Desktop Metal™

[E-BOOK]

Manufacturing the Cars of Tomorrow

www.desktopmetal.com

01 Introduction

More than a century ago, Henry Ford installed the first simple moving assembly line in a Model T plant, and the world of automobile manufacturing was forever transformed.

Just as the assembly line opened new doors for a then-nascent industry, the rise of additive manufacturing creates new opportunities at every phase of the automotive manufacturing life cycle - from functional prototyping to mid- and high-volume production to aftermarket and spare parts.

And many of those opportunities relate to production speed and part complexity - or a combination of the two.

Because it's not bound by the same limits as traditional manufacturing, 3D printing allows designers and engineers to access a vast new design space and create increasingly complex parts. The complexity enabled by 3D printing doesn't just translate to new part designs - it also enables the lightweighting of existing part designs, as well as the use of generative design tools to create fully-optimized, organic shapes that would be otherwise impossible to produce.

Using additive technology, automotive manufacturers can then create functional prototypes of those parts in just days - as opposed to weeks or months - and quickly iterate on designs. Printing parts also opens the door to assembly consolidation by combining multiple parts into one larger structure that can simplify manufacturing and reduce material waste.

Once a design is finalized, additive technology fills a crucial gap between prototyping and high-volume manufacturing. By eliminating the need for expensive tooling, 3D printing makes it far more economical for manufacturers to produce pilot runs of various parts or create smaller numbers of parts for limited-production vehicles, like high-performance sports cars.

When parts are ready for high-volume production, additive technology eliminates the need to redesign parts for mass manufacture, allowing the systems to compete with traditional manufacturing in terms of speed and per-part cost. Using 3D printing, manufacturers can also print replacement parts on demand, and could make legacy parts - particularly hard-to-find parts for vintage cars - easy to recreate.

The benefits of 3D printing also extend to the automotive manufacturing supply chain. By enabling “digital warehouses” that hold files, not parts, additive manufacturing can reduce the need to send trillions of dollars of raw materials and parts around the world, and instead ship digital designs across borders, allowing manufacturers to produce only the parts they need, precisely when and where they need them.

With the ability to make parts faster, cheaper and more complex than ever before - this is how the cars of tomorrow will be manufactured.

Innovation is in our DNA at Ford - we've been innovating ever since the moving assembly line, and we've carried that forward with the work we do here (at the Research and Innovation Center in Dearborn, Michigan.)

We are absolutely in a time of amazing change...I think the technology of 3D printing is going to affect not only Ford but all other car makers.

As you look into the future, we're looking at many ways to integrate 3D printing into what we call the factory of the future. We see the possibility of creating future factories where 3D printing is an integral part of manufacturing. That's why we're so excited to be partnering with Desktop Metal, because it's opening up the possibility for that scale to be realized at Ford.

Ken Washington
Chief Technology Officer, Ford Motor Company

02 Additive In Today's Automotive Industry

In fact, many of the earliest adopters of additive manufacturing for automotive applications weren't car makers themselves, but the race teams they sponsor.

For decades, companies from Ford to Ferrari have used racing as an incubator for testing new technology. Many of the features that are now standard on new cars - regenerative braking systems found in hybrid vehicles, push button ignitions and even rear-view mirrors - can trace their roots to the track.

