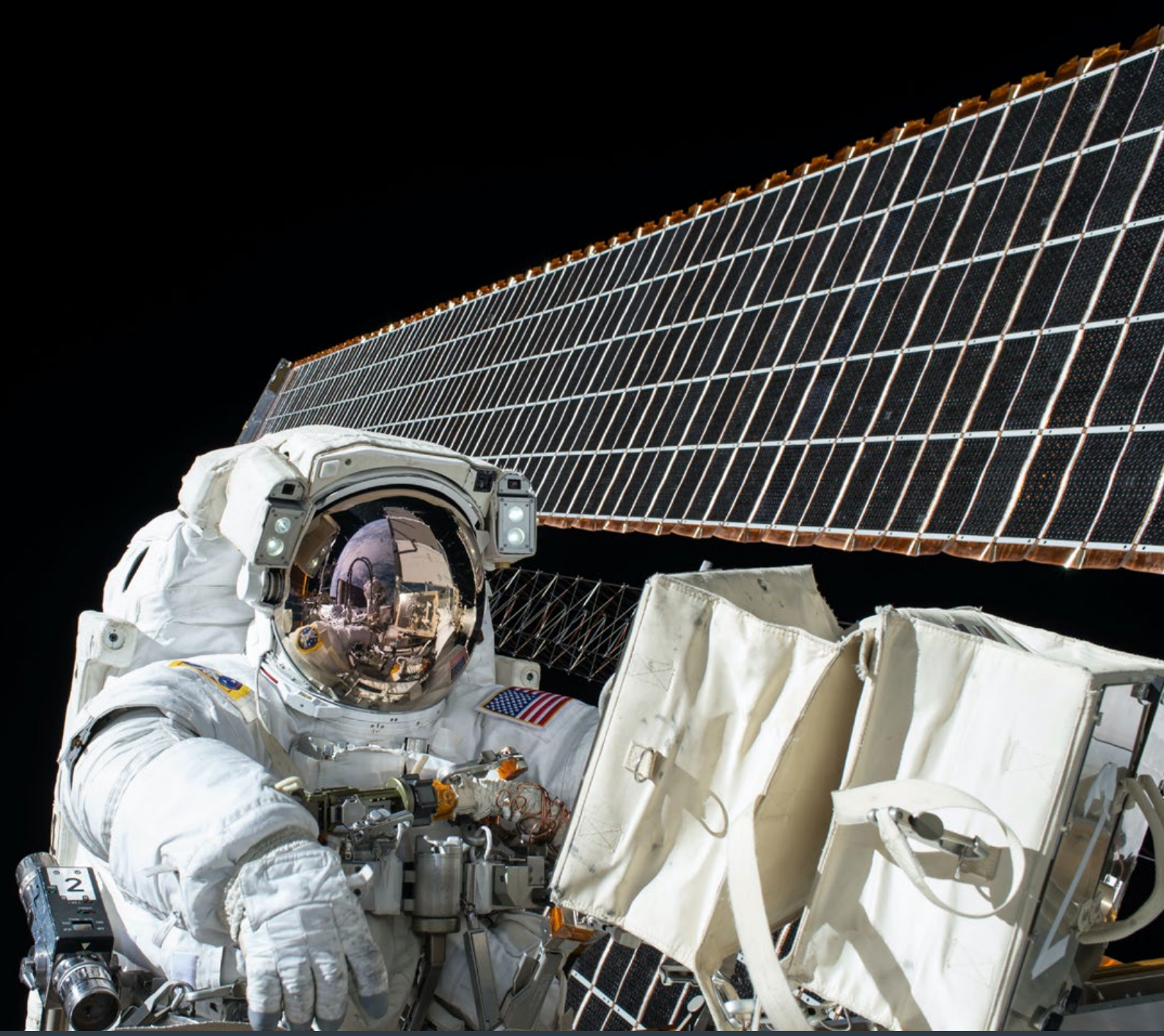

3dpbm | Insights

Aerospace AM

Flying high with additive manufacturing

June 2021

About

3dpbm is a leading media company providing insights, market analysis and B2B marketing services to the AM industry. 3dpbm publishes 3D Printing Media Network, a global editorial website that is a trusted and influential resource for professional additive manufacturing.

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Other image credits on Page 38

Hello

When we published our 2020 aerospace eBook, the future of the industry—for the first time in a long time—seemed uncertain. A year on, and the industry—especially commercial aviation—is still struggling, though there are reasons for optimism, especially when it comes to AM.

Additive manufacturing and aerospace have been linked from the very beginning—of AM, that is. Aerospace companies were among the first to really understand the manufacturing technology's potential, especially when it came to designing more efficient and lightweight components. Over the years, the two sides have formed a mutually beneficial relationship, with aerospace and aviation companies helping to evolve and qualify AM processes, and AM processes enabling the aerospace industry to further increase the efficiency of aircraft and manufacturing workflows.

In the following pages, we take stock of additive manufacturing's increasingly prominent role in the aerospace industry, looking at various applications—from aircraft tooling, to drones, to space-ready components—and mapping out the key players providing AM solutions to the aviation sector. To kick things off, an expert analysis, with data from 3dpbm's Index, breaks down where in the world the biggest aerospace AM innovations are taking place. So buckle up and get ready for takeoff with our Aerospace AM 2021 eBook!

Tess Boissonneault
Editor in Chief, 3dpbm

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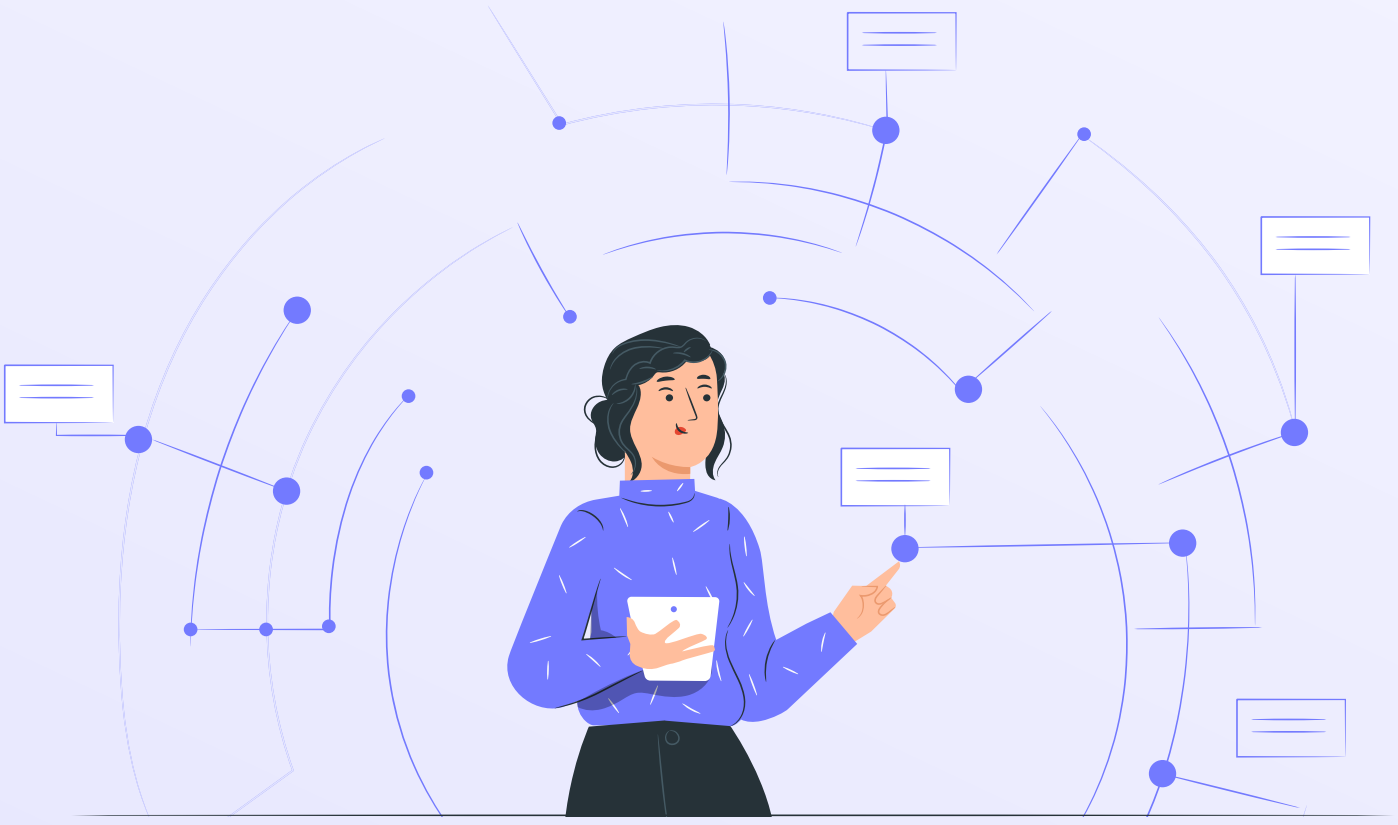
Newsletter

Join over 10,000 professionals and get AM industry insights sent directly to your inbox every week.

