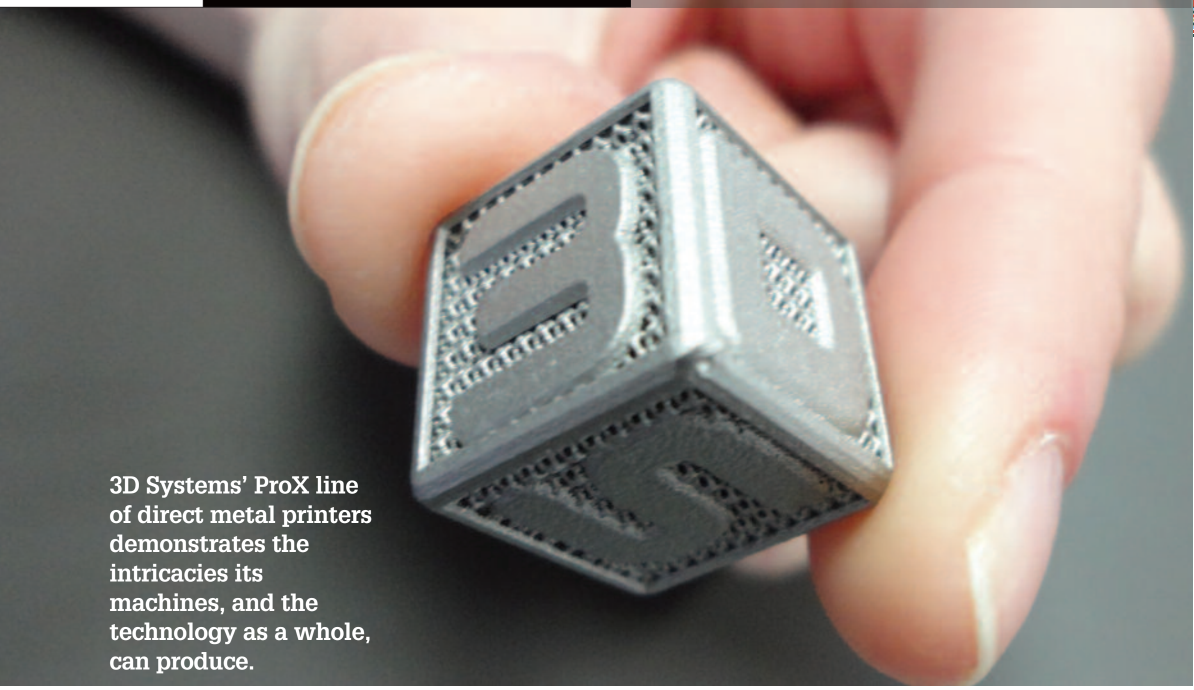
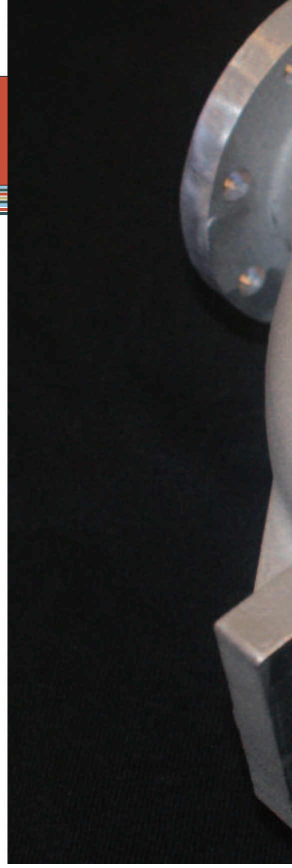
BY NICK WRIGHT, EXECUTIVE EDITOR



3D Systems' ProX line of direct metal printers demonstrates the intricacies its machines, and the technology as a whole, can produce.



