes. The rapid solidification during the build job produces a very fine microstructure with unique properties. This structure can be up to two orders of magnitude finer in comparison to the investment cast counterparts, even for the same type of alloy. Because of this, a tailored HIP cycle can have a huge positive impact on the properties of an AM part and the AM production chain itself,"* he adds.

"A typical HIP cycle starts with heating where pressure and temperature are increased. During the holding/soaking the combination of high temperature and pressure up to 200 MPa closes the pores and cracks in the material. The materials are virtually fused to a defect-free state. After a specific amount of time, the cycle is terminated via cooling. Modern HIP equipment can set desired heating and cooling rates as some processed materials require fast or fixed cooling rates," he continues.

Figure 1: Mono-lithic vessel design (top) and pre-stressed wire-wound vessel design (below). Without pressure applied (left) and with pressure applied (right). Source:
Heat treatment of PM parts by Hot Isostatic Pressing by Anders Eklund

What we learned from Lane is that **temperature, pressure** and **hold time** are the three main parameters in an HIP cycle that determine densification. On another note, even though powder-based 3D printing materials are usually very dense, they can still lead to defects like pores and internal cracks. These defects including their size and occurrence depend on the type of powder and how it's printed. They can therefore alter the mechanical properties of the material – especially fatigue behavior. HIP can help address these challenges and help deliver a relatively dense material.

The decisions that may lead to the use of HIP rather than another alternative post-processing process

Many are familiar with the use of HIP for the densification of castings for industries with very high demands on fatigue resistance, such as the aerospace industry and industrial gas turbine industry. Interestingly, AM yields an ever-increasing demand for HIP beyond these industries.

HIP has already led to the manufacture of different types of components such as the large and massive near net shape metal parts used in the oil & gas industry, weighing up to 30 tonnes, or net shape impellers up to one metre in diameter – all of which can be produced via AM processes. Other applications range from orthopedic implants to racing cars and rocket engines.

So, when and how does one know that HIP is the post-processing step one should use for a given application? For Lane, it all comes down to **porosity**:

"A well-controlled build job can minimize the tendency to introduce internal defects such as porosity in AM components to an acceptable level for some non-demanding applications. However, for use in critical applications in demanding industries such as energy, aerospace, defense and medical, where performance and safety are key, porosity must be eliminated. In the as-built condition because without HIP, the remaining porosity can lead to differences in mechanical strength (scatter of properties), either between parts from the same built plate, or in different cross sections of larger parts. A residual network of pores makes crack propagation very easy when subjected to cyclic loading in jet engines (blades) or within the human body (HIP-implants)."

To explain how HIP can generally improve productivity and product quality of critical 3D printed parts, he adds:

"The HIP process is often just one part out of the total processing route. A traditional route would include a pre-HIP stress relief treatment and post-HIP solution annealing and/or precipitation hardening carried out in a vacuum furnace.

The state-of-the-art HIP equipment offers the possibility to incorporate stress relief and the solution annealing/hardening into the HIP cycle because defined heating rates with intermediate holding plateaus as well as fast cooling rates can be realized. This streamlines the AM post-process chain, increases productivity of the printers and, in the end, improve mechanical properties and the lifetime of AM components."

The table below summarizes the benefits of HIP captured when applied to AM parts and the areas where operators should still pay attention:

Key benefits	Pay attention to:
Removing printing defects regardless of their number	Residual stresses in the material introduced during the AM process may take place
Enhancing fatigue properties	Due to their differences, the properties of printed metals may pose challenges during the HIP phase
No distortion of the net shape AM parts is to be expected during HIP	
A lean manufacturing route, leading to shorter production lead times	
Reduced Environmental Impact (in the case of near-net-shape and net-shape parts)	

Concluding thoughts

While HIPing processes are well-established and understood for processes like castings, a whole book still needs to be written to document the specifications of these processes for AM parts. While the article above provides a first introduction to HIP, it's crucial to keep in mind that the diversity of material properties in metal 3D-printed parts continuously changes the way HIP can be applied.

Nevertheless, as per the words of Lane, HIP remains a post-processing step that significantly improves product performance while offering the potential for shorter overall printing times and reducing the final costs for AM companies.

Editor's notes

To discuss this topic, we invited one company whose expertise in the field has been acknowledged across several industries adopting AM technologies and beyond:

Aalberts surface technologies, a global surface technology service provider. As a full-service provider of specialized heat-treating solutions, state-of-the-art HIP systems were added to the company's existing thermal processing capabilities (vacuum heat treating) in its Nadcap facility in Greenville (S.C.) to meet the special needs of the aerospace and power generation industries. As a full-service provider under one roof, the cost avoidance benefits of logistics and material handling along with improved turn-around time over standard industry benchmarks places their customers at an advantage over their competitors. This advantage enables them to increase their cash flow through faster turn times and allows for getting products to market faster.

AM Shapers

AGILE SPACE INDUSTRIES ON THE USE OF ADDITIVE MANUFACTURING IN IN-SPACE PROPULSION SYSTEMS

Dustin Crouse, Lead Process & Development AM Engineer at Agile Space Industries

Apart from electric propulsion systems used for commercial communications satellites, most of the rocket engines in service today are chemical rockets. This means that they rely on combustion reactions between a fuel and an oxidizer to produce high-velocity exhaust gases. The thing is, this type of propulsion system presents several challenges that need to be prioritized to deliver high value for the in-space propulsion market. In its list of priorities, ***Agile Space Industries*** *discusses the challenges where Additive Manufacturing plays a pivotal role.*

For me, space exploration comes down to how far we can travel, how quickly and cheaply we can get there, and what we can bring along. With in-space propulsion systems at the heart of the new space economy, Agile Space Industries happens to be one of the few companies that continuously bets on AM.

Although the company was founded in 2009, **Agile Space Industries** appeared on our radar for the first time in 2021 when it acquired 3D printing service bureau **Tronix3D**, a long-term supplier based in Pittsburgh, PA, USA. Those who have been following the company since the very beginning probably witnessed its rebranding from AMPT – its first name – to Agile Space Industries.

"AMPT was awarded one of the first SBIRs for the additive manufacturing of rocket injectors in 2009, but at the time the technology for additive manufacturing simply wasn't at the same state of maturity that it is today. As the field of metal additive manufacturing evolved, and with the emergence of a new generation of moon landers requiring innovative propulsion solutions, the timing was perfect for us to begin crafting our own designs. In 2019, AMPT became Agile Space Industries, and we started developing our own thrusters which are uniquely designed to be additively manufactured," **Ben Graybill**, Additive Manufacturing Operations Lead and **Dustin Crouse**, Lead Process & Development AM Engineer at Agile Space Industries told 3D ADEPT Media.

With the acquisition of Tronix3D, what started as an operation to optimize the performance of propulsion systems used to power NASA and SpaceX's lunar missions turned out to be another core activity of the company.

Mounted in building

"While we are our own primary additive manufacturing client and are thoroughly satisfied with the results, we also engage in several external additive projects, typically maintaining 3-4 multi-year programs at any given time.

Our scope of work is diverse, covering a range from in-space propulsion systems to naval applications to petroleum extraction systems. A key aspect of our services is leveraging the expertise of our engineers in Design for Additive Manufacturing (DFAM). The project involves intricate product design challenges and the use of specialized and exotic alloys.

Moreover, when it aligns with our strategic objectives, our process development team takes on the task of integrating new alloys into our workflow. This requires defining and implementing new production processes from scratch, which are tailored at each step to meet the unique demands of the material and application. This approach allows us to continuously expand our capabilities and offer cutting-edge solutions across various industries", Graybill and Crouse explained.

To date, Agile Space is known for the manufacture of thrusters and rockets engines, providing a set of services that range from design, AM services, subtractive manufacturing to testing capabilities.

