GF Machining Solutions

Additive Manufacturing

Additive manufacturing for motorsports: an end-to-end solution for improved turbochargers

Introduction

Speed is critical in motorsports, both on and off the track – and at the highest levels of competition, that includes the speed of engineering and manufacturing. While consumer automotive manufacturers typically focus on optimizing volume production following lengthy design processes, for example, Formula 1 teams often have to design and produce complex components in the time between one race and another, or between the time trials and race day. Furthermore, because the state of the art in racing has grown so sophisticated, these teams have to leverage the most cutting-edge manufacturing technology to keep up with the competition.

As a result of these complications, succeeding in the world of manufacturing for high-performance motorsports requires the perfect combination of digital solutions and manufacturing equipment for cost-effective production. However, achieving this kind of seamless workflow has rarely been simple. Traditional methods like investment casting require multiple time-consuming steps, few of which can be automated, and integrating new processes into existing workflows can present significant difficulties.

A truly end-to-end solution

is the only method for overcoming all of these challenges, and additive manufacturing (AM) has been a key technology in developing this workflow. With the incredible part-design and prototyping possibilities that metal AM enables, F1 race cars can reach even higher speeds and greater levels of efficiency. These advantages, as well as the ease of integration made possible with turnkey systems from GF Machining Solutions, give manufacturers the tools they need to achieve incredible feats of engineering in the time between one race and the next.

