3dpbm | Insights

Automotive AM

Additive manufacturing finds its role in the ever-evolving automotive sector

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3dpbm

About
3dpbm is a leading media company providing insights, market analysis and B2B marketing services to the AM industry. 3dpbm publishes 3D Printing Media Network, a global editorial website that is a trusted and influential resource for professional additive manufacturing.

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Hello

Happy new year and welcome to our first AM Focus eBook edition of 2021! In this new series we will explore an array of AM topics, including ones we started to delve into last year and new subsegments.

In this inaugural publication, we revisit the ever-evolving automotive sector and its activities in AM—with a special focus on electric vehicles (EVs). The automotive and additive manufacturing industries are more closely entwined than ever. What was once a prototyping technology used sparingly by automotive manufacturers is now transitioning to become an integral production method, for prototyping, tooling and end-use parts. Excitingly, AM is giving automakers a new degree of freedom, opening up opportunities to explore new car designs and more efficient production workflows.

The eBook begins with an insightful analysis of the market for 3D printed automotive and EV parts. This is followed by the jewel in the crown: an exclusive interview with automotive giant General Motors looking at its AM strategy. We are also excited to present a look at some of our favorite 3D printed car restoration projects from over the years as well as a map of AM's most influential players in the automotive space.

Tess Boissonneault
Editor in Chief, 3dpbm

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ANALYSIS

The market for Automotive and EV AM parts

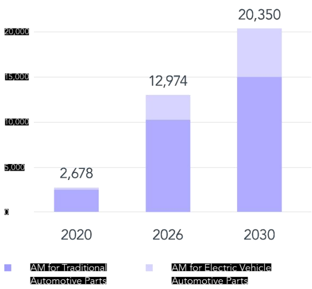
Today, the total global market for car parts is worth over $1 trillion. How much of this is going to be represented by EVs? And how much of this can be produced by AM?

Image: Tesla, Inc

Cars are made up of four main types of parts: body, auxiliary electronics, interior and powertrain parts. If we combine the global turnover generated by all these groups of parts, we obtain a collective turnover of about $1.1 trillion, more than half of which is represented by powertrain components. Within this $1 trillion, between $25 and $50 billion (2.5% to 5%)—growing to $160 billion according to ResearchAndMarkets—is generated by EVs, with EV powertrain elements representing between $15 and $30 billion. If we factor in the attractive (especially in terms of AM) business for after-market and replacement parts, the total TAM approaches $1.5 trillion.

Expected revenues associated with AM for production of automotive parts ($USM)

Source: 3dpbm Research



How many of these components could be 3D printed and how much could AM realistically generate in the broader automotive industrial sector and more specifically in the rapidly growing EV segment? We think the business potential for AM in automotive parts (including tools and prototypes) can grow to top $20 billion by 2030, of which about 25% is relative to EV parts production.

Let's take the vehicle apart to take a closer look and understand how accurate this forecast is.

CAR BODY PARTS

According to a realistic figure provided by Markets and Markets, the global automotive body parts market size is expected to be generating $29.7 billion in 2020, growing at a CAGR of 3.8% and projected to reach $37 billion by 2026. This market segment—the smallest among the ones we are going to be analyzing in terms of revenues—includes body components (including trim), doors and windows.

AM applications

Besides obvious applications in prototyping, AM has shown it can play a role in the market for car body parts. One of the first possible applications is in custom trim body components, including bumpers and fenders. This was initially demonstrated by BMW Group with the (now discontinued) MINI Yours Customised program, which allowed customers to design certain exterior (and interior) components themselves, for example with computer-based laser lettering for the production of the door sill with customer-specific styling.

More immediately, 3D printing is being implemented in certain smaller and less obvious serially manufactured parts, such as the guide rail for the window of the BMW i8 Roadster (using polymers with HP MJF technology) and the cover which unfolds when opening the roof of the open-top hybrid sports car (using metal PBF).

A bit more long term, EV firm Local Motors has been demonstrating the ability to 3D print entire car bodies using LFAM composite 3D printing technologies. After 3D printing the first entire car bodies, the Strati and its successors, starting in 2014, Local Motors is entering the market with the Olli smart EV shuttle, which integrates an entirely 3D printed body. Another interesting attempt at 3D printing a car body—this time using a

large-format metal DED technology—the "La Bandita speedster" was presented in 2018 by the startup Hackrod in collaboration with Siemens. However the project has not yet seen the light of day.

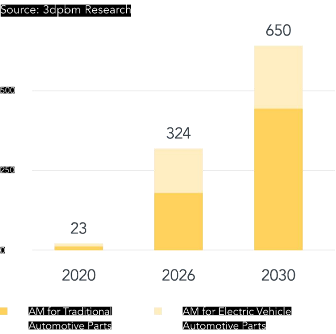
AM potential

Long-term and moderate at around 1% market penetration by 2030

AM applications in the production of car body parts, for both traditional vehicles and EVs, are definitely a more long-term opportunity. However, some smaller body components and connectors are already being mass produced in both metal and polymer materials. And, because EVs are expected to have increasingly fewer parts in the future, 3D printing will have a more significant penetration in the EV car body parts production market than in traditional vehicles. XXXThis market includes audio/video devices, cameras, low-voltage electrical supply systems, gauges and meters, ignition system components, lighting and signaling systems, as well as several different types of sensors.

Expected revenues associated with AM for production of car body parts ($USM)

Source: 3dpbm Research



AUXILIARY ELECTRICAL SYSTEMS AND ELECTRONICS

The global automotive electronics market size was estimated at $250 billion by Grand View Research in 2019 and is expected to be worth $270 billion in 2020. This market includes several small and intricate products which could significantly benefit from AM in production, at least to certain batch numbers of several tens of thousands and—3dpbm expects—even into the millions of parts by the end of this decade.

This market includes audio/video devices, cameras, low-voltage electrical supply systems, gauges and meters, ignition system components, lighting and signaling systems, as well as several different types of sensors, electrical switches, wiring harnesses and, of course, electronic enclosures.

AM applications

In terms of applications, AM is already used significantly in the production of custom electronic enclosures and switches. Other key applications include the use of copper, which is skyrocketing in metal AM—in both metal PBF and bound metal/binder jetting technologies.

AM part production firms and AM factories such as Slant 3D (along with most 3D printing service providers, to different extents) have demonstrated the cost efficiency of 3D printing electronic enclosures (and related products). An advantage of high-volume 3D printing is its ability to produce custom parts at scale without the cost of molds. This freedom allows for products to evolve during production and reduces inventory requirements. Electronic enclosures cannot accommodate the millions of PCB designs that are used in cars, which feature more and more electronic elements—a trend that will increase by several orders of magnitude with EVs and with increased demand for customization. With 3D printing, enclosures can be produced on demand, as the parts are sold, with no molding cost.

Local Motors has relied heavily on 3D printing to develop and manufacture its electric shuttle vehicle, the Olli.
Image: Local Motors

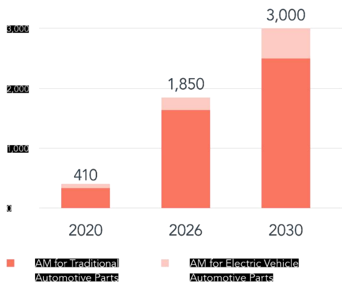
AM potential

Short term and moderate at up to 1% market penetration by 2030

The application of AM in the production of electronic components—especially enclosures and switches—is expected to increase rapidly to serial production levels, as combustion engines become more compact and EVs become more streamlined. Polymer 3D printing with high-temperature materials already enables the production of several under-the-hood components for combustion engine vehicles. With EVs and, in general, smart vehicles, adoption of AM is expected to be even more significant, as temperatures become less of an issue (outside of batteries), and the need for complex electronic parts increases.

Expected revenues associated with AM for production of car electronics ($USM)

Source: 3dpbm Research



INTERIOR PARTS

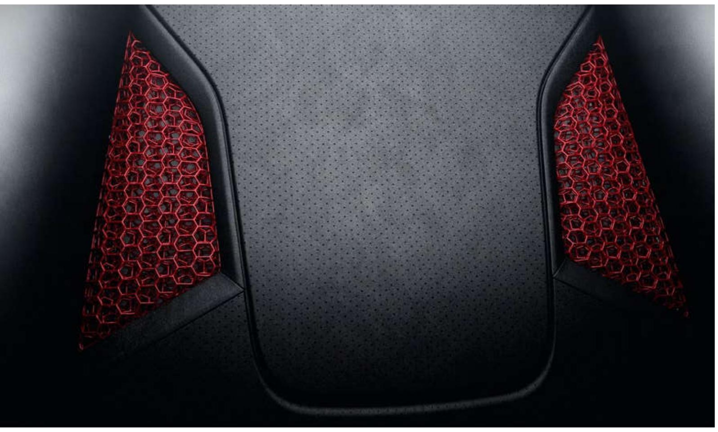
The global automotive interiors market was valued at $171 million in 2017, and is projected to reach $240 million by 2025, registering a CAGR of 4.7% from 2018 to 2025, according to Allied Market Research. This industrial segment includes all floor components and parts, dashboards, finishing and trim, accessories and, of course, the car seat. This last area in particular, has recently instigated a number of innovative 3D printing approaches.

