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INTRODUCTION

For the automotive industry recent advances in additive manufacturing (AM) have opened doors for newer, more robust designs; lighter, stronger, and safer products; reduced lead times; and reduced costs. In 2015, the annual Wohler's report stated that the automotive industry accounted for 16.1% of all AM expenditure. While automotive original equipment manufacturers (OEMs) and suppliers primarily use AM for rapid prototyping, the technical trajectory of AM makes a strong case for its use in product innovation and direct manufacturing in the future.

This article will present an outline of additive manufacturing in the automotive industry. It will discuss the design requirements for parts used in vehicles as well as present design recommendations for common automotive applications. A range of popular AM materials suitable for the automotive industry are presented along with several case studies where AM has successfully been implemented.

AM IN THE AUTOMOTIVE INDUSTRY

Communication	Designs in the automotive industry often begin as scale models showcasing the form of a vehicle. These are often also regularly used for aerodynamic testing. SLA and material jetting are used to produce high detail, smooth, scale models of automotive designs. Accurate models allow design intention to be clearly communicated and showcase the overall form of a concept
Validation	Prototyping using AM is now commonplace in the automotive industry. From a full size wing mirror printed quickly with low cost FDM to a high detail, full color dashboard, there is an AM technology suited to every prototyping need. Some AM engineering materials also allow for full testing and validation of prototype performance.
Pre-production	One of the areas AM has been most disruptive is the production of low cost rapid tooling for injection molding, thermoforming and jig and fixtures. Within the automotive industry this allows for tooling to be quickly manufactured at a low cost and then used to produce low to medium runs of parts. This validation mitigates the risk when investing in high cost tooling at the production stage.
Production	Since production volumes in the automotive industry are generally very high (greater than 100,000 parts per year) AM has predominantly been used as a prototyping solution rather than for end part manufacturing. Improvements in the size of industrial printers, the speed they are able to print at and the materials that are available mean that AM is now a viable option for many medium sized production runs, particularly for higher end automobile manufacturers that restrict production numbers to far fewer than the average car.
Customization	AM has had a significant impact on the competitive automotive industry when the cost of highly complex one-off components is justified by a substantial improvement in vehicle performance. Parts can be tailored to a specific vehicle (custom, lightweight suspension arms) or driver (helmet or seat). AM has also allowed part consolidation and optimize topography of many custom automotive components. This is further highlighted in the case studies found at the end of this article.

AUTOMOTIVE MANUFACTURING REQUIREMENTS

WEIGHT - FINAL PARTS

One of the most critical aspects relating to the automotive industry is the weight reduction of components. Automotive applications make use of advanced engineering materials and complex geometries in an attempt to reduce weight and improve performance. AM is capable of producing parts from many of the lightweight polymers and metals that are common in the automotive industry.

COMPLEX GEOMETRIES - PROTOTYPES AND FINAL PARTS

Affecting weight and aerodynamics (and therefore vehicle performance) is the geometry of a part. Automotive parts often require internal channels for conformal cooling, hidden features, thin walls, fine meshes and complex curved surfaces. AM allows for the manufacture of highly complex structures which can still be extremely light and stable. It provides a high degree of design freedom, the optimization and integration of functional features, the manufacture of small batch sizes at reasonable unit costs and a high degree of product customization even in serial production.

TEMPERATURE - TESTING AND FINAL PARTS

Many automotive applications require significant heat deflection minimums. There are several AM processes that offer materials that withstand temperatures well above the average 105 C sustained engine compartment temps. SLS nylon as well as some photocured polymers are suitable for high temperature applications.

MOISTURE - TESTING AND FINAL PARTS

Most components that go into the production of automobiles must be moisture resistant, if not moisture proof, entirely. One major benefit of additive manufacturing is that all printed parts can be post processed in order to create a watertight and moisture resistant barrier. Additionally, many materials, by their very nature, are suited for humidity and moisture plagued environments.

PART CONSOLIDATION - PROTOTYPING AND FINAL PARTS

The number of items in an assembly can be reduced by redesigning as a single complex component. Part consolidation is a significant factor when considering how AM can benefit the reduction of material usage, thereby reducing weight and in the long run, cost. Part consolidation also reduces inventory and means that assemblies can be replaced with a single part should repairs or maintenance need to take place; another important consideration for the automotive industry.