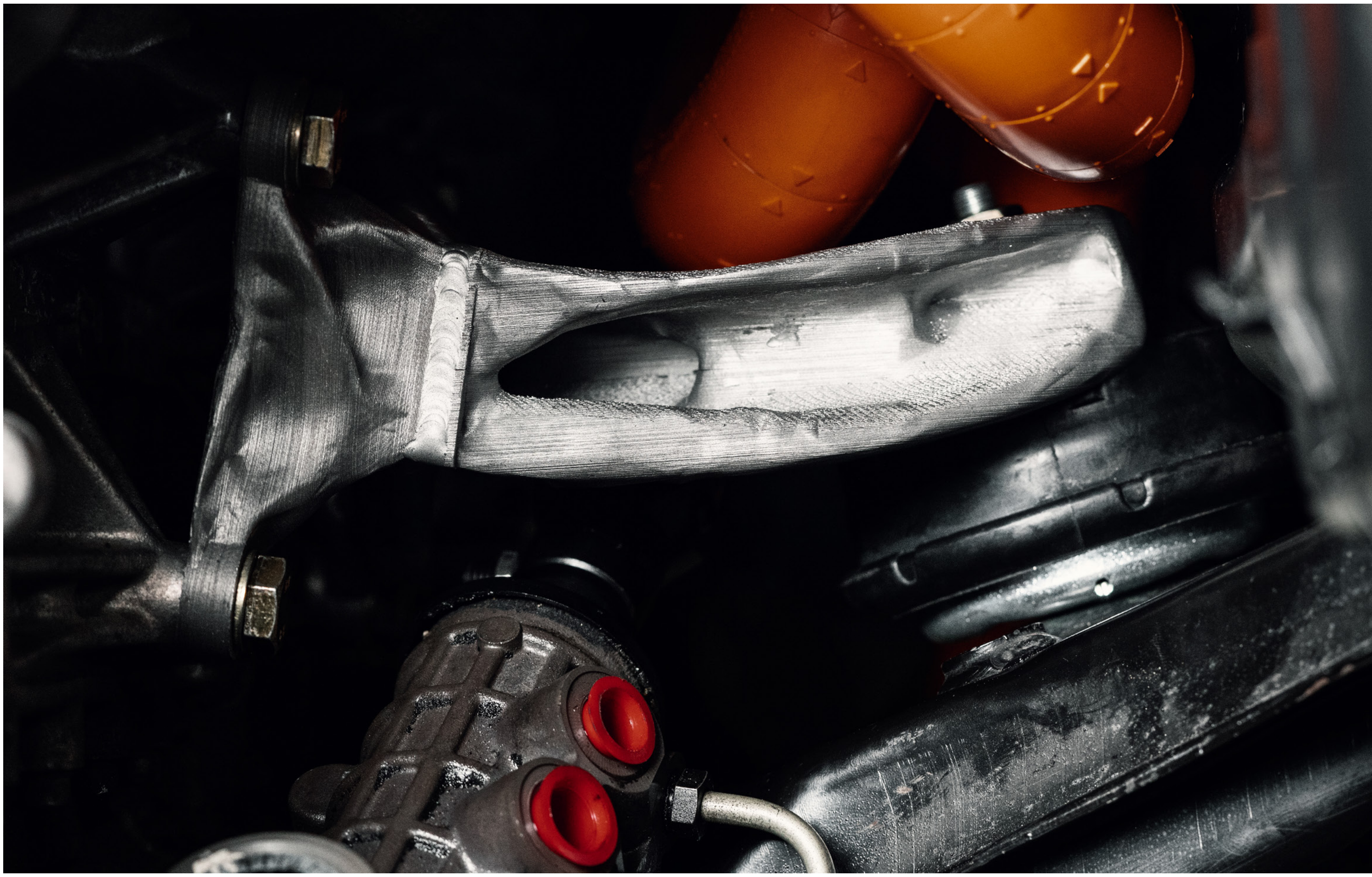
The same goes for 3D printing - especially in metal.

Formula 1 teams, World Endurance Challenge teams, Formula E teams and more have experienced first-hand how the benefits of additive manufacturing - quick iteration on designs, rapid prototyping and lightweighting of parts - can translate to improved performance on the track.

And though 3D printing has been successful on the track, its often-prohibitive cost has kept it there.

While their focus on winning makes it easy for race teams to justify the high cost of complex printed parts, it's not until companies can cost-effectively print them that 3D printed parts will become a widespread part of automotive mass production.

In other cases, 3D printing allows engineers to create one-of-a-kind vehicles destined for the racetrack.



Turner Motorsports engineers used additive technology and generative design to create one-of-a-kind engine mount brackets as part of a project to create “the most fun to drive car ever,” by combining a 2001 BMW M3 with a modern, V8 engine taken from a 2013 M3.

Part of the challenge was to ensure the brackets didn’t interfere with the steering linkages - the highly responsive steering of the 2001 M3 is one of it’s signature features - so the team created custom geometry using Desktop Metal’s Live Parts software to create a custom, generative part.

03 What's Stopping Broader Adoption?

If the benefits of 3D printing metal parts are so clear, why aren't car makers already doing it?

Essentially, it boils down to three factors - cost, materials and speed.

To date, many 3D printing systems have relied on laser powder bed fusion, in which a laser melts a thin layer of metal powder to form a part layer by layer. These systems require massive up-front investment - $1 million or more for the equipment, and the facilities needed to run it - to produce just one metric ton of parts annually, not enough to justify the expense.

Once printed, DMLS parts require labor intensive post-processing to remove support structures, leading to higher per-part costs.

The systems also have a limited range of compatible materials - they only work with low-oxygen metal powders. The cost of their raw materials can reach as high as $60 per kilogram, and finished parts can cost hundreds of dollars per kilogram - far too costly for mass production.