AM applications

Major automotive manufacturers are already exploring and bringing to market 3D printed interior vehicle parts. One of the most popular applications to date is using AM for car seat components. In 2018, GM and Autodesk famously developed a 3D printed seat bracket using generative design. Made from stainless steel, the seat bracket benefitted from part consolidation (from eight parts to one) and weight reduction (by 40%). HP is also rumored to be working on a new approach to car seat production, leveraging complex lattice geometries to modify the flexibility of elastomeric materials (TPU and TPA) used to produce car seat sections using MultiJet Fusion technology.

Further, luxury car manufacturer Porsche unveiled a new concept for a 3D printed bodyform full-bucket seat in 2020. The bucket seat, designed for sports cars, integrates a sandwich construction that combines expanded polypropylene (EPP) and a 3D printed lattice layer made from polyurethane-based materials. Notably, the 3D printed layer can be customized for the driver's comfort preferences.

Porsche's concept for a new full-bucket seat integrates 3D printed lattices for custom cushioning.
Image: Porsche AG



Most recently, Rolls-Royce introduced the Extended Ghost model with a number of 3D printed parts, including several interior components. Polymer components were crafted using MJF and SLS technologies. Lamborghini also regularly includes custom components 3D printed using Carbon technology in its new vehicles. Of course, 3D printed interior components are today still largely limited to luxury vehicles, which often come in increasingly limited editions.

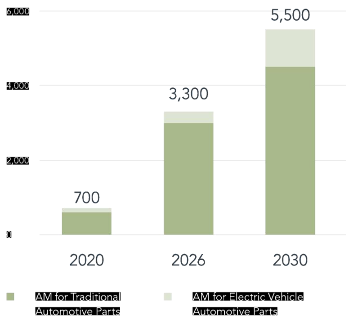
AM potential

Medium term and significant at above 1% market penetration by 2030

Interior components in both metal and durable plastics are expected to grow into a major revenue opportunity for additive manufacturing companies. This is due to the large variety of parts that can be cost-effectively 3D printed, along with rapidly increasing customization requirements, lightweight requirements, complex part geometries and on-demand production capabilities.

Expected revenues associated with AM for production of interior parts ($USM)

Source: 3dpbm Research



POWERTRAIN AND CHASSIS

This brings us to the most significant segment for automotive production. The global powertrain, powertrain parts and chassis market was worth $607 billion in 2019 according to Research and Markets. It is expected to grow at a compound annual growth rate (CAGR) of 8.76% and reach $849 billion by 2023. While car body and interior parts for traditional and EV automotive are generally the same, powertrain elements can differ significantly. Grandview Research estimates the global electric powertrain market size to be around $20 billion in 2020, growing at a compound annual growth rate of 13.6% from 2020 to 2027 to near $40 billion by 2027.

Combustion powertrain parts and AM applications

Combustion-engine-specific components and parts refer mainly to the engine and transmission. Combustion engines include a number of parts that could benefit from both metal and high-performance polymer 3D printing, however the level of part demand in the mass automotive industry is such that no AM technology can cost-effectively meet it today.

The irony is that as AM technologies become more productive, combustion engines are likely to be progressively phased out. However, as combustion engines begin to be produced in lower numbers and optimized for increasingly higher performances (reducing emissions), AM technologies may prove increasingly useful. In particular, AM can be used to optimize the shape and reduce subassemblies for complex parts such as exhaust manifolds, valves and even pistons, while increasing the performance of integrated cooling systems by leveraging geometry and new materials for improved heat dissipation.

Besides experimental display models, there are no published cases of directly 3D printed engine blocks to date. These parts may eventually be produced either

"Czinger uses additive manufacturing to create performance-engineered componentry, including the chassis."

via direct metal 3D printing or—more likely—indirect 3D printing molding technology. voxeljet has already demonstrated the reconstruction of a historic Delage racing engine using sand binder jetting. The entire sand core package was printed using their VX1000 system.

Hybrid powertrain parts and AM applications

Several powertrain and chassis parts are common to both vehicles with internal combustion engines and EVs, although they may take different forms. Several of these have been 3D printed in some form, starting with the high-profile Czinger 21C hybrid supercar project, which integrates a number of 3D printed parts. Czinger uses additive manufacturing methods to create performance-engineered componentry, including the chassis derived from the project predecessor, the Blade supercar which was produced using SLM Solutions metal PBF technology.

Bugatti, another major combustion-engine supercar manufacturer—which we look at in a little more detail on page 36)—has publicly used AM on a number of parts, including the revolutionary titanium 3D printed brake calipers. More recently, the company produced hybrid components, such as the 0.5-meter-long auxiliary drive shaft, combining carbon fibers with 3D printed titanium end fitting to reduce weight by around half to 1.5 kilograms and increase performance due to the reduction of the rotating masses.

Electrified powertrain parts and AM applications

EVs use the electricity saved in the battery to cycle the motor and generate the power necessary for driving. As such, EVs have no need for the engine and transmission, the two of the most crucial components for internal combustion vehicles. Instead, EVs carry several components for electric power: the motor, the battery, the on-board charger and the Electric Power Control Unit (EPCU). All are essential components to achieve the conversion of the battery's electricity into kinetic force. The motor is also in part an electric generator—it converts the kinetic energy generated while in neutral gear (e.g. while the car is going downhill) into electric energy saved to the battery. The same energy-saving idea applies when the car is slowing down.

In electric motors, a particularly interesting focus for AM is on copper. German firm Additive Drives presented promising applications cases. One, in cooperation with the Racetech Racing Team eV of TU Freiberg, involves 3D printed single coils used on the racing engine. In another project, copper 3D printed hairpin windings reduced the time required for the development and production of an electric traction motor prototype to one month. In addition, direct production of individual lots was achieved for Dresden-based pedelec manufacturer Binova: using 3D printed individual coils, Binova produced several different types of electric bikes with an unconventional electric motor design and no tool

Porsche and SLM Solutions developed a E-Drive housing using the latter's 12-laser NXG XII 600 PBF system.
Image: Porsche AG

adjustments. More recently, Porsche and SLM Solutions revealed a project centered on manufacturing a complete housing for an electric drive using 3D printing. The 3D printed E-Drive housing on the engine-gearbox unit produced using the additive laser fusion process passed all the quality and stress tests. In the future this may become a viable production method.

In EVs, the reducer is a kind of transmission that serves to effectively convey the motor's power to the wheel. The motor has a far higher RPM than that of an internal combustion engine, so with the reduced RPM, the EV powertrain can take advantage of the resulting higher torque. This part is a fairly complex metallic component that could be optimized with AM for fast production, improved performance and weight reduction in the future. The Electric Power Control Unit is another complex enclosure that could benefit from AM processes. It includes the inverter, which converts the battery's DC into AC, and is used to control the motor speed; the Low voltage DC-DC Converter, which supplies the vehicle's various electronic systems; and the Vehicle Control Unit. The VCU oversees nearly all the vehicle's power control mechanisms, including the motor control, regenerative braking control, A/C load management and power supply for the electronic systems.

The battery stores electrical energy and is the equivalent of a fuel tank in an internal combustion engine: the higher the capacity, the higher the driving distance.

Czinger develops hybrid supercars that integrate a number of 3D printed components, including a metal chassis.
Image: Czinger

However, the battery's size and weight also have large implications on vehicle performance. A larger and heavier battery takes away from cabin/storage space and worsens the energy efficiency and fuel economy. The best way to optimize performance, then, is to maximize the battery's energy density—that is, having a small, lightweight battery that stores as much electric energy as possible.

Batteries are tricky and particularly interesting for AM in (a rapidly approaching) future. Several efforts have been made to produce batteries using different 3D printing technologies, with both polymer and ceramic materials. Because batteries can take many different shapes and sizes for improved efficiency, AM could prove instrumental for testing—and eventually manufacturing—several new design iterations. The batteries used in EVs today are basically rows of hundreds of small-sized batteries fastened together to increase capacity. The Tesla 85kWh pack, for instance, is made up of 7,104 cells roughly the size of AAs. With 3D printing, the individual cells don't have to be manufactured and assembled: the module can be designed and printed in the desired overall shape. AM can also make a difference in the structure of the electrodes of a battery: porous electrodes increase energy density, and AM is ideally suited to build electrode materials into lattice shapes that have more exposed surface area for the chemical reactions to take place, resulting in a more efficient battery. Swiss firm Blackstone Resources has recently achieved a series of important milestones for its proprietary 3D printing technology to print lithium-ion solid-state batteries. Blackstone's 3D printing process claims to offer substantial advantages over conventional battery cell designs that use liquid electrolytes. These include significantly lower costs, a higher level of production flexibility—when it comes to the format of the cell—and a 20% increase in energy density. Moreover, by using this technology, the number of materials that do not store energy (such as copper and aluminum) could be reduced by up to 10%. The Swiss company also developed a workflow to mass-produce these batteries in 2021 in any shape or form using proprietary battery printing technology.

