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Case Study for the use of Additive Manufacturing in the Automotive Industry

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Executive Summary

Additive Manufacturing (AM) is the process of constructing a 3-dimensional object directly from software. It enables users to quickly produce any complex or customized shape and has transformed the way products are designed and manufactured. Over the past few years, significant progress has been made in additive manufacturing for numerous applications over various industrial segments.

For this project, I was hired by a management consulting firm to evaluate the application of Additive Manufacturing in the Automotive industry. In this case study, I present a specific example of how Additive Manufacturing is being used today, analyze the viability of the application, and offer recommendations for future direction.

Additive Manufacturing is revolutionizing the traditional manufacturing and supply chain workflows, and the leaps and bounds are causing many automotive manufacturers to start experimenting with the technology. While manufacturers have already been making car parts using the technology for a few years, no manufacturer has released a fully 3D printed car yet.

One automaker who is leading the industry in its use of this breakthrough technology is Bugatti, who first introduced 3D printed parts in 2018, in their Divo supercar. In 2020, Bugatti released the Chiron Pur Sport, which was made with several 3D printed components. More recently in 2021, they announced extensive use of additive manufacturing in their new concept car, the Bugatti Bolide.

While the Bolide is an impressive hyper-car that boasts unprecedented performance thanks to its lightweight parts (53% weight reduction) and optimized structure (0.67 kg/PS weight-to-power ratio), I believe we can achieve even better product specifications when the industry as a whole adopts Additive Manufacturing into their design workflow. This would push even more components to be reimagined, 3D printing materials to be improved, and production times to be shortened.

Problem Description

Large automotive companies have been using additive manufacturing technologies to rapidly produce prototype parts for over three decades. Today however, automobile manufacturers are using the technology to reduce the weight of many structural components to make their vehicles more efficient and produce less pollution.

The limit in weight savings is no longer due to constraints in the manufacturing processes, but instead it is caused by constraints in design methods.

By deploying optimization techniques, Bugatti was able to maintain the weight to strength ratios of its components while reducing the weight of its car by designing thinner walls, hollow interiors and changing the design of the structure.

- The Bolide weighs just 1,240 kilograms and has a weight-to-power ratio of 0.67 kg/PS.

Photo 1 - 3D-printed titanium mounting brackets

- The front wing is mounted by a 3D-printed titanium bracket which weighs just 600g, has a hollow interior and wall thickness of 0.7mm, and can handle 800kg of downforce. The mounting bracket is designed so that the front wing can be mounted at three different heights, which offers greater customization options.

- The rear wing is held in place by a 3D-printed titanium component that only weighs 325 grams despite being able to withstand up to 1.8 tons of downforce.

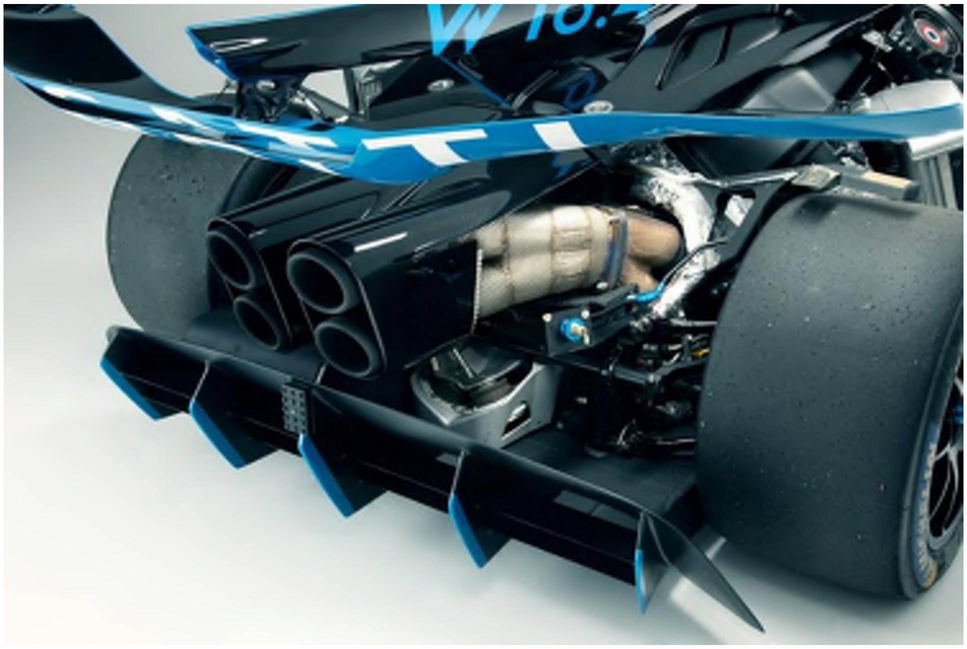

Photo 2 - 3D-printed titanium component that holds the rear wing

- The Bolide has an innovative 3D printed titanium brake caliper which weighs only 6.4 lbs (versus the standard aluminum calipers which weigh 10.8 lbs). The car also has a 3D printed titanium exhaust which has thin walls and is very resistant to temperature changes.