Carefully curated by our editors, our weekly newsletter keeps executives, engineers and end-users updated on the AM developments that really matter.

Check out an example or sign up to join them.



3dpbm

ANALYSIS

Where in the world are the aerospace AM hubs?

An inside look at the geography of AM adoption in the aerospace industry, based on 3dpbm's proprietary Index

3dpbm

Image: SpaceX

Aerospace and additive manufacturing, a match made in heaven. Ever since the early days of AM for parts production, it has become clear that the first industries to reap the many benefits of AM technologies, processes and applications would be the ones that needed to fly: aviation, space, helicopters, drones.

The benefits of lightweighting parts through complex geometries have been too evident to ignore, especially when—as is often the case in aerospace—part price is not really a limit. AM hardware manufacturers and AM service providers have aggressively targeted the aerospace segment and published dozens of relevant application cases to validate their unique value-added propositions.

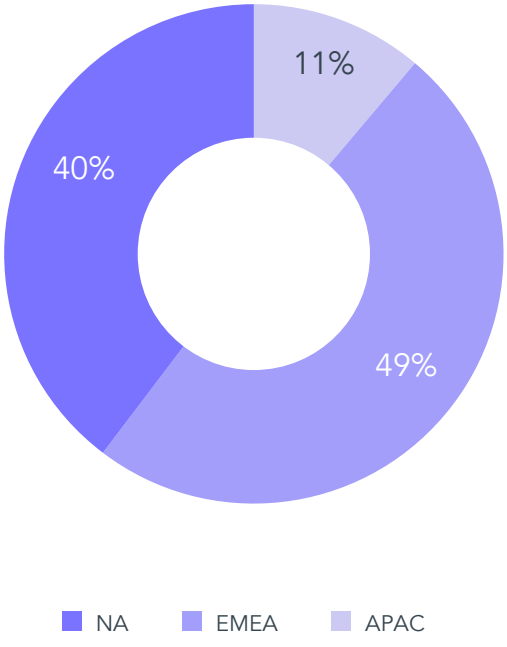
In fact, some AM service providers have become some of the largest producers of 3D printed aerospace parts. On the other hand, beyond some of the largest OEM and tier 1 companies, such as Airbus, GE, Safran and Lockheed Martin, AM adopters have not always been as keen (or as able) to promote their progresses in AM, so drawing an actual map of AM adoption in the aerospace segment has not been an easy task.

Through the 3D Printing Business Directory index, 3dpbm has been tracking and collecting information on aerospace AM adopters for nearly a decade, building a database of 150 aerospace industry companies that have been verified as users of AM. We can now exclusively use this information to provide the first ever bottom-up analysis of the geographic distribution of AM adoption in the global aerospace industry.

AM adoption in the global aerospace market

3dpbm's Index lists a total of 153 aerospace companies from 26 different nations in the three major geographic regions: EMEA, North America and Asia Pacific. These companies were assigned a coefficient according to a number of variables describing their level of internal adoption of AM. These variables included elements such as overall company size and productivity, published application case studies, specific aerospace segments targeted, types of known AM applications (prototypes, tools, final parts), number of known internal AM systems and the number of years since AM was first implemented. Based on these coefficients, we were able to produce the most accurate estimate to date of the level of adoption of AM for each geographic region. According to this analysis, the EMEA region today accounts for 49% of all AM adoption by aerospace industry companies, with North America accounting for 40%. The APAC region only accounts for 11%. The significant difference in the level of AM adoption within the APAC region, as compared to EMEA and North America, may be due to a number of factors, including the more limited amount of information available from countries such as China and Japan, as well as greater and more affordable availability of traditional forming technologies in Asian markets, which make AM adoption less immediately advantageous.

AM adoption by aerospace companies by region
Source: 3dpbm Research



AEROSPACE AM IN EMEA

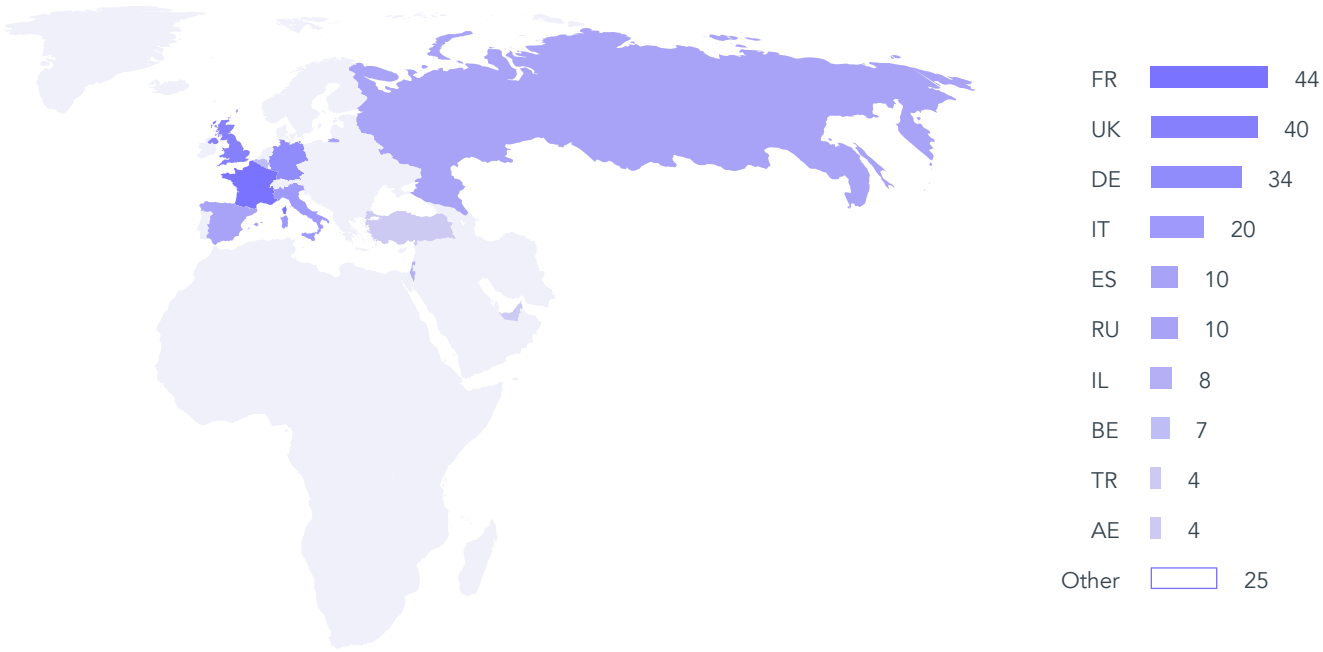
The fact that EMEA, the area that includes Europe, Russia and Middle East, is the largest for AM adoption in aerospace should not come as a surprise. A significant share of aerospace AM adoption in Europe has been driven by Airbus, the largest aerospace company in the world today, which has facilities in France, the UK and Germany but also drives AM demand from many of its EMEA-based tier 1 and tier 2 suppliers. At the same time, several airlines— especially the rising powers from the Middle East, such as Etihad and Emirates—are users of AM for MRO and even cabin parts production.

France's Aerospace Valley

According to 3dpbm's Index, France is the country which features the most aerospace companies that have adopted AM internally. France's famous "Aerospace Valley", a cluster of aerospace engineering companies and research centers, located in the southwest of France (in and around the cities of Bordeaux and Toulouse), includes major AM adoption companies such as Airbus, Airbus Space & Defense, Lisi Aerospace, Ariane Group, as well as 3D printer manufacturers, including 3DCeram, AM service providers, AM material suppliers and AM software companies.

Also located near Bordeaux is the new Safran Additive Manufacturing Campus, where most of the French aerospace manufacturer's AM activities will be located. While Safran has a global presence, most of the company's AM activities have been counted here as being part of France's overall capabilities. Thales, one of the largest space systems companies in the world, is also headquartered in France and its AM activities (especially in satellite manufacturing) counted as part of the French cluster.

AM adoption by aerospace companies in EMEA
Source: 3dpbm Research



The Safran Additive Manufacturing Campus near Bordeaux is where most of the company's aerospace AM activities take place.
Image: Safran

The UK's space-hub

While the UK also has a powerful tradition in aerospace innovation and can be considered a major country for AM adoption, one particularly interesting recent development for AM is the country's race to space, with both the Cornwall region and Scotland emerging as ideal spaceport locations (the new Spaceport Cornwall currently under construction just hosted the recent G7 meeting). Airbus has a strong presence in the UK—with Airbus Defense and Space, as well as a facility producing wings for Airbus aircraft—and has made progress in AM for satellite manufacturing. Other local giants of aerospace that are known to use AM include BAE, Rolls Royce Civil Aerospace and GKN. In particular, GKN is also one of the companies that has invested the most in the development of additive manufacturing processes and materials for end-use part production. The UK is also home to some fringe innovation in aerospace and AM, with innovative startups such as Gravity Industries pushing the limits of personal aerial transportation.

