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Integrating Metrology into Manufacturing

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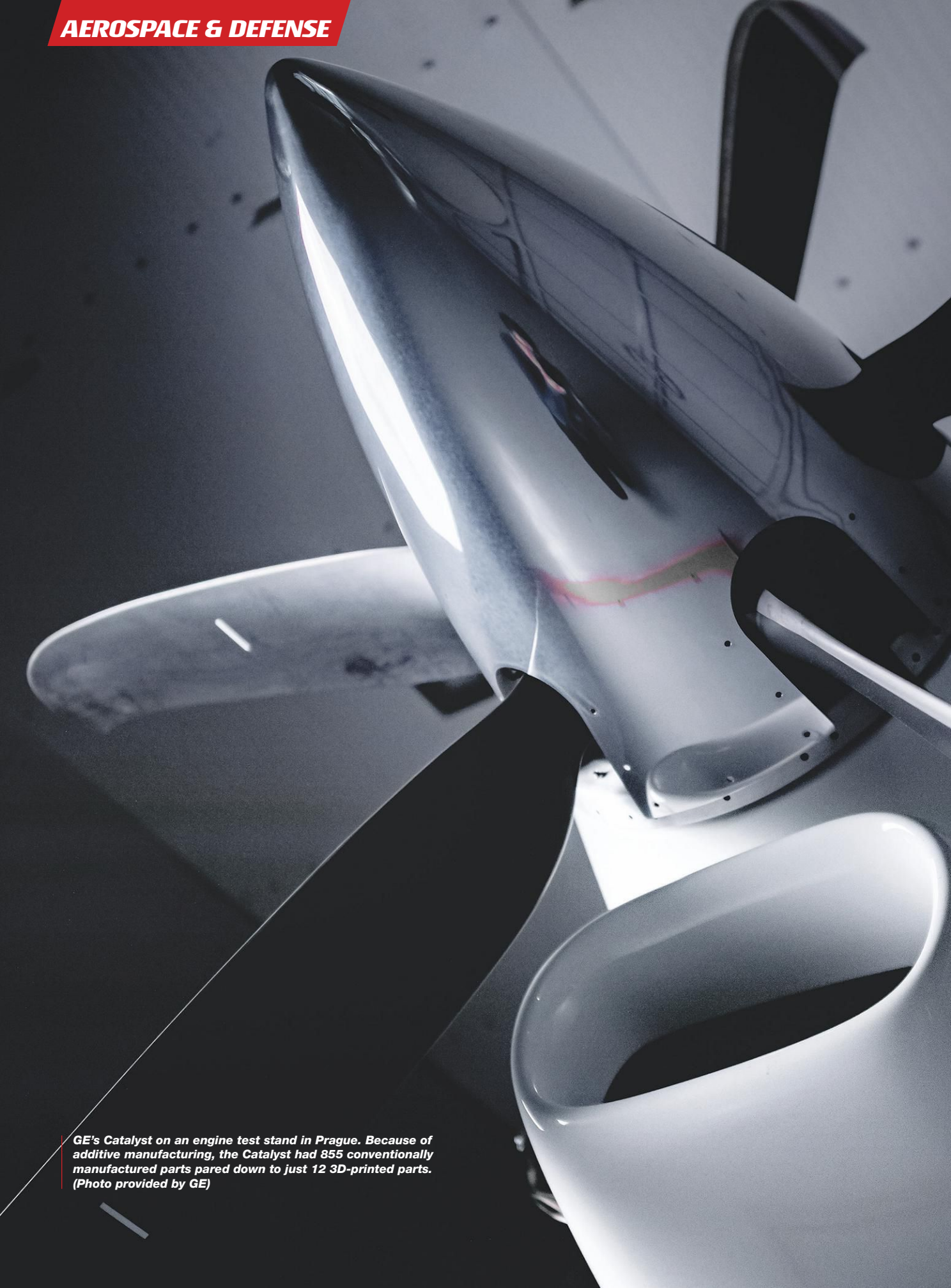

GE's Catalyst on an engine test stand in Prague. Because of additive manufacturing, the Catalyst had 855 conventionally manufactured parts pared down to just 12 3D-printed parts. (Photo provided by GE)

3D Printing Cleared for Takeoff

Aerospace looks to additive manufacturing to boost efficiency, reduce waste.