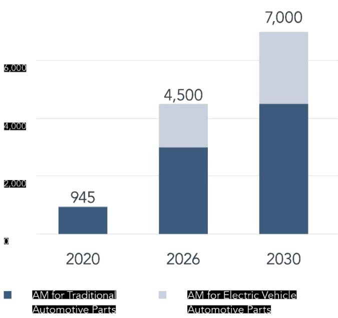
AM potential

EVs - Medium term to long term and very significant at above 1% market penetration by 2030
ICE – medium to long term and moderate at below 1% market penetration by 2030

Powertrain components are the single largest subsegment of the automotive parts market, and they are expected to be the largest segment for AM as well. Applications differ greatly between combustion and electric powertrains, which is why we are treating these as two separate categories. Because of the complexity of the parts and the number of subassemblies, the penetration of AM in combustion engine parts is more feasible today than in electric motors. However, this only applies to low production numbers (motorsports, luxury vehicles). As AM evolves to meet the requirements for mass automotive production, combustion engines are expected to be progressively phased out so that when AM will be fully ready and industrialized as a technology for combustion engine parts manufacturing (valves, manifolds, even engine blocks), EVs may be represent the majority of cars being produced. In EV powertrains, the use of AM is particularly effective for part reduction, leading to weight reduction and

performance improvements, which in turn will enable higher mileage. However, the actual penetration of AM in EVs—beyond applications shared with combustion engine powertrains, such as chassis, brakes and fluid flow applications—is highly dependent on the ability to implement AM in serial battery manufacturing. Efforts in this sense are already underway but still a long way from becoming a consolidated business opportunity.

Expected revenues associated with AM for production of powertrain parts ($USM)
Source: 3dpbm Research

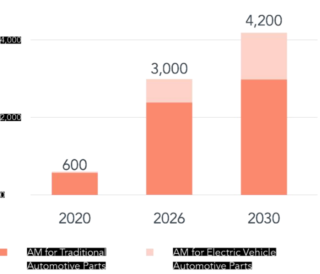


AFTER-MARKET REPLACEMENT PARTS

The global automotive aftermarket size was valued at $380 billion in 2019 by Precedence Research, and is expected to grow at a compound annual growth rate (CAGR) of 3.8% from 2020 to 2027 to $513 billion. This market segment, which includes replacement parts, obsolescence management, restorations and car modification/performance kits, is one of the most attractive for additive manufacturing due to the possibility of reducing physical stock costs through digital warehousing and on-demand part production.

The automotive aftermarket includes post-sales replacement of vehicle parts or components to maintain the efficiency and its mobility affordable throughout the life of a vehicle. Segment operators in the automotive aftermarket that stand to benefit from polymer and metal AM implementation include OEMs, tier 1 and tier 2 suppliers, including multi-brand repairers, parts distributors, tools manufacturers, parts manufacturers and—on a more long-term basis—roadside rescue service providers.

Expected revenues associated with AM for production of aftermarket parts ($USM)
Source: 3dpbm Research



AM applications

Some of the most high-profile application cases in the use of AM for replacement parts were presented by the Daimler-Benz Group, first with polymer replacement parts for Daimler buses (in partnership with EOS' Additive Minds) and later for the Mercedes-Benz Classics cars. These included the inside mirror base for the Mercedes-Benz 300 SL Coupé (W 198 model series), 3D printed using metal PBF; the spark plug holder from the tool kit; and the sliding sunroof rollers for the W 110, W 111, W 112 and W 123 model series, all 3D printed using nylon in polymer powder bed fusion.

Recently, aftermarket luxury car kit manufacturer 1016 Industries confirmed the company is planning to debut its first full-body 3D printed kit at the beginning of 2021. The company also plans to provide directly printed tooling molds for the McLaren 720S and other supercars, with the goal to manufacture aftermarket products directly as 3D printed parts.

AM potential

Short-term and significant at above 1% market penetration by 2030

While companies targeting the automotive industry through high productivity metal binder jetting technologies are ultimately looking at serial production, replacement parts can be a viable opportunity for current polymer and metal PBF processes as well as a relevant short-term opportunity for metal binder jetting processes. The extreme cost reduction obtained from not having to stock parts or produce and stock expensive molds and casts, can easily be transferred to producing parts on demand, even with significantly higher materials costs and machine costs. ◆

INTERVIEW

The integration of AM at General Motors

Exclusive interview with General Motors' Ali Shabbir and Dominick Lentine.

For over a century, Detroit-based General Motors (GM) has been a key pioneer and player in the global automotive sector. Today, GM holds the title of being the United States' biggest automotive manufacturer, followed by Ford Motor Company and Fiat Chrysler. As one can imagine, it has not maintained this leading position by resting on its laurels. No, the company has had to continually innovate and stay up-to-date with changing trends, both on the consumer and manufacturing sides.

It is no surprise therefore that GM is a keen adopter of additive manufacturing. The technology, whose applications are growing rapidly across many industries, has always had a special place in the automotive industry: initially just for prototyping and now also for tooling and end-use production. GM has been exploring the use of 3D printing for automotive production for over a decade and is now aiming to fully integrate the technology as an essential tool in its production toolbox.

To better understand the company's perspective on additive manufacturing and its potential, we caught up with Ali Shabbir, Engineering Group Manager for Product Applications, and Dominick Lentine, Engineering Group Manager for Manufacturing Applications.

Manufacturing matchmaker

Part of Shabbir's mandate at GM is identifying the right type of manufacturing technology for specific production applications, a matchmaking of sorts. In other words, he and his team find automotive applications where it makes technical and commercial sense to use additive manufacturing, and then identify which AM technology is best for the job.

"We holistically evaluate all the technologies that we typically use for our production applications—which can be parts or tools. Processes that have higher throughput and integral isotropic material properties are typically better suited in the plastics space. For instance, we are using HP's Multi Jet Fusion technology for Cadillac V-Series HVAC ducts. The selective laser sintering process that we also have in-house at the Additive Industrialization Center [which opened its doors in December 2020] would be well suited to that type of application as well. On the metal side, we are using laser powder bed fusion to produce parts like electrical brackets."

Binder jet metal technology is another AM process that is becoming very interesting for GM. According to Lentine, binder jetting has the potential to reduce the price for printed metal parts, which will open up more production applications and opportunities down the line. "It's still an early technology within the additive technology space," he adds. "We have lots of work going on with our industry partners to figure out where that will fit, but it's promising. In regards to production tools, 90% of what we do within AM right now is FDM, nylon carbon fiber.

"There is also a fair amount of metal, but we don't talk about it as much because it's almost the status quo. Metal 3D printed die-cast components are a big part of what we do with our manufacturing today. Our casting plants in Indiana, Ohio and Michigan have a significant amount of 3D printed metal production tools."

Shabbir goes on to emphasize GM's priorities in terms of successful AM adoption. "Application selection is absolutely paramount for using AM for production components. There are certainly things we need to do to ensure repeatable quality over time, but most of the challenge has to do with the identification and development of the application itself. You want to make sure that you're not just 3D printing something because it's cool, but that it actually makes sense, whether it's leveraging additive-only design, or part consolidation, or lightweighting. These are some of the considerations for picking the right application, and then from there you can scale."

Image: Steve Fecht for General Motors

"You want to make sure that you're not just 3D printing something because it's cool, but that it actually makes sense"

Lentine agrees: "Our challenge is less of a technology hurdle and more about education and awareness so that people see 3D printing as a tool in the toolbox."

An industry-wide effort

Continuing to address the topic of AM awareness, Lentine explains that GM's Manufacturing Applications Group is also focused on working with the company's network of tool suppliers, supporting them through the AM education and adoption phases. "As we go and launch plants, we help our tool suppliers to learn how to utilize AM and design for additive manufacturing. We help give them access to that knowledge."

In other words, GM is not only utilizing AM technologies internally, it also has many external manufacturing partners that it works with. From the part production angle, Shabbir elaborates: "At GM, we have a pretty holistic supplier qualification process that we use for additive manufacturing. It's sort of a two-fold approach. We want to ensure that we are working with a very capable supplier, both in terms of their additive knowledge, but also in their ability to support the automotive industry and be part of the automotive supply chain because there are some unique quality systems and requirements that come with being an automotive supplier.