Photo 3 - 3D-printed titanium brake caliper and exhaust

- The car has 3D-printed titanium springs, stainless steel wishbones and titanium rocker brackets that only weigh 95 grams each and have a tensile strength of 1,250 N/mm2. This allows the parts to be extremely lightweight, rigid and aerodynamically optimized.

- The titanium coupling pushrod has a hollow structure and is capable of transferring forces of up to 3.5 tons. The pushrod is optimized for stress and weight, and has thin walls of varying thickness across its length - thick towards the center and thin towards the edges.


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Photo 4 - 3D-printed pushrods

Instead of engineers using traditional CAD software to design and manufacture a part to test it, the new workflow allows them to validate the design of a component and simulate the manufacturing process using software before a product is physically prototyped.

- In the case of the Bolide, the number of design iterations for optimizing weight and rigidity were reduced because simulation techniques were deployed. The 3D-printed titanium bracket has a tensile strength of 1,250 MPa, a material density of 99.7% and a weight reduction of 53%.

- During simulation, it was shown that the Bolide has a top speed of over 310 mph (500 km/h) and is still able to maintain excellent handling and agility.

Bugatti engineers were also able to leverage Additive Manufacturing techniques to streamline multiple components into a single part.

- To reduce heat transfer from the motor, a small motor bracket with integrated water cooling was added to the car. This example of Conformal Cooling also allowed the components to be cooled faster.

- Mountings, segmented parts, screws and fasteners were combined into a single part to reduce number of connection points.

- To cool the brakes, the Bolide was designed with wheel-mounted radial compressors.

Photo 5 - 3D-printed wheel-mounted radial compressors

Design for Additive Manufacturing is also a key technique that was used in the design of the Bolide. It ensures that engineers can account for the type of manufacturing process used in the part designs.

- This paved the way for engineers to design new “hybrid” materials and alloys to increase strength and improve temperature resistance for industrial applications. Bugatti introduced ceramic elements into the 3D printed titanium housing of components because ceramic transfers heat less effectively compared to titanium. They also made the outer skin from carbon fiber so that it would not damage at high exhaust gas temperatures.

- The car has multiple components which were made with multi-material fabrication. The tailpipe trim cover was made of a hybrid titanium and ceramic material that weighs less than 750g - reduced around 50% when compared to the model with only one material.

Additive Manufacturing Approaches

Additive Manufacturing allows us to produce new, unique designs for components that are difficult or impossible to manufacture using traditional production methods. Due to the growing number of technologies in the metal printing space, users can tailor the technique to what they want to make, instead of adapting the part to fit the traditional casting, machining and forging process.

The additive manufacturing technique used for this application was Selective Laser Melting (SLM). This process is used for making parts with metals (in this case titanium) and works by fully melting the metal material into a solid.

Selective Laser Melting is a type of Powder Bed Fusion where a laser beam selectively melts layers of powdered metal onto previous layers. This output is a complex metal part which has “grown” out of a bed of powdered metal. This implementation of Selective Laser Melting allows engineers to design parts that are lightweight, complex, stylish and functional.

Advantages:

- Very strong parts with good mechanical properties
- High precision parts
- Allows for a wide range of metal materials
- Unused powder can be reused
- Can work with very fine powders
- Flexible processing parameters
- Growing selection of materials
- Easier process monitoring

Disadvantage:

- Expensive machine and materials
- Uses metal powder which, due to tremendous surface area, is very flammable
- Requires supports due to metal warping
- Requires extremely high temperatures
- High residual stresses in the printed part
- Requires post-process anneal
- Requires part to be cut from the build plate
- Printers are large and not portable

