Printing Success Stories in 3D

By: **Alan S. Brown**

Additive manufacturing has been around for 30 years, but faster machines, lower costs, and a string of successes have made engineers take notice.

ADDITIVE MANUFACTURING HAS ARRIVED. Not that it was ever gone. Engineers have been making solid parts from digital models for more than 30 years. But when makers latched onto it several years ago–promising a 3D-printed future of everything from spare parts to entire automobiles–it seemingly exploded on the scene.

That rosy future will not bloom so fast. But don't let the hype get in the way of 3D printing's solid achievements, especially over the past few years.

Over the past five years, engineers, designers, and manufacturers sat in the driver's seat. While additive was once used mostly for prototypes, it is now appearing on factory floors and in products ranging from aircraft, rockets, and satellites to medical implants, automobiles, and, surprisingly, sneakers.

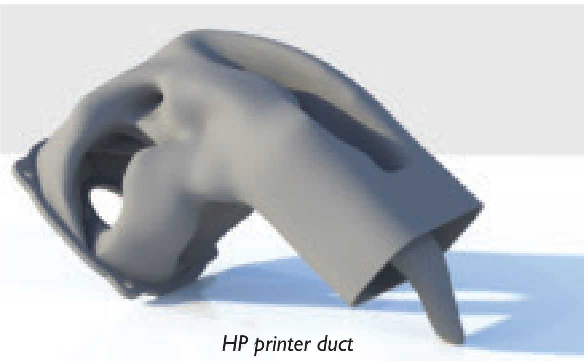
The surge of additive manufacturing shows in the numbers. According to Terry Wohlers, a consultant who has tracked the industry for more than 20 years, revenue from additive products and services is projected to reach $15.8 billion worldwide in the 2020s.

That is not much compared with conventional manufacturing, but additive is growing fast. Wohlers expects 3D revenue to more than double to $35.6 billion by 2024. And metal additive manufacturing is rising even faster, more than 40 percent annually for the past five years.

More importantly, though, additive manufacturing is scoring wins where it counts.

This year, for example, Adidas® expects to make and sell more than 1 million of its 4D sneakers, which feature 3D printed lattice soles. Stryker recently opened a $400 million factory in Ireland to print knee, hip, and spinal implants.

GE expects to ramp up to 40,000 to 50,000 printed fuel nozzles annually for its new LEAP jet engine. Boeing has more than 70,000 3D parts flying. Meanwhile, Relativity Space opened a facility to 3D print an entire launch rocket.



HP printer duct

Changes

Despite these successes, engineers have good reason to be skeptical. Additive manufacturing is almost always the most expensive way to make parts. The process is slow—metal parts can take days—costly, and used expensive, proprietary materials whose properties did not reach the standards of conventional metals and resins. Consistency varied even between machines made by the same manufacturer. Parts, which are built layer by layer, were usually weaker along the z-axis.

A lot has changed over the past few years. Patents have expired and new companies have entered the market. The result has been an explosion of innovation.

"We have more capability with hardware than we did before," Wohlers said. "In materials, we're seeing companies opening up their machines and allowing you to use third party materials, which is good for customers. Software companies now are beginning to catch up with those hardware capabilities, though they have always been a bit behind."