"This means we go through a fairly robust qualification process with suppliers. These can be, let's say, the traditional service-bureau-style additive suppliers or the existing Tier One or Tier Two suppliers that GM has that have additive capabilities. Over the last few years, we've developed a pretty strong network around the world of qualified GM additive suppliers."

As he continues to explain, GM does have some key 3D printing technologies and materials that it uses internally. However, when it needs to access a technology it doesn't have for part production, it turns to its external supplier partners.

On the tooling side, Lentine reveals that the supplier partnerships work a bit differently. "Our work with manufacturing tool suppliers is a little less rigorous than it is for suppliers providing end-use vehicle parts. When we launch a new plant or a new area within a plant, we have strategic suppliers that own commodities—the lowers and uppers of the body, the general assembly of components, the paint shop, etc. These strategic suppliers allow us to be very efficient and quick when launching traditional programs."

GM's strategy therefore is to help these partners and bolster their capabilities to better utilize additive manufacturing. "We hold a ton of training sessions," Lentine adds. "We work directly with a lot of our strategic tool suppliers on evaluating parts and tools, we give them access to our sites. The Additive Industrialization Center is a big part of that, because now our partners have a place they can come try and learn about AM before they start investing millions of dollars into the equipment.

General Motors is today using various AM technologies for both part production and tooling applications.
Image: Steve Fecht for General Motors

"We think it's very effective because it allows our GM manufacturing engineers to utilize existing resources and relationships, but it also helps to grow the automotive industry and supply base. A big part of our mission is to help all the automotive tool shops that are supplying GM programs to learn, invest and grow with GM."

Is it a numbers game?

From a media perspective, there is a notable appeal to citing numbers. We can't deny there is a draw towards news items that declare quantitative milestones, like when HP celebrated 3D printing 10 million parts in one year. According to GM, in the automotive space these numbers are perhaps not the point, largely because AM's role will be to complement existing manufacturing processes as a low-volume technology.

"Overall, our view is that additive manufacturing is a low-volume manufacturing technology," Shabbir says. "We want to make it as ubiquitous as casting, stamping and injection molding." Lentine continues: "As we're pushed into new vehicle spaces, like electric vehicles and autonomous vehicles, we're seeing a higher frequency of smaller build units. What this means, is that we're not necessarily looking at it from a pure volume per part perspective, but more of a total parts per year implementation. These numbers will show that our engineering workforce is utilizing AM more regularly. Our efforts right now are to get thousands to hundreds of thousands of parts a year." To clarify, these volumes of parts are not indicative of mass serialization for AM. GM sees the value of AM as a low-volume process, and wants to make a wide variety of parts. "We're not really looking for that one

General Motors' Additive Industrialization Center—part of the GM Tech Center in Warren, Michigan—opened its doors in December 2020. The new facility houses a broad range of AM equipment, including EOS, HP and Stratasys 3D printers.

Image: Steve Fecht for General Motors

killer application that is going to save us a little bit of money on a program," Lentine says. "We're trying to change the culture on how we use 3D printing."

Shifting gears

Overall, the picture of additive manufacturing at GM is an exciting one: the technology is creating new possibilities and helping to usher in a new, more agile era of automotive production. "It's almost a shift in mindset, because it is changing how we've made vehicles for decades and decades," Lentine says. "We're constantly challenged with doing things differently and doing things more efficiently. AM is one of the processes that is enabling this. There are a ton of efforts at General Motors in different advanced manufacturing technologies. AM is just one piece of the puzzle that's enabling us to move into that space and become more agile, bring vehicles to market faster and receive responses from our customers quicker." Evidence of this can be seen with GM's new Hummer EV, which was unveiled this past fall. AM enabled the GM team to speed up the prototyping process for the vehicle. For instance, 17 parts for the vehicle's battery pack were functionally prototyped using additive manufacturing, which saved GM 50% on time and 58% of costs.

"A lot of our electric vehicle products that are coming out have accelerated timelines," Shabbir adds. "Additive is just one part of the equation in terms of all the different advanced technologies that we are looking to implement to help bring these vehicles to market quickly, reliably and safely." ◆

AM is creating new possibilities at GM and ushering in a new era of automotive production.

Image: Steve Fecht for General Motors

SPOTLIGHT

Reviving the past: our favorite 3D printed auto restorations

3D printing in automotive isn't just about the future, it's also about maintaining the past.

Image: Bugatti Automobiles S.A.S.

3D printing in the automotive sector is not just about creating new parts with innovative geometries and pushing vehicle design into the future. In fact, some of our favorite 3D printing automotive projects have looked backwards in time. We are, of course, talking about the increasingly influential role of AM in automotive restoration.

With its propensity for custom, one-off designs, it is really no wonder that 3D printing, and other 3D technologies like scanning, have been eagerly adopted by automotive restoration professionals. The technologies have given them the tools to bring vintage and rare cars back to their former glory, not just in look, but often also in terms of performance. Used to reproduce obsolete components for a vintage model or to replicate car body parts, 3D printing is now an intrinsic part of automotive restoration projects. Below are just a few of our favorite examples from over the years, which showcase how AM can be used to rev up old cars.

ALFA ROMEO TIPO 33/3

KW Heritage, a division of UK-based engineering solutions provider KW Special Projects, utilized 3D printing in an inspiring way to restore an ultra-rare Alfa Romeo Tipo 33/3 sports car.

The 1970s Alfa Romeo Tipo 33/3 that was restored was one of only 12 models ever produced. It was first introduced in 1967 but it became most popular in 1971 when it participated at races in Buenos Aires, Sebring and Brands Hatch. In its restoration of the vintage car, KW Heritage used CAD, 3D scanning and 3D printing to recreate the Tipo's engine cover—a part that had suffered from deterioration and caused ignition problems. "With key components and interfaces scanned, and the part re-designed and prototyped in just a few days, the engine cover shows how quickly the digital remanufacturing process can take for historic and classic vehicles with parts that have become obsolete," said KWSP.

FERRARI 365 GT 2+2

Pittsburgh-based HV3DWorks LLC, a specialist in using 3D printing for automotive restoration and customization, uses the technology (specifically ExOne's metal binder jetting process) to reproduce many obsolete or hard-to-source parts. In one case, HV3DWorks was hired to recreate a worn Weber 40 DFI-6 carburetor for a Ferrari 365 GT 2+2 V-12 engine. Using AM, Vorbach and his team were able to model, prototype, test and print the part in just 12 weeks. The final part was printed from 316 stainless steel with bronze infiltration using ExOne's M-Flex metal binder jetting system. The final printed part was also $1,300 cheaper than the original.

RUSTON HORNSBY MOTOR CAR

In 2018, England-based Siemens Industrial Turbomachinery Ltd infused new life into a 100-year-old Ruston Hornsby motor car with the help of AM. The car was originally released in 1920 by industrial equipment manufacturer Ruston & Hornsby Limited, now part of the Siemens Group, and was known for its solid and well-built structure.

This structure, though solid, came with an incredible weight, which made it very expensive. Priced between £440 and £1,000 (about £18,695 to £42,490 today), the car was much costlier than other, mass-produced models on the market, which weighed significantly less and only cost about £120 to £200. Because of this, Ruston & Hornsby stopped its motor car production in 1925 after only 1,500 cars were sold. Siemens decided to restore two of the original motor cars, which had been stored at its facility in Lincoln. The two car models that underwent restoration were still equipped with many of their core components—both their engines and major parts were still mostly intact—but the restoration teams struggled with finding smaller, ancillary parts and sourcing components which haven't been in production since the 1920s. To add to the challenge,

much of the manufacturing information for the motor cars had been lost. 3D printing played a critical role in the re-engineering of a steering box component, which had suffered damage and did not have any of its original drawings. The broken part was thus 3D scanned and digitally restored before being 3D printed using metal powder sintering. The impressive feat was achieved in just five days (about 2.5 years faster than if they had used an external machine shop for the task).

THE BUGATTI BABY

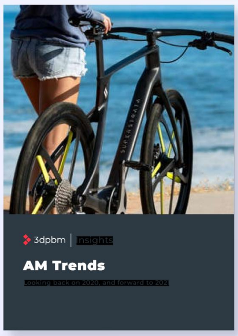
In 2019, French carmaker Bugatti charmed the automotive industry by reproducing the vintage Bugatti Baby from 1926. The child-sized car, a half-scale model of the Bugatti Type 35 race car, was originally created as a birthday gift for Ettore Bugatti's four-year-old son.