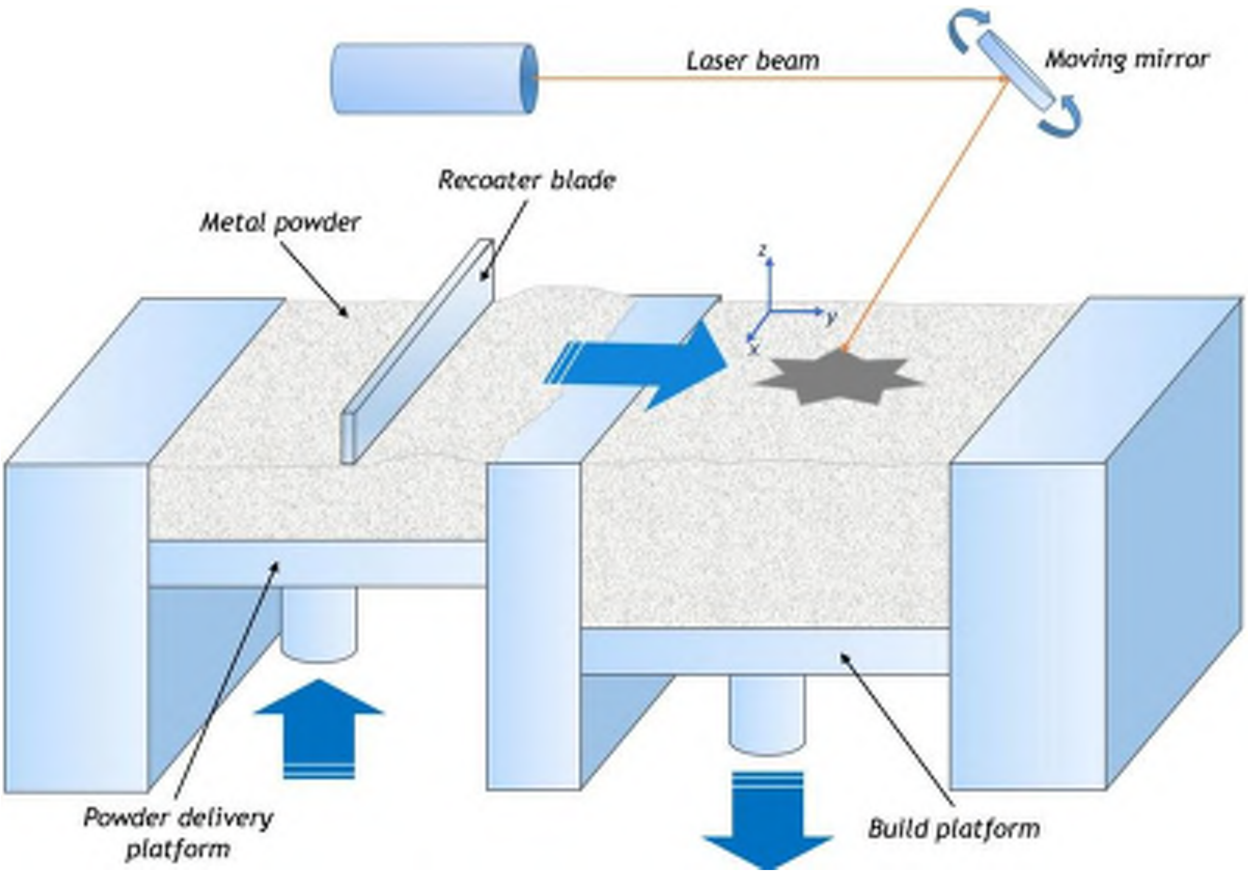

Photo 6 - Selective Laser Melting process

Analysis

Complexity:
Topology Optimization and Generative Design principles can generate hundreds of different design options in a relatively short amount of time. However, it does not cost more to manufacture more complex things and the Bolide includes several parts which are very complex.

Variety:
Parts can be customized for any application, but the manufacturing cost remains the same. This also allows engineers to make part versions - like software updates - and not have to worry about changes in the manufacturing process since it will remain the same. Bugatti can reuse the same Additive Manufacturing machine across multiple vehicle programs and design generations.

Assembly:
Pre-assembled parts can be printed, thus requiring less human labor to assemble parts and fewer connection points (so fewer points of failures). As we can see, Bolide has several components which were combined into a single part for manufacturing.

Lead Time:
Parts can be built in a matter of hours since manufacturers do not have to build a special tool first, they can go straight to building the part. The time from when a part is designed to when you can physically hold it, has decreased significantly. Bugatti engineers used this to rapidly prototype multiple parts and reduce the number of design iterations.

Constraints:
All types of components can be made, no matter how complex the shape. The Bolide has many parts of all shapes and sizes, and they can all be manufactured using Additive Manufacturing.

Skill:
Selective Laser Melting technologies do not require much skill since the machine is doing all the constructing once the user enters the parameters. Bugatti is able to hire from a much larger pool of applicants to make their products.

Portability:
Generally, 3D Printers are more portable and can be used in a wide variety of locations. In this case, Selective Laser Melting machines are not as compact, but they are smaller than other traditional metal manufacturing machines.