The challenges of in-space propulsion systems

Those who do not have an engineering background may keep in mind that space propulsion is a branch of aerospace engineering that sheds light on methods and technologies that propel spacecraft and satellites through outer space.

The problem is the methods used to propel spacecraft and satellites are complex and sometimes hard to combine with new manufacturing technologies. They include **Cold Gas Space Propulsion, Nuclear Propulsion, Electric Space Propulsion** and **Chemical Space Propulsion** – the most widely used method and the specialty of Agile Space Industries. As said above, this propulsion technique relies on combustion reactions between a fuel and an oxidizer to produce high-velocity exhaust gases.

With the integration of manufacturing technologies in the development process, space companies have to deal with major hurdles that are both economic (economies of scale), and technological (material science, and miniaturization).

"Top 5 challenges for in-space propulsion are thermal management, ground test

Ben Graybill, Additive Manufacturing Operations Lead

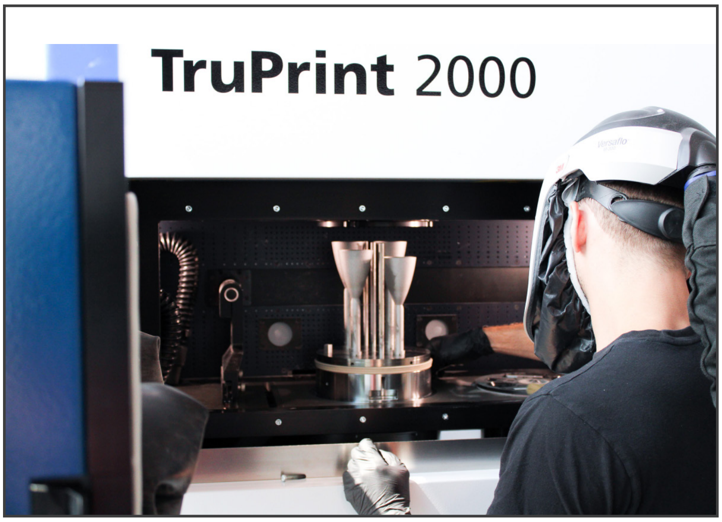
capabilities, performance over durations exceeding a year, flight rates, and then material science (kind of plays into thermal management)," Graybill and Crouse said.

However, despite the wide range of considerations to take into account, AM can help to address a couple of these challenges. We learned from Agile's experts that AM can help with thermal management, flight rates, and material science. *"Thermal management and materials because of the geometry you can print and the materials we're now experimenting with. Flight rates, AM works well for if they're low, which they generally are – allowing you to not have a lot of engine specific tooling,"* they added.

Furthermore, beyond development, what really matters is the size of your system and the production rate. According to Graybill and Crouse, *"AM is not favourable for a LOT of engines a year, but for niche components, it's a great fit (complex cooling channel geometry, etc.) even at higher volumes. It can be great for miniaturization, especially if what needs to be miniaturized is in a hard-to-manufacture location."*

AM: key applications and challenges

Before we delve into the specific added value AM brings to the Agile table, it's important to consider the investments Agile made so far to achieve their AM operations. The Mount Pleasant-based advanced manufacturing center which is ISO9001, AS9100 certified as well as ITAR Registered and NIST-SP-800-171 Compliant takes care of AM operations that range from initial process development to serial production of qualified flight hardware. To do so, they leverage a wide range of specialized equipment that includes metallographic and inspection solutions, such as a **Keyence VHX7100** which serves the needs of process development and characterization.



As far as 3D printers are concerned, one finds the basic FDM and SLA 3D printers in their production environment as well as a range of industrial 3D printers from **TRUMPF**. In the list of qualified materials these 3D printers can process, the team at Agile focuses on **nine unique manufacturable alloys**, including **oxygen-sensitive refractory alloy Nb C103**.

"Occasionally, we encounter situations where off-the-shelf components or systems don't meet our specific requirements. In such cases, our team has innovatively designed and manufactured proprietary lot mixing and depowdering flushing systems, enhancing our part yield and overall efficiency," Graybill and Crouse pointed out.

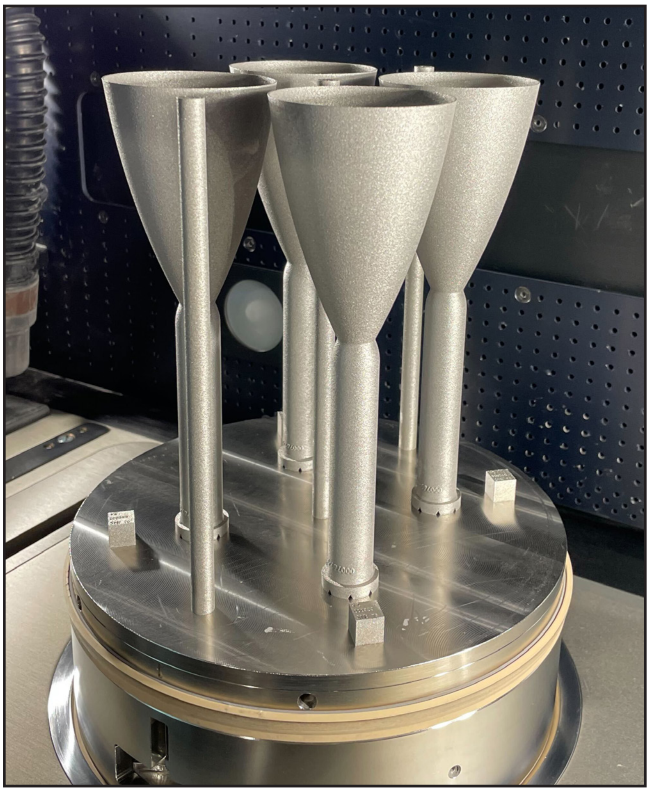
When we only look at Agile's activities as an in-space propulsion solution provider, AM can be used in every new product development:

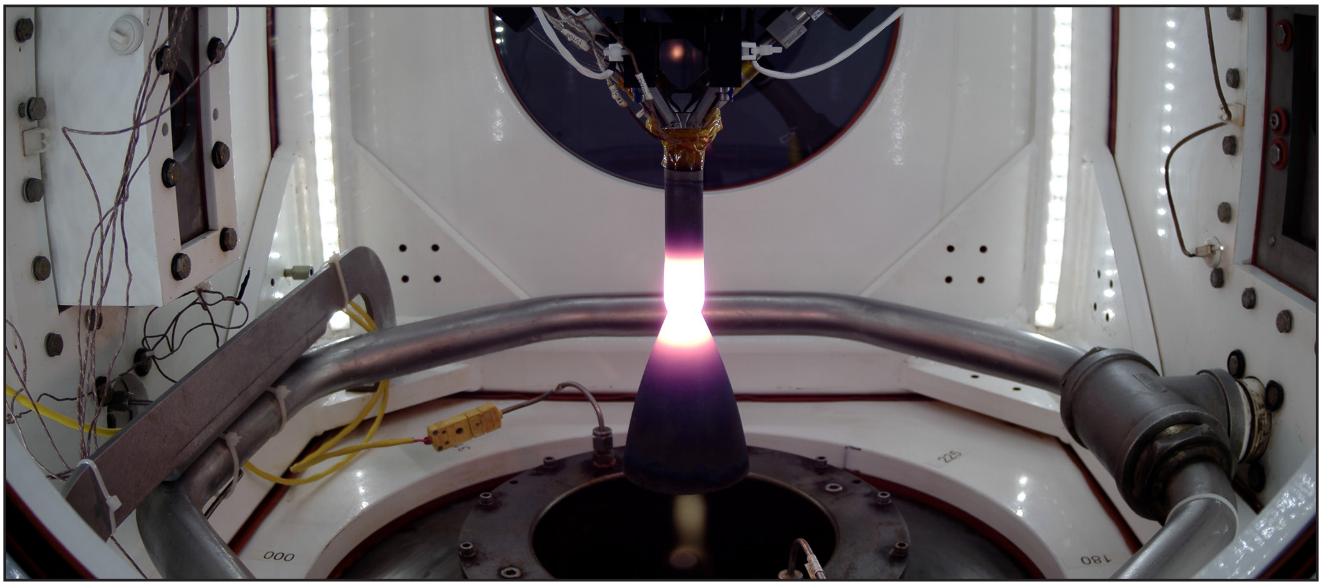
> ***"Its most significant advantage lies in its rapid turnaround capability, which enables us to iterate designs within weeks. This agility allows us to bring a new product to the test stand in as little as a month. In fact, many of our products are composed of over 85% additive components by weight, demonstrating the extensive use of AM in our production process."***