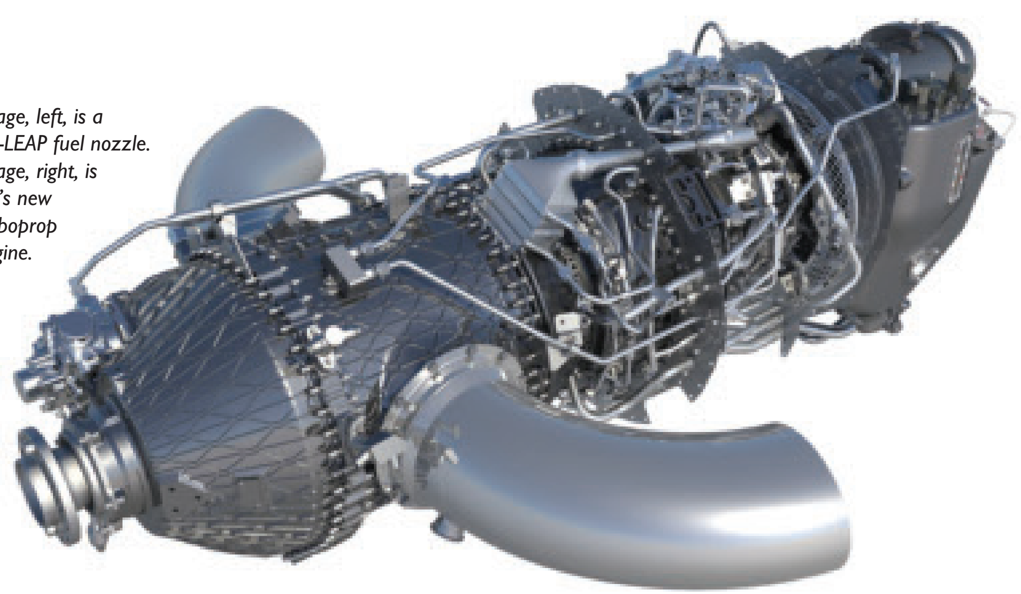
"Probably the biggest change, though, is the respect that it's getting and that it deserves. With that comes investment at the corporate level."

Corporations are paying attention because additive manufacturing brings a lot to the table. Its economics often work for short production runs of hundreds to several thousand parts. While individual printers are not as fast as injection molding or die casting, they are much faster than waiting weeks or months for a vendor to complete a mold for those processes. This makes it possible for companies to beat competitors to the market with new or upgraded designs, then switch to a less expensive production method later if it is successful.

Additive manufacturing also excels at making complex parts for no more than a simpler print. By building parts layer by layer, it can reproduce just about anything an engineer can model in CAD. It can, for example, print twisting organic brackets that are stronger and weigh less than the massive parts they replace. Or build complex ductwork to optimize flow, lattice-strengthened walls to reduce weight, and conformal passageways to remove heat from a curved surface.

Those changes can make a big difference in product performance. Hewlett-Packard, for example, redesigned the duct that cools the printheads in its Fusion 3D printer. The asymmetrical organic shape optimizes air flow, removing heat so efficiently that the printer now runs 15 percent faster. And it costs 10 percent less to print than the part it replaced.

Image, left, is a GE-LEAP fuel nozzle. Image, right, is GE's new turboprop engine.



Use Cases

The growing number of high-profile use cases also stimulated interest in 3D printing by showing managers and engineers how additive could be used to gain competitive advantage.

If there was any single application that opened management's eyes, it was the fuel nozzles for the GE Aviation-Safran Aircraft LEAP jet engine used on single-aisle passenger jets.

The fuel nozzles disperse fuel into the hot combustor so that it burns evenly and efficiently. The original nozzle did that by brazing and welding 20 parts into 24 intricate interior passages.

GE redesigned the nozzle to take advantage of additive manufacturing's ability to make complex structures. The final design consolidated the 20 parts into a single structure.

This consolidation eliminated a series of complex assembly operations and simplified inventory. It slashed weight by 25 percent, and saved tens of thousands of dollars in fuel costs over the lifespan of an aircraft. The nozzle is also five times more durable than the original, since it has no welds for the hot combustor gases to corrode.

The nozzle was certified three years ago. Meanwhile, GE has been applying additive manufacturing to other engine parts, from sensor housings, heat exchangers, particle separator, and even blades.

GE's new turboprop engine takes that to another level.

"We consolidated what would have been 855 parts in a conventional engine design into 12 parts," said Steven Taub, managing director of GE Ventures, which invests in additive and other technology companies.

"That means it performs better in terms of actually mixing gases, heat transfer, and things like that. It's lighter because there are fewer parts, like fasteners, flanges, and other things that add weight. It's more durable because nozzles tend to fail at the joints and it has none. And it takes a huge amount of complexity out of the supply chain."