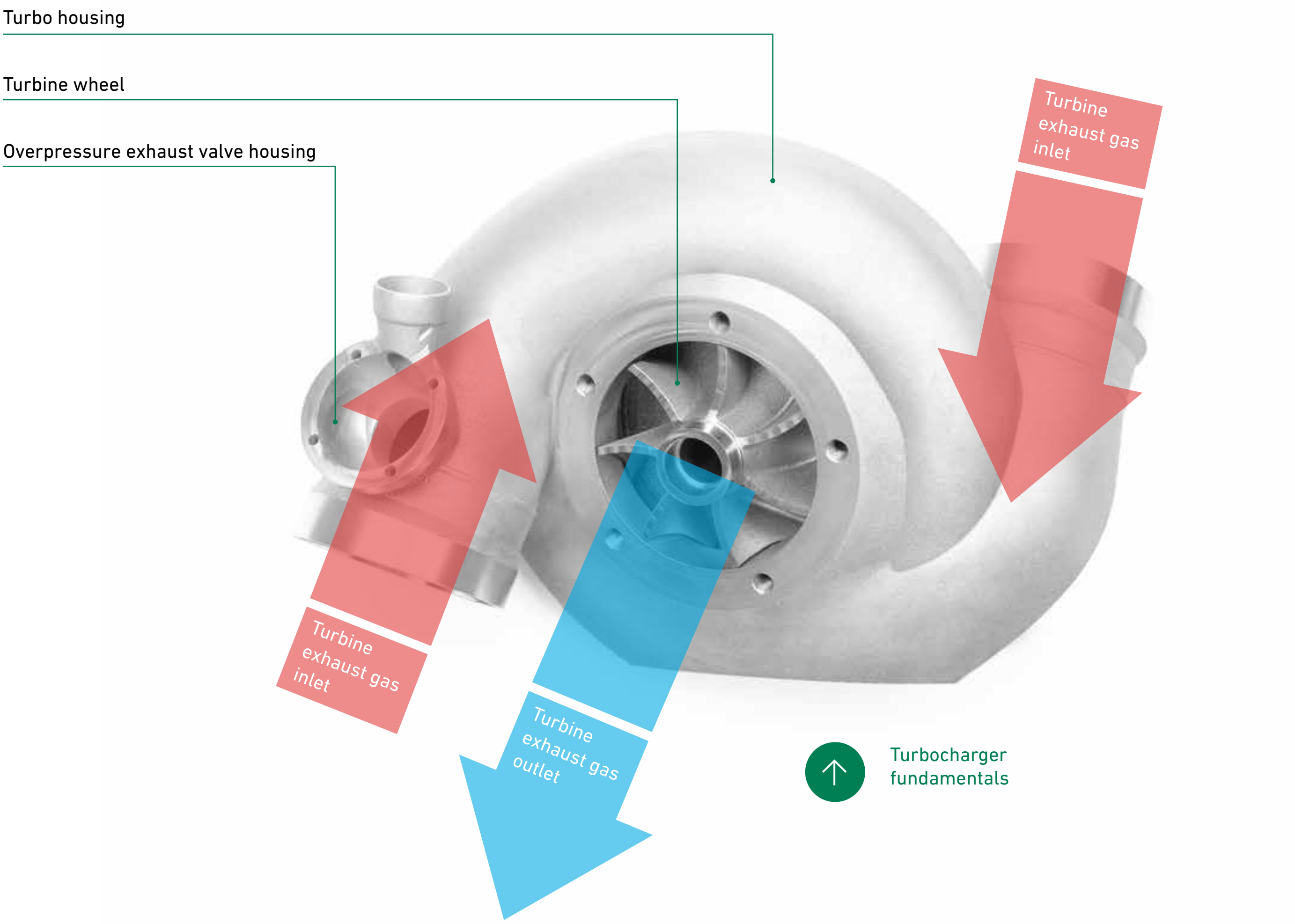
Challenges

The role of a turbocharger is simple: It uses an engine's exhaust to power a centrifugal compressor, pressurizing the intake air that will be mixed with fuel in an engine's cylinders.

Final 3D printed turbocharger housing (with 3D printed impeller)

Greater pressure means higher density, and by increasing the mass of air entering the cylinders' combustion chamber, the turbocharger augments the engine power output. The gas expansion and air compression stages have necessitated numerous continuous improvements in the decades since the turbocharger's invention, and today's high-performance versions have functional geometries designed around thermal isolation and optimal flow.