Interestingly, Agile goes beyond the widely known benefits of AM to highlight its strength when it comes to manufacturing specific parts. For our experts, that strength lies in the ability to produce complex internal manifolds across various scales within the same machine:

"This capability is particularly crucial in components such as injectors and chamber designs, which often require intricate internal structures. For instance, some of our injectors incorporate over 50 internal curved manifolds, each terminating in orifices smaller than 0.5mm in diameter. This need for high precision contrasts with the broader scale requirements of features like the regenerative cooling jackets in our A2200 engine, which are more than 5mm wide" Graybill states.

And Crouse continues: *"To ensure consistency and mitigate any risk of dimensional or process variation, we use the same printers for both development and production. Before transitioning a printer from development to production, it undergoes a series of rigorous process checks to qualify for production use. This seamless transition from prototyping to production underscores our commitment to maintaining high standards of quality and reliability in our AM processes, making it a cornerstone of our operations in providing innovative in-space*





propulsion solutions."

Moreover, to give a tangible example of the **essential role of AM and its ability to accelerate production speed**, the experts told the **story of a novel chamber** that was in the machining queue and scheduled for a hot-fire test within a week. The thing is, due to the unique surface profile and external manifolds, none of their mills or lathes could hold the component for a necessary cutting operation. Within 48 hours, they designed a 3-part clamshell from scratch, 3D printed it in Ti64, and on the lathe-making chips.

Despite its numerous advantages, we need to be mindful of the potential limitations of the technology. While these limitations are experienced differently from one AM user to another, some challenges are common to everyone who is looking to industrialize AM. Some of these challenges include **data integration and management**.

As a reminder, managing AM data is crucial for establishing part traceability, understanding AM processes and making decisions during the product development lifecycle. In this vein, their curation, integration, fusion, sharing and analysis become complex when one has to deal with the volume, velocity, variety and veracity of these data.

When asked how they are addressing this challenge, the experts at Agile said they rely on a **combination of in-house strategies and third-party applications**:

"These tools are designed to process the substantial amount of data collected in-situ and correlate it with data from both upstream and downstream of the process.

For instance, we implement a statistical Design of Experiments approach during process development, focusing on key process parameters. We collect in-process data, primarily thermal signatures, during printing and analyze it to identify key material properties such as porosity. This process enables us to optimize our operations based on empirical evidence. Crucially, our in-house propulsion testing facility, which is extensively instrumented, allows us to validate material properties through functional testing of the actual components, rather than relying solely on representative coupons or samples. This approach provides a more accurate and direct assessment of how materials will perform in our end-use applications for our customers.

While our Agile in-house solutions may accelerate process development and qualification, we are not a software development company. Therefore, we remain vigilant and aggressively adopt advances in software and hardware that can further enhance our ability to transform vast datasets into actionable insights."

Despite their focus on AM technologies, Agile recognizes that "***AM is not a panacea***" and this is crucial to map out a broader manufacturing strategy. As I have said before, AM does not benefit from the century of research into the production of components that is the hallmark of precision subtractive techniques. This means that, at some point, despite the current mediatisation of AM, along the manufacturing value chain, there are still certain things that subtractive manufacturing processes do better, and that still require a lot of improvements on the AM side.

At AGILE, it's about ensuring a synergistic approach to production:

"The additive team would like to thank Oqton and TRUMPF for letting us break things. Part of being an 'agile' company is pushing software and hardware beyond current capabilities. We appreciate the companies' application and development teams working with us to add functionality where we need it. Readers of this magazine [3D ADEPT MAG] may live and

breathe additive, but almost all programs require machining operations. So, this is another reminder to consider and thank your machinists."

Future outlooks

With a decade of expertise in hot-fire testing and system design and development, Agile Space has nothing to envy others. While its growing use of AM makes it one to watch in this New Space era, I am hoping to see the company explore AM processes that go beyond LPBF and am curious to discover the lessons they would have learned in that exploration.

However, the company is eager to soon explore a range of technologies that extend the capabilities of laser powder bed fusion.

"While fun stuff remains behind closed doors, I can share our growing interest in incorporating more refractory-based alloys and the exciting prospects of experimenting with computationally designed materials. Our focus is on advancing our expertise in thermal-mechanical compensation and additive design software to create innovative thrusters. For example, newer components may incorporate intricate features that have remained difficult to qualify, such as functional lattice or require repeatable orifices smaller than 100 microns in diameter. Furthermore, as we progress into 2024, some of our legacy components might move away from laser powder bed fusion, adapting to newer additive technologies that better align with our evolving production needs.

Beyond the realm of our AM department, AGILE's

experience in developing thrusters for various clients has given us deep insights into the diverse needs of the satellite propulsion market. As a leading developer of in-space rocket engines, we've gained a comprehensive understanding of our customers' requirements for mission enablement. AM, being a cornerstone of our manufacturing process, will play a critical role in these ventures. We plan to leverage AM's capabilities in these new applications, and we anticipate sharing more updates on this front in the near future. Our strategic direction in 2024 is not just about advancing our AM technology but also about aligning it with the broader needs and aspirations of our customers, ensuring we remain at the forefront of in-space propulsion solutions," Graybill and Crouse concluded.

*All images: courtesy of Agile Space Industries

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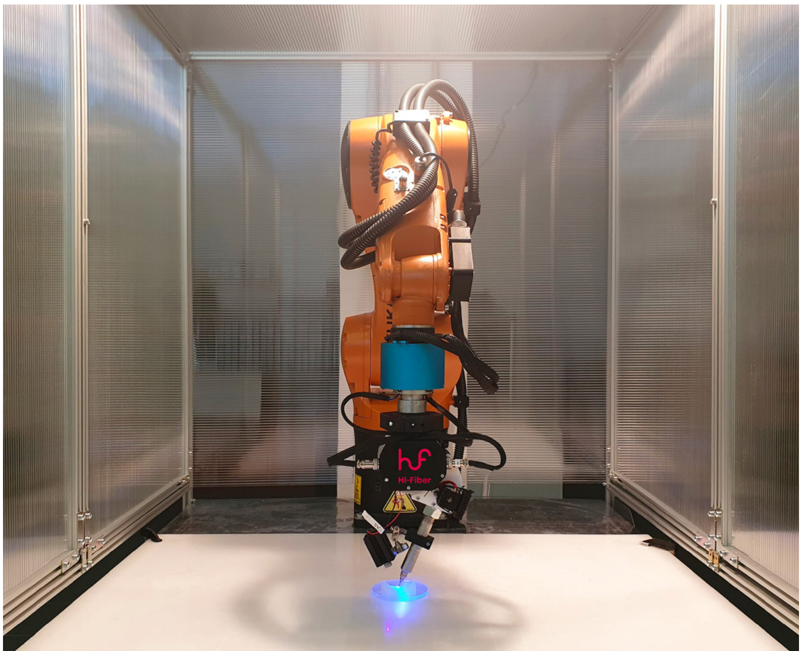
Prototype of the Mambo boat – 3D printed by Moi Composites. Credit: Moi Composites

USING COMPOSITES TO REPLACE METAL PARTS IN ADDITIVE MANUFACTURING: WHEN AND HOW?