BILL KOENIG
Senior Editor

Aerospace was an early, and enthusiastic, adopter of additive manufacturing. The technology has been used to make brackets inside of aircraft. It has been used to print engine parts, greatly reducing the number of components. It has even been used to produce an unmanned, 21-kg aircraft for testing new technologies.

"Parts made with our 3D technology are routinely being used in aerospace products," said Rick Lucas, chief technology officer of ExOne, a binder jetting technology company based in North Huntingdon, Pa. One example is the Sikorsky CH-53 heavy-lift helicopter, which is using composite air ducting made with ExOne 3D printing tooling.

The benefits run both ways. The interest by aerospace companies has also encouraged advancements in 3D printing.

"You've got the Airbuses of the world telling their story," said Todd Grimm, president of T.A. Grimm & Associates, Edgewood, Ky., an additive manufacturing consulting firm. "It gave us a nudge, a push. It validated, which allowed us to take it more seriously for more demanding applications. Aerospace has a strong appetite for the capabilities of additive."

'Lots of Scrap'

Aerospace was drawn to additive for various reasons. For one, the industry extensively uses expensive metals such as titanium. With traditional subtractive manufacturing, more than 90 percent is cut away, resulting in a grim buy-to-fly ratio. 3D printing enables new shapes, which means that fewer parts are made. By printing, there is less waste.

"They have to use a lot of titanium," said Lonnie Love, group leader of Oak Ridge National Laboratories (ORNL) Manufacturing Research Group, Oak Ridge, Tenn. "You're getting a lot of scrap."

Also, he said, "Titanium is brutal in terms of cutting tools. That's down time and tooling cost…Titanium is hard to machine but it's easy to print."

The Airbus Thor, an unmanned aerial vehicle made via 3D printing, takes off during a test flight. (Photo provided by Airbus)

3D printing also is seen as a way to use lighter materials. In addition to titanium, such materials include aluminum, carbon fiber and composites. For some parts, weight can be cut by about half.

"Lightweighting is critical," Love said. "The heavier something is, the more energy it takes to keep it in the air." The aerospace industry, he added, "is willing to pay a premium" for additive manufactured parts. "All the aerospace companies have done the math and said additive is how we're going to be competitive."

General Electric Co., Boston, has been among the most prominent adopters of additive. GE Aviation and CFM, a 50-50 joint venture between GE Aviation and Safran Aircraft Engines, have four 3D-printed parts certified by the U.S. Federal Aviation Administration. They are the T25 sensor for the GE90-94B, the CFM LEAP fuel nozzle tip, the GEnx-2B power door opening system (PDOS) bracket and the GE Passport air-oil separator.

The fuel nozzle system for the CFM LEAP engine first went into production in 2015 at a plant in Auburn, Ala. It was one of the first aerospace systems to receive publicity for being 3D printed. Last year, the operation manufactured its 30,000th fuel nozzle tip. The operation also makes the GEnx PDOS bracket.

GE also is developing the GE Catalyst, a turboprop engine that combines more than 800 conventional parts into 12 as well as the GE9X, which combines more than 300 conventional parts into only seven 3D printed components. The company says it has identified more than 80 other parts for 3D printing.

Fundamental Changes

"Additive at GE Aviation started with a lot of new product introduction, [but] has also shifted focus into opportunities to take cost out of existing products," Nick Hurm, a spokesman for GE Aviation, Evendale, Ohio, said in an email.

"Additive provides GE engineers a whole new degree of creative freedom, fundamentally changing the way we approach design," he added. "The paradigm between the cost of manufacturing and the complexity of a design has been upended. With additive, designs are optimized for performance."

GE says 3D printing can accelerate part production and testing. The company completed Catalyst combustor rig tests six months ahead of schedule because of faster part output.

