THE RISE OF ADDITIVE MANUFACTURING IN AEROSPACE

Operate at the Speed of Relevant to Maintain Flight Readiness

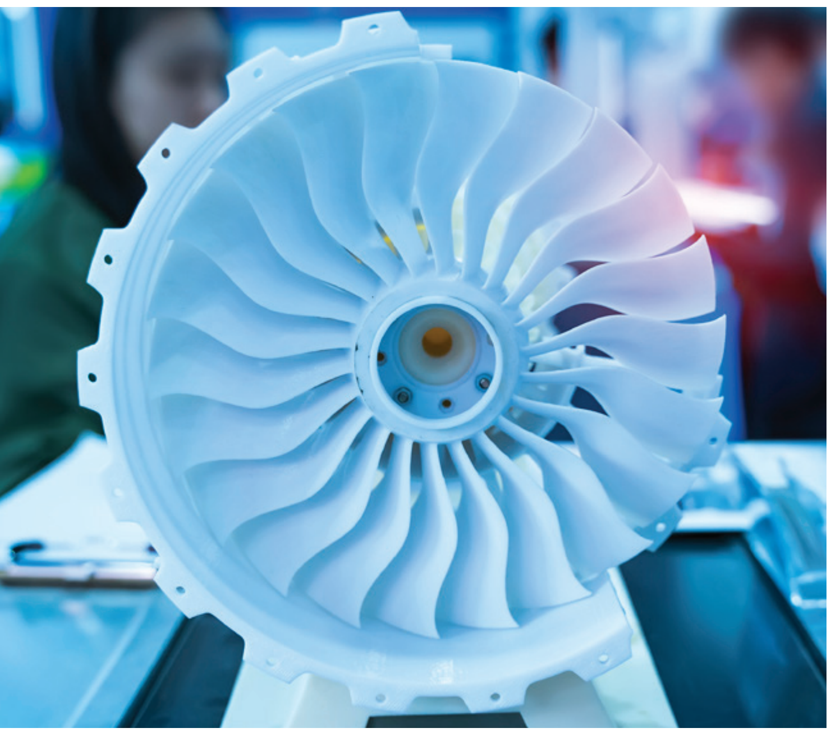
ESSENTIUM

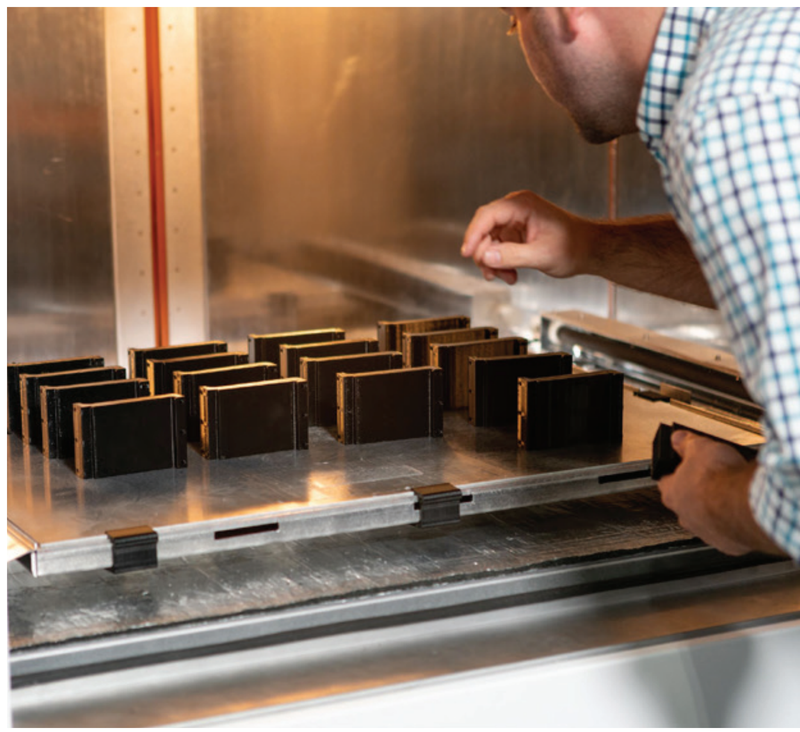
Executive Summary

3D printing is poised to take flight in many exciting ways within the aerospace and defense industry. Given its near unlimited flexibility in design, a wider choice of high temperature materials, and its ability to lightweight virtually any part or tool used to make an aircraft, additive manufacturing is gaining traction in both the commercial/private and defense/government sectors of the aerospace industry.