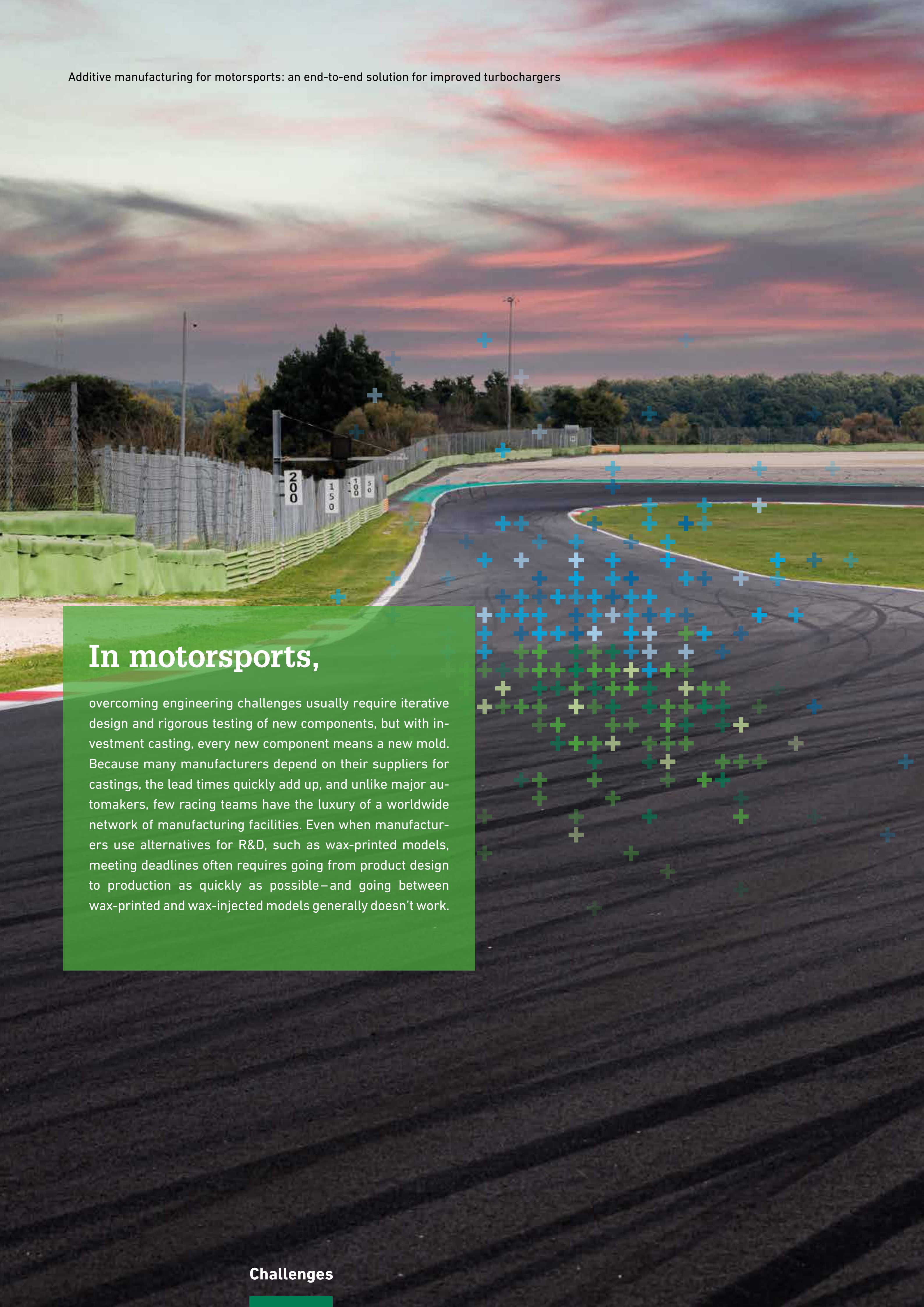
On the consumer side of the auto industry, turbochargers are typically used to improve fuel economy, and manufacturers generally use high-pressure die casting for lightweight aluminum bodies with other components produced with sand-casted steel or other high-temperature alloys. This is efficient, but for the more complex turbocharger geometries, features and materials found in motorsports, investment casting has been one of the only available processes. Unfortunately, this process has numerous disadvantages, all of which are particularly difficult in the fast-paced world of motorsports.