GE also invested in the technology, acquiring majority stakes in Concept Laser GmbH, Lichtenfels, Germany, and Arcam AB, Mölnlycke, Sweden. "With the development of GE Additive, GE's businesses can give feedback and get tweaks made within hours instead of months," Hurm said. "As we continue to develop our additive engineering and manufacturing capabilities, these investments position us to be better providers of additive equipment."

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Love of ORNL said GE did a lot to get 3D printing going in aerospace. “I tip my hat to GE,” he said. “They’ve built up a strong team of engineers that understands the full supply chain.”

THOR Soars

Aircraft maker Airbus, based in Leiden, Netherlands, is another company that’s been working with 3D printing. Since 2015, Airbus has conducted test flights of its THOR (Testing High-tech Objectives in Reality) small pilotless plane. About 90 percent of its structural components are 3D printed from plastic polyamide powder. Airbus describes THOR as “a platform to enable low-risk and fast-track development of different technologies in real flying conditions.”

Airbus utilized additive manufacturing for speed in developing THOR. It took seven weeks to print 60 structural segments and another week to assemble the aircraft.

The company has expanded its use of additive in other ways. Five years ago, Airbus had begun making brackets using 3D printing or what it calls Additive Layer Manufacturing (ALM).

“This was the first step of a long-term strategy to progressively introduce ALM technology,” said Jerome Rascol, vice president and head of additive manufacturing platform for Airbus. “Over the past five years, Airbus has gradually increased the number of applications of ALM in serial-produced and in-service aircraft.”

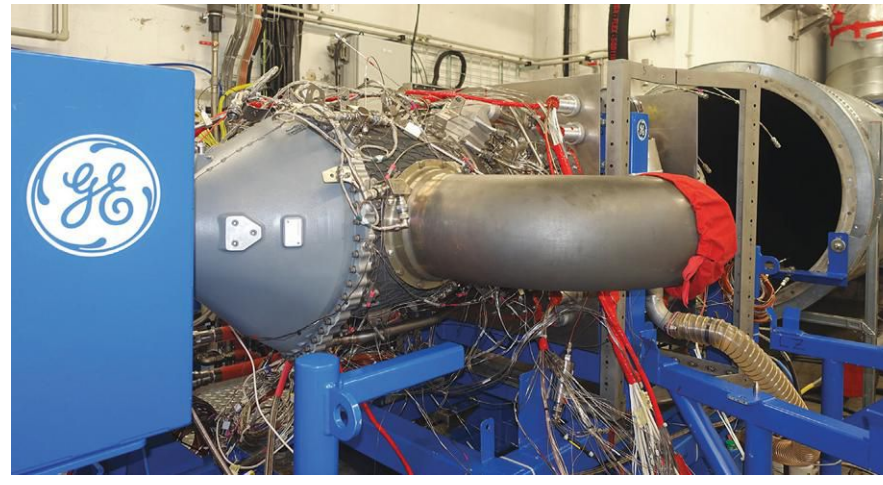
The executive said the company has produced and installed more than 70,000 printed parts on Airbus planes. Most of the parts were printed in polymer but a growing proportion are being printed in titanium and nickel-based alloys.

Spare Parts

Printed spare parts made of polymer are on Airbus A350 XWB serial aircraft, according to Airbus. Some Airbus A320neo and A350 XWB test aircraft are equipped with metal printed cabin brackets and fuel pipes. More metal parts are in the certification process, the company said.

Specific additive technologies used by Airbus include filament deposition and powder bed polymer technologies, metal powder bed and metal wire directed-energy deposition.

For now, the aircraft maker is satisfied with the number of materials available for 3D printing. “Qualification efforts for the use of ALM in the aeronautical industry are very demanding both in terms of cost and time,” Rascol said. “Consequently, Airbus’ focus is on the introduction of the technology on a few well-known metal alloys for which we have identified value creation opportunities.”



GE’s Catalyst engine undergoes testing at GE Aviation’s facility in Prague. (Photo provided by GE)

Airbus is working with Autodesk’s generative design, which uses artificial intelligence to redesign parts for 3D printing, among other manufacturing applications.

In 2015, Airbus introduced what it called the “bionic partition,” a metal 3D printed wall and jumpseat support structure that divides the passenger compartment from a plane’s galley. The partition was about 45 percent lighter than conventionally manufactured partitions. Airbus intended the partition for its A320 aircraft.