While the shape of a plane hasn't changed much in the last 100 years, the internal systems that keep it in the air have evolved greatly. This is an opportunity for 3D printing in aerospace. 3D printers enhance the self-sufficiency of manufacturers and aircraft maintenance companies to weather any disruption in their supply chains by being able to print needed ground tooling, support parts, and non-critical air-worthy parts on demand. Additive manufacturing can fend off obsolescence in aging aircraft and offer cost-effective customization in new ones.

This white paper examines the advantages additive manufacturing brings to commercial and governmental aerospace applications, and how open ecosystem 3D printers like the Essentium High Speed Extrusion 180•S Series enables aerospace companies to print jigs and fixtures at the *speed of relevant*.





3D Printing: Ready for Takeoff

Aerospace is perhaps the most innovative industry on earth. Where would we be if the Wright brothers hadn't thought outside the box? After all, humans aren't supposed to fly. Yet we are constantly pushing the envelope on size, speed, altitude, and distance. Therefore, everything about the mechanics of an aircraft needs to be designed, tested, and certified across multiple standards for flawless performance and safety.

The constant drive for innovation led the aerospace industry to be one of the first adopters of additive manufacturing technology. But early implementations of 3D printing did not meet expectations. The printers themselves were expensive, slow, and offered small build areas. A limited choice of high temperature materials further narrowed the scope of aerospace applications that 3D printing could address. Perhaps the biggest obstacle to adoption was the concept of the *closed ecosystem*. Some 3D printer manufacturers required customers to use only their brand of extrusion materials approved for use with their machines. Fear of vendor lock-in prevented many companies from committing.

Today, additive manufacturing technology has overcome many of these challenges. The printers are faster, more affordable, and offer larger build areas. Improvements in software enable the accuracy and repeatability necessary to meet precise dimensional tolerances. There is a wider choice of certified polymers that provide the required properties for strength and flexibility to guard against shrinkage and warpage, while also meeting flame/smoke/toxicity standards. But most importantly, key industry players like Essentium have transitioned to support *open ecosystems* to give customers greater control over their innovations.

Next-generation tools are now ready to meet the aerospace challenges of tomorrow with unmatched speed and scale. Essentium's HSE 180•S HT 3D printer, for example, offers a large build area that fits up to 85% of global jigs and fixtures, and is five to 15 times faster than any other extrusion printer on the market. Essentium's open ecosystem, comprised of the HSE 3D Printing Platform and a broad choice of open-sourced filaments, allow customers to tweak designs to their unique needs and use materials of their choosing to print at the *speed of relevant.*

What is the speed of relevant? Essentium defines it as the ability to produce a part or tool on demand—anytime, anywhere—to keep the wheels of manufacturing in motion and planes in the air.

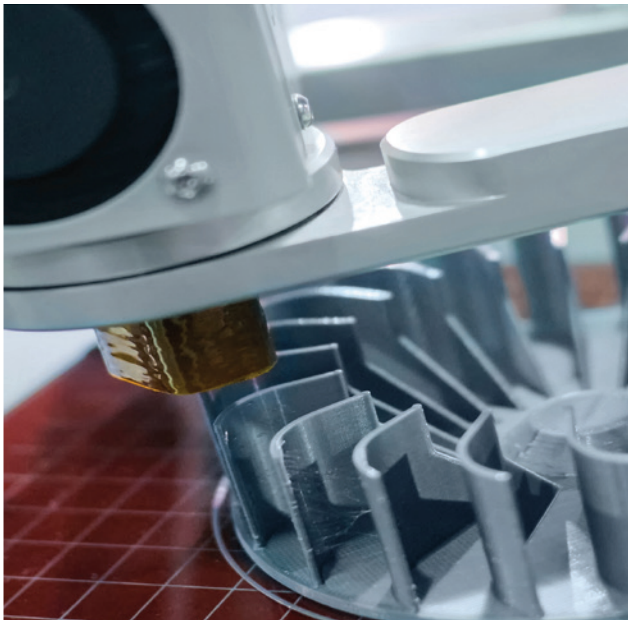
Opportunities for Additive Manufacturing in Aerospace

Innovation in aerospace actually progresses at a fairly slow pace with respect to outer body aircraft design, especially in light of the multitude of FAA regulations any modification must clear. That makes change hard. It is difficult to get buy-in from decision-makers when a current process is proven, and even more so in an industry where failure is not an option. That's the battle additive manufacturers fight every day in changing mindsets about the advantages of additive versus traditional subtractive manufacturing methods in aerospace.