Picking up the pace of production

For most automotive manufacturers, the lead times involved in producing a turbocharger are not especially significant. Part design is often handled in large part, if not entirely, by the customer, and usually far enough in advance that developing the molds for sand or high-pressure die casting can take place at the same time the previous design is in production. While a global supply chain brings its own challenges, for automakers, cost per part is the primary consideration provided that quality standards are met, and these casting technologies are extremely cost-effective in this context.

Challenges



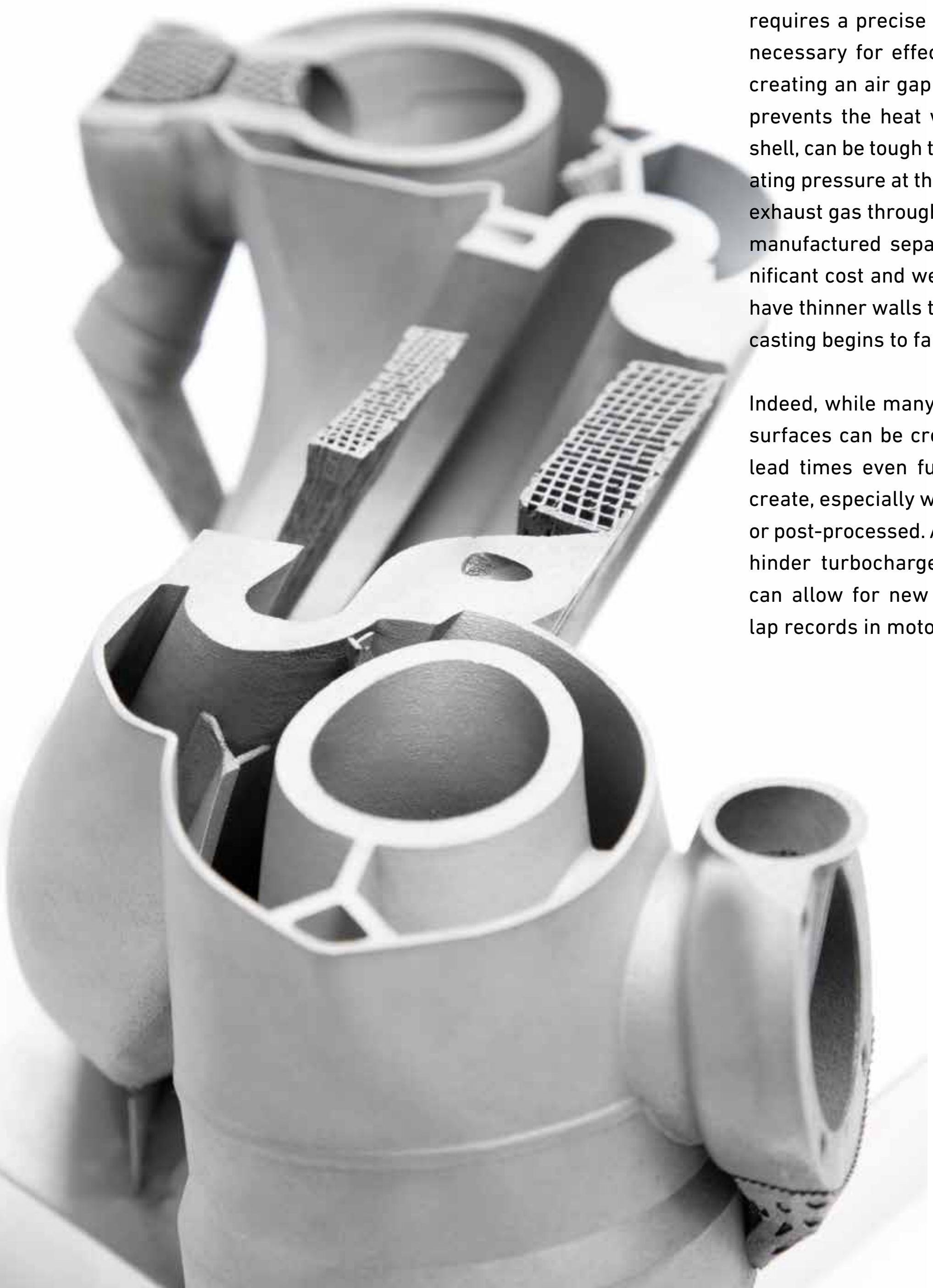
In motorsports,

overcoming engineering challenges usually require iterative design and rigorous testing of new components, but with investment casting, every new component means a new mold. Because many manufacturers depend on their suppliers for castings, the lead times quickly add up, and unlike major automakers, few racing teams have the luxury of a worldwide network of manufacturing facilities. Even when manufacturers use alternatives for R&D, such as wax-printed models, meeting deadlines often requires going from product design to production as quickly as possible—and going between wax-printed and wax-injected models generally doesn't work.

Reaching a higher level of performance

These frequent design changes become more and more necessary as racing teams reach higher levels of competition and performance – and while a turbocharger may work according to simple principles, maximizing its performance requires a precise balance of forces. Thermal insulation is necessary for effective operation of the turbocharger, but creating an air gap using a double-wall construction, which prevents the heat within the core from reaching the outer shell, can be tough to manage with casting. Keeping the operating pressure at the optimal level generally involves venting exhaust gas through waste gates, but these will generally be manufactured separately and assembled later, adding significant cost and weight. All of these components could also have thinner walls to produce a more lightweight engine, but casting begins to falter with thin wall thicknesses.

Indeed, while many complex internal features or functional surfaces can be created via casting, they will likely extend lead times even further. Others are simply impossible to create, especially within closed cavities that can't be molded or post-processed. As a bottom line, the limitations of casting hinder turbocharger design. More advanced technologies can allow for new developments – which translate to new lap records in motorsports.



3D printed part with unique thin wall thicknesses

Finding an integrated solution

Of course, casting is only one part of an entire challenging turbocharger workflow. Tough turbocharger materials like Inconel and other superalloys make finishing parts a tough milling application – and machining can only occur after reference points on the cast part have been established, a time-consuming operation in and of itself if not carefully managed throughout the entire part-production cycle.

Conventional machining process of high-temperature resistant material are complex due to high cutting forces, low material removal rates and high tool wear.

Major automakers and other global manufacturers excel at this kind of process management due to the resources they can devote to the problem. For smaller manufacturers, including most working in the motorsports industry, it can be difficult to bring a diverse group of suppliers and technology providers together into a single, effective workflow. Integrating an entirely new technology is an even larger challenge – one with enough risks that many manufacturers will avoid by sticking with what they know.