Metal 3D printing has proven so many times its efficiency across applications that it's almost always mentioned as the route to go in demanding applications. One key limitation experts often deplore is its expensive cost compared to other AM techniques –especially when exploring mass production. This urges OEMs to explore the capabilities of AM with other materials that could potentially serve as alternatives to metals. One category that is worth mentioning today is ***composites*** *which benefit from a century of research into the production of components with subtractive techniques. However, when combined with AM, a couple of points need to be considered: What type would be a great alternative to metal 3D-printed parts? For chich manufacturing purpose? Are there any specific manufacturing and design choices to consider? The article below ambitions to answer these questions.*

We've already had a first introduction to composites 3D printing and the first steps one should take when working with this young branch of AM. AM companies might call it "the youngest branch of AM", but composites are just like alloys to me. I find it fascinating to see the number of materials that can be combined to deliver a specific range of physical and chemical properties – and form in the end one single material that will be 3D printed to fabricate a part.

AM applications we have already witnessed with composites show that these materials bring opportunities for lightweighting – which is the hallmark of AM –, and interestingly, the ability to build onto a custom tool.



CFM robot printing. Credit: Moi Composites

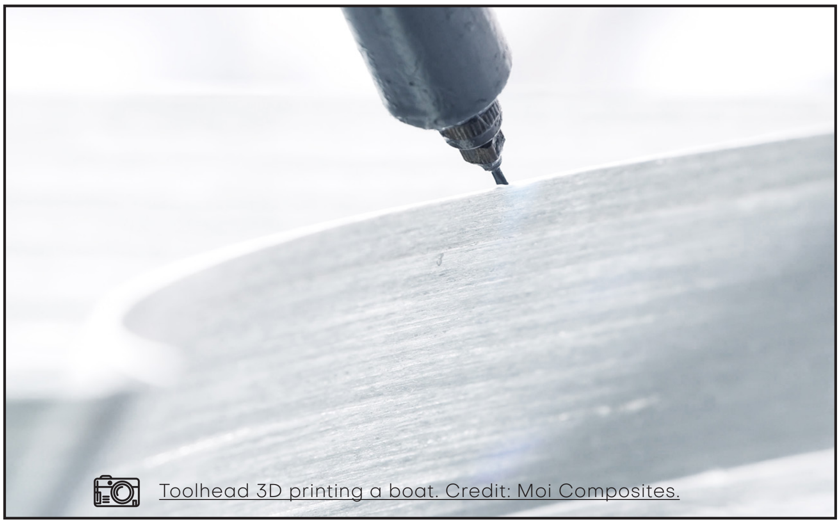
Furthermore, one of our first dossiers on composites reveals that two reinforcement types of fiber are compatible with AM technology: chopped and continuous. According to **Michele Tonizzo**, CTO of **Moi Composites**, a company that specializes in Continuous Fiber Manufacturing, *"From a structural point of view, the performances obtainable through the use of continuous fiber composites are unbeatable, with tensile strength surpassing 1.5 GPa (*1) and reaching 30 times those of chopped fibers reinforced polymers (*2). Unfortunately, the intrinsic limitation of having a coherent, always-solid part during extrusion limits the geometrical complexities obtainable by using only a single-material approach. This is why the approach pioneered by Markforged and Anisoprint, and extended in three dimensions by Moi Composites, is the best one discovered yet. By depositing unreinforced, or chopped fiber-reinforced, matrices able to describe complex geometries, and continuous fiber-reinforced matrices only in strategic places, thus also shortening print times, it is possible to obtain structural parts with complex geometries such as cavities and internal reinforcements. The approach conceived by Moi Composites takes this idea to a three-dimensional level. In fact, by taking advantage of robotic multi-axis freedom, it is possible to describe complex geometries using short-fiber reinforced polymers, then adding layers of unidirectional continuous fibers following the external geometry to achieve the desired structural integrity."*

There has always been a battle between those who advocate for chopped and continuous fiber reinforcement. In this vein, it's important to keep in mind that each material brings its own set of characteristics, application areas, and technologies associated with them.

The table below summarizes a few of the most important characteristics captured so far:

Continuous fiber reinforcement	Chopped fiber reinforcement
More strength and stiffness: its strength lies in the continuity of the strands which can absorb and distribute loads across their entire length.	Stiffness can significantly be improved depending on the material
Described as more strong and reliable than metal structures	Ideal for improving surface quality, wear resistance or even the look of a part while reducing the weight of the part
Compatible with several technologies	Cheap material

When we talk about aerospace 3D printing with composites though, even though there is a predominant use of continuous fiber reinforcement, we did notice a couple of applications made up of chopped fiber reinforcement materials.



Toolhead 3D printing a boat. Credit: Moi Composites.

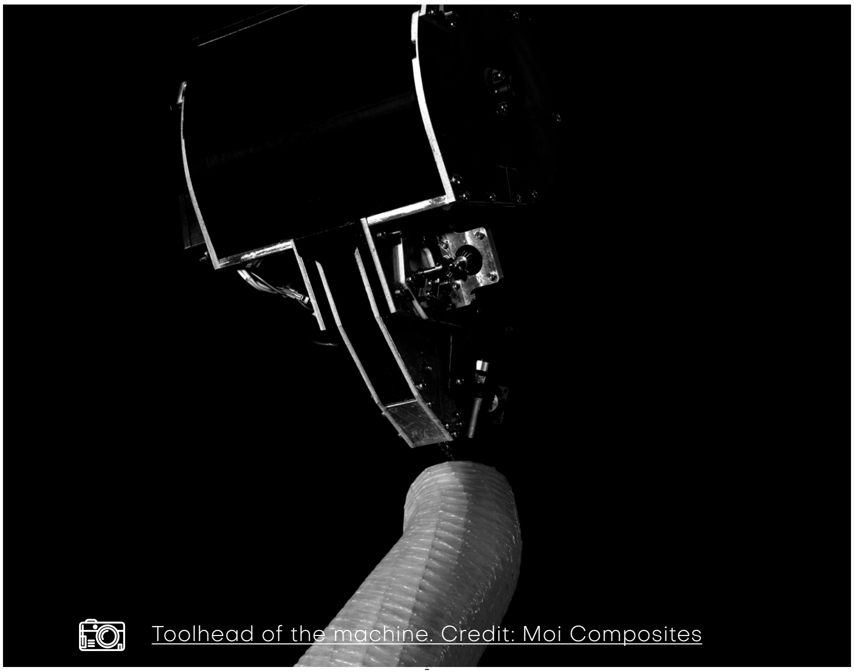
Tonizzo has been involved in several projects that all aim to reduce weight or lead times for aerospace parts. He said one that was particularly successful aimed to reduce the overall weight of the plane by redesigning non-structural parts, in this case, the **brackets holding the seats to the floor**. *"The weight reduction came from removing material not contributing to the structural integrity while maintaining the unidirectionality and continuity of the fibers, something impossible with traditional manual or automated methods of composites production,"* he explains.

"The part obtained presented similar mechanical performances while reducing the weight by a significant amount. From my experience, the competitive advantage of composites additive manufacturing for the replacement of metal parts in a production environment has almost always been related to the performances obtainable by creating truss-like geometries, elevating the strength-to-weight performances of the part," Tonizzo adds.

Interestingly, whether one deals with AM or conventional manufacturing processes, the most important driver that leads to the use of composites rather than metal remains "the strength-to-weight performances only obtainable with unidirectional carbon fiber reinforced polymers" – according to Tonizzo.

Applications & limitations

If brackets have been mentioned as a key application in aerospace AM, composites AM also remain an ideal production candidate for **fasteners**, also used in aerostructures. Despite the complexities of this application, Thermwood has demonstrated several times that autoclave tooling can be a key application of composites AM in the aerospace industry.