But if you look beneath the surface, under the skin of the airplane, innovation is occurring at a very rapid pace. The electronics and the sub-systems for fuel, engines, avionics, and even materials that make up the interior of an aircraft are very different than they were 30, 20 or even just 10 years ago. There's a lot of modernization happening in those spaces, and therein lies a great opportunity for 3D printing.

Most of the applications best suited for additive manufacturing in aerospace today relate to the production of jigs and fixtures for ground support tools and some non-critical, in-flight parts to maintain fleets of aircraft. Once a plane is built and delivered, it is the responsibility of the owner to maintain it either directly or through subcontractors, just like when buying a car or a boat. Given the size and scope of the investment in an aircraft, and the quality with which it is made, we are now seeing planes in service for decades longer than originally intended—both on the commercial and defense sides. Maintaining flight-ready status for the life of aging airplanes is perhaps the biggest driver for additive manufacturing in aerospace.

Other opportunities for 3D printing in aerospace are emerging in true extra-orbital space applications such as satellites and in the development of drones and unmanned aircraft, where strong yet lightweight materials and innovative design with rapid iteration are critical to mission success.



The Advantages of Additive Manufacturing to Aerospace Enterprises

Additive manufacturing is uniquely positioned to address multiple aspects of maintenance and support in aerospace, especially for aging aircraft. The coronavirus pandemic taught us very quickly that 1) supply chains can be interrupted for indeterminable lengths of time and 2) the sudden decline in passengers means airlines have to find new ways to cut costs. That's why a growing number of aerospace manufacturers and fleet owners are taking a serious look at how additive manufacturing can increase flexibility, help them become more self-sufficient, and save money. Essentium's open ecosystem is like a blank machine tooling suite waiting to unlock innovative solutions. Here is a sampling of the advantages 3D printing brings to aerospace:

Cure for Obsolescence. A commercial airline or military command may acquire an asset that is 20 or more years old. Examples of planes flying for 50 or 60 years are not uncommon. Perhaps some of the subcontractors that made parts for the plane are no longer in business, or original replacement parts are no longer available. Maybe the plans for a needed fixture are lost, or a specialized tool broke. 3D printing allows for reverse engineering; the original part can be CAD-scanned and a new one printed in a just few hours or overnight to keep aging aircraft operational.

New, Safer Polymers. Some of the materials used to manufacture aircraft parts decades ago have since been found to be carcinogenic, made from toxic resins, and/or may release harmful emissions during machining or if it catches fire. As fleets age, some replacements parts can no longer be made using the same processes or materials. Fortunately, a new generation of safe, high-strength extrusion materials such as PEEK and carbon-reinforced nylons are available that can withstand the high temperatures and exposure to corrosive agents common in aerospace environments. 3D printing is excellent for making replacement parts and tools without recreating the dangers of the original piece (and with much less waste).

Cost Savings. 3D printing changes the financial equation in many ways.

1. The cost to remake a jig or fixture using traditional tooling methods and materials is time consuming and expensive. Lead times could keep a plane on the ground for weeks, impacting revenues, pilot training, or mission-readiness. To speed things up, the part can be made in-house, on-demand without the time and cost of producing a mold.

2. Because 3D printing doesn't require tooling for a replacement part or to make prototypes for design changes, aerospace companies could save hundreds of thousands of dollars over the life of the printer. And for tasks that <u>do</u> require jigs and fixtures, 3D printers can quickly make the replacement parts or molds in-house as needed.

3. 3D printing also reduces warehousing/inventory costs, transportation expenses, and waste. The raw materials for additive manufacturing are compact filament spools that occupy little space. The effort and expense of shipment is negligible compared to the care that must be taken when packing and transporting a finished part. And when the materials arrive, there is much less waste in the manufacturing process.