LAYER BY LAYER

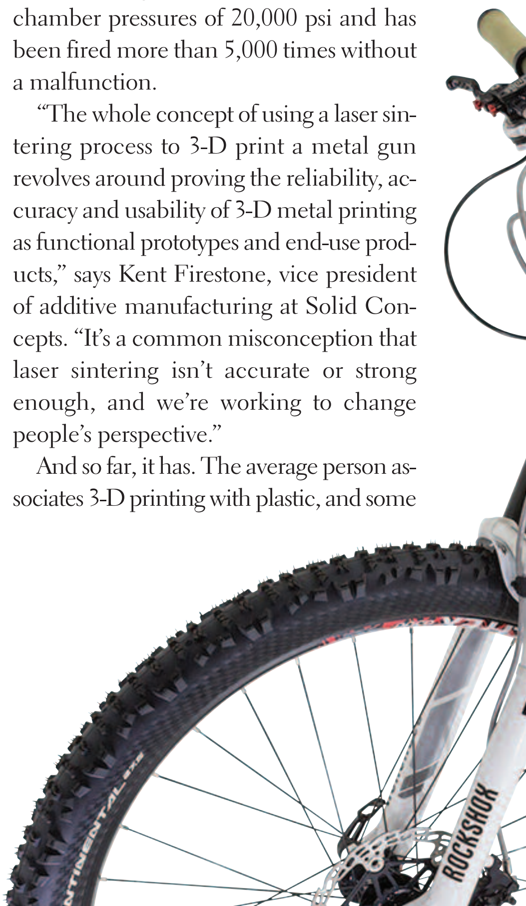
As 3-D printed metal proves itself from gears to guns, fabricators should consider the technology in coming years

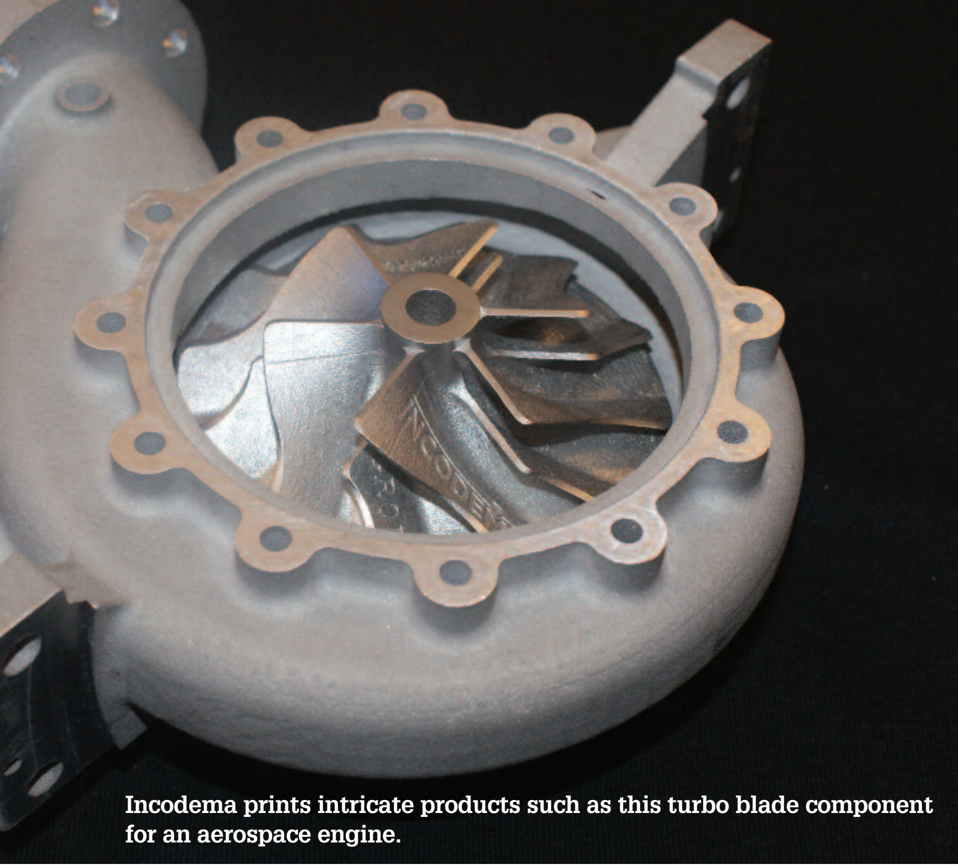
WHEN AUSTIN, TEXAS-BASED Solid Concepts Inc. unveiled last year its metal 3-D printed Browning 1911 pistol, the first metal firearm ever produced via additive manufacturing, the world reacted with a mix of awe and apprehension. Solid Concepts isn't in the firearm business. Rather, the custom manufacturer was simply out to prove to the world that 3-D printed metal is robust enough to be used for production applications and can compete with machined metal parts. The technology can be used to produce real, accurate, production parts in nearly every industry whether it's aerospace, medical or consumer products.