The big, complicated parts take days to print and need machining afterwards, Taub said.

"But you can still produce them faster than conventional components because you're just making one part," Taub said. "And you don't have to source all these different forgings and castings and do all kinds of complicated assembly steps.

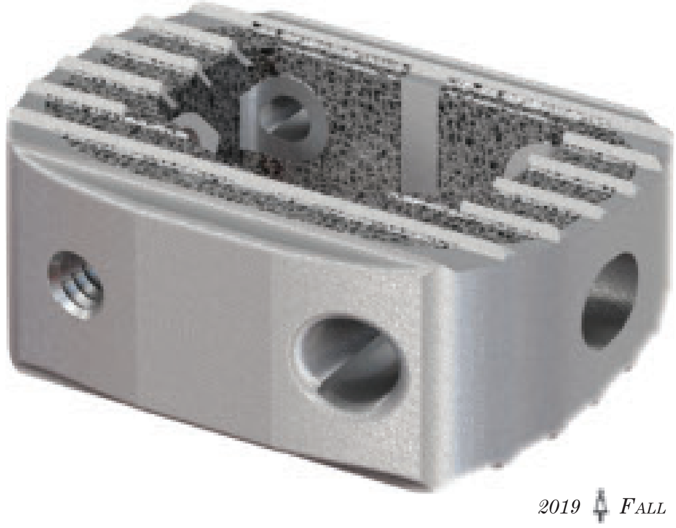
That eliminates all kinds of inventory worries and quality control issues. You turn what might have been 20 or 30 suppliers into one. It's actually something we've done in house. It's a massive reconfiguration, not only of how we design things but of how we make things."

Another landmark application was Stryker's 3D printed titanium Triathalon knees, Tritanium spinal cages (for spinal fusion), and Trident hips.

In the past, surgeons cemented knee implants onto bone. Over time, however, the body degraded the adhesive and the knee grew unstable. To overcome this problem, implant makers wanted to modify the implants' surfaces so bone would grow into it, anchoring it in place.

After investigating several processes, Stryker turned to additive manufacturing, Lewis Mullen, Stryker's manager of additive manufacturing, said. The process enabled Stryker to optimize pore size and distribution, creating a roughened surface that resembled the natural bone around it. This encouraged bone cells to grow into the implant.

The part was a triumph, though it took years to ensure 3D printing consistency and repeatability, Mullen said.



A Stryker Tritanium implant. *More images and details on page 21.*

Factory Floor

Additive manufacturing has also excelled in factories, where engineers use the process to build jigs, fixtures, tools, enclosures, and replacement parts to solve production problems.

"This is 3D printing's killer app," said Greg Mark, founder of Markforged, which builds composite and metal 3D printers.

For 30 years, he said, 3D printing was "trapped in plastic," which was not strong enough for industrial use. By adding carbon or Kevlar fiber to plastic or using metal, engineers can now make parts they can use in a factory.

Mark and his team have spent a lot of time walking factory lines and can point to examples.

"We have a coordinate measuring machine fixture out there where you put a piston in it, clamp it down, and the CMM scans it," he said. "That fixture would cost $1,300 if the engineer designed it, but they can print it for $40."

"So the engineer prints the first one, they start using it, and they're happy because they saved a bunch of money, and then he realizes that if he adds a chamfered edge where the piece comes in, it will load and unload much quicker."

"He doesn't have to ask his boss for a purchase order or an approval. He just prints another part for $40 and now his throughput has gone up and his boss thinks he's a rock star. All these companies around the world are going through that learning in parallel. And that's why additive is taking off now."

This is true for both large and small companies.

At Boeing, Tracy Daly, production engineering chief for 747 and 767 airplanes, manages 15 innovation cells on the factory floor. They have 50 3D printers between them. If an engineer or technician has an idea for a part, he or she can quickly build it and see if it works.

One example is a brush used to apply sealant to certain parts of the airplane. The original brushes were hard to grip and fit into the crevices, Daly said. So workers created a set of adjustable brushes and scrapers designed for those specific locations.