Germany's industrialization of AM

Airbus also has a major presence in Germany, with a large production plant located near Bremen's airport making significant investments in the industrialization of AM technologies (or ALM processes, as they are called internally). Airbus' presence in Germany is particularly relevant in terms of AM for driving major tier 1 suppliers to develop these capabilities. Companies such as Liebherr, Premium AEROTEC and APWorks (which was initially part of Airbus and later became part of Premium AEROTEC) have been pushing the boundaries of AM

GE Avio Aero's facility in Cameri, Italy, where aerospace components, like fuel nozzles and turbine blades are manufactured using metal AM.
Image: Avio Aero

adoption in aerospace, both in terms of part production and material development (APWorks is known for developing Scalmalloy, the first AM-specific aluminum alloy, developed mainly for aerospace applications).

Italy's aerospace AM factories

Like France's Aerospace Valley, many of Italy's aerospace activities are located in one centralized region, Piemonte. The Piemonte aerospace cluster includes 280 SMEs accounting for a €3.9bn turnover and 17% of national exports from within the sector. World-leading players—and major AM adopters—located in the area include Leonardo Airborne & Space Systems, Leonardo Aircraft, GE Avio Aero, United Technologies Corporation (UTC) and Thales Alenia Space. In particular, GE Avio Aero has been at the forefront of AM aerospace adoption when it became the very first company in the world to establish a full AM factory for the production of end-use flying parts. These include the fuel nozzles and turbine blades that make up the over 300 3D printed components in the newest GE9X aircraft engines, the largest and most powerful ever built. GE Avio Aero and Leonardo also have a presence in Brindisi, in the Southern Italian region of Apulia, which represents another key cluster for AM and aerospace adoption.

Other relevant EMEA hubs

Besides the largest aerospace manufacturing regions of Europe, several other key clusters for AM adoption in aerospace have emerged in EMEA. These include several industrially advanced areas of Spain, such as Catalunya and Basque Country, as well as emerging

aerospace nations such as Israel and the UAE. Not to forget, of course, Russia, which is a powerhouse for space, defense and helicopters.

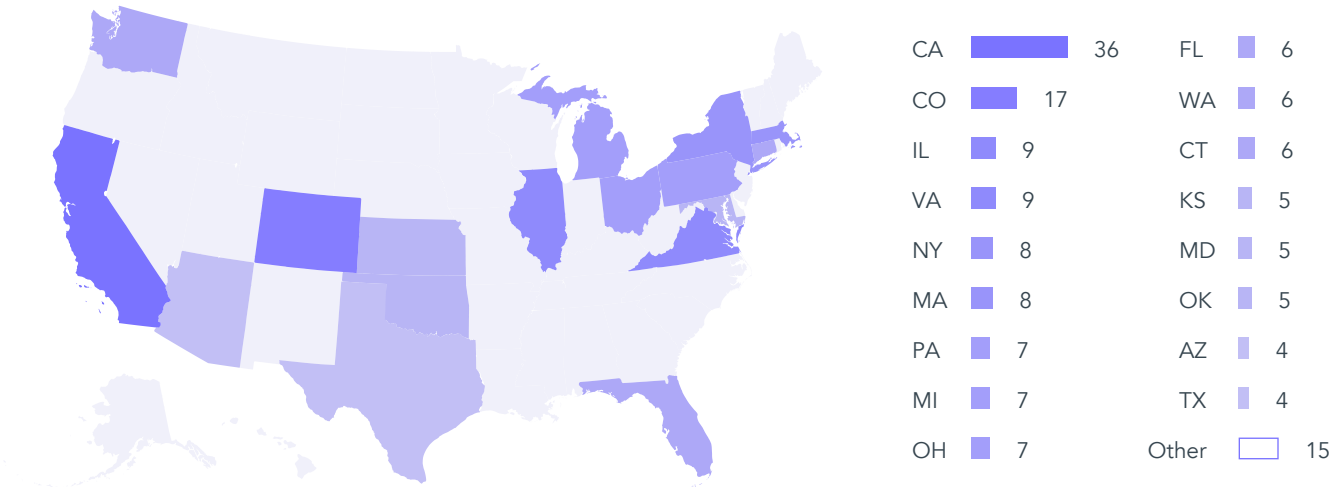
Possibly one of the largest Spanish AM adopters in aerospace is Aernnova, a company specialized in the design and manufacturing of aerostructures and components. Other relevant companies include Pangea Aerospace in Catalunya, which is developing a reusable launch vehicle for ESA. Russia is, of course, a major power in the space industry, with the national agency Roscosmos evaluating several projects implementing AM for and in space. Russian Helicopters has also been a user of AM in parts production since 2020.

Israel has a very strong tradition in both aerospace (including defense) and AM (with PolyJet technology originating here). The Rehovot cluster hosts several AM companies as well as aerospace systems companies like Elbit Systems. Other major Israeli users of AM in aerospace include IAI (Israel Air Industries) for both drone and commercial aircraft parts production. In the UAE, one company in particular, Strata Manufacturing, has emerged as both a major supplier for aerospace (with customers including Airbus, Boeing and Leonardo) and a major AM adopter for production of cabin parts through a close collaboration with Stratasys, Siemens and the large local carrier Etihad.

AEROSPACE IN AMERICA

In this article we propose the first ever state by state analysis of aerospace additive manufacturing adoption in the USA, which provides a number of interesting insights. Once again we are leveraging information collected—since 2013—by 3dpbm's Index, which features exact company location. There are a total of 64 aerospace companies (confirmed as AM adopters) listed in the Index from across the United States. Most of these companies are located in California, with other relevant hubs in Colorado and on the East Coast.

Aerospace hubs for AM adoption by US State
Source: 3dpbm Research

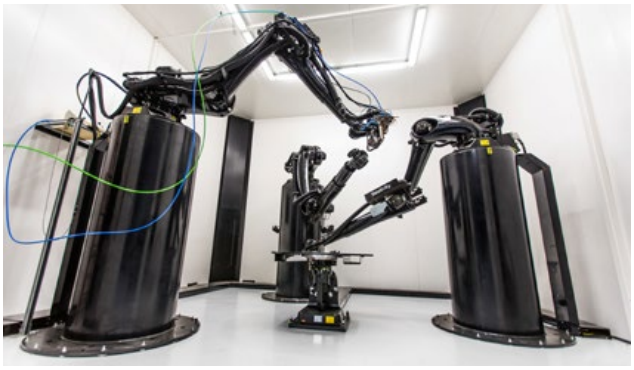


The California "Space Beach"

There are a large number of aerospace companies in California and most of them are space companies. So much so that Long Beach is becoming known as Space Beach. In fact, some of the best known space companies in the world are based there, and among them are some of the biggest adopters of additive manufacturing. The first among these is of course SpaceX, which has publicly shared its use of AM ever since the production of the first Draco engines. SpaceX conducted several launches from its West Coast facilities although most of the recent StarShip development and assembly takes place at SpaceX's Rocket Development and Test Facility in McGregor, Texas, which is used for research and development of new rocket engines and thrusters as well as for testing final manufactured engines, various components, and engines during development.

Another huge user of AM, although still in the startup phase, is Relativity, a company that developed an extra-large format DED system to produce entire rockets (and has raised nearly a billion dollars to date to support this vision). It doesn't end there. Virgin Orbit has a base in California and so do other major AM adopters, including Space Systems Loral and Masten Space. While it is not a commercial entity, and as such it is not counted in this analysis, we should also mention NASA's Jet Propulsion Laboratory (JPL) as a major California-based user of AM technology for space applications.

Image: Relativity Space



Flying high in Colorado

Sometimes it's curious to consider that Colorado is known for being both the first state to legalize recreational marijuana and as a major space hub: either way they are flying high in this part of the US. One of the reasons why so many space companies are based near Denver, Colorado is that Lockheed Martin Space, one of the four major business divisions of Lockheed Martin (and possibly the largest in terms of AM adoption) has its headquarters there—with additional sites, incidentally, in California as well as in other US and UK locations. Denver is also the hometown of United Launch Alliance, a joint venture between Lockheed Martin and Boeing, which manufactures and operates a number of rocket vehicles that are capable of launching spacecraft into orbit around Earth and beyond.

Another key aerospace AM adopter located near Denver is Boom Supersonic, one of the most exciting companies to emerge recently in the aerospace segment. Boom is developing the Overture, a new commercial supersonic airliner making heavy use of both polymer and metal AM for prototypes, tools and end-use parts. United is the first major carrier to have ordered up to 50 Overtures to add to its fleet.

Eastern and central hubs

The truth is that some of the major aerospace companies in the US—even in terms of AM adoption—are fairly spread out across the country, especially on the Central-Eastern side. New York State is home to some exciting aviation and space AM startups and companies. They include Launcher (although the company just opened a new facility in California) and Norsk Titanium, a metal 3D printing service provider exclusively dedicated to producing parts for Boeing airplanes using proprietary RPD technology. Another large NY company, Moog, has invested in developing systems for on-demand aerospace spare parts production via AM. Other key companies for aerospace AM in the US

Some of the best known space companies in the world are based in California, and among them are some of the biggest adopters of additive manufacturing

include GE Additive, the primary provider of AM parts for GE Aviation, with its AM factory of the future located in Ohio; and the giant Raytheon Technologies Group. Raytheon Technologies Group includes a number of major AM adopters, including United Technologies (with which it merged in 2020) and UT-owned Canadian aerospace manufacturer Pratt & Whitney.