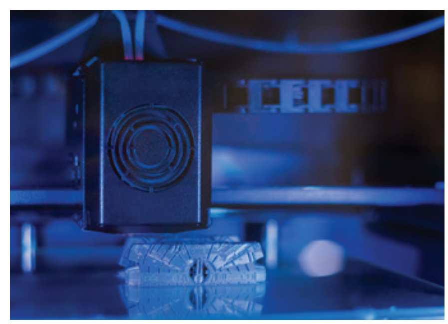
Cut Links Out of Lengthy Supply Chains. Now more than ever, the aerospace industry needs to implement more efficient procurement and shorter production cycles. Additive manufacturing not only allows the freedom to innovate and to make new things faster in different ways, it also allows for innovation in the supply chain. Customers are no longer constrained by long lead times or forced into redundant warehousing of spare parts on multiple continents. They no longer need to vet multiple suppliers, negotiate pricing, or manage transportation logistics; they can bring the factory with them. Simply procure the best materials identified for the job and produce the needed parts directly. Commercial airlines perform inspections and service at most every major hub. Military missions may require planes to be stationed in another country for extended periods. If a jig or fixture breaks, rather than source replacement parts from a distant vendor and wait for shipment, an on-site 3D printer can make spare tools and parts in a matter of hours in-house, wherever the house (or hangar) may be. Additive manufacturing is not intended to displace traditional manufacturing in aerospace. However, if the supply chain is disrupted for any reason—war, disease, natural disaster, or trade embargo—the enhanced self-sufficiency afforded by on-site 3D printing will allow aerospace manufacturers and maintenance providers to print parts and tools to their own exacting specifications without relying on global suppliers. Simply download the plans for the needed part or tool and print at the point of need without waiting for factories to reopen, container ships to clear customs, or couriers to arrive. Finally, 3D printing offers faster speed to part, which keeps planes in the air and costs to a minimum.

Applications for Additive Manufacturing in Aerospace

Part of the value proposition for additive manufacturing in aerospace is its inherent flexibility and the fact that unlike mass manufacturing applications, *scale is not necessary to achieve value.* Speaking to the former, keeping planes in the air requires lots of moving parts. Factories with dedicated production lines can take days or weeks to retool for a different part. A 3D printer is a versatile tool ready to print ESD-safe flight-worthy parts one day and chemical- or corrosion-resistant ground support tools the next. With regard to scale, traditional manufacturing dictates a need for volume to achieve a sustainable ROI. Not so with 3D printing. Especially in the world of aerospace where the need for one-off tools or a specialized replacement part to keep a several-hundred-million-dollar investment in flight-ready status is common. Once designed and the plans are stored, the part can be reprinted economically on demand for only the cost of materials.

Identifying the best applications for additive manufacturing in aerospace depends on the active point of the aircraft's lifecycle and the sector of the industry it will serve, civilian or military.

The type of flying the aircraft will perform also influences the applications 3D printing can address. Let's examine some the primary challenges and characteristics unique to each sector, and how additive manufacturing can help.



Commercial/Private Versus Defense/Government Aerospace Applications

Due to some critical differences unique to each environment, Essentium divides the aerospace industry into two basic sectors, commercial/private and defense/government. Basically, it comes down to the fact that flying a commercial airliner roundtrip between New York and Chicago on a precise schedule twice a day presents a very different set of challenges from keeping a military jet mission-ready 24x7 without any hint of where or when the next mission will occur. Commercial aerospace companies are also subject to closer FAA scrutiny and regulations, whereas some military projects are afforded greater latitude in experimental design. This in turn impacts which 3D printed materials can be used for aerospace applications (although the FAA still has final say over both commercial and defense aircraft flying in FAA-controlled airspace).

The commercial side of aerospace includes regional, national, and international airlines, the makers and owners of small personal aircraft and private luxury jets, plus the privately-owned fleets of transportation and logistics enterprises such as Federal Express, UPS, and Amazon. These companies need to move people or packages from Point A to Point B on a schedule. Any delays impact revenue generation and/or customer satisfaction. 3D printers can be a part of the new toolbox engineers and support crews use to minimize downtime by making replacement jigs and fixtures at maintenance hub locations. Customization is another application ideally suited to 3D printing. Think of applications such as logo-imprinted wall panels, window shades and custom-fit interior components for the manufacture or retrofit of private luxury jets.