Waste:
Additive manufacturing, by definition, builds objects by adding material layer by layer. This results in less waste when compared to traditional metal manufacturing techniques, which use subtractive processes (removing material to create parts).

Material:
Materials can be mixed and matched, provided they have similar material properties. The Bolide has used a hybrid of ceramic and titanium in a few of their components to keep the strength, but also reduce its weight.

Repeatability:
Digital Manufacturing allows existing parts to be scanned, optimized and printed. Parts can be easily duplicated with the same level of precision with each print, allowing buyers to replace components with spare parts easily. It would also allow manufacturers to rapidly revise and alter parts through the design process.

Recommendations for Future Direction

To compete on a global scale, manufacturers are pushed to save cost at every step of the way. Today, Additive Manufacturing is revolutionizing the Automotive Industry by changing the way parts are designed. Not only does the technology save time and money, but also improves part performance and reduces design and production constraints. Additive Manufacturing has the potential to enhance global supply chain capabilities across all industries and help cut global warming emissions.

Additive Manufacturing technology is progressing at an exponential rate, and metal printing is becoming more mainstream every day. As more car parts start being developed with this technology, it is clear that a future where a commercially available fully 3D printed vehicle is nearing quickly. To get ahead, companies will need to assess the current state of Additive Manufacturing research and develop standards or guidance documents to meet the needs of the industries where these parts are utilized.

My recommendation to continue pushing the automotive industry forward is to facilitate a collective effort between all stakeholders in the manufacturing process to use Digital Manufacturing technologies. As a professional with the technical ability of optimization and simulation engineers, and expertise in the 3D printing process, I hope to lead this effort to integrate Additive Manufacturing throughout the ecosystem.

Other Additive Manufacturing Processes:

Metal 3D Printing is a field that is evolving rapidly, companies must choose which technique to deploy to have an edge over their competitors. In this case study, we saw how Bugatti used Selective Laser Melting (a type of Powder Bed Fusion) to manufacture parts for their cars.

While this method produced very accurate and strong parts, it also has its own set of disadvantages. Car manufacturers can look at other Metal Manufacturing technologies each with their own benefits and shortcomings, depending on the design considerations that are important to their parts. Some examples of other metal AM techniques are:

- Electron Beam Melting (EBM)
    - Faster than SLM, vacuum based process, higher density, less residual stress, but more expensive and complex
- Powder Directed Energy Deposition (DED) - laser or electron beam
    - Faster and cheaper, useful for hybrid manufacturing, good mechanical properties, but lower resolution and requires post processing for surface finish
- Wire DED
    - Fastest among the rest, cheaper, but low resolution

- Binder Jetting
  - Faster, low cost, higher precision parts, uses a binding material which has to be dissolved, low material density, can lead to porosity
- Metal Filament Fused Deposition Modeling (Extrusion)
  - Higher cost, low material denisty
- Cold Spray
  - Wider range on materials, low material density, cheaper