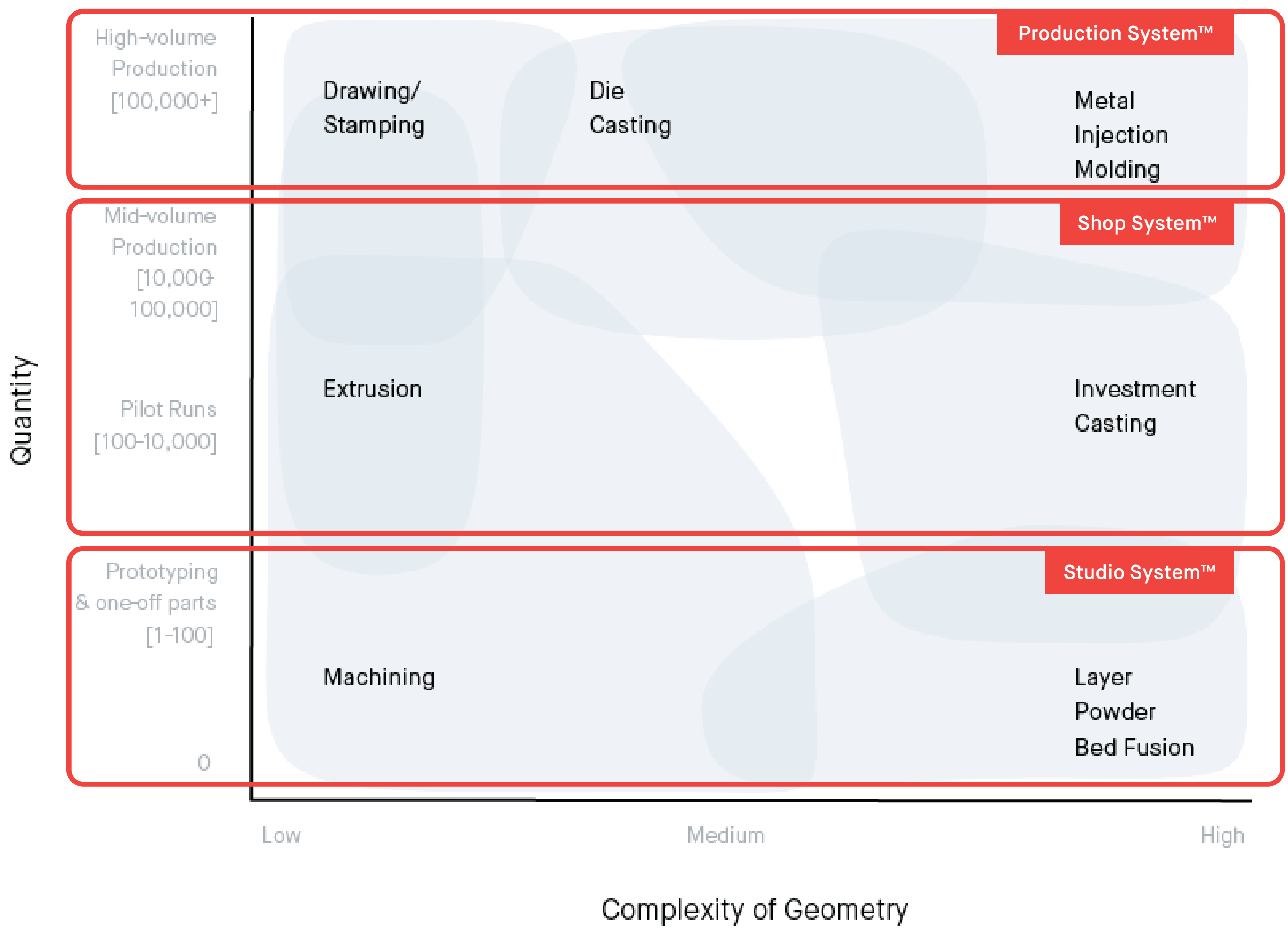
When it comes to speed, even the best machines are simply too slow to compete with mass production. The fastest powder bed fusion printer can produce just 100 cubic centimeters per hour.

Taken together, cost, materials, and speed challenges have resulted in additive manufacturing making only minor inroads into auto manufacturing, and most parts continue to be produced by traditional methods, like casting, forging, machining and stamping.

04 The Desktop Metal™ Solution

The printing technology developed by Desktop Metal is poised to solve those problems and more, and make it possible for car makers to use additive manufacturing more widely than ever before.

Desktop Metal products address every stage of the automotive manufacturing life cycle, from low-volume functional prototyping through mass manufacturing and even aftermarket and spare parts.



04 — The Desktop Metal™ Solution

Prototyping and low-volume manufacturing: Studio System™

About Studio System™

With an office-friendly design that eliminates the use of loose powders and dangerous lasers, the Studio System™ is an easy-to-use, end-to-end solution for printing metal parts in-house, and it just happens to come with a price tag that's as much as 10 times less than laser-based systems.

The system also makes a wide range of materials available - including H13 tool steel, 4140 chromoly steel, 316L stainless steel and 17-4 PH stainless steel - allowing users to print parts that precisely fit their needs.

And with Studio Fleet, the system offers a scalable solution for low- to mid-volume production for a diverse range of business needs.

For car makers in the early stages of designing and building new vehicles, the Studio System™ is an excellent starting point.