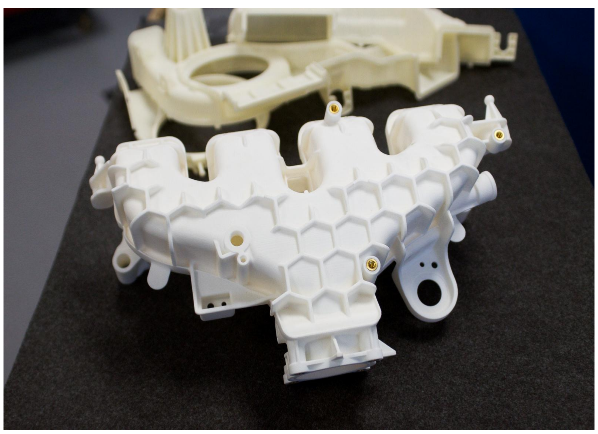
AM MATERIALS SUITED FOR AUTOMOTIVE APPLICATIONS

Application	Process	Material	Features	Example part
Under the hood	SLS	Nylon	Heat resistant functional parts	Battery cover
Interior accessories	SLA	Resin	Customized cosmetic components	Console prototype
Air ducts	SLS	Nylon	Flexible ducting and bellows	Air conditioning ducting
Full scale panels	Industrial SLA	Resin	Large parts with a surface finish comparable to injection molding that allow for sanding and painting	Front bumper
Cast metal brackets & handles	SLA & Cast	Wax	Metal parts made from 3d printed patterns	Alternator mounting bracket
Complex metal components	DMLS	Metal	Consolidated, lightweight, functional metal parts	Suspension wishbone
Bezels	Material jetting	Photopolymer	End use custom screen bezels	Dashboard interface
Lights	SLA	Resin	Fully transparent, high detail models	Headlight prototypes

COMMON APPLICATIONS

BELLOWS

AM (specifically SLS) can be used to make semi-functional bellow pieces where some flexibility is required in assembly or mating. Generally, this material/process is best to consider for applications where the part will be exposed to very few repetitive flexing motions. For projects that require significant flexing, other Polyethylene based SLS materials such as Duraform "Flex" are better suited.



COMPLEX DUCTING

By using SLS to manufacture non structural low volume ducting such as environmental control system (ECS) ducting for aerospace and performance racing, you can design highly optimized, very complex single piece structures. Take advantage of the fact that you can not only engineer in variable wall thicknesses but that you can increase the strength to weight ratio through the application of structurally optimized surface webbing. This is a very costly detail to apply with traditional manufacturing techniques. For SLS there is no cost for complexity, parts are printed without support and to a high level of accuracy.

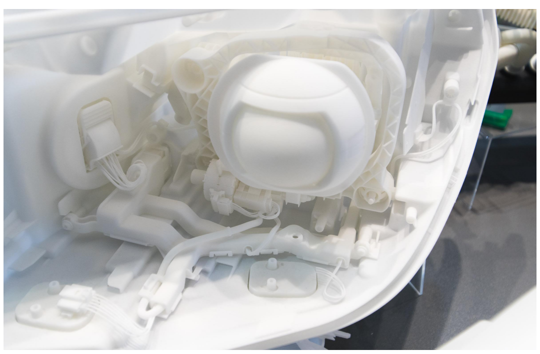
HIGH DETAIL VISUAL PROTOTYPES

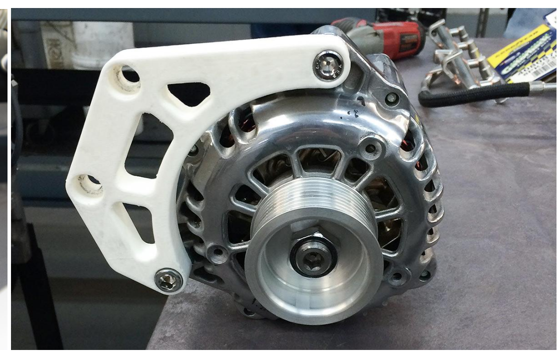
Unlike traditional prototyping methods some AM processes are able to produce multicolor designs with a surface finish comparable to injection molding. These models allow designers to get a greater understanding of the form and fit of a part. This highly accurate method of prototyping is also ideal for aerodynamic testing and analysis as the surface finish that is able to achieved is often representative of a final part. AM is used regularly to manufacture automotive components that rely on aesthetics over function resulting in everything from wing

mirrors and light housings to steering wheels and full interior dashboard designs being produced. Material jetting and SLA printing are the two most common methods used for aesthetic prototypes producing parts from a photocured resin.