Toolhead of the machine. Credit: Moi Composites

Other development opportunities of composites might see **a combination of AM with existing composites manufacturing processes**. One company that is quietly working in this area is **Electroimpact**, a US-based company that is also a Boeing supplier. Electroimpact developed a solution to apply compoistes to the Boeing 787 aircraft. That solution combines **automated fiber placement or AFP**. The company explains that it *"has integrated an in-situ out-of-autoclave thermoplastic AFP process and an advanced FFF 3D printing process into a unified Scalable Composite Robotic Additive Manufacturing (SCRAM) system. SCRAM is an industrial true 6-axis continuous fiber-reinforced 3D printer, which enables the tool-less rapid fabrication of aerospace-grade integrated composite structures. High-performance thermoplastics combined with a high percentage of continuous fiber reinforcement are used to produce parts with exceptional material properties previously unheard of in the world of additive manufacturing."*

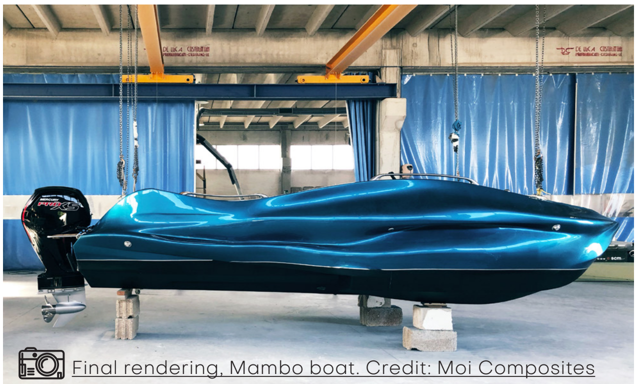
Electroimpact's solution is one of a kind in the industry and we do hope to hear more about it in the future.

The question that remains to be answered now is the one of the manufacturing purpose: **Does composites AM only lead to prototyping and low-volume production?** For Moi Composites' CTO, composites AM remains one of the very few technologies where 3D printing can be employed in a work environment, and not only for low-volume production.

"I found that a product designed from the start with additive manufacturing in mind is easier to be brought to production than a redesign of an existing part. For example, Hi-Fiber, the dental reinforcement product developed by Moi Dental, Moi's spin-off, was designed and can be produced only with composites AM, and with thousands of parts produced per year. Given the fact that high-volume production of composite parts is not closely comparable to the numbers produced via plastic injection molding, I am confident that, if the part possesses enough added value, it can be produced in high volumes with AM technologies", Tonizzo points out.

Tonizzo's expectation unconsciously implies **a limitation that would lead to costs** if/when exploring composites AM in mass volume applications. At a technological level, he also mentions some of the hardly-mentioned complexities of continuous fiber composites: **they cannot be melted and shaped into form, trimmed, or milled down from a solid object.**

"Differently from other manufacturing methods, it's extremely difficult to obtain high performances out of a layer-by-layer produced part, as they suffer even more from the anisotropic behavior of 3D printing. All these limits are well known and already solved by composite manufacturers, who instead highly appreciate the digital approach brought by AM to the composite industry. Therefore, the adoption of CFC AM comes easier from composite manufacturers rather than the AM industries. Due to the heavy design for manufacturing work necessary to produce a part using CFC AM, I doubt there would be a "Shapeways" for composites, unfortunately", he concludes.



Final rendering, Mambo boat. Credit: Moi Composites

Editor's notes

Michele Tonizzo – the key contributor who shared insights into this topic, is the co-founder and President of Moi Composites, a company that specializes in composites 3D printing and that appeared on our radar when it showcased a 3D printed fiberglass boat at Genova Boat Show 2020. Before founding Moi, he was a research lead at Politecnico di Milano University +LAB, researching new methods of AM for polymeric materials, and a winner of the most prestigious award for innovation in composites, the 2017 JEC Innovation Award.

Moi Composites now focuses on the industrial development of **Sistema**, its end-to-end system for simplifying the production of composites through robotics and AM. With the soon-to-be launched beta program, the company is now actively looking for first adopters and testers of Sistema in the R&D departments of universities and industries.

References:

*1: Baur JW, Abbott AC, Barnett PR, et al. Mechanical properties of additively printed, UV-cured, continuous fiber unidirectional composites for multifunctional applications. Journal of Composite Materials. 2023;57(4):865-882. doi:10.1177/00219983221146264

*2: Information based on Markforged's Onyx ESD Material Datasheet

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Interview

How 7 decades of expertise in electron beam technology have helped position JEOL in the AM market

*With the dozen players that entered the electron beam melting market during the past five years, the electron beam melting status has evolved from a "spare wheel" technology to a solution that could provide strong advantages that laser powder bed fusion (LPBF) does not. Among these newcomers, one that could potentially disrupt the current technology landscape is **JEOL LTD**, a company founded in 1949 and headquartered in Akishima, Japan, with seventeen overseas subsidiary companies located throughout the Americas, Europe, Asia, and Australia. We caught up with **Bob Pohorenec**, President of JEOL USA to understand why.*

Bob Pohorenec,
President of JEOL USA

JEOL USA, Inc., located outside of Boston, was established in 1962. The company first appeared on our radar in 2021, with the launch of its JAM-5200EBM metal Additive Manufacturing machine but the company's beginnings in the AM industry go back to 2014 when it joined the Japanese government's Technology Research Association for Future Additive Manufacturing project, or TRAFAM. It collaborated with **Dr. Akihiko Chiba** of Tohoku University on a four-year project to build an **EB-PBF machine** based on JEOL's advanced electron optics and automation that resulted in the development of a prototype machine installed at Tohoku University.

Credit: JEOL - 3D printer

If the company's Electron Beam Powder Bed Fusion (EB-PBF) 3D printing technology is at the heart of this conversation, it's important to keep in mind that AM users also use the company's metrology and analytical instruments to support various research projects or manufacturing processes.

That being said, when a company brings over 7 decades of expertise in electron beam technology as a supplier of electron microscopy and e-beam lithography, one assumes that they will not face the same challenges as other OEMs when entering the AM market – challenges related to the novelty and maturity of the technology and how they can shape a specific business.

Nevertheless, the similarities between the AM market and the semiconductor equipment market have somehow helped JEOL position itself in the electron beam melting niche. As per **Pohorenec's words**, similarities that are critical to both markets include *"performance, cost of ownership, equipment up-time, spare part and technical support availability."*

"However, the semiconductor equipment market is very mature and has gone through a great deal of consolidation. The AM market is still developing which makes it very exciting for us," he continues.

To date, looking back at the key milestones that have marked JEOL's AM activities ever since the company launched its JAM-5200EBM metal 3D printer in 2021, Pohorenec mentions three key moments.

The installation of their first unit at Cumberland Additive Inc., in the Neighborhood 91 Additive Manufacturing Production Campus in Pittsburgh in September of 2023; the AMS7032 operational qualification (OQ) standards the company met while achieving the AMS7011 material requirements for Ti-6Al-4V alloy and a recent order received in December for the second unit to be installed in the United States from a top-tier research university that is working with a National Laboratory on AM using refractory metals.

"The next milestone will be the first installation of a JAM-5200EBM in Europe at the Technical University of Munich (TUM) which will happen in the next few months," he enthuses.

Credit: JEOL

Beyond these promising outlooks, what truly makes JEOL's Electron Beam Powder Bed Fusion 3D printer outstanding?

First and foremost, for beginners in this space, electron beam powder bed fusion (EB PBF) relies on the use of a high-powered electron beam to melt conductive metal powders like copper and titanium together layer by layer.