At first glance, the 1911 looks like any other pistol—even to the most discerning eye. But each of its 33 components—the spring being the sole exception—is made from 3-D printed Grade 17-4 stainless steel and Inconel 625, and finished with a selective laser sintered (SLS) carbon-fiber filled nylon grip. The barrel withstands chamber pressures of 20,000 psi and has been fired more than 5,000 times without a malfunction.

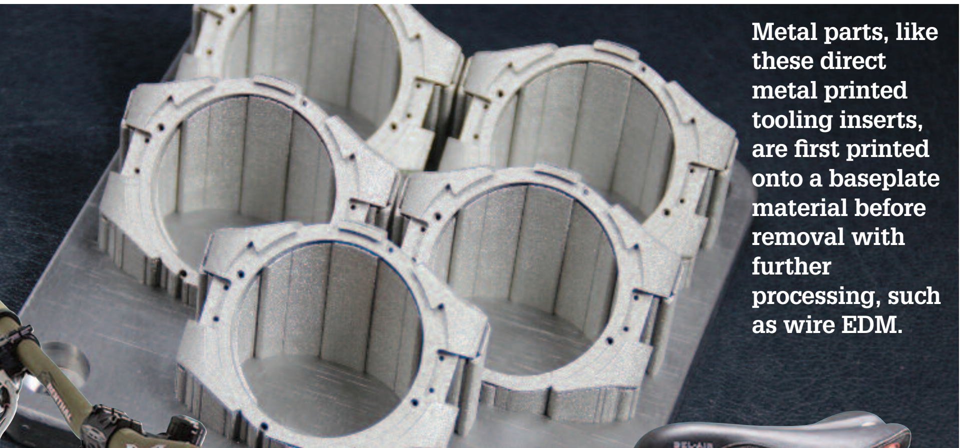
"The whole concept of using a laser sintering process to 3-D print a metal gun revolves around proving the reliability, accuracy and usability of 3-D metal printing as functional prototypes and end-use products," says Kent Firestone, vice president of additive manufacturing at Solid Concepts. "It's a common misconception that laser sintering isn't accurate or strong enough, and we're working to change people's perspective."

And so far, it has. The average person associates 3-D printing with plastic, and some





Incodema prints intricate products such as this turbo blade component for an aerospace engine.



Metal parts, like these direct metal printed tooling inserts, are first printed onto a baseplate material before removal with further processing, such as wire EDM.

form of it has existed for almost 30 years. But metal printing, a process also referred to as direct metal laser sintering (DMLS), is quickly becoming a viable material to print, as companies like Solid Concepts have demonstrated. The price of admission to print metal isn't cheap for a job shop or midsize manufacturer. The GEs, Rolls Royces and Airbuses of the world with capital to invest in such equipment—with price tags near $1 million—are at the forefront of part production with metal 3-D printing. The majority of smaller manufacturers, which might have one or more metal 3-D printers, derive value from rapid prototyping or high-mix, low-volume manufacturing. Either way, it's not a question of if, but when, every fabrication shop will have a metal 3-D printer.