AEROSPACE AM IN APAC

Due to the language barrier, especially in the key markets of China and Japan, we have less information on Asian aerospace companies adopting AM than we do for Western companies. At the same time, both China and Japan have been trailing behind Europe and the US in their implementation of AM processes for production.

There are different reasons for this: China is slower in adopting AM because it has more affordable local access to traditional production technologies and thus focuses on mass manufacturing. Japan has been slower in adopting AM as most Japanese manufacturers were initially skeptical about its real potential as a production process. Nevertheless, both markets are now stepping up their AM adoption, with obvious impacts on local space and aviation manufacturing companies. Singapore, due to its strategic location as a business hub and a generally greater openness towards foreign companies and investments, is also emerging as a key hub for AM in Asia, including AM for aerospace applications.

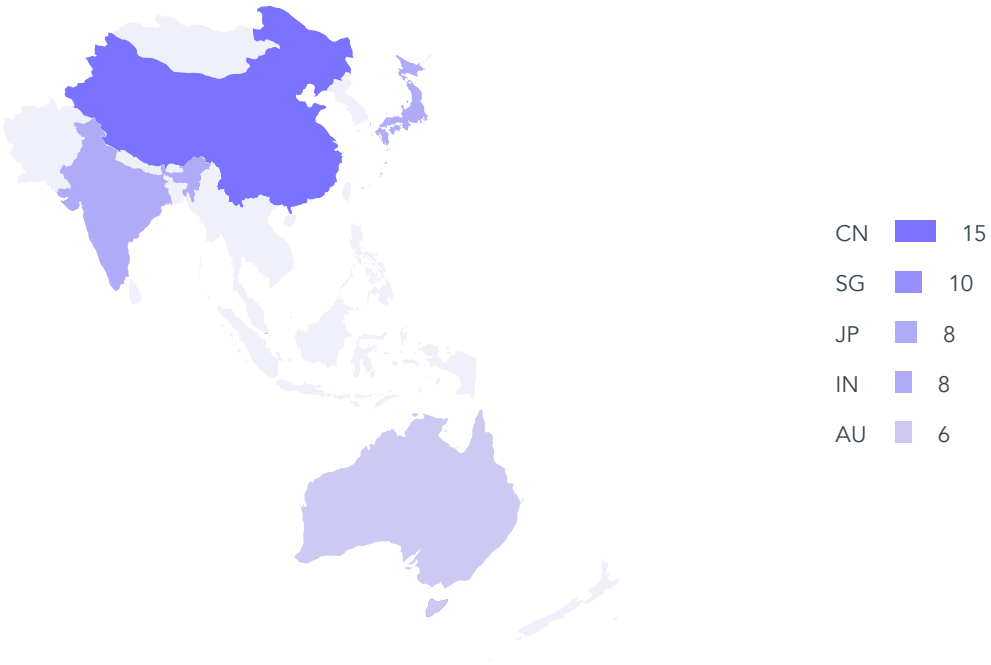
China below radar

While Chinese AM companies are now increasingly making themselves visible outside the local market—not just for hardware but also as service providers—the internalization of AM by Chinese aerospace manufacturers is generally kept secret or at least not publicized. Over time, 3dpbm has identified only a handful of companies and only COMAC, the country's biggest aircraft manufacturer, has made its adoption of AM public.

According to BLT, one of the largest Chinese AM hardware companies, several 3D printed titanium parts were installed on COMAC's C919 starting in 2019 to reduce the aircraft's weight and increase its safety. 28 3D printed cabin door parts and two fan inlet structural parts were also installed on the aircraft. In addition, the Chinese National Space Administration (CNSA) and the China Academy of Space Technology have produced several 3D printed parts—and even a space-based composites 3D printer—which have been installed on the Long March rockets and on the Mars Rover that recently touched down successfully on the Red Planet (the AM parts were produced by Farsoon). In March

AM adoption by aerospace companies in APAC

Source: 3dpbm Research



2019, the 211 Factory of the First Academy of China Aerospace Science and Technology Corporation had completed the batch production of the first batch of core-stage binding supports for the Long March 5 series of carrier rockets.

Japan rising

The Japanese industry has some of the largest automotive OEMs in the world, as well as some giant material manufacturers and several aerospace companies. One of these companies, IHI Aerospace, recently stated that "we are now strongly promoting the use of 3D printers [for the manufacturing of a 22N rocket thruster utilizing hydrazine]" indicating that additive manufacturing is starting to be increasingly recognized. Several Japanese AM companies, including large groups such as Mitsubishi, develop and implement specific metal AM technologies tailored for the production of dies and molds that are used in aerospace manufacturing.

Singapore's all star hub

Leveraging the powerful NAMIC and A*STAR public-private collaborations, Singapore has emerged as a key hub for AM in all transportation industries, particularly maritime and aerospace. In fact, Singapore is considered so strategic for aerospace AM that Stratasys formed a joint venture with SIAEC to provide aerospace part solutions to airline customers around the world. The resulting company, Additive Flight Solutions, aims to accelerate the adoption of 3D printed parts for commercial and military aviation.

Another Singapore-based aerospace AM adopter is ST Engineering, a company specializing in the production of on-demand aerospace parts. ST Engineering is one of the first adopters of the large-format Arcemy WAM metal AM system from AML3D, also a Singapore-based company targeting APAC transportation markets with its hardware technologies. ◆

CASE STUDY

Windform® XT 2.0 accelerates new possibilities for space-ready PocketQubes

Space research devices are now smaller than ever

3dpbm × CRP

Image: CRP courtesy of Alba Orbital

CRP Technology is a manufacturer of advanced 3D printing materials for SLS 3D printing and one of the leading players in the AM space to offer carbon reinforced composite powders. At the top of its material portfolio is Windform® XT 2.0, a durable and strong carbon fiber composite well suited for functional prototypes and small series end-use parts in demanding industries such as motorsport, UAV and, as we'll see in more detail, aerospace.

The material itself was released in 2011, replacing CRP Technology's previous Windform® XT formula and introducing new and improved properties, including an +8% increase in tensile strength, +22% in tensile modulus and +46% increase in elongation at break. These properties, combined with the design freedom of SLS 3D printing, have lent themselves to many applications over the years, including end plates and fences for F1 and IndyCar vehicles; drone structures, such as the arms of Hexadrone's Tundra-M; wind tunnel models for LEONARDO HD's tiltrotor AW609; and more.

In the aerospace segment specifically, Windform® XT 2.0 has become a popular option in the development of small satellites, also known as CubeSats and PocketQubes. Both Italy-based CRP Technology and CRP USA have worked on 3D printed small satellites, collaborating with partners to create fully functional, flight and space-ready prototypes. Let's take a closer look.

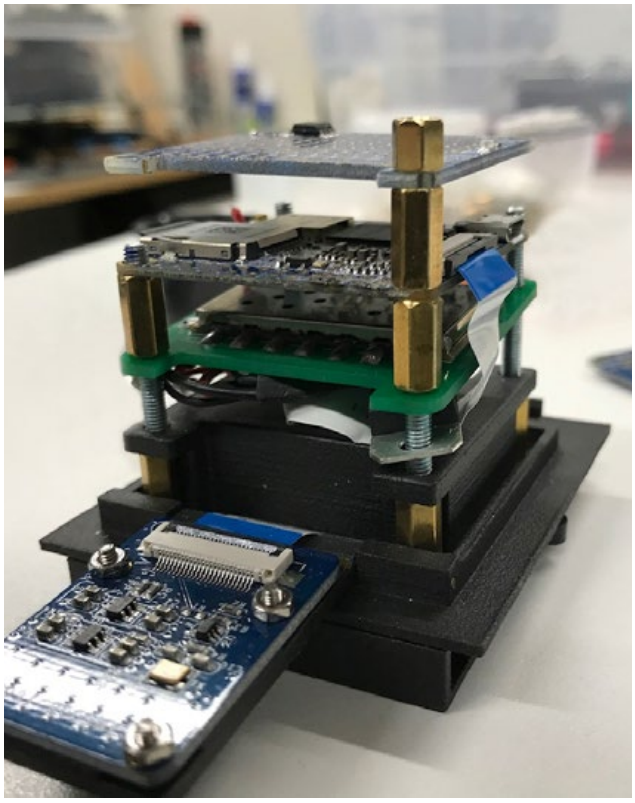
Alba Orbital's AlbaPod v2

Let's begin in Italy, where CRP Technology formed a fruitful partnership with Alba Orbital to 3D print a deployer for advanced PocketQube satellites. A PocketQube is a small satellite—weighing no more than 250 grams—used for gathering data in space. Based in Scotland, Alba Orbital is an SME that specializes in the development of these small innovative devices. The company became involved with CRP Technology when it undertook a project to update its PocketQube satellite deployer, the AlbaPod v2.

