A Path to Certification

Qualifying the first polymer additive manufacturing material for aerospace

White Paper

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Additive Manufacturing's Promise for Aerospace

The importance of additive manufacturing (AM) isn't lost on the aerospace industry. One simply needs to look at the actions of industry leaders like Boeing and Airbus to see this truth in play. Airbus chose the technology to create parts using ULTEM™ 9085 resin for their A350 XWB aircraft. Boeing touts the installation of more than 50,000 AM parts flying on their commercial, space and defense products.[1]

But it's not just the giants of the industry that recognize the advantages. Smaller, innovative companies like Aurora Flight Sciences also see the benefits. Aurora developed and flew the first 3D printed jet-powered unmanned aerial vehicle, capitalizing on the strength of FDM® (fused deposition modeling) ASA thermoplastic for the main wing and fuselage structures. The aircraft's main purpose was to demonstrate the speed at which a design can go from concept to a flying aircraft. It also illustrates the validity of AM for flight-capable parts, beyond the traditional role of prototyping.

[1] *"Insights Into Additive Manufacturing at Boeing with Leo Christodoulou" – 3D Printing Industry, online article, https://3dprintingindustry.com/news/insights-additive-manufacturing-boeing-leo-christodoulou-106718/.*

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The jet-powered UAV developed by Aurora Flight Sciences is made with 34 parts; 26 of those are 3D printed.

While the methods and applications of additive technology may differ among these companies, the reason they use it is common: it provides multiple benefits that collectively make a positive impact on their bottom line. That might come in the form of meeting the delivery schedule, improving performance, reducing waste, optimizing the supply chain or a combination of all of the above.

From Rapid Prototyping to Flight Parts

Since its inception, a common use case for additive manufacturing has been rapid prototyping, allowing aerospace companies to validate fit, form and function in addition to reducing product development time. The next step in use case evolution, one that provides multiple benefits, is the production of flightworthy parts for use on certified aircraft.

The reasons for this are obvious: additive manufacturing helps aerospace companies attain important goals of reduced weight and lower buy-to-fly ratios (the ratio of procured material weight to the final part weight). As an example, 3D printing allows the creation of organic shapes that aren't otherwise possible with conventional manufacturing methods. This lets engineers design optimal strength-to-weight geometries, reducing weight by minimizing the amount of material needed to carry the load. Aurora Flight Sciences used this approach on their UAV to achieve a stiff but lightweight structure, using material only where it was necessary.

This capability to apply material only where it's needed also results in little to no scrap, unlike a subtractive process that removes material to arrive at the final part. This is how AM offers a

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much more favorable buy-to-fly ratio, by using only what's necessary to create the part. Buy-to-fly ratios for machined aircraft components can be in the range of 15-20 compared to ratios close to one for AM parts, making material waste an important cost consideration.[2]

Other benefits of the additive process include part count reduction by 3D printing multiple components as a single part. This results in fewer individual parts, less manufacturing and inventory, and reduced assembly labor. United Launch Alliance reduced the part count on an environmental control system duct for their Atlas V flight vehicle from over 140 pieces to just 16 AM components with ULTEM™ 9085 resin.

The AM process also enables the creation of complex designs and intricate geometries without the time and cost penalty of traditional manufacturing methods. In some cases it allows the creation of parts that otherwise wouldn't be possible with traditional manufacturing. The fuel nozzle for the GE LEAP engine is a good example. The configuration that engineers developed to meet restrictive performance requirements included intricate internal passages and geometries. The final design was ultimately not possible to manufacture with machine tools and could only be achieved with additive manufacturing.

From a supply chain perspective, the ability to economically produce parts on-demand gives manufacturers much greater flexibility to make and locate parts when and where they're needed. This alleviates the expensive process of producing and stocking sufficient spare parts to support demand scenarios that are difficult to predict. It also gives manufacturers the flexibility to overcome hiccups in the supply chain, should they occur. Airbus used this strategy in the production of the A350 XWB aircraft, 3D printing parts to maintain the aircraft delivery schedule.

Additive manufacturing is the perfect fit for geometries shaped by topological optimization, producing shapes that would be difficult or impossible with conventional machine tools.

A portion of the additively manufactured ULA environmental systems duct used to cool avionics in the Atlas V payload fairing.

[2] Arcam EBM - http://www.arcam.com/solutions/aerospace-ebm/.