At the time, the mini racing car was so popular that the car marker put it into limited production, creating about 500 units. Today, the Bugatti Baby is highly sought after by car collectors. This legacy is what inspired today's Bugatti engineers to recreate the small car using 3D printing. A 3D printed model of the Bugatti Baby II was unveiled in 2019 at Bugatti's 110th anniversary. Like the original run, Bugatti plans to release 500 models of the resurrected car. (We should note that the Bugatti Baby II is actually slightly larger than the original: at 3/4 scale, adults can use it too.)

Bugatti revealed that it is using a combination of old and new technologies in the manufacturing process, including 3D scanning and printing. The car's design is actually based on a precise digital scan of an original Type 35 race car, which was built for the 1924 French Grand Prix in Lyon. ◆

Siemens restored a 100-year-old Ruston Hornsby motorcar using this 3D printed steering box.
Image: Siemens

Recent Editions



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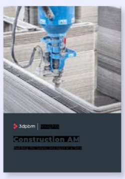

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In this eBook, we not only analyze the current state of metal AM for industrial applications, but also look at where the technology, in all its iterations, is headed and what trends to watch out for.

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MAPPING

How major automakers use AM for production today

An overview of the latest progress made by each major automaker group and some of the key activities

Image: Steve Fecht for GM

BMW GROUP

German company BMW, which owns the brands MINI and Rolls-Royce, has been a major adopter of AM since 2016. At the BMW Plant in Landshut, metal parts are currently made by laser beam melting and the company operates an Additive Manufacturing Campus in Oberschleissheim, just north of Munich. Partners for SLS and SLA parts include 3D Systems' On Demand Advanced AM Center near Turin, Italy. BMW i Ventures has also invested in several AM companies, including Carbon, Desktop Metal and Xometry.

BMW was the first carmaker to 3D print a production run of several thousand metal parts: a 3D printed fixture for the soft top of the BMW i8 Roadster, printed using aluminum PBF. In 2018, BMW announced it had printed over a million parts in the past 10 years. More than 200,000 of those were in 2018, which was over 42% more than in 2017.

Unfortunately, MINI recently discontinued its MINI Yours Customized program, which used polymer PBF technology to allow customers to design and print certain customized components themselves. AM partners on the program included HP, Carbon and EOS.

Luxury brand Rolls-Royce, meanwhile, has used 3D printed parts on a number of recent vehicles. A few years back, the brand revealed it had already produced over 10,000 parts using AM for its Phantom models. As recently as a few months ago, Rolls-Royce revealed it used AM to expand the body of the new Rolls-Royce Ghost Extended without sacrificing internal comfort. Utilizing generative design and 3D printing technologies allows the company to create topology-optimized solutions that significantly improve form and function. Granted, Rolls-Royce's numbers are not comparable to those of mass-produced cars but this is nonetheless a major step in the direction of serially 3D printed automotive parts.

DAIMLER

Daimler, the German automotive corporation that owns Mercedes-Benz, Smart and other brands, uses AM for many production parts. Since 2017, Daimler has worked with EOS (and other partners) on the NextGenAM project, developing a workflow for the industrialization of metal PBF technology for large-scale serial automotive manufacturing. The project, which came to its conclusion in 2019, is already being utilized for the production of truck parts, and its potential is being evaluated for the production of car and electric car parts.

In its commercial vehicles segment, Daimler has fully integrated AM into development and series production. The first replacement parts for Mercedes-Benz Trucks are brackets for truck diesel engines, while 3D printed aluminum replacement parts for Daimler Buses are being examined at the company's Centre of Competence for 3D printing. Other Daimler companies are currently working on AM for spare parts and the digitization of part inventory.

Daimler Buses is also using polymer SLS technology to produce spare parts of the buses' interiors in the Mercedes-Benz and Setra brands. The parts, now produced in a single step, formerly consisted of several and in some cases even moving components. Over 1,000 components (drawers, cover moldings, retaining strips, adapters and surround rings) have reportedly been 3D printed to date. The process proved particularly economical in small series involving batches sizes from 1 to 50 units.

Mercedes is a heavy adopter of AM in motorsports, having used metal 3D printing for several parts of its very successful F1 racecars for nearly a decade. Mercedes-Benz Classic also 3D printed the inside mirror base for the Mercedes-Benz 300 SL Coupé using metal PBF and the spark plug holder from the tool kit is 3D printed using nylon in polymer PBF.

STELLANTIS

Stellantis was formed when the French automaker PSA Group and the Italian-American automaker FCA Group merged in January 2021.

FCA itself was formed by the merger between the Italian Fiat Group, which includes the brands Ferrari, Alfa Romeo, Lancia and Iveco, and the American group Chrysler, which includes Dodge and Jeep. Fiat was Italy's first adopter of 3D printing for prototyping, and FCA's activities are mainly concentrated in the Fiat Design for Additive Program.

Both Jeep and Fiat use HP MJF technology for serial production. Jeep says it uses the technology for an average of four to five print jobs per week, while Fiat reportedly relies on external service providers, such as 3D Systems on Demand, for short SLA and SLS production runs. Both Ferrari and Alfa Romeo use AM for their Formula 1 division, and the latter also used AM to develop the grille of the Alfa Giulia.

More recently, FCA and Fraunhofer IAPT collaborated on a 3D printed wheel carrier with an integrated brake caliper. Using topology optimization, the prototype weighs 36% less than the 12 individual parts of the conventionally manufactured component. This design reduces the assembly required, increases the fatigue strength and should also perform better in terms of noise, vibration and harshness (NVH).

The majority of known AM activity by the PSA Group revolves around its investment in automotive metal AM start-up Divergent3D which uses SLM Solutions PBF technology for part production. Another known application includes one of the first mass customization use cases for metal PBF in a mid-level priced car: the special edition DS3 Dark Side which features titanium 3D printed interior parts. These were 3D printed by French 3D printing service Spartacus3D on EOS systems.

Ford

American carmaker Ford has, more than any other automotive company, conducted extensive practical research in AM industrialization, focusing primarily on polymers and composites. In fact, Ford purchased one of the first 3D printers ever made back in 1988. Most of the company's AM activities take place at its new Advanced Manufacturing Center in Redford, Detroit, where the company operates 30 industrial-grade 3D printers from Stratasys, HP, Carbon, EOS, Desktop Metal and SLM Solutions.

The Redford facility uses Carbon's Digital Light Synthesis technology to produce digitally manufactured, end-use parts, including heating, ventilation and cooling (HVAC) lever arm service parts for the Ford Focus; auxiliary plugs for the Ford F-150 Raptor; and electric parking brake brackets for the Ford Mustang GT500. Elsewhere, Ford's Michigan Assembly Plant utilizes five different 3D printed tools to build the Ranger pickup, helping to reduce time-to-market. In total, Ford operates almost 100 3D printers globally and has 3D printing capabilities in over 30 plants around the world.

After leading a $65 million investment round, Ford became one of the first adopters of Desktop Metal's Studio System and Production System in its Research and Advanced Engineering Organization in Michigan and was one of the first to receive Desktop Metal's intermediate version of its P-50 Production System, the P-1. Ford has also worked with Stratasys and Siemens to serially produce very large parts and composite parts using a multi-axis extrusion system.

Recently, Ford Spain integrated Formlabs' Form 3L into its workflow, allowing engineers to develop prototypes with a high surface quality that resembles the final product. The company also uses SLA to replace broken push buttons from electronic devices using the transparent Clear Resin, in order to be able to see the internal LEDs.

gm

General Motors, the largest US automotive manufacturer which produces Buick, Cadillac, Chevrolet and GMC cars, conducts AM activities in various locations around the world. GM was an early adopter of AM and for over a decade has been using industrial SLA and filament extrusion technologies for parts and tooling. Today, the core of GM's AM research is the Warren Tech Center in Michigan, where over 30,000 prototypes are produced yearly, primarily using FDM in PA carbon fiber.

One of GM's most relevant production application case was conducted in collaboration with Autodesk in 2018, when the two firms produced a generatively designed seat bracket. The steel 3D printed bracket was 40% lighter and 20% stronger than the standard part, and GM used the experiment to predict that up to 100 parts could be suitable for cost-effective AM production.

GM has partnered with GKN on the industrialization of HP Metal Jet technology for part production, and is conducting extensive work on the industrialization of metal PBF processes, including separate collaborations with Italian service provider Beam-IT and GE Additive.

It is also implementing AM to create tools used during automotive production. An example is a tool used to align engine and transmission vehicle identification numbers which can cost less than $3 to make using FDM. If outsourced, the part would have cost the plant $3,000. To date, the company's Lansing Delta Township assembly plant has saved over $300,000 on that single tool.

GM partnered with Michelin on Uptis, a concept for an airless, 3D printed, fully recyclable car tire that is produced using entirely renewable materials. The project demonstrated Michelin's and GM's shared commitment to delivering safer, more sustainable mobility solutions. Read our full interview with GM on page 18.