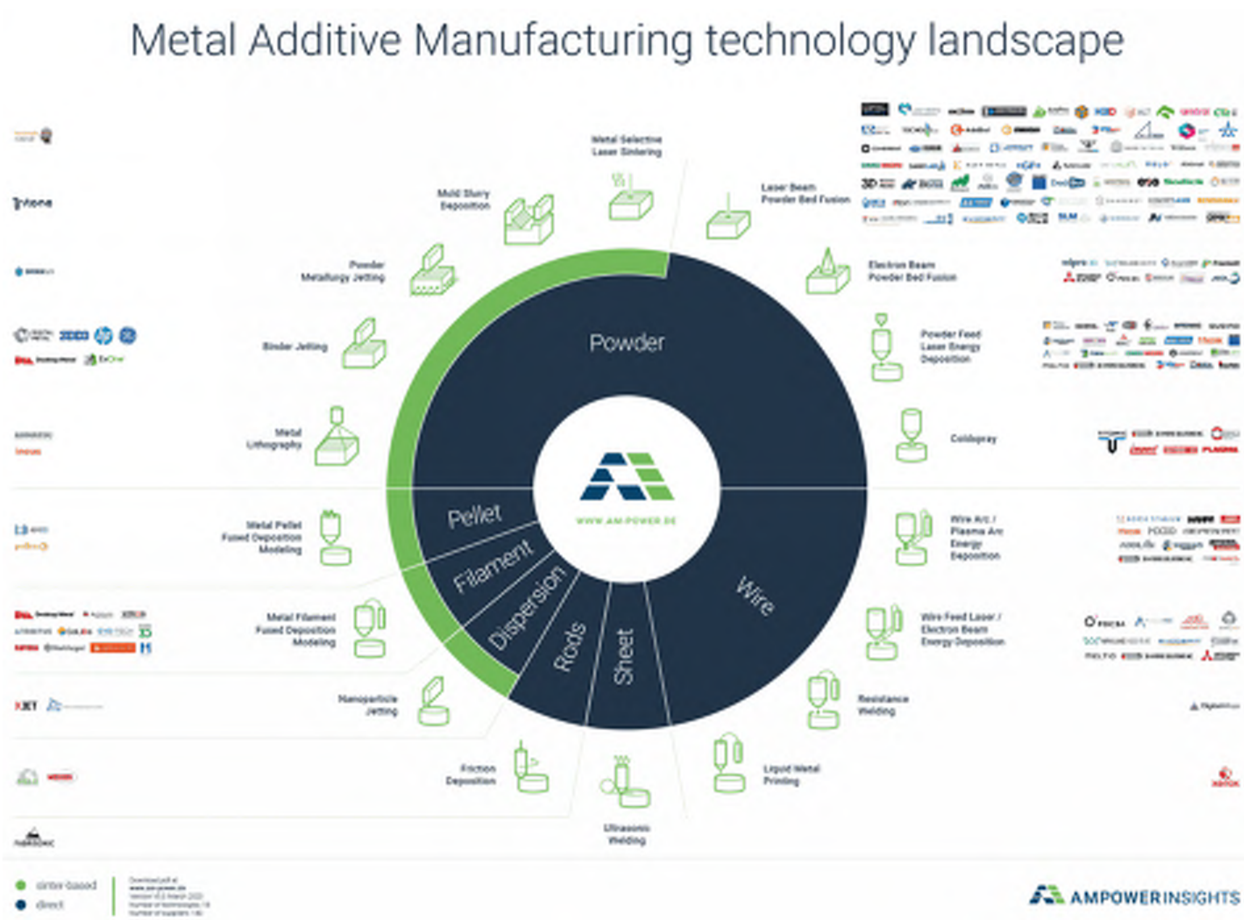

Photo 7 - Different metal manufacturing technologies and the companies working on them

Improving quality of prints:

- Software Advancements
  - Simulation of printing process
  - Correcting for print-induced distortion
- Post-printing Treatments
  - Heat treatments
  - Surface laser treatment
  - Hot isostatic pressing
- Surface Finishing

Impact on the Transportation Sector:

Moreover, the lightweighting capabilities of new design tools and the flexibility of Additive Manufacturing to bring advanced designs to life can make a big impact on the wider Transportation Industry.

- For electric vehicles, reducing the weight of the car lowers the energy consumption (thus requiring a smaller battery) and increases the driving range and performance goals.

Photo 8 - General Motors (GM) BrightDrop EV600 which uses GM's new Ultium Battery platform

Photo 9 - Tesla Cybertruck can accelerate 0-60 mph in as little as 2.9 seconds and has up to 500 miles of range

- For the trucking and shipping industries, reducing the weight of the vehicle would help increase the truck's carrying capacity (increase payload) thereby saving the company a lot of money.

Photo 10 - Truck carrying an Amazon shipping container

- This would also help the environment by reducing green house gas emissions since fewer vehicles will be needed if each vehicle can carry more load, or existing vehicles would require less power if they were to carry the same load.

Photo 11 - Walmart shipping containers on a train

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Appendix

Glossary of terms

Additive Manufacturing (AM) is a process of constructing a 3-dimensional object directly from software.

Topology Optimization is a type of structural optimization technique which can optimize material layout (shape and topology) within a given design space.

Selective laser melting (SLM) is an additive manufacturing technique using a high power-density laser to melt and fuse metallic powders together.

Intermodal Container (Shipping Container): Durable closed steel boxes (mostly 8x8.5x20 feet) designed and built to be used across different modes of transport – from ship to rail to truck – without unloading and reloading their cargo.

Background Information

The maximum gross weight of a shipping container (container weight plus load) cannot exceed 67,200 lbs. However, in the US, it is recommended that intermodal containers hold no more than 42,500 lbs of freight. This is because of the weight limit the Federal Highway Administration (FHWA), the maximum gross weight for a truck (truck plus container with load) is 80,000 pounds.
Between differences in tractor size, chassis weights, container weights, and the amount of fuel in the truck, there needs to be a cushion between how much freight could theoretically be loaded, and how much freight should be loaded to prevent a gross weight greater than 80,000 pounds.
Reducing the weight of the truck would help increase the truck's carrying capacity (increase payload) thereby saving the shipping company a lot of money and help the environment by reducing green house gas emissions.