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Certification Headwinds

These are just a few examples that demonstrate the merit of additive manufacturing for end-use aircraft parts. But the challenge faced by aerospace companies in achieving these benefits lies with airworthiness certification. Parts installed on aircraft must be certified flightworthy as part of the overall certification of the aircraft. For engineers wanting to design additively manufactured flight parts, that's easier said than done. The reason is because there are no industry-standard design allowables characterizing the properties of AM materials, like there are for traditional materials and processes.

Without this fundamental but necessary information, aerospace companies are faced with either avoiding the use of AM flight parts altogether or developing the design allowables themselves. Depending on the specific application, the latter scenario likely requires a very expensive and lengthy test program. In the highly competitive aerospace industry, neither option is optimal.

Overcoming the Challenge

Despite this challenge, some aerospace companies have done what it takes to qualify non-metallic materials, such as polymer-based composites, for use on aircraft. However, manufacturers that take this approach typically view the data as proprietary due to the cost and effort involved, and they don't share it within the aerospace community. This creates an "everyone-for-themselves" environment and results in a lack of industry-wide material and process standards. While large aerospace companies may be able to justify the time and cost for this effort, it can be prohibitive for smaller companies, without publicly funded programs to support the process.[3] At a very practical level, requiring each manufacturer to duplicate the process for a material that's already been evaluated by another manufacturer is simply counterproductive and only serves to drive up industry costs and inhibit innovation.

Airbus uses additively manufactured parts made from ULTEM 9085 resin on the A350 XWB aircraft.

An Industry Solution

A solution to this problem was indirectly borne out of an effort in the mid-1990s to rejuvenate the general aviation market. The Advanced General Aviation Technology Experiments (AGATE) effort involved the participation of NASA, the FAA, the aerospace industry and academia in the development of improved technologies and the standards and certification methods governing them. Part of this project involved the development of standards to qualify new materials and their production while abbreviating the certification timeline.

The AGATE initiative eventually evolved into a new process, which bears the name of the organization that administers it: the National Center for

[3] *"Easing the Process of Composites Qualification" – Granta Material Intelligence Blog, http://blog.grantadesign.com/composites/easing-the-process-of-composites-qualification/.*

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Advanced Materials Performance (NCAMP). The NCAMP process is now the established method for qualifying new material systems and developing a shared database of design allowables for those materials. The benefit for aerospace companies looking to certify their designs, beyond having access to resultant material data, is that the certification authorities (FAA and EASA) accept dataset and material process specifications for key components of the qualification process.

From Composites to Additive Manufacturing

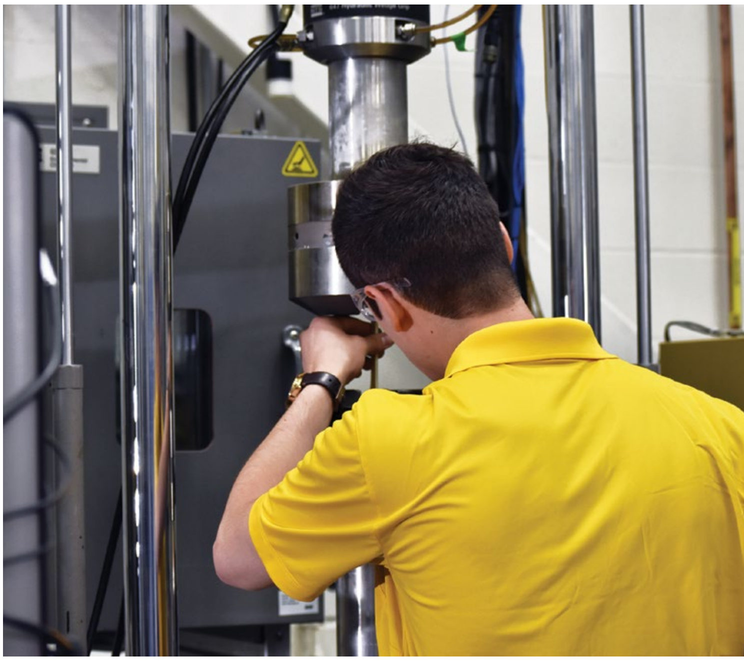
The initial focus of the AGATE initiative and the follow-on NCAMP process was the qualification of polymer-based carbon-fiber composite materials. That made sense as composite technology advanced and offered benefits to the aerospace industry in the form of strong, lightweight structures. As a result, a number of different composite material systems have been qualified through the NCAMP process, providing the aerospace community with a shared database of corresponding design allowables.