JAGUAR LAND ROVER

The Jaguar Land Rover Group (JLR) was formed when Indian company Tata Motors bought out Jaguar and Land Rover in 2008.

At both Jaguar and Land Rover, AM had been used to develop prototype parts since the early 1990s. In 1992, the Austin-Rover Group, which owned Land Rover, became an early UK adopter of AM. For years, both companies had been printing 3D parts for prototype use only but that changed, when JLR secured early access to new AM technologies. Notably, it became the first automaker in the UK to use HP's MJF process.

Most of Jaguar Land Rovers's AM activities take place at the Additive Manufacturing Centre, located within the company's Gaydon Centre, in Warwickshire, England. The 4,000,000m² centre houses a design, research and development center, and is one of JLR's principal engineering centers.

Today JLR uses all major polymer AM technologies including Carbon DLS systems. The current portfolio of materials for AM includes nylons, polyurethanes, epoxies and composites, among others. AM is often used by the team for building prototype parts that require a high-quality surface finish as well as relatively low-cost functional parts.

The Jaguar XE SV Project 8 is one of the first vehicles to feature 3D printed parts. The super saloon features multiple parts from the company's Additive Manufacturing Centre, such as the rear parking sensor mounts bonded to the inside of the carbon fiber bumper and racing harness bezels fitted around the track edition seats.

The Additive Manufacturing team has also been creating small runs of obsolete parts for older cars, such as the third-row seat handle for the Land Rover Discovery Series 2.

VOLKSWAGEN

Volkswagen Group, the German automotive company whose subsidiaries include Audi, Lamborghini, Porsche, Bugatti and several other recognizable brands, is one of the largest adopters of AM for production. Volkswagen, the primary VW Group brand, is now looking at HP's high-productivity binder jetting technology for its mass-produced vehicles. Most of Volkswagen's additive manufacturing activities happen at the automaker's state-of-the-art 3D Printing Center in Wolfsburg.

The group relies on this center to test and learn about AM technologies, while also conducting some tooling and final part production. Production of larger batches is generally carried out through partnerships with external AM services. In late 2018, an Additive Industries MetalFab 1 system was installed at the site to 3D print advanced tooling and spare parts, and in late 2020, Volkswagen purchased two Stratasys J850 printers to enhance its ultra-realistic prototypes capabilities for both interior and exterior applications.

Electric vehicles are also a big driver for new manufacturing tech at VW: when developing the I.D. R Pikes Peak electric racing car, Volkswagen engineers used a model for which a large number of individual parts had been produced using 3D printing. These parts have also been used in test drives and even in finished race cars—in the form of small components such as cable mounts and switches.

AM is regularly used by some of VW's luxury brands:

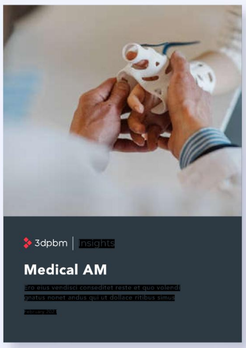
Audi engineers at the 3D printing center in Ingolstadt, Germany are working on spare-part and serial part production. Replacement parts that are rarely needed, such as water connecting pipes for the W12 engine, have been produced with 3D printing using metal PBF supplied by SLM Solutions. Projects involve using SLM Solutions AM technology to integrate additional functions such as cooling or current, along with weight reduction. Audi first applied 3D printing to equipment and prototypes and has deployed the technology in its motorsports division. Along with inserts for die casting molds and hot working segments, the company can positively influence the process of series production by conformal cooling—thus producing parts and vehicle components more cost-effectively.

Porsche's research and production activities with AM are concentrated in the Weissach Development Center. Porsche invested in Markforged in 2017 and uses its continuous fiber composite and bound metal FDM technologies primarily for toolmaking. The company also works with DMG Mori on the production of tools and metal final parts via DED processes. In 2020, the company 3D printed pistons for the high-performance engine in the 911 GT2 RS. Manufactured in collaboration with partners Mahle and Trumpf, the 3D printed pistons are 10% lighter than the forged series production pistons and integrate a closed cooling duct in their crown. More recently, the carmaker successfully 3D printed a complete E-drive housing as a proof of concept with the SLM Solutions' NXG XII 600.

Lamborghini is a long-time user of Stratasys FDM and PolyJet technologies for prototyping and tooling. In 2019, Lamborghini partnered with Carbon to leverage their DLS technology, initially used to produce end-use components, including a textured fuel cap and clip for an air duct, for Lamborghini's Urus SUV. But Lamborghini has since used Carbon printers to produce air vents on the Sián FKP37, a vehicle designed to offer a wide range of user customizations. The new Lamborghini Huracán STO features a 3D printed key used to regulate the supercar's comprehensive aerodynamic solutions.

Bugatti is another Volkswagen Group brand that uses AM extensively in its cars. Ever since it developed a groundbreaking fully 3D printed titanium brake caliper, Bugatti has been increasingly creating topology-optimized parts with AM. We've taken a closer look at the company on page 36 of this eBook. ◆

Upcoming Editions



FEBRUARY 2021 **Medical AM**

An in depth look at the latest developments in the medical additive manufacturing sphere, with a special focus on everything bioprinting.

- Analysis
- Interviews
- Case Studies
- Mapping

2021 Calendar

JAN	Automotive	JUL	Maritime
FEB	Medical	AUG	Post-Processing
MAR	Consumer	SEP	AM Services
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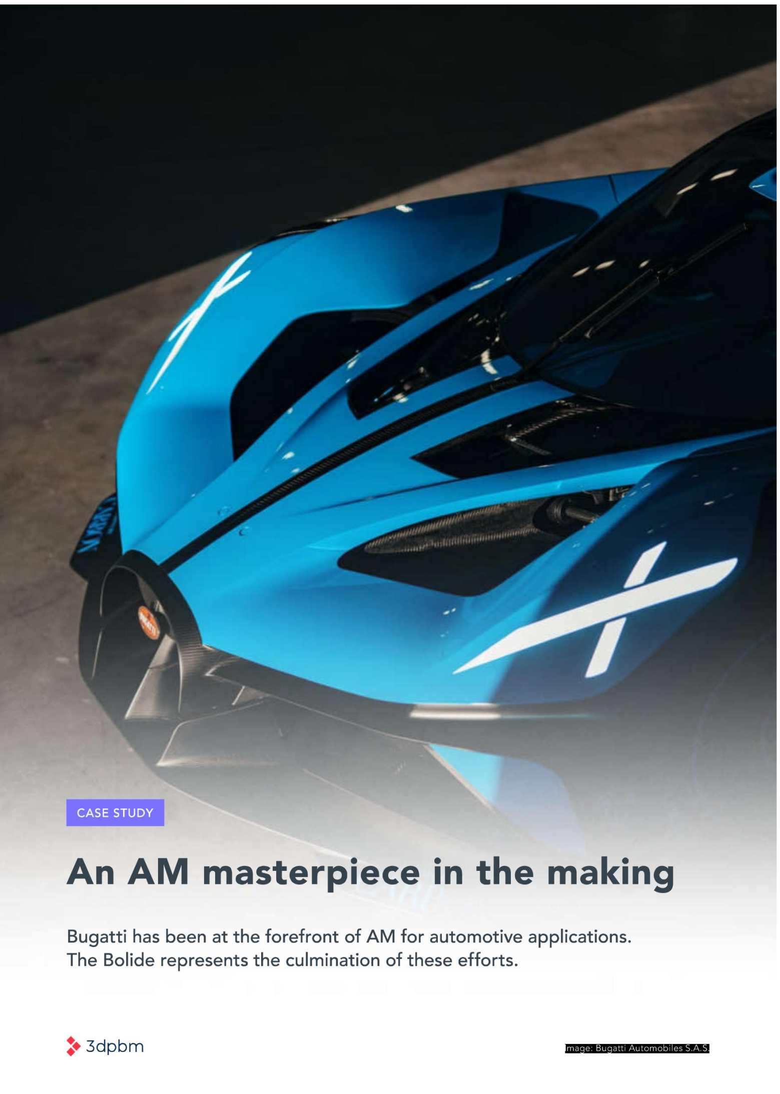


CASE STUDY

An AM masterpiece in the making

Bugatti has been at the forefront of AM for automotive applications. The Bolide represents the culmination of these efforts.

Image: Bugatti Automobiles S.A.S.

The Bolide is arguably Bugatti's best and most powerful product to date. It is also the most 3D printed one. Ever since the development of a groundbreaking fully 3D printed titanium brake caliper, Bugatti has been increasingly applying principles from the field of bionics to give printed components a bone-like structure: featuring thin walls, a hollow interior and fine branching.