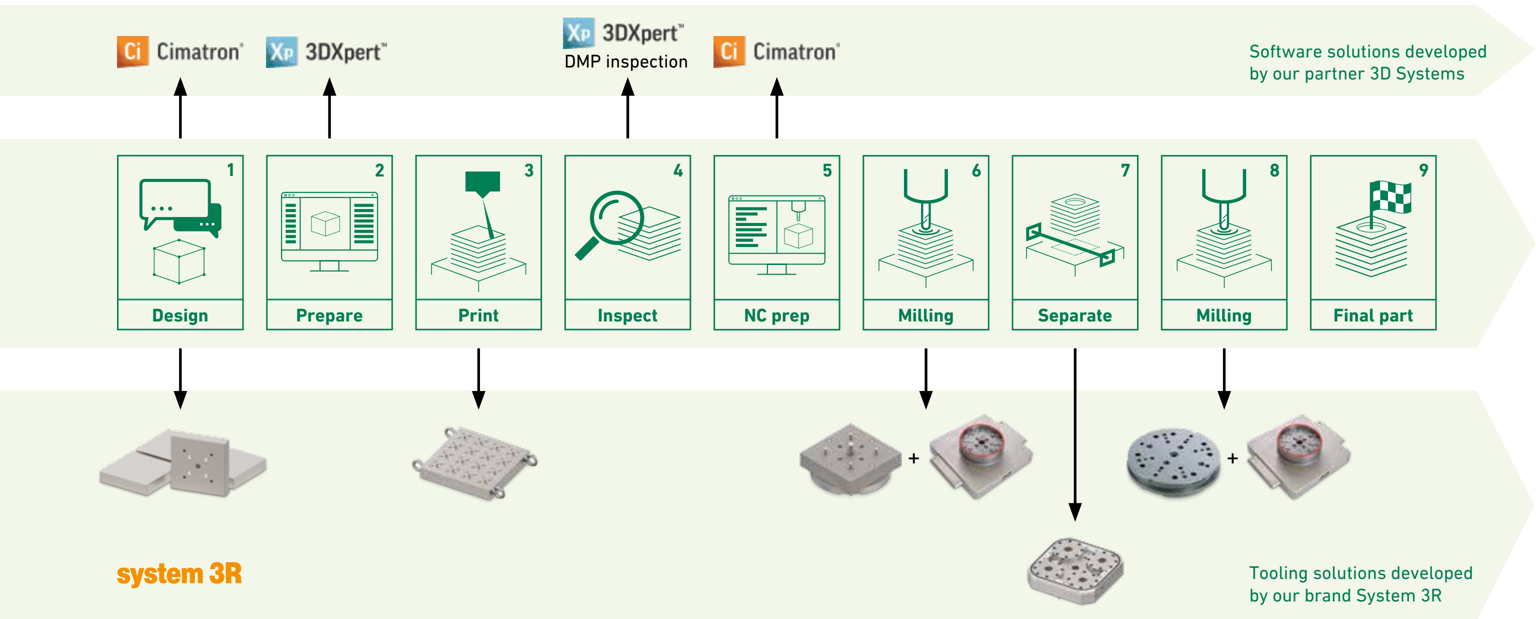
Solutions

The GF additive workflow advantage

For many industries, additive manufacturing has been a revolutionary technology, but its integration into conventional processes and workflows has been even more important. The end-to-end AM production methodology created by GF Machining Solutions draws on the company's extensive portfolio of technologies to create a truly turnkey system. The resulting workflow enables manufacturers to explore new frontiers in part development at the same time they save significant costs.

High-performance turbochargers serve as a great example of the kind of part that benefits from these new AM production methodologies. Single parts can be designed and produced in their entirety within a single digital workflow, which itself has been designed for the utmost in simplicity and ease of use. Given that shops have historically had to rely on investment casting, a traditional process that usually has to be overseen by an expert for good results, AM is a massive improvement – the only lead time is the build time.

Diagram: per GF suggestion, show as three "parallel" workflows

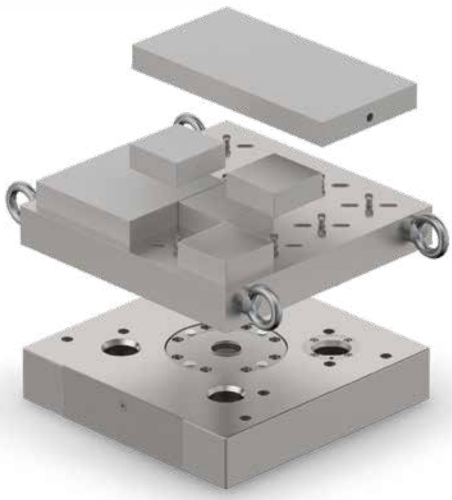


Software and design

Thanks to 3DXpert™ and Cimatron™, the entire production process can be managed within a single software ecosystem that handles everything from part design, build preparation and CNC preparation to in-process inspection and part validation.

Additive and subtractive manufacturing

The DMP Flex 350 metal AM machine builds parts quickly, while the CUT AM 500 removes them from the build plates through an innovative horizontal EDM process and the MILL E 700 U high-performance milling machine performs post-build machining on a full 5-axis platform ideal for complex parts.