That's because the system is an ideal tool to rapidly prototype a myriad of parts in-house, saving time and money in what is often a long and costly design cycle.

The end result is lower development costs and better designs as companies are able to quickly test different ideas and explore new geometric possibilities, as well as increased revenue, as a company quickly moves from design and validation to production. At the same time, it also helps cut costs by reducing material waste and eliminating the need for staff who are dedicated to operating a single machine.

The benefits of the Studio System™ also extend to the market for replacement parts.

In every car, various components wear and eventually need to be replaced. The Studio System™ could make it possible for repair shops to produce parts locally for a variety of car makes and models, including hard-to-find parts for vintage cars for which tooling may no longer exist.

04 — The Desktop Metal™ Solution: Studio System™

Material:
17-4 PH Stainless Steel

Part Example:

Shock Absorber Piston

Shock absorbers provide damping to reduce movement in the shock assembly and provide a smoother ride by directing hydraulic fluid through complex internal channels.

Unlike conventional manufacturing, which requires pistons to be assembled from multiple parts due to their complex internal geometry, the Studio System™ can print the part in a single step, reducing lead time and cutting costs.

The geometric freedom that comes with 3D printing also allows manufacturers to rapidly prototype and explore new piston designs while eliminating the need to outsource work to costly job shops.

Prototyping parts on the Studio System™ also smoothes the transition to mass production, because higher volume Systems like Shop and Production are capable of producing those same complex designs.

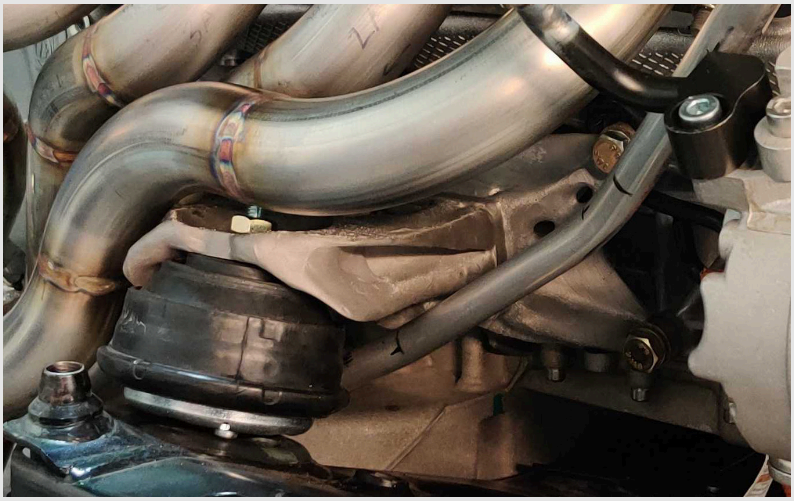
04 — The Desktop Metal™ Solution: Studio System™

Material:
17-4 PH Stainless Steel

Part Example:

Engine Mount Bracket

Like any other engine mount bracket, the part shown here is used to hold the engine inside a car - but unlike the standard part found in passenger cars, this one was intended for a very particular purpose.



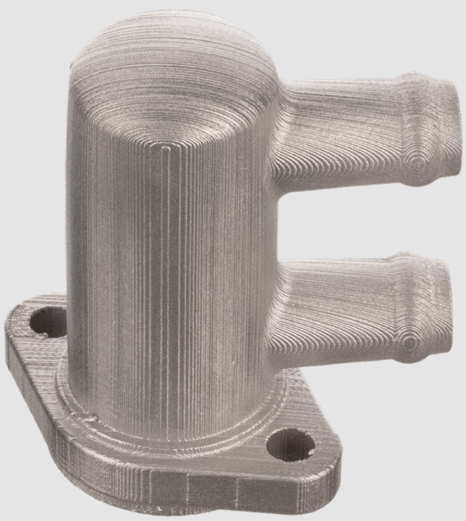
Built for Turner Motorsports as part of a project to make “the most fun to drive car ever,” this mount was specially-designed to allow the team to combine a 2001 BMW M3 with a modern, V8 engine taken from a 2013 M3.

But to ensure they didn’t interfere with the steering linkages - the highly responsive steering of the 2001 M3 is one of its signature features - the new engine mounts needed custom geometry.

To create it, Turner scanned the existing mounts, then used Live Parts, Desktop Metal’s generative design software, to optimize the shape of the mount before printing them using the Studio System™ and installing them in the car - successfully avoiding all existing geometry with the custom generative bracket.

04 — The Desktop Metal™ Solution: Studio System™

Material:
17-4 PH Stainless Steel



Part Example:

Thermostat Housing

The job of a car's thermostat is to block the flow of coolant to the radiator until the engine has reached operating temperature. By allowing the engine to warm up quickly, the thermostat helps reduce wear, deposits and emissions.