The French luxury car manufacturer now routinely uses AM technology to enhance components with complex structures: imagine ultra-lightweight components that are as strong as a reinforced concrete column. For example, additive manufacturing makes it possible for a 3D printed pushrod—a pressure-loaded coupling rod in the chassis area—that weighs just 100 grams, to transmit forces of up to 3.5 tonnes. The hollow titanium structure with an internal supporting arch gives this part incredible strength and is another engineering breakthrough demonstrated by Bugatti's expertise.

Bugatti began working with SLM Solutions in 2014 to redesign and optimize vehicle components using additive manufacturing. Since then, it has effectively demonstrated how metal 3D printing can accelerate industrial development in the automotive industry.

The first part produced through the SLM Solutions and Bugatti collaboration was a bionically optimized front axle differential housing part. This part was manufactured by Audi AG at its facilities in Ingolstadt and Györ on SLM280 3D printers. This enabled the partners to compare the influencing factors of printing the same part at two different locations. Over the years, Bugatti has leveraged SLM Solutions' metal AM technology to produce a growing range of functional parts for its sports cars, including the brake caliper that is widely recognized as the largest functional component to be 3D printed from titanium. The impressive part, produced from Ti6Al4V using an SLM500 printer, was realized in partnership with Fraunhofer IAPT and Bionic Production AG.

Bugatti also redesigned an active spoiler bracket for the Chiron (again on an SLM500 3D printer). Partnering with Siemens to optimize the bracket, this initiative had a number of production goals: to achieve a more lightweight part that was both more stylish and more functional. Utilizing 3D printed titanium, with a tensile strength of 1,250 MPa and a material density of over 99.7%, resulted in the weight of the part being reduced by 5.4kg—a weight reduction of 53%.

Produced with Fraunhofer IAPT, the spoiler bracket can be adjusted in height and angle for tailored aerodynamics and enables Bugatti's 1,500 hp vehicle to reach speeds of 400 km/h (249 mph) in just 32.6 seconds and bring it back to a stop in 9 seconds.

3D printing has also been leveraged to reinvent a small motor bracket with integrated water cooling for Bugatti's supercars. The part acts as an active heat shield, reducing transferred heat from the motor significantly. The innovative component, printed from AlSi10Mg on an SLM280 Twin, has been installed in all series vehicles since the release of the first Bugatti Chiron. In 2018, SLM Solutions again emphasized its collaboration with the Volkswagen subsidiary by showcasing eight Bugatti W16 cylinder head covers (each measuring 285mm wide, 735mm tall and 65mm thick) which were produced in a single print job using its SLM800.

In 2019, APWORKS, the Airbus-owned industrial 3D printing specialist, revealed that it provided 3D printed exhaust finishers for the Bugatti Chiron, a hypercar that broke a world record when it reached 300 miles per hour (482.80 km/h) in August. The titanium exhaust finishers, part of the car's tail section, serve to push the exhaust emissions further from the rear end of the car to reduce turbulence and improve steering behavior at high speeds.

This brings us to now and the latest Bugatti masterpiece, the Bolide, which you can admire in all its unique beauty throughout the following pages.

REAR WING BRACKET

The downforce of the rear wing, which can reach up to 1.8 tonnes at 320 km/h, is introduced via the Bolide's central carbon fin into the upper structural matrix, which forms the upper termination of the high-strength stainless steel rear frame. Inside this central fin, there is a laminated and 3D printed titanium component for connecting the fin to the wing, for which the angle can be adjusted by means of a coupling rod. Despite its rigidity, it weighs just 325 grams.

STEERING COLUMN BRACKET

The engineers also used titanium to 3D print the bracket for mounting the steering column, which features integrated dashboard support, the support collar for the steering column through feed and the two air vents in the vehicle interior. All components are designed as lightweight hollow structures, with a uniform wall thickness of 0.5 millimeters.

SCREWS AND FASTENERS

All the screw and fastening elements of the Bolide are made completely out of titanium. In addition, hollow, thin-walled functional components made of an aerospace titanium alloy are used in many places. These, of course, are 3D printed and feature extremely thin wall thicknesses of up to 0.5 millimeters. However, they are still very stable with a tensile strength of 1,250 newtons per square millimeter.

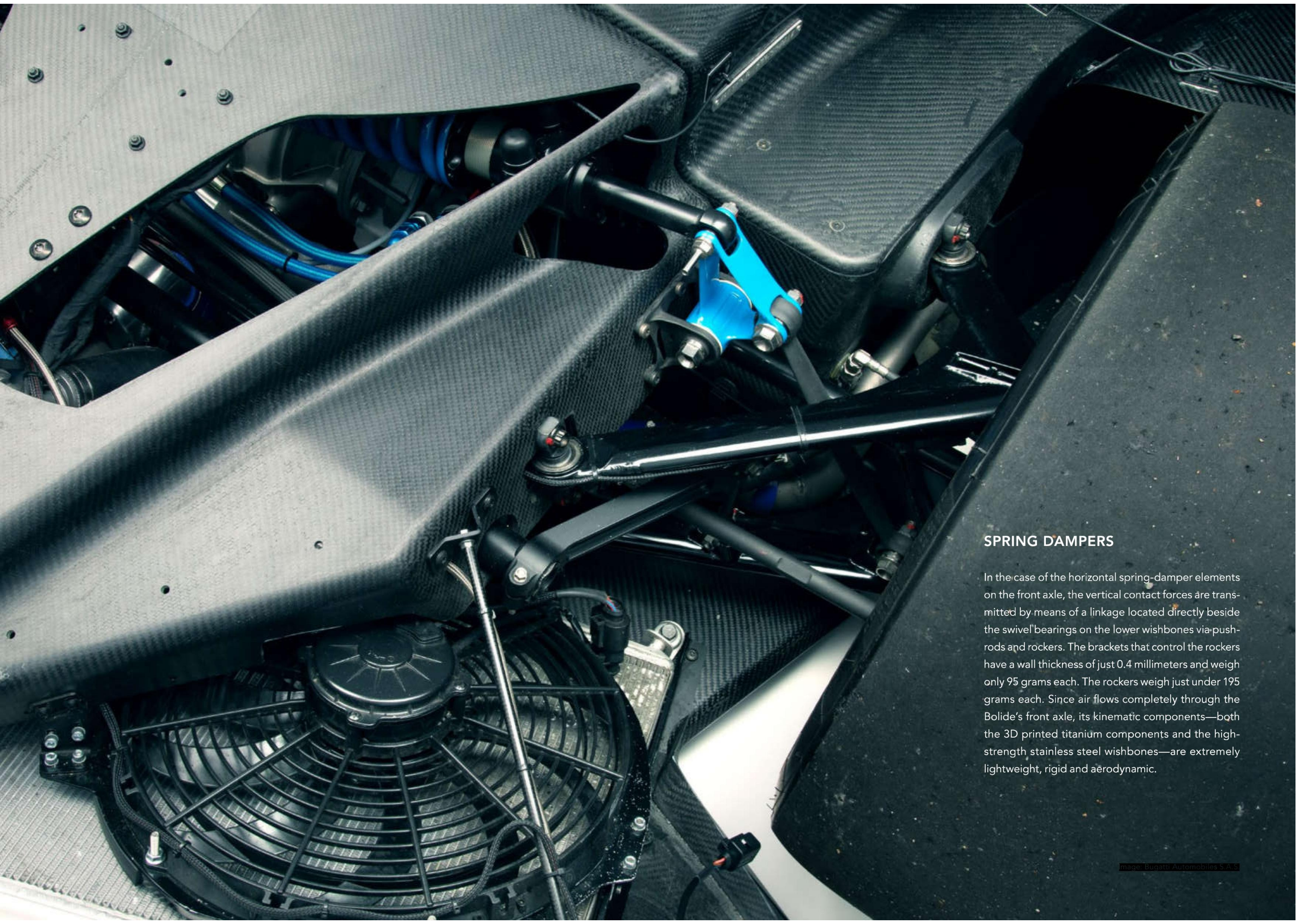
FRONT WING BRACKET

Highly complex 3D printed components are also used in hidden places. A mounting bracket for the front wing, on which the front wing can be mounted at three different heights, is printed in titanium with a hollow interior and a wall thickness of 0.7 millimeters. The mounting bracket can withstand an aerodynamic downforce of up to 800 kilograms with a weight of just 600 grams.

PUSHRODS

The engineers are particularly proud of the 3D printed titanium pushrod—a pressure-loaded coupling rod in the chassis area weighing only 100 grams. The part transfers a force into the rockers which, depending on the driving maneuver, is equivalent to a weight of up to 3.5 tonnes. For the first time, Bugatti varied the wall thickness of the thin-walled, hollow rods meaning that they are optimally adapted to localised stress.

Image: Bugatti Automobiles S.A.S.