This has been a benefit to companies that want to use those materials on certified aircraft, but want to avoid the long, expensive process of qualifying the material on their own. Instead, they simply need to demonstrate "equivalency," the process of proving they can duplicate the material characteristics of the base qualification dataset, but on a much smaller, shorter and less costly scale than a full qualification program.

Unfortunately, the same cannot be said for aircraft manufacturers looking to use additively manufactured parts on certified aircraft programs. Although aerospace companies have leveraged additive manufacturing for its more traditional benefits like faster prototyping and agile tooling, the barrier to certification still exists due to the lack of a qualified additive manufacturing material that is tested and validated using the NCAMP process. This prevents the aerospace community from realizing the full benefit of additively manufactured production parts that includes real performance, supply and cost efficiencies.

Qualifying the First Polymer AM Material

The task of solving that problem was tackled by America Makes, also known as the National Additive Manufacturing Innovation Institute. Its mission is to promote the advancement and development of additive technology within manufacturing, facilitating and funding collaboration among industry, research and government entities. It chartered the initiative to qualify the first AM material for certification purposes using the NCAMP process, with funding from the Defense-Wide Manufacturing Science and Technology



Tensile testing an ULTEM 9085 resin test coupon at the NIAR laboratory.

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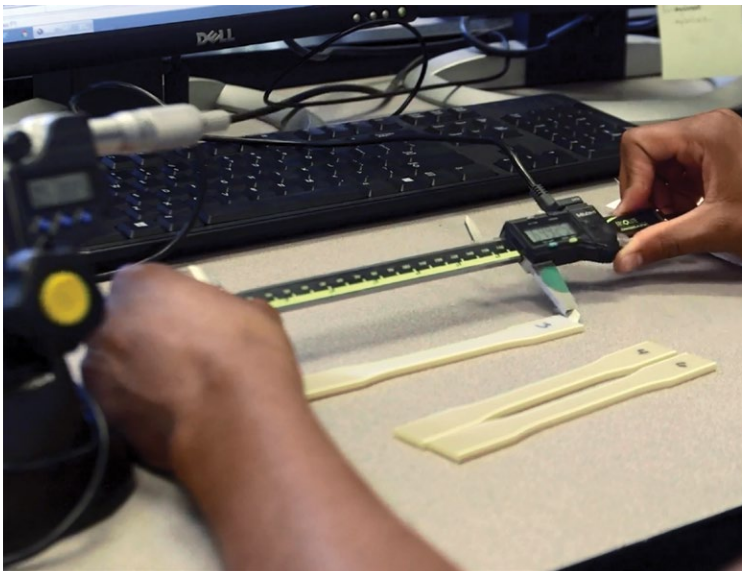
program. Key collaborators include Rapid Prototype and Manufacturing (RP+M), the National Institute for Aviation Research (NIAR) at Wichita State University, and Stratasys.

This qualification process is what ultimately results in the establishment of design allowables that aerospace companies can use to design aircraft parts, supplying a major piece of the certification puzzle. ULTEM™ 9085 resin was chosen by an industry steering group as the first AM material for NCAMP qualification. The material and the FDM process were selected because of their wide acceptance and use within the aerospace community.[4]

The NCAMP Process

Material testing and qualification using the NCAMP process is performed by the National Institute for Aviation Research (NIAR) at Wichita State University. The process begins with the establishment of a material specification to control the material manufacturing and processing quality. Next, a process specification is developed to control the build process using that material. This is necessary to remove any process variability and establish a controlled means of production.

These specifications exist because an important part of the certification process is the assurance that each manufacturer is making parts to the same standard. As Paul Jonas, Technology Development Director at NIAR, described it, “The first part you make has to be equivalent to the hundredth part, to the thousandth part, to the part you make 10 years from now, to be good enough to be certified for the FAA.” Once the production method is established, any decision to create parts using another system, process or material requires a separate qualification process for that production



The dimensions of all ULTEM 9085 resin test coupons are precisely controlled to avoid variability in test results.

method and/or material. The specifications also include controls for ongoing process validation, to ensure that production standards are maintained.

After the process specification was established, the ULTEM™ 9085 resin material qualification plan began, which involved testing approximately 6500 test coupons, the bulk of which were built by RP+M in Avon Lake, Ohio. The coupons are evaluated for specific mechanical properties and exposed to fluids typically found in an aircraft operating environment like engine oil, hydraulic fluid and jet fuel. Test results are then statistically analyzed to determine the material characteristics and corresponding design allowables dataset.