To meet the goals of the project—including minimizing weight, improving safety features and manufacturability—Alba Orbital reached out to CRP Technology to leverage its composite materials and 3D printing know-how. Specifically, the company was interested in CRP Technology's Windform® TOP-LINE materials, some of which are suited for aerospace applications and have undergone NASA and ESA outgassing tests. Ultimately, the partners chose to work with Windform® XT 2.0 for SLS 3D printing, which had previously been used for the construction of the innovative TuPOD 3D printed smallsat and had passed JAXA outgas testing.

"As the product needed to withstand a launch to space while containing several satellites, the pod needed to withstand high vibrations and, in the worst case scenario, contain any satellite that breaks free internally," the Alba Orbital team said. "Windform® XT 2.0's toughness and strength made it a perfect candidate for this use case."

Image: CRP courtesy of Mini-Cubes



"Windform® XT 2.0's toughness and strength made it a perfect candidate for this use case."

ALBA ORBITAL

After a successful collaboration, CRP Technology delivered to Alba Orbital a number of 3D printed PocketQube deployers that were 60% lighter than the original AlbaPod and could deploy up to six satellites each. The deployers also passed all necessary tests and complied with Alba Orbital's launch standards.

The first 3D printed AlbaPod v2 was successfully launched into orbit in late 2019. In March 2020, it celebrated its 100th day in orbit. Another launch (Alba Cluster 3, mission "That time of the year") is expected soon, while more launches are already scheduled for this year and 2022.

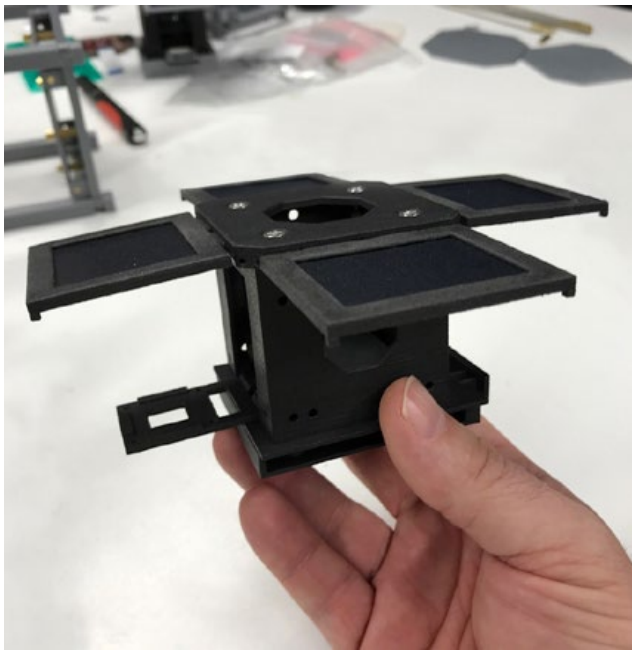
Mini-Cubes' PocketQube satellites

On the other side of the Atlantic, CRP USA demonstrated that Windform® XT 2.0 and SLS 3D printing could also be implemented for the development of small satellites. The American company, which has pioneered the use of Windform® materials for space applications, 3D printed several functional prototypes for Pennsylvania-based Mini-Cubes. They were the first entire, flight-ready PocketQube functional prototypes made using a carbon fiber reinforced composite material (Windform® XT 2.0).

The collaborative work with Mini-Cubes was focused on the development of a new space-ready PocketQube called Discovery. One of the goals of the project was to test the viability of adding a camera to the small satellite for visual observation. CRP USA's extensive experience with 3D printing proved to be essential in this mission. Together, the Mini-Cubes and CRP USA teams designed a PocketQube prototype that could fit the necessary electronics, including the radio system and camera.

Windform® XT 2.0 was used to print the entire satellite structure. "The combination of strength and ease of use made the material a natural choice for us," said Joe Latrell, CEO of Mini-Cubes. "We knew we wanted

Image: CRP courtesy of Mini-Cubes



Alba Orbital team attaches first AlbaPod 2.0 to the kick stage of a Rocket Labs rocket in the lead-up to launch
Image: CRP courtesy of Alba Orbital

to use additive manufacturing for Discovery but understood that it would be hard to find something that would work in the harsh environment of space. We discovered Windform® XT 2.0 and after looking at its properties, it was a simple choice."

In the end, CRP USA produced three 1P PocketQube functional prototypes, two of which were used for testing and one of which was destined for orbit. The prototypes all surpassed testing criteria, meeting NASA vibration and thermal specifications. The third prototype is now readying for launch into orbit in Q2 2021, where it will undergo final validation. More 1P PocketQube launches are expected to follow.

In the end, 3D printing was integral to the development of the AlbaPod v2 and the Discovery PocketQube. Used in combination with CRP Technology's durable composite Windform® XT 2.0, the technology enabled Alba Orbital and Mini-Cubes to iterate prototypes quickly, test them and, if needed, tweak their design without drastically increasing project time and costs. ◆

MAPPING

The AM companies taking aviation to new heights

Who are aircraft OEMs and aviation firms working with?

3dpbm

Image: Tom Barrett

While the commercial aviation industry has taken an unprecedented hit due to the COVID-19 pandemic, there are signs that it will begin to recover as borders reopen and vaccinations campaigns progress. Behind the scenes, 3D printing is playing a small but important role in this recovery, offering aircraft manufacturers and aviation companies the means to evolve production, through increased automation, streamlined spare parts and inventories and improved sustainability through intelligent design.

Today, we are looking at the 3D printing companies whose technologies have become vital tools in the aviation sector, revolutionizing aircraft manufacturing from prototypes, to tooling, to end-use parts. Evidently, this is a non-exhaustive list, but the following companies represent some of the major AM players in aviation.

No stranger to industrial applications for polymer-based AM, 3D printing giant Stratasys has established its technologies as viable solutions for many applications in the aviation and aerospace sectors, from rapid prototyping, to composite tooling, to production parts. One particular area Stratasys' technology has excelled in the aviation space is in the production of aircraft interior components, largely enabled by its flame-retardant ULTEM 9085 resin material.

Today, Stratasys' technology is used by a number of aircraft manufacturers, including Airbus, which announced in 2020 that it had successfully used Stratasys FDM production 3D printers and ULTEM 9085 resin to produce over 1,000 flight parts for its A350 XWB aircraft. Stratasys has also sold production-grade systems to Latvia-based AM Craft, which is utilizing 3D printing for aircraft interior applications, and has worked with UK-based BAE Systems to strengthen the company's use of AM in land, maritime and air sectors. Last year, Stratasys partnered with Singapore Airlines Engineering Company to establish a local AM center for aviation MRO services. The partners actually founded an aerospace AM venture, Additive Flight Solutions (AFS) in 2018, which last year received AS9100D certification and successfully became registered with the International Aerospace Quality Group (IAQG).

While we could write an entire eBook on GE Additive and Aviation's AM-related aerospace and aviation activities, we'll do our best to summarize their key operations here. GE Aviation, which works closely with GE Additive, has pioneered the development and implementation of many 3D printed flight-ready parts. Perhaps most notably, the GE9X aircraft engine, the largest and most powerful jet engine ever made, integrates 19 3D printed fuel nozzles. Designed for the 777X wide-body passenger jet, the GE9X had its maiden test flight in 2018; in September 2020, it received FAA certification.

GE Aviation has also achieved other milestones for AM in aviation. In 2015, it received its first FAA clearance for the production of a 3D printed part in a commercial jet engine. The part in question was a sensor housing for a compressor inlet temperature sensor made using SLS technology. GE and Boeing used the part in over 400 GE90-94B engines for Boeing 777 aircraft. In 2018, GE Aviation revealed it had printed 30,000 fuel nozzles for its LEAP engines, which it first started manufacturing in 2015. The titanium parts are made at GE Aviation's facility in Auburn, Alabama, which has over 40 metal 3D printers in operation. GE Aviation also relies on AM for a range of other applications, including functional prototyping for the Future Affordable Turbine Engine (FATE) with the United States Army and the ITEP engine for Apache and Black Hawk helicopters. Most recently, it received Engineering Change Proposal approval from the US Air Force for an F110 3D printed sump cover.

Image: EOS | MTU Aero Engines

Based in Lübeck, Germany, SLM Solutions has been involved in a number of highly innovative additive manufacturing projects in the aviation industry. Its selective laser melting technology and aerospace-grade materials, including TIAl6V4, IN625 and AlSi10Mg, have been employed by a number of aerospace users. For instance, Safran Landing Systems worked with SLM Solutions to produce a nose landing gear component for a bizjet. The part, which was redesigned for AM and achieved a 15% weight reduction, was made using the SLM 800 and a titanium powder. The objective of the project, which was revealed earlier this year, was to demonstrate the viability of using SLM to produce a main aircraft fitting.

SLM Solutions' technology has also been employed by CellCore GmbH for the production of a monolithic thrust chamber, which benefited from part consolidation and faster production times; as well as by Asco Industries for a Gooseneck Krueger Flap Actuation Bracket, which saw a 31% weight reduction and was printed using SLM Solutions' SLM 280 Twin. These case studies have helped to demonstrate how SLM technology can be beneficial for innovative aerospace applications through the reduction of weight and turnaround times.