This thermostat housing was originally cast, but as demand for replacement parts dwindled, it was discontinued, and the parts became difficult to find.

Attempts to recreate the part have been frustrated by the fact that the molds and tools used to produce it no longer exist, and geometry that is too complex for machining.

Using the Studio System™, however, aftermarket parts suppliers can quickly reproduce rare parts like this housing, making them available for car enthusiasts who want them.

04 — The Desktop Metal™ Solution

Mid-Volume Manufacturing: Shop System™

About Shop System™

Designed as a turnkey solution for mid-volume manufacturing, the Shop System™ features the highest-resolution print head - 1600x1600 DPI - of any single pass binder jetting system on the market, capable of producing 670 million drops of binder per second.

That high-speed print engine enables the system to produce up to 70 kilograms of metal parts per day, a dramatic increase in throughput versus laser powder bed fusion.

In cases where a manufacturer needs just a few thousand - and not a few hundred thousand - of a particular part, the Shop System™ fills the gap between low-volume prototyping and mass production.

There are a handful of reasons why manufacturers may need smaller numbers of parts before committing to mass production.

Early in the production of a particular vehicle - even one that might eventually be produced in the hundreds of thousands - an auto maker might make just a few hundred vehicles as a pilot run for product and market tests, before going into mass production.

In another case, high performance vehicles like the Ford Mustang Shelby GT500 are often produced in limited numbers - in 2010, Ford made just 2,000 of the cars - meaning car makers may only need to make a few thousand of any one part.

Manufacturers might also use the Shop System™ to support a line of cars that are already on the road, where a car maker would need to make parts for just a small fraction of the total number of vehicles.

For aftermarket parts, meanwhile, the numbers may be even smaller - in the case of hard-to-find parts for classic cars, there may be demand for only a few hundred of a specific part.

04 — The Desktop Metal™ Solution: Shop System™

Material:
17-4 PH Stainless Steel

Part Example:

Gear Shifter

In most cars, the shifter is the only visible part of the gear stick, a metal lever that is attached to the shift assembly in manual transmission vehicles.

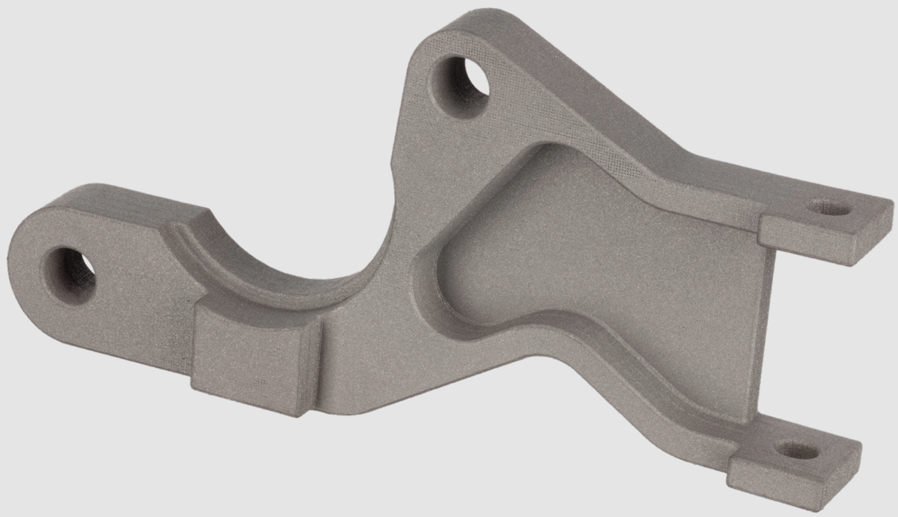
Long a popular part for customization inside a vehicle, custom aftermarket shifters have been created out of everything from billiard balls to baseballs and everything in between.

Using additive technology, though, car makers can offer customers an option to customize shifters - the part shown here illustrates just one option - when purchasing a new car.

While the shifters in many cars are made from plastic, this part was printed using metal to give the shifter a more luxurious, high-end look and feel.

04 — The Desktop Metal™ Solution: Shop System™

Material:
17-4 PH Stainless Steel



Part Example:

Parking Brake Bracket

Part of a vehicle's parking or emergency brake assembly, brackets like this one are used to keep the brake engaged until the driver releases it.

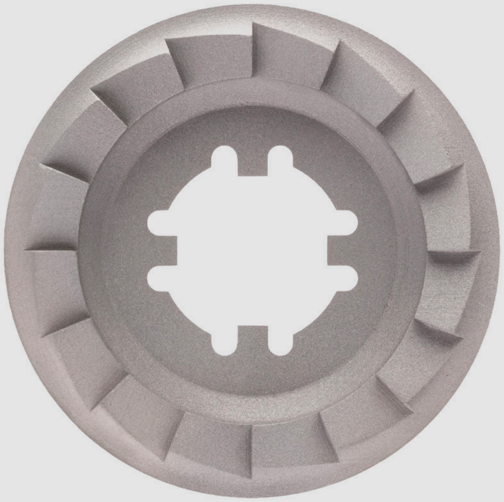
With a complex shape that's difficult to create using other traditional methods, this bracket would normally be produced using metal injection molding (MIM), forcing manufacturers to deal with long lead times related to tooling.