Sheet metal solutions

If the initial investment in metal 3-D printers is so high, what fabricators are using them? The 3-D printers club has few members so far. One sheet metal manufacturer, Incodema Inc., Ithaca, New York, offers insight as to what metal manufacturing operations could look like in coming years.

Founded in 2001, Incodema specializes in rapid prototyping using sheet metal

Empire Cycles printed the frame for its MX6-R mountain bike with a Renishaw AM250. The frame is made from nine printed titanium alloy parts that are bonded together.

stampings, laser cutting, metal forming, finishing and welding. It has about 250 employees and 250,000 sq. ft. of manufacturing space. Incodema bought its first metal 3-D printer in 2012 after hiring engineers with expertise in the technology. Its 3-D printers are mostly used for aerospace parts, including turbines, intricate turbos and parts featuring integrated cooling lines.

"Parts with flow lines throughout are where we're seeing this technology strive," says Sean Whittaker, Incodema's president. Machining a flow line can be difficult or even impossible. One of Incodema's production parts requires CNC machining for which there are 16 different setups on vertical and horizontal mills. "If one setup is bad, you've lost your part." Machine time and labor are wasted, too.

With its 3-D printers, Incodema can integrate difficult-to-machine contours into parts. Using the technology it reduced its post-machining operations and finishing to three. But getting to that point didn't happen overnight: The learning curve can be more of a cliff without in-house knowledge to optimize the equipment, Whittaker says.

"It's another tool in your crib. It's not a stand-alone technology. That's the key to integrating this technology. It's not something you can build a business around, but it's a tool within your shop," he explains.

The company prints "anything that's available" in terms of materials, including titanium, stainless and high hardness alloys like Inconel and Hastelloy. Metal 3-D printed parts almost always need secondary processing, though, to remove support structures or achieve a polished finish. Incodema now has six units: four EOS M280s, one Renishaw AM250 and one 3D Systems ProX 300, with "many more on order," Whittaker says.

While there are dozens of 3-D printing manufacturers for all sorts of materials ranging from plastic to food, some of the big players focused on metals applications are 3D Systems, Renishaw, EOS and ExOne. Other iterations include Maatsura's (MC Machinery Systems) Lumex Avance-25, and DMG Mori-Seiki's Lastertec 65, a combined five-axis CNC

A English Racing's Mitsubishi Evo (right) set a new record as the fastest four-door vehicle, reaching 196.678 mph with its direct metal sintered (DMS) underdrive oil pump pulley (B). C The 17-4 stainless oil pump pulley, at the center of the photo, installed in the Evo's engine.

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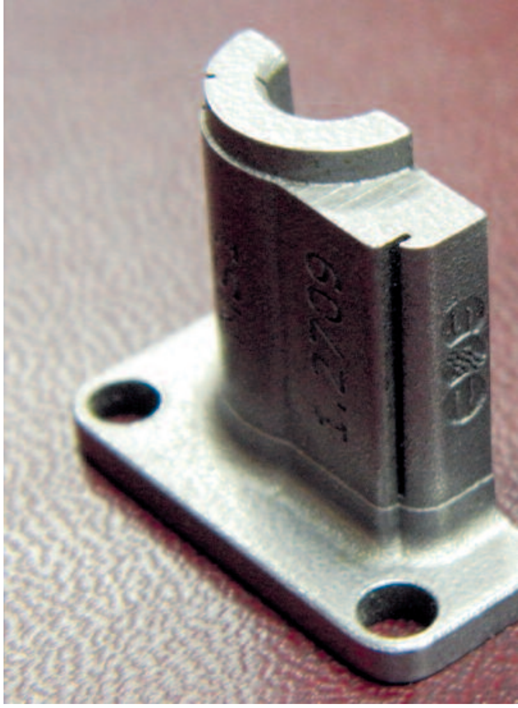
Sean Whittaker
Incodema

mill and 3-D printer. The latter two machines are each marketed for companies making metal molds to form plastic.