Image: SLM Solutions | Asco Industries

German additive manufacturing company EOS has worked with a number of aviation companies in recent years, helping them to achieve increasingly sophisticated and lightweight aircraft components with its 3D printing solutions. Among its partners are MTU Aero Engines, which has optimized EOS 3D printers for the production of borescope bosses for the geared turbofans of Airbus A320neo's PurePower PW1100G-JM engines; German-Swiss manufacturing firm Liebherr, which developed a high-pressure hydraulic valve block for Airbus A380 aircraft using EOS' metal AM (successfully flight tested); and aeronautical engineering company Vectoflow, which optimized a probe design for measuring the speed and temperature of turbo engines using the EOS M 290 machine and a nickel-chromium alloy.

Beyond that, EOS played a vital role in an environmental life-cycle assessment back in 2014 in cooperation with EADS (now Airbus) to compare two key production technologies: rapid investment casting and Direct Metal Laser Sintering (DMLS). The LCA determined that for the production of nacelle hinges, DMLS resulted in an almost 40% reduction in CO2 emissions over the whole lifecycle thanks to weight saving. This study was helpful at the time in understanding the tangible ecological benefits of AM (and specifically DMLS) for aircraft manufacturing.

Florida-based Sintavia specializes in the production of aerospace assemblies using state-of-the-art metal additive manufacturing.
Image: Sintavia - Business Wire

SINTAVIA

Florida-based Sintavia—though not an AM hardware supplier—plays a key role bridging the aviation and additive manufacturing industries. The company specializes in the design and production of critical assemblies for aerospace, defense and space using additive, and especially metal additive manufacturing. With various aerospace accreditations and certifications, Sintavia operates as a specialized AM service, providing high-quality AM parts for a range of aviation and aerospace applications. In 2018, for instance, the company became the first company to receive internal approval from Honeywell Aerospace to 3D print production parts using powder bed fusion. Today, the company's offering is supported by a fleet of high-speed 3D printers from five leading OEMs—including GE Additive, EOS and TRUMPF—a hot isostatic press, vacuum heat treatment furnaces, wire EDMs and various state-of-the-art testing equipment. The company is also a founding member of the Additive Manufacturer Green Trade Association (AMGTA), and is dedicated to pushing for a more sustainable future for the aviation industry with the help of AM.

materialise

Belgium-based Materialise is active in many industries, including aerospace. The company has worked and is working with partners across the aerospace supply chain, from leading OEMs, MROs, tier one and two suppliers as well as eVTOL startups. In aviation specifically, the company is qualified to produce flight-ready parts thanks to POA certification, as well as manufacturing processes that meet Airbus AIPI and EN9100 standards.

Materialise software programs, specifically Streamics and Magics, are currently used by Avio Aero to facilitate the production of lightweight titanium blades for jet engine turbines. The Belgian 3D printing company is also partnered with Airbus, having helped it to rapidly iterate aircraft interior panels in small batches at its aerospace manufacturing facility. Most recently, Materialise was qualified by Airbus to manufacture flight-ready parts using EOS' laser sintering technology and flame-retardant PA 2241 FR. The qualification, which was announced in May 2021, sees Materialise and EOS become the first suppliers certified for the production of laser sintered parts in compliance with Airbus Process Specification AIPS 03-07-022. Today, Materialise is responsible for 3D printing roughly 100 different part numbers for the Airbus A350 for a total of nearly 26,000 parts a year.

Materialise produces nearly 26,000 3D printed parts a year for Airbus, including cabin parts for the A350 XWB.
Image: Airbus SAS

Image: Norsk Titanium

NORSK TITANIUM

Based in Norway with a growing global presence, Norsk Titanium is another metal AM company that has found a role in the aviation industry. The company's proprietary Rapid Plasma Deposition (RPD) process is FAA approved and is compaitble for use with aerospace-grade titanium wire. Today, Norsk Titanium is a Tier 1 supplier to commercial airframe and engine OEMs, leveraging its technology to help reduce the cost of aerostructures and jet engines.

Notably, the company received a production purchase from Boeing in 2017 for the manufacturing of 3D printed structural titanium components for the 787 Dreamliner. By 2018, the partners were qualifying the 3D printed aircraft parts. Fast forward to late 2020, and Norsk Titanium successfully delivered a series of 3D printed components for the Boeing 787 aircraft to Leonardo's Grottaglie Plant in South Italy. The company also announced a contract with Airbus in 2019 for the qualification and serial production of structural aircraft components using its RPD process.

VELO 3D

VELO3D's support-free metal additive manufacturing process has been of keen interest to a number of aerospace companies. Since the company launched its Sapphire 3D printer in 2018, it has formed partnerships with innovative aerospace startup Boom Supersonic, Honeywell Aerospace and, most recently, Primus Aerospace. One of VELO3D's most high-profile customers, Boom Supersonic has implemented the company's Sapphire 3D printer to produce a number of titanium parts for its XB-1 aircraft. The companies, which collaborated on a series of trial parts in 2019, have progressed to using AM for the production of critical test parts for the XB-1, including manifolds for the Variable Bypass Valve system, exit louvers for the environmental control system, NACA ducts and more. One of the key advantages of VELO3D's technology according to Boom Supersonic is its ability to preserve original design intent, eliminating the need for significant part redesign.

Last year, VELO3D joined up with Honeywell Aerospace with the aim of qualifying its Sapphire metal 3D printing system for the production of aircraft components. Most recently, the company made a system sale to Primus Aerospace, a leading contract manufacturing partner to aerospace, defense and space OEMs, for the production of cube satellites, hypersonics and turbine engines.

Image: VELO3D

Ultimaker

On the polymer end of things, Dutch 3D printer manufacturer Ultimaker has positioned its technology strategically. Today, a number of airlines and aviation companies utilize its desktop systems to produce custom tools as well as to explore the creation of functional components.

In late 2019, for instance, British Airways implemented Ultimaker's technology as part of a trial program to understand the benefits of 3D printing on-site at airports. Specifically, the airline was interested in testing the viability of printing non-critical parts like cutlery, tray tables, aircraft windows, flight deck switches and aircraft shells, among others.

Dutch airline KLM has also caught the 3D printing bug, using the technology to print tools from recycled plastic (derived from in-flight water bottles) for repairing and maintaining aircraft. Finally, Ultimaker's printers are also employed by the Royal Netherlands Airforce, which 3D prints custom tools and jigs for helicopters and other aircraft.

Image: Ultimaker

Image: GKN Additive

As a leading tier 1 aerospace supplier, GKN Aerospace has not shied away from the use of additive manufacturing. The company, which serves all major aircraft and engine manufacturers, regularly uses 3D printing for custom and replacement tooling as well as fixtures to facilitate manufacturing and reduce downtimes. The company is also at the forefront of industrializing additive manufacturing, spearheading two research programs—AIRLIFT and DAM—which aim to prepare AM (and specifically laser metal deposition by wire, LMD-w) for serial production and establish cutting-edge design tools for aerospace AM.

While much of the company's additive undertakings take place at its in-house AM center at its facility in Filton, Briston, England, GKN Aerospace is also exploring the creation of large-scale structural aircraft components using LMD-w cells at the U.S Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL). This past May, GKN Aerospace delivered a partially 3D printed Intermediate Compressor Case (ICC) to Rolls Royce for the UltraFan demonstrator engine, which is part of the Clean Sky 2 programme.

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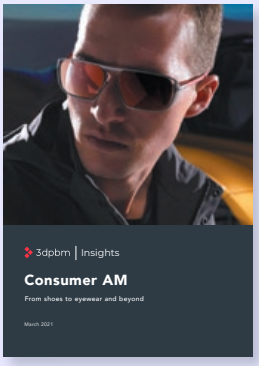