With the Shop System™, car makers can eliminate tooling altogether, dramatically reducing those lead times, enabling manufacturers to bring parts like this one to market faster.

The system is also more cost effective, allowing car makers to achieve low per-part costs over smaller print runs, as compared to MIM, which typically needs to produce many thousands of parts to balance the up-front cost of tooling.

04 — The Desktop Metal™ Solution: Shop System™

Material:
17-4 PH Stainless Steel



Part Example:

Clutch Plate

A key part of the electric starter system for motorcycles, the clutch plate transfers rotation from the starter motor to the crankshaft, starting the engine.

To ensure they were tough enough to stand up to regular wear, these clutch plates would traditionally be manufactured via casting or forging, which limited their complexity.

By 3D printing the plates, however, manufacturers are able to design parts with more complex shapes, like the beveled teeth in this part.

And because additive manufacturing eliminates the need for tooling required with casting or forging, manufacturers can dramatically reduce their lead times, allowing them to produce parts faster.

04 — The Desktop Metal™ Solution

High-volume production: Production System™

About Production System™

Using a breakthrough Single Pass Jetting system, the system is capable of printing at speeds of up to 12,000 cubic centimeters per hour, more than 100 times faster than quad-laser metal printers and over four times faster than the closest binder jetting alternative.

That high throughput, combined with the use of low-cost MIM powders and simple post-processing makes it possible for the Production System™ to deliver per-part costs that are similar to traditional manufacturing processes, and up to 20 times lower than current metal 3D printing systems.

For parts that do need to go into mass production, car makers can turn to the Production System™.

One of the key advantages of additive manufacturing, the ability to eliminate tooling, allows engineers to send designs that have already been refined - either on the Studio System™ or with traditional prototyping methods - to the Production System™ for mass manufacturing.

And with print speeds that are able to compete with traditional mass manufacturing processes, the Productions System™ makes it possible to produce thousands of parts in a single print run, with prices and production rates that rival processes like casting, forging and machining.

That speed, combined with the use of low-cost MIM powders and simplified post-processing, makes it possible for the system to deliver per-part costs up to 20 times lower than other 3D printing processes, and make additive manufacturing a viable alternative to casting, forging and machining.

04 — The Desktop Metal™ Solution: Production System™

Material:
17-4 PH Stainless Steel

Part Example:

BMW Water Wheel

An innovative new design for automotive water pumps, this water wheel was originally built for the automaker's DTM-series race team.

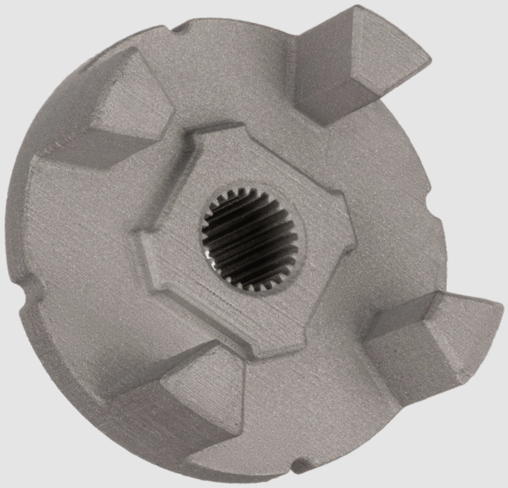
Like a standard water pump, the water wheel circulates coolant through the engine and radiator to dissipate the heat produced during combustion. Unlike other pumps, however, the wheel is designed as a single-piece, allowing it to operate more efficiently and improve performance on the track by reducing weight.

With a complex geometry that is impossible to create by casting or forging, the water wheel was initially 3D printed in plastic. To make the part more durable, however, BMW switched to metal 3D printing, and made the parts used in their race cars on laser-based systems.

While creating the part using SLM worked well for the race team, the per-part cost was far too high for production vehicles. Using the Desktop Metal Production System™, the company was able to create up to 150 of the parts at once, and reduce the cost to just $5 per part, making it far more economical to use the part in road cars.

04 — The Desktop Metal™ Solution: Production System™

Material:
17-4 PH Stainless Steel



Part Example:

Power Steering Joint

Power steering systems are a key driver assistance technology, and use either hydraulic or electric actuators to reduce the effort needed to turn the steering wheel of a vehicle.