Complexity solved

What undoubtedly attracts metal manufacturers to 3-D printing isn't only quick prototyping, but the infinite possibilities of part shape and thickness that can be achieved. The most complex, organic shape can be manufactured without scrap, which makes metal 3-D printing ideal especially for medical and dental uses. Topographical optimization software that can tweak geometry to add strength only where it's needed minimizes material use.



For elaborate metal assemblies, multiple separate parts can often be joined in additive manufacturing. "Having fewer parts reduces cost by eliminating assembly labor and reducing the amount of quality control work," says Tyler Benster, a 3-D printing industry consultant.

Those benefits emerge on all scales of manufacturing that print metal. Take the behemoth General Electric Co.: Nearly every division is experimenting with additive, says Prabhjot Singh, GE's additive manufacturing lab manager, based in Schenectady, New York.

"It has been a tremendous product design accelerator. Another area of growth is additive in shop floors as a productivity enhancer," that is, producing fixtures or jigs—overnight. "Our manufacturing community has embraced additive and the number of machines is proliferating globally," Singh says.

Aviation is using direct metal laser melting, another metal printing method, to fabricate fuel nozzles for its next-generation jet engine, called LEAP, which Airbus will use for the A320neo beginning in 2016. The 3-D-printed nozzles are five times more durable than the previous model, and would be tough to make by conventional means. The technology enabled engineers to use a simplified design, reducing the number of brazes and welds from 25 to only five. The nozzles, as well as other components, are made from turbomachinery-relevant alloys such as cobalt-chromium, Inconel 625 and Grade 64 titanium. With more than 7,000 con-

These test parts demonstrate MTI's capabilities to fabricate C-103, a niobium alloy, for space applications. They have internal cooling channels and flow chambers with 3-D printed fuel flow paths as fine as 0.005 in.

firmed orders worth more than $78 billion, LEAP has already become GE Aviation's best-selling engine, according to the company. Benster says GE Aviation will print 45,000 fuel nozzles in the next six to seven years.

On a smaller scale, fabrication and machine shop Metal Technology (MTI), Albany, Oregon, has translated some of its metal component manufacturing to 3-D printing. Known for working with high-hardness and exotic alloys for space applications, MTI came up with a solution for English Racing in Camas, Washington. English Racing had problems with its modified Mitsubishi 4G63 engines, which can hit 10,000 rpm in some races. The car's factory oil pump drive pulley turned those high rpms into excessive oil pressure, which may cause engine failure.

Using its ProX 300 metal 3-D printer from South Carolina-based 3D Systems, installed in March, MTI developed a new, larger diameter pulley that turns more slowly, thus lowering oil pressure in the race car. Made from grade 17-4 stainless, the first working prototype was printed in just five hours. This compares with the traditional method of developing

> **"Opportunities for [additive manufacturing] in production applications are orders of magnitude greater than for modeling and prototyping. The money is in manufacturing, not prototyping."**
>
> **Tim Caffrey, Wohlers Associates**

a mold and tool, which would have been both cost-prohibitve and excessively time consuming. By July, English Racing's Mitsubishi Evo set a new record as the fastest four-door vehicle, reaching a top speed of 196.678 mph with its direct metal sintered underdrive oil pump pulley.

"This [printer] gives our customers almost complete freedom of design," says Tom Charron, vice president of product marketing at 3D Systems. "It really changes the idea of how to design products that can reach high-margin markets quickly."

Even Empire Cycles, an England-based bicycle manufacturer, proved to the world that a full-suspension mountain bike frame could be 3-D printed. Using Renishaw's AM250, Empire developed its MX6-R model from printed titanium sections that are bonded together using a 3M structural epoxy. The frame weighs about 3 lbs.