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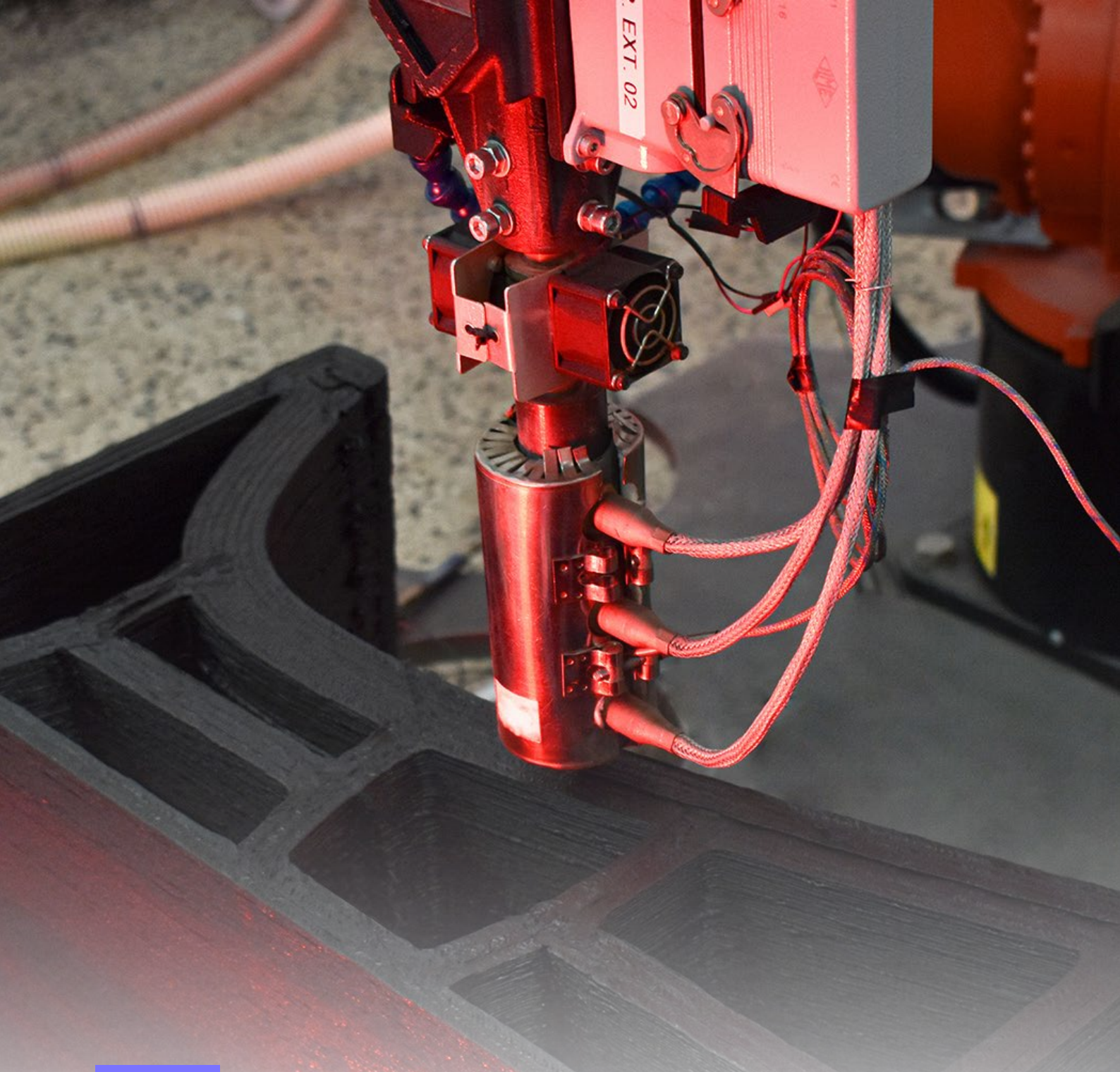

SPOTLIGHT

Pushing the limits with Caracol additive manufacturing

Italian company's large-format AM technology finds footing in aerospace

3dpbm × CARACOL

Image: Caracol

Italian 3D printing company Caracol is no fan of limits. This is evidenced by its large-format robotic 3D printing technology—capable of printing massive parts measuring up to five meters—as well as by the seemingly limitless applications for its manufacturing process, which range from the medical, architecture and automotive industries, to the aerospace sector.

In the context of aerospace, Caracol's large-scale extrusion AM technology has found a number of uses, including the production of aerospace tooling and satellite components. These specific case studies, which we'll dive into below, have been enabled not only by the Italian company's 3D printing technology, but also by its extensive knowledge of generative design, composite materials and applications.

A one-stop shop for aerospace AM

Caracol defines itself as a one-stop partner for clients requiring AM services, providing everything from design and concept development to final part production. At the core of its offering is its robotic AM technology, based on a patented extrusion system.

The 3D printing process is not only capable of producing large, highly complex components, but also of printing composite materials, such as PP, PA12 and PPS with carbon or glass fiber reinforcement of up to 40%. Moreover, because the process uses pellet materials, it reduces production costs and easily minimizes material waste through re-use—a key element in the company's sustainability mission.

In recent years, the company has increasingly turned its focus to the aerospace sector, identifying it as an area that could both benefit from and help to evolve its AM solution. To date, it has worked on various projects within aerospace, including the production of aerospace tooling and molds, satellite deployer parts, avionic systems casings and composite parts for autoclaves.

"Caracol believes additive manufacturing has great potential for evolving and improving technologically within the aerospace sector," the company says. "Both on composite polymers and metals, there is still huge untapped potential. The technology's flexibility, low production volumes and the possibility of manufacturing complex geometries with a wide range of materials make it ideal for aircraft, space and drone applications."

A new path for aerostructure tooling

While tooling for aerostructures has traditionally involved CNC milling and metal materials (both of which are costly), as well as long production and assembly lead times (up to four months for a single tool), additive manufacturing is offering a highly interesting alternative.

Caracol is working in collaboration with a number of aerospace players to explore the use of large-scale AM for aerostructure tooling and to exploit the benefits it offers, including faster tool development and production, lower production costs and less material waste.

Image: Caracol

In one case, the Italian AM service helped to produce tools for positioning and vacuum-gripped drilling of airplane fuselage panels. This particular project resulted in Italy's very first large-scale aerospace tool 3D printed from composite materials. The fuselage panel tooling was printed in a single piece, while CNC milling was used post-printing to achieve tolerances of 0.1mm and a surface roughness of 1.6 µm.

Overall, several of Caracol's aerospace clients have benefited from the use of its AM technology, seeing dramatically shorter production times, eliminating the need for manual assembly and reducing material waste. All these benefits have also led to a reduction in tooling costs of 30% to 50%, as well as to the reduction of the tool's weight by 600%—facilitating storage and logistics for the client.

Hybrid approach for satellite production

In addition to forging new paths for aerostructure tooling production, Caracol has also made progress in satellite production, working in collaboration with D-Orbit, an Italian aerospace company founded in 2011.

Among several research projects spearheaded by the two companies is an effort to develop nitrous oxide tanks for satellite deployers. Traditionally, standard metal tanks have been used for this application thanks to their ability to withstand high degrees of pressure. These tanks have been assembled together aboard satellite deployers until the necessary gas capacity is reached. However, this approach does pose certain challenges, first of which is the weight of the metal tanks. Because the cost of launching satellites increases

Caracol's large-format 3D printing technology has found a number of applications in the aerospace sector, including satellite parts and aerostructure tooling.
Image: Caracol

Caracol uses a hybrid manufacturing approach in the construction of nitrous oxide tanks for satellite deployers.

Image: Caracol

relative to the device and payload weight, cutting back on grams and kilos wherever possible is paramount. As Caracol and D-Orbit have discovered, AM is a promising solution to this problem.

Together, the companies have identified what they call an experimental hybrid solution that combines 3D printing and lamination processes. In short, Caracol's technology is used to 3D print the tank's liner using a composite material (such as PPS or PEEK reinforced with carbon fiber). This liner is then laminated with multiple impregnated layers of carbon fiber, providing extra strength and durability.

This unique approach has demonstrated a range of benefits, including tank weight reduction, lower production costs and a greater degree of sustainability. Caracol also adds that this approach can lead to lower turnaround times for custom parts, enabling aerospace companies like D-Orbit to stay on top of launch timelines.

Overall, Caracol is keen to explore the various uses of its large-scale robotic 3D printing technology in the aerospace sector, working with various partners to bring new and improved manufacturing solutions and workflows to life. ◆

INSIGHT

Drone mass production is taking off with 3D printing

How Skydio, Digital Aerolus, Quantum Systems, Kespry, Dive Technologies are printing hundreds of parts

3dpbm

Image: Clay Banks

Personal and unmanned aerial mobility is rapidly changing as drones bring us closer and closer to humanity's long-standing vision of flying cars.

Amolak Badesha, CEO of Orbital Composites, a specialist in large-scale composites additive manufacturing, once pointed out to 3dpbm that this new generation of mobility products would not be able to exist without composites enabling the production of extremely light parts. And mass manufacturing with composite materials cannot truly exist without 3D printing.

The same is true for more short-term products, such as unmanned drones for consumer and commercial use. Both in the sky and under the sea: drone mass production via AM is coming.

Composites AM for drone mass production

Skydio was among the first to publicly implement a type of composites additive manufacturing technology for drone mass production. For this, the American drone manufacturer partnered with Arris, first to redefine airframe design leveraging Arris' additive molding process for the Skydio X2 drone. The collaboration led to the first-of-its-kind production use of Arris's technology in the UAV industry, further extending Skydio's technology leadership and enabling advantages, such as replacing a 17 part assembly with a single, multi-functional structure, with parts as stiff as titanium at a fraction of the weight, as well as enabling the Skydio X2 to increase range and speed. All with scalable US-based manufacturing and innovation to bring peak aerospace performance at a lower cost.

"We are excited about the value that our partnership with Arris will bring to our customers. At Skydio, we pursue cutting edge innovation across all facets of drone technology. The unique properties of Arris's Additive Molding carbon fiber allows us to optimize the strength, weight and radio signal transparency of the Skydio X2 airframe to deliver a highly reliable solution that meets the needs of demanding enterprise, public safety and defense use cases," said Adam Bry, Skydio CEO.