The government side of aerospace encompasses the many branches and commands of the US Department of Defense (DoD) and allied nations with bases and aircraft carriers stationed globally. Here, the mandate is maintaining *mission-readiness*, which is defined as the ability of an aircraft to take off and execute its orders on a moment's notice. This does not necessarily mean combat; the mission may be pilot training, reconnaissance, or moving people and supplies after a natural disaster such as a flood, earthquake, or tornado. However, these planes may be forced to perform in-flight maneuvers or fly at speeds and altitudes not required by civilian aircraft. Further, there may not be a back-up plane or spare part in stock at the command.

Having a 3D printer on-site to make the fixture needed to bend a pipe, for example, can be the difference between executing a mission or cancelling it. Military aircraft also have advanced weapons, radar, and guidance systems not found on commercial planes. 3D printing using ESD-safe materials is a valuable asset to ensure these specialized systems remain operational no matter where they are based.

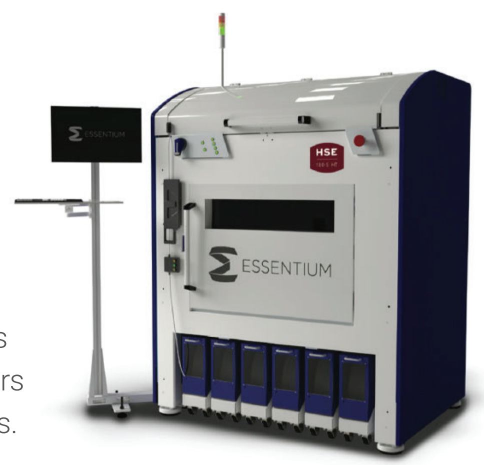
Ground Support Tools Versus Air-Worthy Parts

The flip side of the aerospace application coin is *where* the 3D printed fixture or part will be used, regardless of whether the plane is used for military or civilian purposes. There are ground support tools and non-critical air-worthy parts, but the common denominators are strength and lightweight materials. Any enhancements that reduce the weight of a part or tool will not only impact fuel efficiency and speed, they can also improve employee productivity and reduce repetitive motion injuries from using heavy equipment.

Ground tooling and support tools represent the bulk of opportunities for 3D printing today. These are defined as 3D printed items used in the manufacturing process or maintenance of an aircraft. Examples range from something as simple as a wheel chock to a fixture used to clamp a section of sheet metal or pipe for bending. It may be a wrench designed to tighten a specific-shaped bolt or to quickly change a tire on the landing gear. Lightweight tools and jigs can be printed from materials that match the strength of metal tools, and still resist damage from exposure to heat, chemicals, solvents, and fuels commonly found in the hangar. Most importantly, ground support tools are not subject to the same scrutiny as air-worthy components. Customers do not have to worry about getting FAA approval for a jig or fixture; they are free to innovate on the production floor.

Air-worthy applications for 3D printed parts are still few in number. Whether for commercial or defense customers, air-worthy materials and parts undergo much more rigorous testing and certification procedures and are therefore less common. While we can point to some examples such as cup holders, lavatory toilet lids, air ducts, and customized interior panels, 3D printing is currently limited to non-critical, non-load-bearing parts. But when a critical replacement part cannot be sourced through typical supply chains, 3D printing is sometimes the only alternative to recreate it through 2D to 3D reverse engineering. Looking forward, Essentium sees a growing list of air-worthy applications as more materials are certified for in-flight use.

Essentium: Operating at the Speed of Relevant



Additive manufacturing is uniquely positioned to address multiple aspects of aerospace maintenance and service to fend off obsolescence of aging aircraft, as well as to support the customization of new aircraft. Essentium is uniquely equipped to address the most challenging problems in aerospace.

The Essentium HSE 180•S Series delivers the speed and scale to operate at the speed of relevant—the speed at which companies and governments need to do business. Our open ecosystem approach means Essentium is able to offer users the freedom of materials that had hindered innovation in the past, so manufacturers can overcome the barriers of implementing 3D printing in aerospace applications.