"In the case of the JAM-5200EBM we employed quite a bit of know-how and technology from our electron beam lithography systems which are used in semiconductor manufacturing environments. The result is an electron optical system that can allow user's a high degree of adjustability in beam current without impacting the beam's diameter. This system also delivers at least 1500 hours of electron emitter lifetime which is more than double that of other EB-PBF systems and translates into increased tool availability. Another major differentiator is our patented "e-shield" which eliminates the need of helium gas during the build process. We will be releasing several new features this year that will be very useful to machine owners," JEOL USA President explains.

Regular readers of 3D ADEPT Media may remember that we recently discussed the reasons why Electron Beam Additive Manufacturing in general could be an ideal production candidate for large-scale parts, yet still lags far behind in adoption. Electron beam melting has found applications across the medical, aerospace and other industries.

If he didn't mention exactly which ones, Pohorenec confirms there are applications where EB-PBF is not an appropriate fit. Speaking of applications where the technology can play a key role, he counts aerospace, defense, and medical device verticals because they *"require metals such as Ti64, Inconel, copper, and tungsten and they need to meet stringent property requirements. Replacement of low-volume cast parts within a relatively short lead-time is also an area that EB-PBF can play a valuable role."*

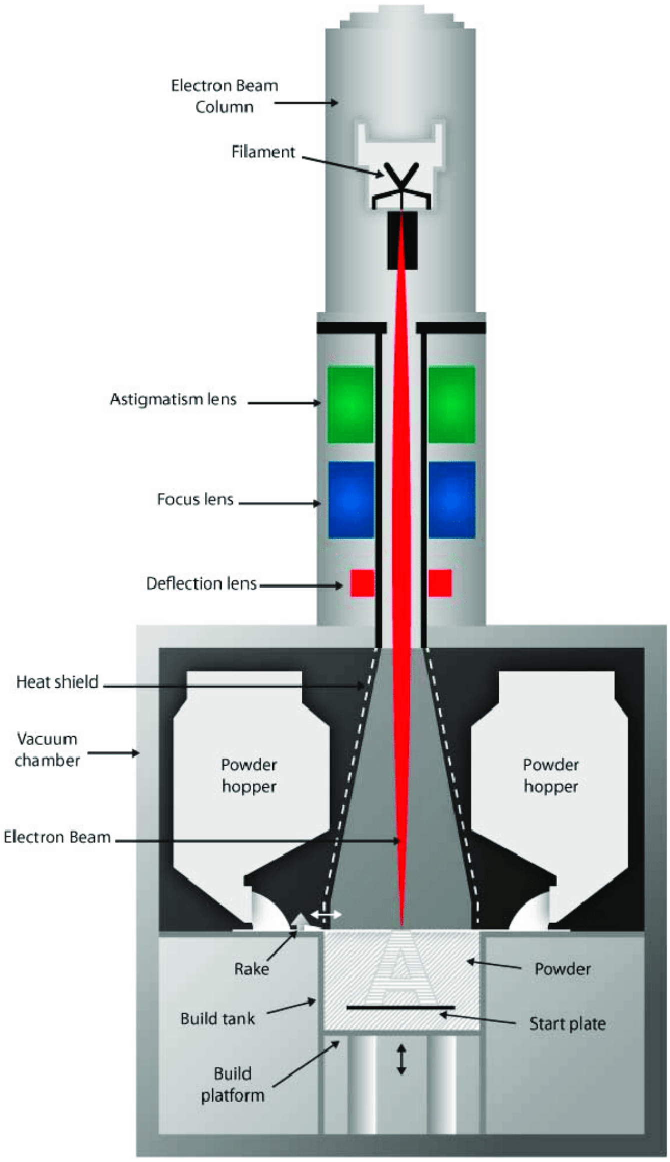
The everlasting comparison with PBF technologies

Electron beam powder bed fusion has always been described and seen as the fiercest competitor of LPBF. If I believe they shouldn't be labelled as competitors, one needs to recognize a few advantages this process has over LPBF. For instance, the ability to process very pure metals with no porosity or oxidation, the processing of materials at highly elevated temperatures, the minimized need for heat treatment or even the possibility of reusing up to 98% unused powder.

On another note, EPBF has often been criticized for its lack of material selection and multi-material options, as well as the long time the vacuum may take to build up and less detailed resolution compared to PBF.

Needless to say, these benefits and drawbacks may vary from one machine to another. Speaking of a few advantages that could be associated with aerospace parts production and more, Pohorenec said: *"EB-PBF's ability to build free-standing or support-free structures inside a large volume is a major time and cost advantage compared to other PBF technologies. Additionally, this allows for a variety of parts to be built within the volume which allows the design engineers to maximize the productivity of the machine."*

Among the wide range of aerospace applications that could be achieved through EPBF, one that **Pohorenec** highlights is the **jet engine turbine blade** whose designs can be improved for higher efficiency engines. For the president, *"the ability to stack those blades without supports and obtaining the same metallurgical properties as traditionally manufactured blades has real value."*



Schematic of the electron beam melting (EBM) process. Source: Structural Integrity of an Electron Beam Melted Titanium Alloy

Image credit: CCDC Army Research Laboratory

And now?

If I do not doubt there are exciting times ahead for companies that specialize in EPBF, I strongly believe those who could make a difference in the market are the ones who will focus on improving customer support. That's anyway, what JEOL intends to do.

"Some of the industries we support require service level agreements with guaranteed response times, meaning a service engineer on-site within a specified number of hours or days, and quick delivery of spare parts. Over the years we have developed a large and expanding customer service infrastructure to support our equipment owners. We locate field service engineers throughout the geographies where our equipment is installed to shorten response times. In North America alone we have over 180 engineers in the field. We take customer service very seriously and treat it as a key component of our value proposition," **Pohorenec** concludes.

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Interview

Greg Morris, the AMUG "Innovations Award Winner" on his journey, the adoption of AM across industries and the future of Zeda

*In an industry like Additive Manufacturing (AM), there are so many bright minds that it's often a real conundrum to select who should be recognized for an "Innovators Award" – an AMUG award bestowed on those who have cultivated innovative ideas that have advanced the AM industry. Because AMUG is truly a one-of-a-kind event, the organization continues to reflect its dedication to one-of-a-kind innovators. This year, **Greg Morris** will be the recipient of this esteemed "Innovators Award", and it took a conversation with him to understand his numerous achievements. Interestingly, that conversation goes beyond his journey to encompass the adoption of AM technologies across vertical industries and the future of Zeda.*

Greg Morris - CTO of Zeta Technologies

We've first known Morris as one of the five founders of **Vertex Manufacturing**, a company that merged last year with PrinterPrezz and now operates as Zeda. Actually, Morris is a man with multiple hats and it would probably require the whole chapter of a book to highlight them. The common thread among those hats is that they have always had a link with **additive metals**.

"When our company at the time, Morris Technologies, introduced laser powder bed fusion metal technology to the North American market back in 2003, I feel that we were fortunate to have been at the 'right place at the right time'. We quickly realized this technology had a lot of promise, and we invested in it heavily over the years to follow. Fortunately for us, that 'bet' paid off in that the technology evolved and matured in such a way that we were able to work with our customers to use it for functional prototypes and eventually production parts. As many know, we worked closely with GE Aviation to develop the additive portion of their LEAP fuel nozzle tip. Once that was disclosed to the public, many other companies saw the potential and started to leverage the technology for their own products and purposes. With the development of more alloys, a much better appreciation of how to 'design to the process' and overall machine technology advancements, we have seen metal 3D printing become a potent tool for many companies looking to leverage the inherent benefits of design flexibility and freedoms for their products, helping to give products new capabilities, reduce costs and often alleviate supply chain constraints that have helped reduce lead times. Today, we continue to see not only technology advancements with many of these types of machines, such as multi-laser systems, enhanced machine and quality monitoring and many other such items, but we are also seeing a number of interesting metal modalities that are helping to address specific applications that also broaden the ability of engineers and designers to select the type of metal 3D printing that might best fit their applications and uses", Morris told 3D ADEPT Media.