Digital Aerolus' local production

US-based Digital Aerolus needed to manufacture next-generation confined-space drones/unmanned aerial vehicles (UAV) and a new ground control unit (GCU). They turned to 3D printing service provider Fast Radius as a long-term production partner dedicated to making more efficient products and finding innovative new solutions while still meeting their aggressive schedule.

Initially, Digital Aerolus needed two 3D printed parts for the Aertos 120, a drone that operates in confined spaces, such as inside pipes, nuclear reactors, chimneys, or mines. Fast Radius introduced Digital Aerolus to HP Multi Jet Fusion 3D printing technology and manufactured parts that exceeded performance expectations, were faster to produce and were within the allocated budget. Digital Aerolus then approached Fast Radius to produce 50 functional prototypes of a ground control unit (GCU) for its new family of autonomous industrial platforms, including the flagship Aertos 130IR.

Image: Arris | Skydio

Fast Radius handled production for almost every mechanical component in the GCU, managing manufacturing across traditional processes and AM technologies, such as Carbon Digital Light Synthesis and HP Multi Jet Fusion, as well as a variety of texturing and graphics processes. The partnership between the companies is now expanding to include newer platform models.

"We make the most advanced drones in the world, with hundreds of computer processing elements and dozens of sensors —all enabled by cutting-edge AI, control systems and software," commented Jeff Alholm, CEO and Co-founder of Digital Aeolus. "Our customers expect extraordinary performance, and we expect the same from our partners. Fast Radius consistently delivers the precision, proactive solutions, rapid results and professionalism we need to keep manufacturing exceptional products."

Drone manufacturing encompasses everything from large military products all the way to mass-market products. At all levels, 3D printing can make drone manufacturing more streamlined and accessible. Applications range from the hobbyist category to top-secret industrial production for military operations.

Quantum Systems goes serial with Shapeways

Companies like Quantum Systems work with online 3D printing service provider Shapeways to develop and manufacture efficient 3D printed parts that are meant for multiple uses with 'integral functionality'. The main benefit of using AM is the ability to reduce the number of pieces made while still delivering a quality, high-performance product. Parts are lighter in weight too—which is especially critical for any type of aeronautic application. Founded in Munich in 2015, Quantum Systems used 3D printing from its inception, taking advantage of the ability to make numerous prototypes before moving on to final production parts 3D printed via selective laser sintering through Shapeways. While Nylon 12 has been a constant in terms of 3D printing materials, Quantum Systems has also used other materials such as MJF Plastic PA12 with Shapeways.

"We used 3D printing right away, so there is no comparison. Quantum Systems is a young company. Only because of the fact that we have integrated this manufacturing method into our manufacturing and development process, have we been able to significantly reduce development time," said Florian Seidel, CEO of Quantum Systems. "For injection molded parts we save around 10 weeks by using 3D printed samples to release the CAD data. The probability that these parts need a second loop of corrections is quite low in this way. For CNC-manufactured parts it is the same, and we just often skip the first round of samples with 3D printed parts which save us 3 to 4 weeks. In general, I would say 3D printing saves us 20-50% in time, depending on which parts we design."

Specializing in advanced electric vertical takeoff and landing (eVTOL) with drones that merge the benefits of larger aircraft like helicopters and airplanes, Quantum Systems has successfully tested its drones for delivering medical samples—evidence of one more application where such technology could make a real difference.

The use of drones for delivery services goes far beyond futuristic hype, and especially when the technology is already being used for time-critical transport of medical samples or supplies in limited form. Drones can be used to drop supplies into most remote areas, where accidents may have occurred, or where it is not initially possible for humans to enter for whatever reason. They can also be used to assess geography and assist with collecting necessary data for search and rescue missions. Drones for military applications in the future are nearly unlimited, but today they are already of critical importance for surveillance and reconnaissance missions, delivery of supplies and weapons, and even use in combat.

Headquartered in Menlo Park, CA, Kespry has been 3D printing with Shape- ways since the very beginning.
Image: Kespry

Kespry's vision

Aerial intelligence firm Kespry exemplifies the adaptability of drones, showing off its obvious power to disrupt long-standing conventional industries and practices through autonomous, hyper-detailed land surveys. Founded in 2013 and headquartered in Menlo Park, CA, Kespry has been 3D printing with Shapeways since its beginnings. Together, the two companies developed and manufactured something completely new with 3D printed drone models for end-use parts in Kespry's Aerial Intelligence Platform. "We were a very small company trying to scale up our product and get it out to market as quickly as possible. We were looking for a supplier who had reasonable scale and the right combination of lead time and cost," said Jordan Croom, Kespry's lead mechanical engineer who has a background in AM research and development in both metal and plastic—from his previous work in aerospace. "We were in a unique place to be able to incorporate additive manufacturing into full-scale production, which I think is somewhat rare, even though it's becoming more common these days. So that was new for me—to be making multiple hundreds of something per order and incorporating them into our production line."

Shapeways worked with Kespry as it continued to scale its business, going from 3D printing just a few parts each week to hundreds a month—all without affecting quality, functionality, or accuracy in parts. As a result, Kespry drones are now used for tasks like establishing risk assessment, assisting insurance agents in closing claims, managing inventory and planning mines, helping to oversee earthwork operations in large-scale construction projects, collecting site data and surveying large factory operations like pulp and paper mills.

“We were in a unique place to be able to incorporate AM into full-scale production, which I think is somewhat rare, even though it’s becoming more common”

JORDAN CROOM, KESPRY

“Getting the right partner is definitely important to us. Somebody with repeatable quality, where we can prove a design once. We don’t have to worry about changing or breaking in future orders,” said Croom.

Dive Technologies’ large dive into AM

The potential that lies with drone technology today is not limited to the sky: drones are also needed under the sea. Massachusetts-based Dive Technologies develops autonomous underwater vehicles, leveraging 3D printing for the production of components like fairings.

The driving technology behind the DIVE-LD is the Dive Technologies AUV-Kit. The AUV-Kit is composed of core, proven subsystems for autonomy, propulsion, control, energy, communications, navigation and mission safety. Rapid reconfiguring and scaling of these systems results in the right vehicle for the mission every time. Combining the AUV-Kit with Dive Technologies’ proprietary hull and structure manufacturing processes leads to a different size and shape vehicle to satisfy a unique job, application, or mission, once the AUV-Kit is owned. This process utilizes Large Format Additive Manufacturing (LFAM) techniques (the BAAM systems from Cincinnati Inc), provided by specialist Additive Engineering Solutions (AES). These capabilities bring complex designs to physical robust hull forms in less than 48 hours for an entire vehicle. Producing a custom AUV can be accomplished in under 4 weeks with this AUV-Kit.

Cobra Aero flies with metal AM

It’s not all about composites and polymers: metal AM is going to have a part in drone manufacturing as well. Renishaw worked with engine manufacturing company Cobra Aero to optimize its design processes for aircraft and motorcycle engines. After working with Renishaw to develop new manufacturing processes, Cobra Aero invested in the AM 400 system to increase its additive manufacturing capabilities. To optimize the design of its engine cylinders for motorcycles and aircraft, Cobra Aero visited a Renishaw Additive Manufacturing Solutions Centre and collaborated with Renishaw engineers to use AM to improve the design of a cylinder for an unmanned aerial vehicle (UAV). Using AM technology allowed Cobra Aero to design a lattice structure to increase airflow easily and also allowed them to produce one solid, lightweight part. ◆

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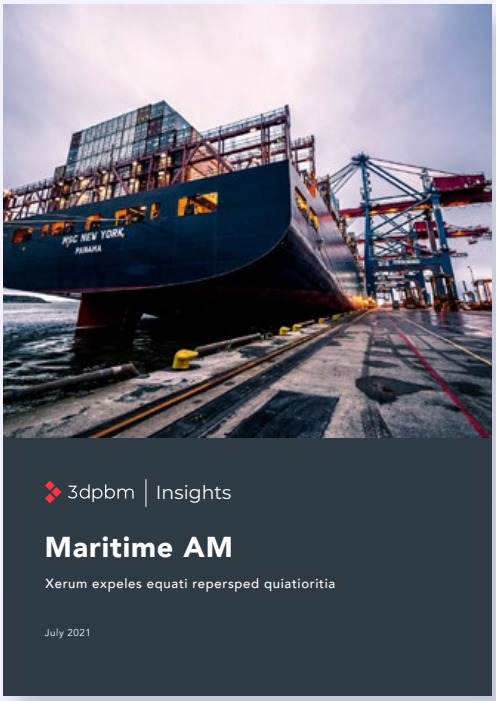

JUL 2021

Maritime AM

In our upcoming eBook we take to the seas, navigating the growing number of applications for AM in the global maritime sector, from streamlining logistics and port inventories to manufacturing ship spare parts on-demand.

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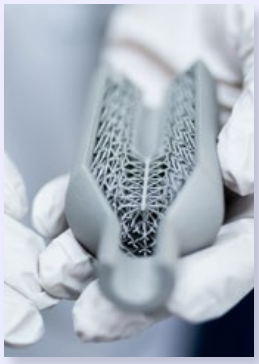

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