Boeing also printed stretchable urethane gaskets to keep debris from entering casings and devices to lock down spring loaded doors and latches so they were not trip hazards. They were all small projects, but they sped production and improved quality and safety.

"We run a fail fast environment," Daly said. "We want to do it quickly, see if it works, and improve the design if needed."

Fast turnaround also matters to Bryan Rogers, a senior additive manufacturing engineer at Wilson Tool. Headquartered in White Bear Lake, MN, the company makes tooling for companies that do stamping, bending, punching, and tableting.

Its additive business serves the same customers, but faster, Rogers said. "If a customer has a job and needs a short run tool, fabricating that tooling takes weeks. Additive gets tools out fast, so you're making parts and getting qualified in hours or days rather than weeks."

Like Wilson Tool, Centerline Engineered Solutions of Greenwood, SC, makes a variety of 3D tools and parts. One notable success was a carbon-reinforced nylon die to lance 14-gauge sheet metal. Machining would have cost $1,400 and taken 10 days, but 3D printing cost only $200 and took 1.25 days.

Centerline founder Phil Vickery, *SC A '92*, also believes additive manufacturing changes the way his shop operates.

Centerline 3D printed fixture/jig
www.centerlinees.com/additive-manufacturing

Many of the machinists and tradesmen were initially skeptical about 3D printing, he explained. The process was unusual for a machine shop and it produced composites rather than metal.

"We had to show them the advantages. Once you show it's reliable and easier, the buy-ins come. Employees now look for ways to 3D print," Vickery said.

That opened the door to innovation.

"The employees now come to me with ways to make a part or a process better or faster," Vickery said. "It enables more communication between technical people and workers. There's more push from the workers, more 'We can do it this way.' It encourages them to think of creative ways to solve problems."

Vickery's remarks are echoed by Daly, who trains both staff engineers and hourly workers in 3D printing. So far, Boeing's innovation cells have generated 80 invention disclosures and 600 ideas from hourly workers.

"Every mechanic that walks by that space is intrigued by the printer," Daly said. "They feel empowered to submit ideas and eager to make their jobs easier and more efficient."

Potential

Additive manufacturing's successes can be seductive. Boeing, Stryker, HP, and others have all demonstrated designs that improve performance and reduce assembly time. It's easy to think of a future of factory-printed parts.

Yet these applications have been intended for products whose production numbers run a few hundred or a few thousands units. At higher volumes, 3D printing is always more expensive than conventional processes.

However, this gap is narrowing, especially for products where additive manufacturing delivers a performance advantage.

Take for example, the lattice soles on Adidas' $350 4D sneakers. The company plans to make one million of them in 2019. By varying the density of the lattice, Adidas® can optimize stability, support, cushioning, and comfort in a single insert, rather than bonding several parts into one midsole.

Adidas makes the soles using a process developed by Carbon, who claims it is 100 times faster than conventional 3D. It starts with a vat of liquid thermoset resin. A laser at the bottom projects the lattice design into the vat, where it partially solidifies the polymers.

As the emerging sole is pulled upwards, it enters an oxygenated region, which stops further solidification. This ensures that the laser adds lattice only at the bottom. Carbon then heats the semi finished sole to solidify it completely.

Breaking the operation into two steps enables Carbon to run its 3D process faster (since it does not need a full cure) and then size relatively inexpensive ovens to meet the printers' highest speeds.

Desktop Metal and Markforged do something similar in metal printing. They deposit metal powders in a waxy binder, then heat the parts in an oven. The binder evaporates away and the parts shrink into a dense, final shape.

Managing that shrinkage would have been an enormous challenge, but industry had been doing something similar for decades. Powder injection molding shapes metal-binder material in molds, then sinters them. Desktop Metal and Markforged built on its knowledge to manage shrinkage and other sintering issues.

More fast processes are on the way. One comes from Evolve Additive Solutions, a spinoff of 3D leader Stratasys. Instead of rastering a print pattern one line or curve at a time, Evolve prints the way a laser printer does, one complete layer of toner-like plastic particles at a time. The layers deposit on a tray, go to a heater, and then back to the printer.