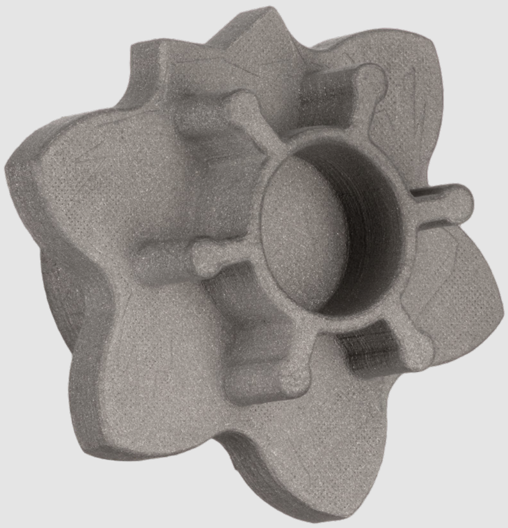
Joints like the one shown here are used to transmit power from an electric power steering motor to the steering shaft. Though often produced using powder metallurgy-based methods, manufacturers have more recently turned to forging these parts to increase the strength of the legs and reduce costs.

Using additive technology, engineers were able to optimize the design of this part, resulting in a 15 percent weight reduction, and eliminating the need for machining the tapered chamfers of the legs.

When combined with other benefits of metal 3D printing - eliminating tooling, reduction in lead times and lower up-front costs - this part could be mass produced to replace forged alternatives.

04 — The Desktop Metal™ Solution: Production System™

Material:
17-4 PH Stainless Steel



Part Example:

Variable Valve Timing (VVT) Sprocket

By ensuring that the opening and closing of an engine's intake and exhaust valves are precisely times, the variable valve timing (VVT) sprocket can help maximize engine horsepower and torque while also reducing emissions and improving efficiency.

Designed specifically to minimize noise, vibration and harshness while also maintaining durability, VVT sprockets must meet strict tolerances to ensure their proper operation.

Though normally produced using powder metal forming techniques, the sprocket shown here was 3D printed on the Production System™, which could allow manufacturers to avoid the costly and time-consuming tooling step associated with traditional manufacturing.

04 — The Desktop Metal™ Solution

Composite Manufacturing: Fiber™

About Fiber™

Combining the strength of continuous fiber with the ease of FFF printing, Fiber™ can create parts that are as strong as steel yet as light as aluminum, and can stand up to the toughest environments.

Designed for versatility, with a range of materials, from high-temperature thermoplastics like PEEK and PEKK to PA6 nylon, Fiber™ is an easy-to-use platform - in a matter of minutes, users can be up and running, printing industrial-grade composites.

The benefits of 3D printing for the automotive industry aren't limited to the thousands of metal parts in a vehicle - they also apply across a range of composite materials.

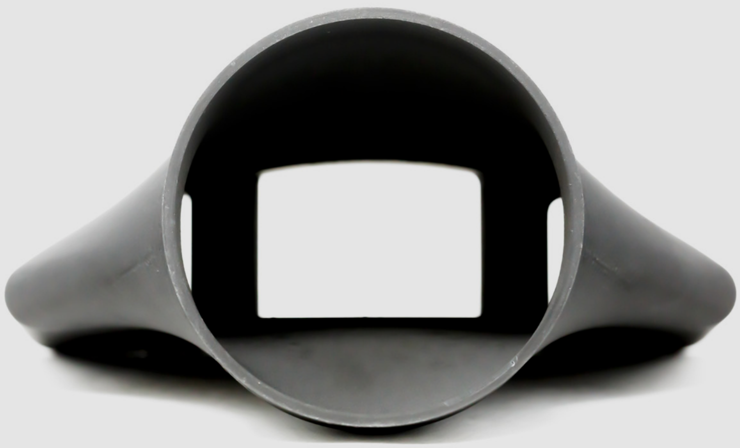
That's where Fiber™ comes in.

Though composites aren't unheard of in the auto industry, making such parts is done almost entirely by hand, limiting their use to the most expensive, high-performance vehicles.

By automating that process, Fiber™ makes it possible for car makers to bring that same technology to everyday passenger cars, as well as next-generation electric vehicles, where weight savings can help translate to improved range and efficiency.

04 — The Desktop Metal™ Solution: Fiber™

Material:
PEKK + Carbon Fiber



Part Example:

Brake Duct

During competition, a race car's brakes can reach temperatures of up to 200 °C. Without cooling, brake performance can fade, leading to safety problems and lower lap times.