This data is currently published on the NCAMP website and findings will be incorporated into CMH-17, the composite materials handbook that provides standardized engineering data on composite and other non-metallic materials.

[4] *America Makes – Response to Stratasys questions, June, 2017.*

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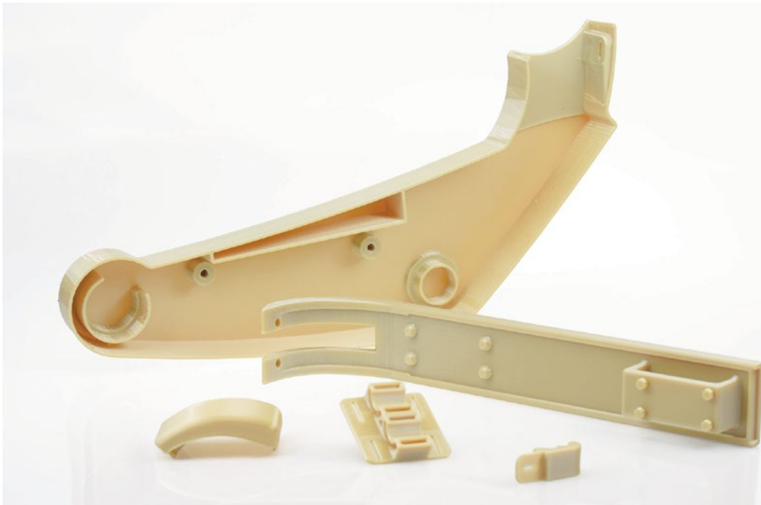
The Stratasys Solution

The final step in the AM certification solution path involves the demonstration of equivalency to the NCAMP dataset. Aerospace companies that want to leverage the NCAMP process need to show that their AM process with ULTEM™ 9085 CG resin results in material properties that are statistically equivalent to the original data. But as previously mentioned, this is achieved with a much smaller sample size, drastically reducing the time and cost for material qualification with a 10x estimated cost savings. Once equivalency is achieved, manufacturers can leverage the NCAMP process for key components of the airworthiness qualification process, having established that their additive manufacturing process is equivalent to the allowable database.

The equivalency process is reliant on two factors: the use of a properly configured Fortus 900mc™ Production System, in conjunction with certified ULTEM™ 9085 CG resin material. Stratasys developed specific capabilities for the Fortus 900mc that include enhanced material deposition, ensuring consistent, repeatable build results needed to produce equivalency test coupons. An AIS Machine Readiness package is available to validate the proper set up and operation of the AM system and demonstrate a means of compliance with the NCAMP process specification.[5] ULTEM™ 9085 CG resin undergoes more testing than standard ULTEM™ 9085 resin material, and is accompanied by documentation that gives manufacturers full traceability back to the raw material.



Aircraft seat parts made from ULTEM 9085 resin.

The certified ULTEM™ 9085 CG resin, the configured Fortus 900mc, and the AIS Machine Readiness package are available as a comprehensive solution from Stratasys. For more information, refer to the Aircraft Interiors Certification Solution Guide found at Stratasys.com.

[5] The NCAMP process is based on and currently supports the Fortus 900mc configuration. The Stratasys F900 configuration is in process of being added to the NCAMP qualification. The NCAMP material specification NMS085 is pending full implementation by Stratasys and material compliant for equivalency qualification is available. Please contact NCAMP for more information prior to beginning qualification.

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CONCLUSION

Additive manufacturing is no stranger to the aerospace industry, having been adopted for rapid prototyping, concept modeling, and tooling. The next level of efficiency involves the manufacture of interior (or other non-flight-critical) components using the NCAMP-certified material and process - a major step in defining the roadmap toward using additive manufacturing in aerospace production.

Compared to traditional materials and machining methods, AM parts minimize waste, reduce weight, enable economical customization and streamline the supply chain. But the barrier to achieving these benefits has been a lack of qualified AM materials and a consistent, reliable production process for using them.

This is changing, thanks to the coordination among AM material and process suppliers, aerospace manufacturers and the airworthiness authorities. Through the NCAMP process, the first polymer AM material to be published by NCAMP is available to provide the aerospace industry with design allowables for ULTEM™ 9085 CG resin, an important tool for producing AM parts for aircraft programs. More importantly, this process sets the precedent for the qualification of other AM materials, clearing the path for faster, broader use of additive manufacturing in aerospace.

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