FUNCTIONAL MOUNTING BRACKETS

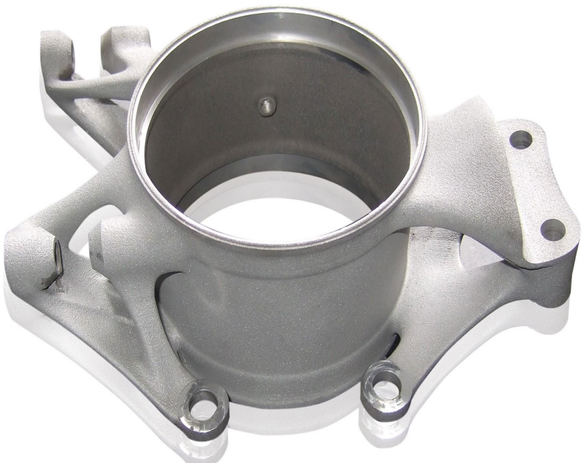
Being able to rapidly manufacture a complex, light weight bracket overnight is a trademark of the AM industry. Not only does AM allow for organic shapes and designs to be manufactured but AM also requires very little input from an operator meaning that engineers are able to quickly take a design from a computer to assembly in a very short amount of time. This is not possible with traditional manufacturing techniques like CNC machining where a highly skilled machine operator is needed to produce parts. Powder bed fusion technologies like SLS nylon and metal printing are best suited for functional parts and offer a range of materials (from PA12 nylon to titanium).





CASE STUDY 1 - FORMULA STUDENT GERMANY

Formula Student is an international student design competition that was initiated in the USA in 1981 by the Society of Automotive Engineers (SAE), and has been held in Europe since 1998. The fiercely competitive international competitions take place on race tracks in Europe, the USA and Asia, and each team decides individually in which competitions it would like to take part.



As part of the optimization of their car, Formula Student Germany set out to design and build a reliable, lightweight axle-pivot (knuckle) with high rigidity, in the shortest possible time. The knuckle needed withstand the dynamic loads that racing cars are subjected to while also reducing the overall weight of the car. The resulting design was a topographically complex single component only capable of being manufactured using AM technologies. For this application DLMS was the best fit as it enabled to manufacture of a functional metal part with complicated geometry.

By optimizing the geometry of the knuckle the final design was 35% lighter than the original design and improved rigidity by 20%. The use of AM technology also resulted in a significant reduction in development and production time and better reliability on the track (which in turn improved safety). Compared with previous aluminum wheel carriers the team was able to save a total of 1.5 kg in vehicle weight, enabling the lightest vehicle so far.

CASE STUDY 2 - MOTO2 MOTORCYCLE RACING

Race winning Moto2 team TransFIORmers is using cutting edge additive manufacturing (metal 3D printing) technology in an unconventional front suspension system to gain a significant competitive advantage. Motorcycles ridden in the MotoGP World Championships are special; the general public can't buy them and they can't be used on a public road. As prototype racing bikes they are custom-built to outdo their rivals and maximize performance on the track.

In the development of new components in Moto2 bike design, achieving a weight reduction is a priority. In particular, reducing the ‘unsprung mass' of the bike is a key consideration. The lower the unsprung mass, the better the suspension is in terms of vibration (chattering) management and responsiveness to both braking and acceleration. The French Moto2 team TransFIORmers, based in Perigueux, South West France, have developed a new front suspension design.

The speed with which the design of a new component can be modified, and how long it takes to remanufacture are important factors in the competitive motorsport world. Quick and accurate part iterations are critical. The weight reduction that metal 3D printing has achieved in the wishbone component has enabled it to bypass traditional weight transfer phenomenon and problems associated with brake drive concerns. More than that, it allows the design of a part that is not only lighter, but far more rigid at the same time. By taking an additive manufacturing approach to Moto2 bike design, TransFIORmers succeeded in reducing the weight of its critical wishbone front suspension component by 40%. Comparing the one-piece titanium component with the original welded steel component, a weight saving of 600 g was achieved.