However, Airbus expected the cost of metal 3D printing would come down quicker than it has. “Airbus wanted to put this in planes that are flying,” said David Benjamin, director at Autodesk Research, New York. “We determined we could make a slightly modified design that had many of the same benefits.”

The second design called for 3D printing a plastic mold for the partition, which would be cast with an alloy already qualified for flight. The mold still allows for more complex

shapes, Benjamin said. The second version of the partition is undergoing the certification process, he added.

New Metals for Aerospace

Additive manufacturing companies are moving to address the needs of the aerospace market. For example, EOS, a maker of industrial 3D printing machines using direct metal laser sintering, has moved to introduce more metals for printing.

"We've come out with an additional 10 metals [in] the past five years," said Scott Killian, business development manager-aerospace for EOS. "It's not a huge amount. You want to be sure you can build quality parts and there's always challenges with that. It takes time to develop that."

For EOS, a key aerospace market is rocket engines. One customer is Launcher, founded in 2017 to develop rockets to launch satellites. Last year, Launcher successfully test fired a 3D printed copper alloy engine printed on an EOS machine.

A worker makes an adjustment on a 3D printed bracket assembly. (Photo provided by Airbus)

EOS has "worked with them on the steps in the progress of their engine development," Killian said. "They expect to do very large payload engines down the road."

Rockets by their nature are low volume. More private companies are getting involved with rockets. Killian said 3D printing has hastened development.

"They can make a design today and maybe a week or two later, I can actually have a part on my desk (and) we can do some testing with it," he said. The rocket industry "is looking pretty exciting right now."

A part being made in an additive laser machine. (Photo provided by GE)

Every Pound Counts

Another EOS customer, which Killian said he couldn't publicly disclose, was able to cut weight with 3D printing. "They had a small box made out of aluminum that went inside the satellite," he said. "When I say small box, I'm talking something maybe the size of a loaf of bread. They took something like 20 percent of the weight out of that small box" with additive. "That maybe wasn't more than a pound or two but when you're talking payload, every pound represents thousands of dollars."

Polished bi-metal rocket engine, 3D printed using a copper-chromium-zirconium alloy on an EOS M 290 metal 3D printer. (Image courtesy of Launcher)

ExOne is also active in aerospace. ExOne's Sand 3D printers have been in the industrial market, including aerospace, since 2002. They create mold cores used for metal casting. "You design the mold one time," said Lucas, the ExOne chief technology officer. "The time to get a good part is substantially reduced from weeks and months to days or hours." That allows for rapid design iterations, in addition to adding complexity without additional cost and no pattern storage.

Foundries, he added, are "coming to us." He describes 3D printed sand casting as "already aggressively being adopted."

Washout Tooling

ExOne invented washout tooling for sacrificial tooling for layup of composite materials, including carbon- and glass-fiber composites. ExOne developed a process where 3D printed tooling is washed out with water. Materials remain water soluble up to 180ºC (356ºF). The process is being used to make composites for Sikorsky, an aircraft manufacturer and subsidiary of Lockheed Martin Co. and Royal Engineered Composites. ExOne also offers a full family of metal 3D printers that directly print metals such as Inconel 718. It can also print ceramics such as silicon carbide.

"We've been able to penetrate [aerospace]," Lucas said. With aerospace, "you tend to have more complex castings. We've done a lot of work with Sikorsky. That really pushes what you can do."

More progress is expected over the next five years. "It's going to be tested and tested and re-tested," said Killian of EOS. "I'm starting to see it open up now. The (additive) supply chain is really going to grow over the next five years."

Rascol at Airbus said the aircraft maker "will follow its plan and progressively extend the fields of applications and the associated value creation opportunities. Competitiveness and market share vs. traditional technology will progressively grow together with the rise of new applications."

Love of ORNL said he expects 3D printing to get bigger in aerospace. "Big, structural components to me is an area that some of the companies are starting to delve into," he said. "The main thing is there is growing confidence in the aerospace industry. Additive isn't a flash in the pan. There really are going to be massive changes."

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