"We wanted to print the entire frame as a demonstration of what can be achieved," says Chris Williams, owner of Empire Cycles. "If simple monocoque structures are required, then using tubes is probably sensible. But we are now experimenting with complex internal structures that can only be manufactured with additive manufacturing."

With such internal structures, Empire Cycles could control the ride characteristics of its frames. Bike frame tubes can only be butted, a process by which tubing manufac-

3D Systems ProX 300

PICK YOUR PRINTER

Outlined below are the different ways metal can be 3-D printed, depending on what machine a manufacturer offers. *FFJ*'s research has learned this is not as easy as uploading a CAD file and clicking "file" and "print," but one day it might.

THE TWO MAIN CATEGORIES USED TODAY:

Powder bed fusion // Direct metal laser sintering (DMLS), electron-beam melting (EBM), selective laser melting (SLM). Uses either a laser or an electron beam to melt metal additive powder as it's deposited. **Offered by:** Renishaw, EOS, Arcam, SLM Solutions, Concept Laser, 3D Systems (which calls it direct metal printing or DMP).

Binder jetting // Either sand-cast or post-processed infiltrating with metal. **Offered by:** ExOne, Voxeljet.

LESS WIDELY-USED TECHNOLOGIES INCLUDE:

Directed energy deposition // Sprays metal powder onto a melt pool created by a laser. **Offered by:** Bright Laser, Sciaky, Optomec.

Hybrid metal / CNC // Combines metal printing with a CNC machine for post-processing and finishing. **Offered by:** DMG Mori Seiki, Matsuura (MC Machinery Systems) - Lumex Avance.

Sheet lamination // Prints layers of metal laminates using ultrasonic welding or glue. **Offered by:** Fabrisonic.

Sources: Tyler Benster, thre3d.com

turers adjust the wall thickness from inside, and the way a bicycle feels when it rides, in so many ways with existing methods.

Price of admission

At the International Manufacturing Technology Show (IMTS) in 2012, additive manufacturing was featured at the emerging technology booth. Contrast that with last month's show in Chicago, where attendees swarmed the booths of 3-D printer manufacturers. Its popularity and viability are accelerating, but as with any new technology, there are obstacles to consider and overcome.

Even a titan like GE faces hurdles. Low throughput, artifacts where supports and anchors are attached, lack of in-process quality assurance and distortion due to residual stresses, are all known challenges with printing metal, according to Singh.

Terry Wohlers, president and principal consultant at Wohlers Associates, Fort Collins, Colorado, explains that the cost of machines, materials and ancillary equipment are high. The group publishes the annual Wohlers Report, considered the bible of 3-D printing. Also, design and redesign to take advantage of the additive process, and understanding of the capabilities and limitations of the process, can take time.

"The industry is transitioning from a prototyping past to a production future," Tim Caffrey, a Wohlers senior consultant and a principal author of the latest report, said in a statement. "Opportunities for [additive manufacturing] in production applications are orders of magnitude greater than for modeling and prototyping. The money is in manufacturing, not prototyping."

The next three to five years is when metal 3-D printers will make their way into smaller manufacturing and fabrication shops, predicts Incodema's Whittaker. Printer manufacturers will likely have a machine that buyers can embed in their operation and make good parts right away.

The metal 3-D printing manufacturers don't necessarily target the smaller manufacturing market out of concern that they would destroy some of their manufacturing base for other equipment sales. "If a \$3 million to \$5 million gross sales fab shop or machine shop were to buy this technology right now, I believe it'd put them out of business within a year," says Whittaker. "The machines can cost a million bucks, and they take a lot of effort to get there," in terms of dialing in the right equation of expertise, material and design to maximize the machines.

Nonetheless, the technology isn't going away, and the cost of buying a 3-D printer will become a reality in the next few years for more manufacturers and fabricators. Whether it's for rapid prototyping or production, there will come a day when it's just another tool in the shop. FFJ