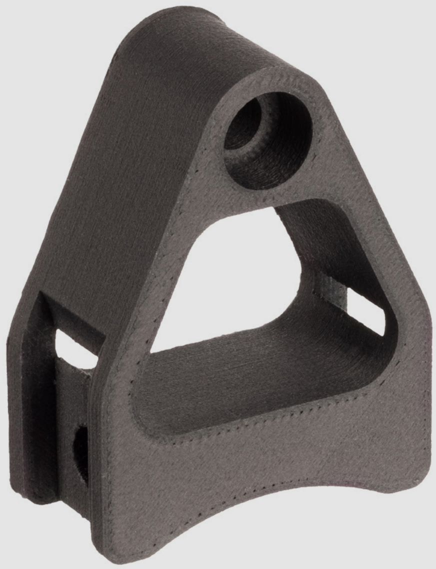
One solution for keeping the parts cool is to add ducting that uses the car's forward motion to pull in cool outside air and funnel it over the brake discs and calipers.

This duct, built for a BMW race car competing in the 2020 Pikes Peak Hill Climb, was custom designed and printed to allow for complex geometry that optimized airflow over the brakes.

By printing the part from PEKK, the race team was also able to save weight versus a similar aluminum part, while making sure the duct could stand up to the temperatures generated by the brakes.

04 — The Desktop Metal™ Solution: Fiber™

Material:
PEKK + Carbon Fiber



Part Example:

Mirror Mount

The average driver commuting to and from work relies on their mirrors to know who is around them on the road. For race drivers, they're equally important, helping them spot other drivers trying to pass, avoid crashes and race in heavy traffic.

Unlike passenger cars, though, where mirrors are often mounted on the windshield, mirrors in race cars use a specialized mirror mount that is attached directly to the vehicle's protective roll cage.

Traditionally, those mounts would be machined from solid aluminum - a time-consuming process due to the mount's complex geometry - resulting in a relatively heavy part.

This mount, printed from PA6 nylon with fiberglass reinforcement, helps the race team shave weight from the car, leading to faster lap times.

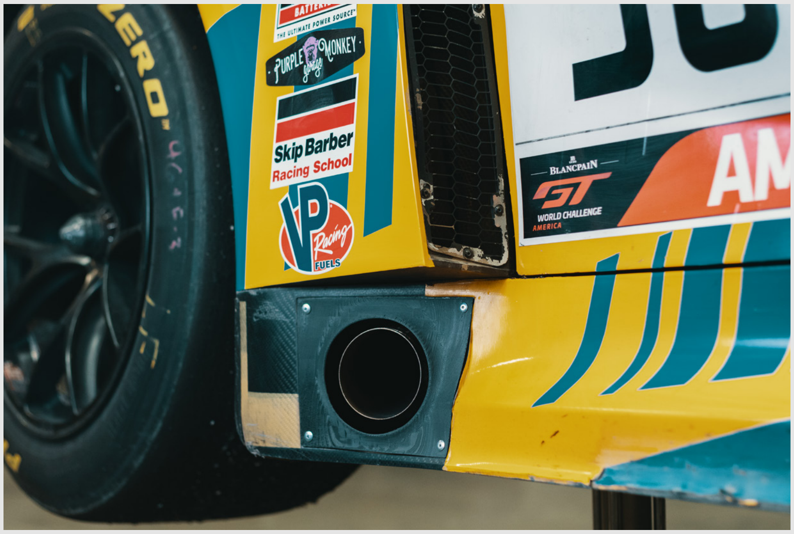
04 — The Desktop Metal™ Solution: Fiber™

Material:
PEKK + Carbon Fiber

Part Example:

Exhaust Heat Shield

Created for a BMW M6 race car, this heat shield was traditionally made from aluminum, and used to prevent high-temperature exhaust from melting carbon fiber components beneath it.



During particularly long races - this car was used in endurance races that could last up to 24 hours at a time - the metal heat shield was exposed to continuous high temperatures, and would become hot enough to char carbon fiber parts.

Using Fiber™, engineers were able to print the heat shield from PEEK, which can withstand the exahust temperatures, and is less thermally conductive than aluminum, reducing the chance of heat damage to other components.

The composite part also saves weight as compared to the aluminum heat shield, which can lead to improved performance on the track.

About Desktop Metal

Based in Burlington, Massachusetts, Desktop Metal is dedicated to addressing the unmet challenges of speed, cost, and quality to make metal 3D printing an essential tool for engineers and manufacturers around the world.

Founded in 2015 by pioneers in advanced manufacturing, metallurgy, and robotics, the company's leadership team includes a number of MIT faculty - including one of the inventors of binder jetting.

The company is today made up of more than 300 employees, most of whom are engineers in the fields of mechanical engineering, materials science, software, robotics and industrial design. More than two dozen Desktop Metal employees hold PhDs.

Since its founding, Desktop Metal has attracted $438 million in funding from investors like Koch Disruptive Technologies (KDT), GV (formerly Google Ventures), GE, BMW, Ford Motor Company, Lowe's, NEA, Kleiner Perkins, Lux Capital and 3D printing leader Stratasys, and has been recognized as one of the world's 30 Most Promising Technology Pioneers by the World Economic Forum and named to MIT Technology Review's list of 50 Smartest Companies.