CEO Steven Chillscyzn claims the process is up to 50 times faster than conventional 3D printing. He believes it will compete with injection molding on strength, feature detail, finish—and cost—for runs of several thousand parts.

Faster, cheaper processes will lead to more 3D printed products. Airbus and Boeing have already done that for interior parts. More encouraging, in 2017, BMW's i8 Roadster became the first car to use metal additive parts in production quantities of several thousand.

The Adidas® FutureCraft sole in production.

The metal 3D parts for the new BMW i8 Roadster.

The Adidas® Futurecraft 4D shoe.

The aluminum part, which lifts, pushes, and pulls the convertible roof into a zigzag pattern, is stiffer and lighter than the design it replaced.

Other companies have begun to 3D print for spare parts. The leaders include Porsche, Daimler, Volvo, and Whirlpool. The reason, again, comes down to economics.

Companies that produce products also make extra parts for spare part inventory. German logistics giant DHL estimates that this excess and rarely used stock accounts for up to 20 percent of all warehouse space. That is just wasted money.

It is also a red flag for UPS, a global logistics company. But Alan Amling, the company's former vice president of strategy, sees a very different future.

It is a world where goods will be produced in lower quantities, more frequently, and closer to the point of consumption.

"That means there's going to be less storage and less shipping," Amling said. "So, UPS is trying to stay on the front end of this change and make sure we're part of the change as opposed to a victim of it."

That led UPS to invest in Fast Radius, a fast-turnaround job shop that combines additive with other machining technologies. UPS installed a Fast Radius 3D print center at Louisville, KY, and plans to build more production centers around the world.

Logistics is not the only place where 3D printers could prove disruptive.

"Digital printing will make it possible to green light new products, take more risks, go after niche markets, and do all sorts of things that you might not consider doing today," said Tim Simpson, who runs Penn State's Center for Innovative Processing-3D.

Take, for example, sneaker lattices. Many running stores already own treadmills that automatically analyze running styles. Combine that with some accurate measurements and an algorithm would have everything it needed to design a user-specific sole.

The main thing Adidas would have to do to produce a use-specific sole is change the digital model running on its printers. It would enable the company to essentially turn a product–sneakers–into a higher-margined service that delivers customized performance.

Another way to gain competitive advantage is through continuous upgrades, changing hardware the way software companies now do when they perform online updates. That is essentially what HP did with its printer duct.

It originally assembled the part from six injection moldings. Switching to a one-part 3D duct shaved the price to $20, from $30, but did not change performance. Optimizing the part's flow improved printing times and also shaved another 10 percent off cost. Because there are no costly molds involved, HP could introduce the part immediately, setting a higher bar for competitive products.

There are so many possibilities. One day, 3D printers may make our spare parts and let us leapfrog our competitors. They may help build or customize products that were not economical in the past.

The future of additive manufacturing remains uncertain but alive with possibilities. And each success—from airplane engines and jigs and fixtures to sneakers and knee implants—provides another clue for creative engineers with problems to solve.

It is a technology that has certainly arrived.

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This Stryker Tritanium Posterior Lumbar Cage is a hollow, rectangular implant that consists of a unique configuration of both solid and porous structures built using AMagine Technology, the proprietary approach to implant creation using additive manufacturing. It can accommodate a variety of patient anatomies.

The new BMW i8 Roadster with metal 3D printed parts. (11/2017) These parts lend the BMW i8 Roadster to combined fuel consumption of 117.61mpg (2,0 l/100 km); combined electricity consumption .2333 kWh/mile (14,5 kWh/100 km); & combined CO2 emissions 118.63 mpg (46 g/km). (Calculated in the EU test cycle, in combination with standard tires).

Reader's Poll

https://www.surveymonkey.com/r/ZNPB3HK

Does your company use 3D printing?
Yes or *No*

Have you used 3D printing, personally or professionally? *Yes* or *No*

Do you think 3D printing would make your job easier or more efficient? *Yes* or *No*