Production environment at Zeda. Credit: Zeda

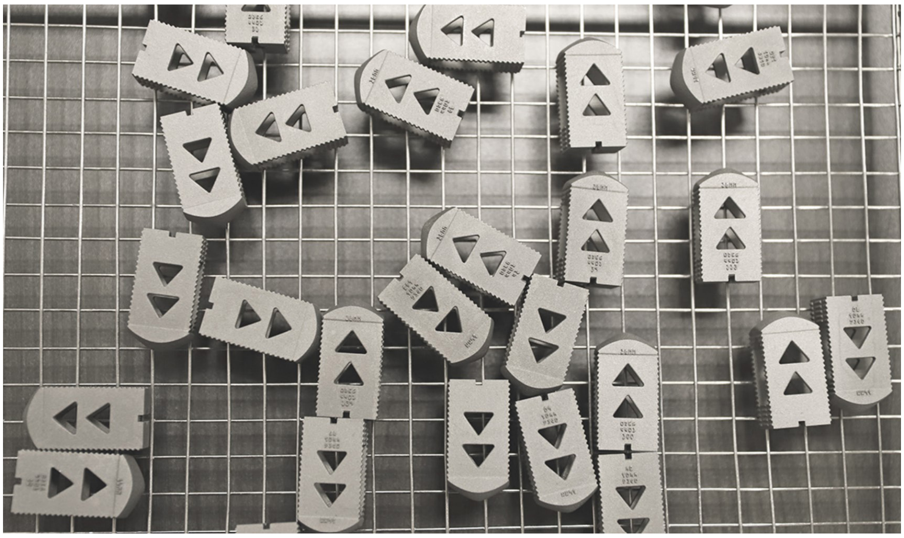
If this is only a small portion of a story that marked his journey, Morris recognizes that this story could not have been shared today without the many hands that joined forces to make it happen. To date, the man we first knew as the CTO of Zeta Technologies is transitioning into a more strategic role within the company while remaining an advisor to some small start-ups and companies.

The adoption of AM across the space, defense and aerospace industries

Vertex Manufacturing was one of the service bureaus that was bold enough to bet on Xerox ElemX™ 3D Printer – a liquid metal 3D printing technology that was still considered "new" in the market but apparently viable enough to 3D print aluminum consistently and reliably.

If we have always hoped that Vertex would make Xerox technology its secret weapon to drive AM across the space, defense and aerospace industries, Morris revealed that they started with a GE Additive LPBF machine and added a GE EBM technology after the integration of Xerox solution. It will therefore be no surprise to hear that **LPBF was, is and will probably remain the primary technology driving the metal AM segment** – at Zeda and for other AM users.

For our expert, there are metal AM technologies that are definitely a better fit than LPBF for certain applications. One such technology is **binder jetting** whose market shares are growing surely, but slowly. *"While I would argue design differentiation can transform how one produces certain components, other factors have the potential to make larger impacts from a volume standpoint, such as cost per part. I think there are a variety of factors that hold back metal 3D printing from being more ubiquitous, with cost probably ranking as a primary one. Technologies like binder jetting and similar technologies can introduce both the design benefits of a layering process with throughput and thus cost competitiveness that technologies such as LPBF sometimes are not able to achieve yet,"* Morris explains.



Zeda uses metal AM to produce a range of medical implants (Courtesy Zeda Inc)

And when you add considerations related to **materials, size of components and qualification of machines**, one obtains the ingredients that could complexify the recipe to get parts for the aforementioned demanding vertical industries.

Far from being pessimistic, Morris focuses on the information we possess and how one can make the most out of it to grow:

- Given the fact that each metal AM technology has its own nuances and design requirements, one should recognize that **it is very difficult to be an expert overnight in any of them, let alone multiple types of metal printing**. As such, he outlines that the knowledge on how best to design a part with any particular technology in mind may not be as efficient as it might until either that experience is built up or additional tools become available that will help engineers and designers with a more 'automated' way of creating a part that will print well and that will achieve most of what they might want it to do.

- **Be aware of promising materials and processes.** Their advancements might be slow, but technologies and processes are being enhanced. Technologies that can produce larger parts efficiently with alloys such as Inconel, Copper and Stainless steel are gaining momentum. Among them, directed energy deposition (DED), friction stir weld (MELD) and others using emerging and novel ways of depositing and consolidating metal materials will be in demand for their speed and ability to deliver mechanical properties.

- **Remain industry and application specific.** For Morris, more efficient ways of producing additive parts (cost), faster lead times, and demonstrated and proven quality and material properties all play an important role in how quickly and deeply metal 3D printing is adopted into any industry, company or application.

The merger of Vertex and PrinterPrezz

If Vertex was acknowledged for producing parts for industries like space, defense and aerospace, PrinterPrezz was all about delivering a similar service to the healthcare and medical industries. We have always been intrigued by this merger as each of these companies operates in distinct fields of activity.

To this, Morris replies: *"When discussions began around merging the companies, Vertex was a vendor to PrinterPrezz, providing post-machining and processing of titanium-produced implants that PrinterPrezz built. The synergy was combining both Vertex's know-how and background of metal 3D printing as well as the capabilities and know-how of post-processing those metal 3D printed parts with PrinterPrezz's desire to vertically integrate all of these capabilities. While Vertex indeed had more of a primary focus on aerospace, space and defense type parts, the ability to cross-pollinate learnings and know-how from these disparate industries was looked at as a strength."*

A 3D printed anatomical model by PrinterPrezz. Image courtesy of PrinterPrezz now Zeda.

Speaking of the differences that set them apart in the use of AM technologies, he adds:

"PrinterPrezz had a pretty specific focus area printing for use in medical applications, whether that was for implants or instrumentation. Because of this, they worked pretty much exclusively with titanium and stainless alloys. They also had very specific post-build steps that were aimed at working with these types of smaller, industry-specific parts. Vertex, on the other hand, was more of a generalist, with a focus on aerospace, space and defense. To that end, Vertex worked with similar alloys as PrinterPrezz, but also produced parts in alloys more specific to other industries that desired nickel-based or other similar type materials. The post-build steps for Vertex also entailed having a broader range of capabilities simply based on the expanded needs being asked from these different customer types. Ultimately though, we find there are more synergies than differences in the various industry focuses."

Moving forward, to drive the use of AM technologies across the aerospace, space and defense markets, Zeda, the company that combines Vertex and PrinterPrezz activities to date, will focus on the production of parts with alloys such as Inconel 718, copper with GrCop42, stainless steel such as 17-4 and 316 and aluminum.

To mark their willingness to continue focusing on the different sectors that were at the heart of Vertex and PrinterPrezz's business, Zeda will have an entire division called ***Zeda Health*** which will soon be based out of Reno, Nevada, while the other side of the business will be the ***Zeda Technologies*** portion based out of Cincinnati.

"Both of these entities reside under Zeda Inc.. As the overall venture capital and private equity investment environment continues to improve, I believe Zeda will have the opportunity to attract the appropriate amount of capital to continue their growth into all of these markets," Morris concludes

Disclaimer: This interview was conducted as part of a media partnership with AMUG.