SPRING DAMPERS

In the case of the horizontal spring-damper elements on the front axle, the vertical contact forces are transmitted by means of a linkage located directly beside the swivel bearings on the lower wishbones via pushrods and rockers. The brackets that control the rockers have a wall thickness of just 0.4 millimeters and weigh only 95 grams each. The rockers weigh just under 195 grams each. Since air flows completely through the Bolide's front axle, its kinematic components—both the 3D printed titanium components and the high-strength stainless steel wishbones—are extremely lightweight, rigid and aerodynamic.

TAILPIPE

In the tailpipe trim cover, a hybrid component made of 3D printed titanium and ceramic, Bugatti reduced the weight by around half compared to the already weight-optimized titanium tailpipe trim covers well known from series production. The component, which measures more than 280 millimeters in length and has a consistent wall thickness of just 0.5 millimeters, therefore weighs less than 750 grams.

Image: Bugatti Automobiles S.A.S.

BRAKE CALIPERS

Although not specifically for the Bolide, Bugatti previously designed and 3D printed a titanium brake caliper—the world's largest functional component produced from titanium using 3D printing processes. With this world debut, Bugatti underlined its lighthouse function for 3D printing within the Volkswagen Group and its role as an innovation driver in the international automotive industry. Vehicle trials for the use of the 3D titanium brake caliper in series production are underway. ◆

Image: Jaguar Land Rover

MAPPING

AM companies to watch in automotive

Here are some of the most active 3D printing players in the automotive game

3D SYSTEMS

3D Systems has had automotive companies as some of its primary customers since the very beginning, with Ford reportedly acquiring the third 3D printer ever made and automotive companies in both North America and Europe as some of its very first customers. 3D Systems' stereolithography technology has been used—and continues to be used—for extensive prototyping of small and even very large automotive parts. 3D Systems caters to the automotive industry through its network of 3D Systems On Demand Services, mainly offering polymer parts produced by SLA as well as SLS technology. Confirmed large automotive clients include BMW, FCA, Opel and PSA. 3D Systems also works closely with the Sauber-Alfa Romeo team in Formula 1. Despite this long running activity in the automotive space, 3D Systems announced in August 2020 a corporate reorganization that will prioritize the healthcare and industrial markets.

hp

HP entered the market specifically to target larger batch production applications, first with its MJF polymer PBF AM technology and then with its MetalJet metal binder jetting process. Today a large number of automotive companies have adopted HP's systems, both for internal production and through external AM service suppliers. HP has rapidly developed the global distribution market. Initially the biggest limit was the availability of one main material, nylon 12, which, however, is fit for a large number of basic automotive applications. Now the company has introduced both PP (polypropylene) and TPU, further extending the range of possible applications. In metal, HP has been working with GKN and the Volkswagen Group to industrialize its technology. Other known automotive partners of HP 3D Printing include FCA (Jeep), BMW and General Motors, primarily for its polymer technology.

Carbon

Carbon's high-throughput layerless photopolymerization technology is able to use key automotive materials, such as epoxy, to produce final parts. The company has been working on production of final parts with both Ford (with several M2 and L1 systems now installed in its AM center) and Lamborghini. We expect Carbon will become a primary player in automotive AM. Carbon is making some of the most significant efforts in automating a workflow around photopolymerization technology. Much like HP, the company's high productivity technology requires improved and accelerated part handling to deliver on the promise of production at scale.

eos

EOS's industry leading SLS technology is used by automakers as well as AM services and automotive parts suppliers around the world to produce prototypes and tools as well as final and replacement parts. EOS offers advanced consultancy through its Additive Minds service to help companies identify parts that would benefit from on-demand production via its AM technologies. The German company has been investing significantly to advance industrialization of its DMLS (laser metal powder bed fusion) technology for the automotive segment and specifically for key automotive materials such as aluminum. In many of these operations, EOS has found in the Daimler Benz Group a key and preferred partner. Other confirmed clients looking to implement EOS technologies for part production include GM and FCA.

SIEMENS

As a key provider of PLM Software solutions to the automotive industry—including CAD, CAE, CAM, MES, digital twin and digital warehouse software—Siemens is playing an increasingly relevant role in AM adoption within this segment. Siemens' software solutions are built on open standards to allow for seamless integration across disciplines. This gives automakers the flexibility to digitalize product development, enabling everyone to access a car's digital twin. More directly, Siemens Materials Solutions in the UK has been a key test bed for EOS' NextGenAM automated AM factory concept and already produces several thousands of metal 3D printed automotive parts yearly.

Additive Industries

Additive Industries was also another first promoter of the "Lights Out Factory." The Dutch company is achieving this vision via its MetalFAB1 system, which includes several stations for powder handling, build, thermal treatment and part/support removal within a single, modular, system, which can be customized in accordance with the user's requirements. Additive Industry systems have been installed at GKN and Volkswagen. The company recently partnered with SMS, a specialist group of companies for steel and nonferrous metals industry, to further evolve their automated factory vision to integrate powder production and heat treatment—with a special eye on the automotive industry.

GKN

GKN is a key supplier of automotive parts to many large automakers, including EV powertrain systems. The company is also a major adopter of AM for aerospace and an early adopter of AM for the automotive segment, not to mention a key producer of metal AM powders. As early as 2016, GKN Sinter Metals integrated Additive Industries' MetalFab1 system to enable series production of precision parts for engines and transmissions and started production at its plant in Radevormwald, Germany. More recently, the company has become a key automotive partner of HP, providing automotive parts using HP's new metal jet technology to automotive industry leaders such as VW. GKN also acquired AM service provider Forecast 3D, which specializes in series production using HP's MJF polymer AM technology. GKN is also one of 12 partners participating in the IDAM project, which seeks to address and overcome limitations of LPBF, which hinder its adoption for serial production in industries like automotive. The IDAM project is specifically building two pilot lines—one of which is at BMW's Munich facility—for fully automated, industrial AM.

SLM SOLUTIONS

SLM Solutions has built up a leadership in the automotive segment over the years. According to our research, SLM Solutions systems remain, today, the most widely used by large automakers. The high-profile work done with the Divergent and PSA teams on 3D printed automotive car frames remains one of the most advanced and relevant applications to date. Other high-profile examples consist of collaborations with Audi and Bugatti. Most recently, the company's 12-laser NXG XII 600 PBF system was used in a proof of concept with Porsche to print a complete E-drive housing.

Image: SLM Solutions Group AG

stratasys

For current polymer additive manufacturing industry leader Stratasys, the automotive segment has always represented a primary field of application, mainly for advanced prototyping, using both its primary technologies: FDM and PolyJet. For instance, Volkswagen recently purchased two J850 3D printers for producing ultra-realistic prototypes for new vehicle design. Stratasys has also begun looking more and more toward tooling and production. One key application is the use of FDM technology for lay-up and sacrificial tooling. Another is the use of high temperature PolyJet materials to produce injection molds for small runs using end-use plastics. In terms of direct part production, Stratasys is working closely with Ford and Siemens on robotic composite CFR extrusion systems. Stratasys' Fortus 380mc CFE is also targeted toward automotive applications for tools and final parts (NASCAR Team Penske was a first adopter). Stratasys also works closely with the McLaren team in Formula 1 racing.

AddUp

If SLM Solutions doesn't retain its leadership in the automotive segment, one of the companies that could challenge it is AddUp. This relatively new entry in the AM industry is the result of a collaboration between Michelin and Fives, a large French machine tool system OEM. One of the first results of this partnership is the development of a fully automated workflow using multiple AddUp FormUp 350 SLM systems to produce custom aluminum molds for the mass production of Michelin tires. The company—which also offers DED 3D printing systems after acquiring French company BeAM—is poised to become a key player in the automotive industry, especially through the support of the Michelin group.

Desktop Metal

Desktop Metal is HP's first competitor for the future of metal binder jetting in the automotive segment and its technology was developed specifically to address the requirements of high productivity industries such as automotive. The company also offers a technology for bound metal deposition that is already widely available and is rapidly building a significant installation base. Automotive giant Ford has implemented Desktop Metal's Studio System and, more recently, its P-1 Production System, based on metal binder jetting technology. Ford is using this technology to advance alloy implementation and to discover new automotive applications for metal binder jetting. Desktop Metal also has the BMW Group among its main funders.

formlabs

Best known for its SLA 3D printing technology, Massachusetts-based Formlabs very recently expanded its stake in the automotive sector. Specifically, in early 2021, Ford Spain became the first car manufacturer in Europe to implement Formlabs' Form 3L 3D printer. Ford Body and Assembly in Valencia is using the technology to produce plastic caps used in vacuum tests to check for any engine leakages. Formlabs' technology is also being used to prototype new tools and parts. For example, Ford has used SLA technology to replace broken push buttons from electronic devices. ◆

Let's Partner

In 2021, our eBook series will look at 12 key AM topics. In our monthly publications, we'll cover important technical advancements, market trends and industry announcements relevant to each area.

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We look forward to working with you in 2021!

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