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KEY SPEAKERS:

- **Alexander Champion**, Additive Manufacturing Project Manager, ***UK MoD***
- **John Sneden**, Propulsion Director, ***US Air Force Life Cycle Management Centre***
- **Beth Dittmer**, Propulsion Integration Division Chief, ***US Air Force Life Cycle Management Centre***
- **Steven Barnes**, AM Process & Capability Lead, ***BAE Systems***
- **Dr Melissa Orme**, Vice President, Additive Manufacturing, ***Boeing***
- **Dr Prabhjot Singh**, Director, Additive Manufacturing, ***RTX***
- **Dan Anders-Brown**, Technology Development and Advanced Manufacturing, ***Qinetiq***
- **Steve Salt**, AM Design Specialist, ***Rolls Royce***
- **Lieutenant Colonel Ramon Macias**, Project Coordinator (Materiel Management), ***NATO Allied Command Transformation***
- **Jonathan Morley**, Programme Director – Material Availability Services, ***Babcock***
- **Bradley Hughes**, Principal Research Engineer – Additive Manufacturing, ***GKN Aerospace***
- **Iain Minton**, Chief Air Technologist, ***BAE Systems***
- **Fernando Lartategui**, Associate Technical Fellow in ALM, ***ITP Aero***
- **Ruaridh Mitchinson**, Technology Manager, AM, ***MTC***
- **Len Pannett**, Co-Chair, Inventory Working Group, ***UK MoD***
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News Round-Up :
AM for Aerospace, Space & DefenseNewcomers

The first weeks of the year were marked by strong collaborations and achievements to push the adoption of AM in the Aerospace, Space & Defense. As this issue focuses on highlighting how the use of AM is evolving in these vertical industries, it makes sense to share below a few announcements from companies we will be watching in this space during the upcoming months.

BUSINESS

Airbus and AddUp install a metal 3D printer in the ISS

Six years ago, in a conversation with Airbus' **Delphine Carponcin**, we learned that the space company was working with the European Space Agency on the development of a 3D metal printer to send it into space. The "Metal3D" project had started in 2016 with the goal of creating a metal 3D printer to safely operate under microgravity, aboard the International Space Station. Metal AM OEM **AddUp** who joined the project co-funded and led by Airbus Defence and Space confirms today that they deliver that **metal 3D printer to the European Space Agency**. This achievement is truly one of its kind for the AM industry that continuously witnesses the capabilities of AM for the space industry.

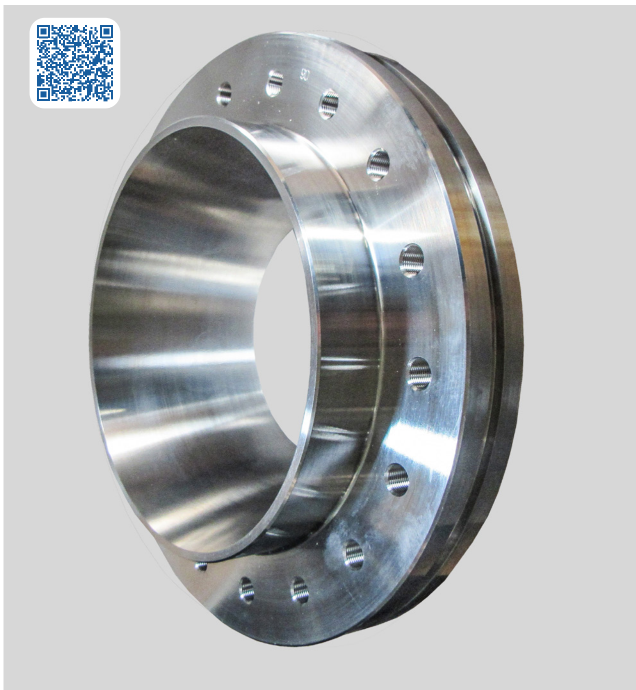
COLLABORATIONS

GKN Aerospace to additively manufacture parts for a solid rocket motor demonstrator

Multinational aerospace and defense technology company **Northrop Grumman** has chosen **GKN Aerospace**, a company that designs and manufactures aerostructures and engine systems, to help with the production of parts for a solid rocket motor demonstrator.

The first Solid Motor Annual Rocket Technology Demonstrator (**SMART Demo**) successfully tested a new motor that was developed in less than a year. That SMART Demo proves the capabilities of AM technologies leveraged by GKN Aerospace, and their ability to reduce production lead times by **up to 75 percent**.

AM will still be part of the manufacturing process for this solid rocket demonstrator. The production will take place at GKN Aerospace's new Global Technology Centre in Fort Worth, Texas.



1000 Kelvin and Fieldmade join forces to support the military sector with AM. Here is how.

1000 Kelvin, the AI-driven additive manufacturing (AM) software company that recently launched AMAIZE, joins forces with **Fieldmade**, an expert in mobile manufacturing for rugged environments.

Together, they ambition to increase the immediate deployment of 3D printing at the front lines, enhancing strategic readiness and operational capabilities within the military sector.

"Our vision is to make deployable 3D printing as easy as using a vending machine. The integration of 1000 Kelvin's AMAIZE into our products is a significant step towards this goal," **Jostein Olsen**, CEO of Fieldmade states.

APPLICATIONS

Gravity-1 Y-1 carrier rocket successfully launches with critical metal 3D-printed parts

Orienspace, an aerospace company known for the design and manufacture of Gravity Series launch vehicles and Force Series rocket engines, has recently launched the Gravity-1 Y-1 commercial carrier rocket.

The rocket delivered the Yunyao-1 No. 18-20 satellites into their predetermined orbits, making this way Gravity-1 Y-1's launch mission a success.

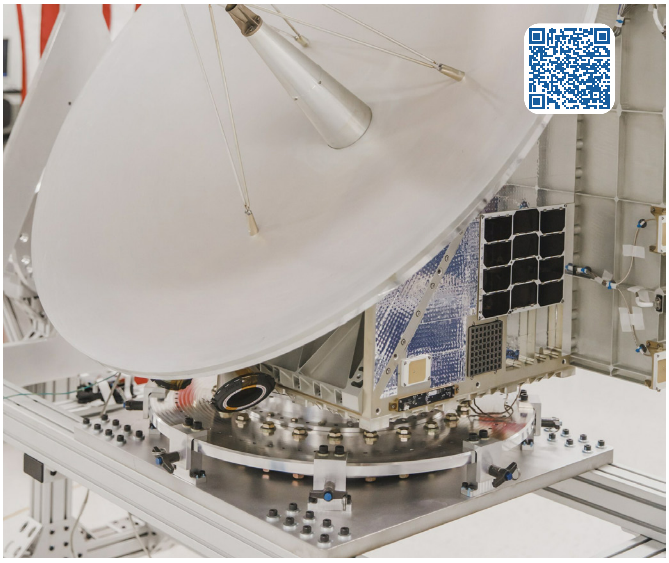
What raises our interest is the fact that at the manufacturing level, the rocket benefits from the use of metal AM for certain critical parts. As is often the case, rockets feature large components with complex geometries that are prone to deformation.

Gravity-1 Y-1 was no exception to this rule.

Vitesse Systems delivers its first 3D-printed satellite antenna

Vitesse Systems, a supplier of antenna, thermal management, and power distribution solutions used in radar, electronic warfare, and data transmission applications, has delivered its first additively manufactured satellite antenna.

Vitesse Systems' journey in Additive Manufacturing would have started in 2021 when it acquired Custom Microwave Inc., a designer and manufacturer of high-performance, passive antennas for space and ground applications. At this moment, it invested in two metal 3D printers and increased design engineering capacity to develop more complex antenna solutions.



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The International Catalogue of AM Solutions

Once you've decided that Additive Manufacturing/3D Printing is right for your project/business, the next step might be quite intimidating. In their quest for the right technology, be it by email or during 3D printing-dedicated events, professionals ask us for advice or technical specifications regarding different types of 3D printing technologies & post-processing solutions that raise their interest. Quite frequently, these technologies are not provided by the same manufacturer.

The International Catalogue of Additive Manufacturing Solutions comes to respond to this specific need: be the portal that will provide them with key insights into valuable AM & post-processing solutions found on the market.

More importantly, an important focus is to enable potential users to leverage the latest developments in Additive Manufacturing. Companies can now feature the strengths of their AM Machine / Material offerings.

Please note that the International Catalogue of AM Solutions is distributed in all industry events where 3D ADEPT is a media partner and to our subscribers at home/in offices

Additive Manufacturing / 3D Printing

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