Tooling

System 3R tooling optimized for AM processes–the Delphin TableTop Chuck, AMCarrier and BuildPal–can be used to preserve reference points and angular alignment at the same time it enables palletized automation throughout the workflow.

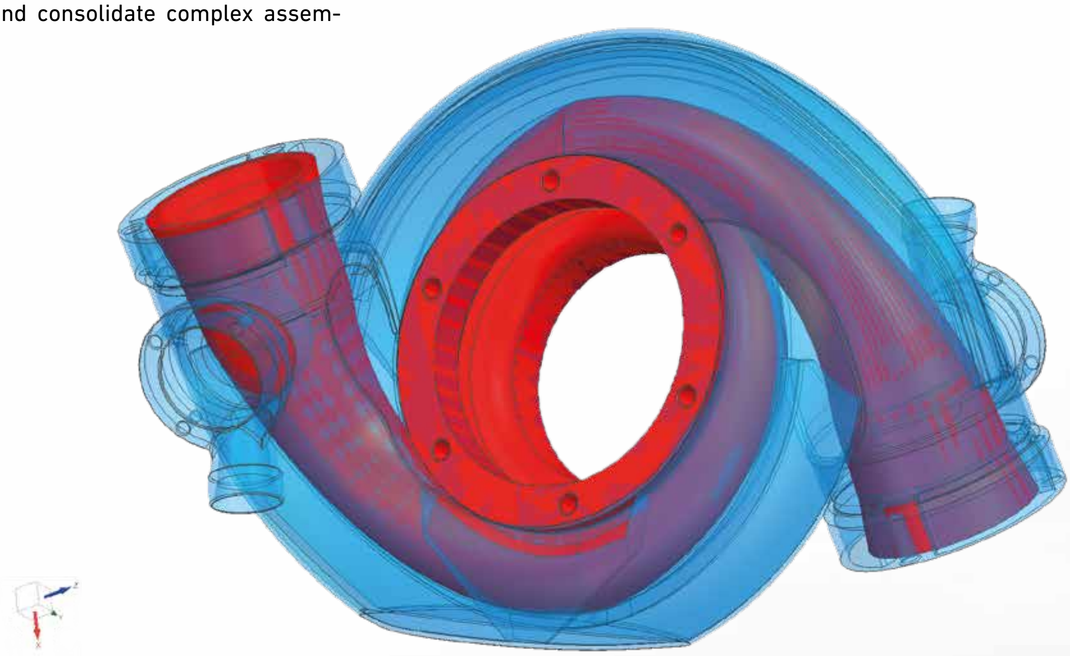
GF Casting Solutions and the AMotion Center: Solving the casting vs. additive problem

Turbochargers for motorsport applications are manufactured by GF Casting Solutions using technologies adapted to customer requirements, but in recent years, the trend from precision casting technology to additive manufacturing has been clearly visible. The AMotion Center and GF Casting Solutions Novazzano SA, located in the south of Switzerland, are specialized in helping its partners develop some of the most advanced manufacturing solutions in the world – and decide which process to use for a given application. For parts such as this F1-style turbocharger, AM is far more cost-effective, and in general, additive processes should be preferred over casting due to the much shorter lead times and ease of use.

Part design

With metal AM, the technology only drives the design insofar as parts usually need additional support structures and stock considerations for post-processing. For the most part, AM allows manufacturers to focus on the functionality of the part. Without the limitations of other processes, AM gives engineers the tools to push their designs even closer toward theoretical optimization – and consolidate complex assemblies into a single part.

Unique double-wall construction design enabled by metal AM



The turbocharger used as a demonstration part by GF would ordinarily be manufactured as three parts: the main housing and two waste gate valves at the side. In addition to casting, this turbocharger would also require welding to attach the double-walled heat shield. With AM, these turbochargers can be produced as a single part in one process, and the waste gate valves require no gaskets or other components in addition to the complete housing. This does more than simplify assembly, it reduces overall weight, a critical factor in a racing vehicle designed for average speeds of >200 km/h.

Often referred to as assembly consolidation, single-piece production increases the overall reliability of the turbocharger as well, avoiding potential leakage at the interface between the different parts and reducing costs as mating surfaces no longer need to be machined to tight tolerances. The usually heavy doubled walls can also be redesigned to reduce the additional weight as much as possible while achieving the thermal insulation required for optimal performance.

3DXpert™ and Cimatron™

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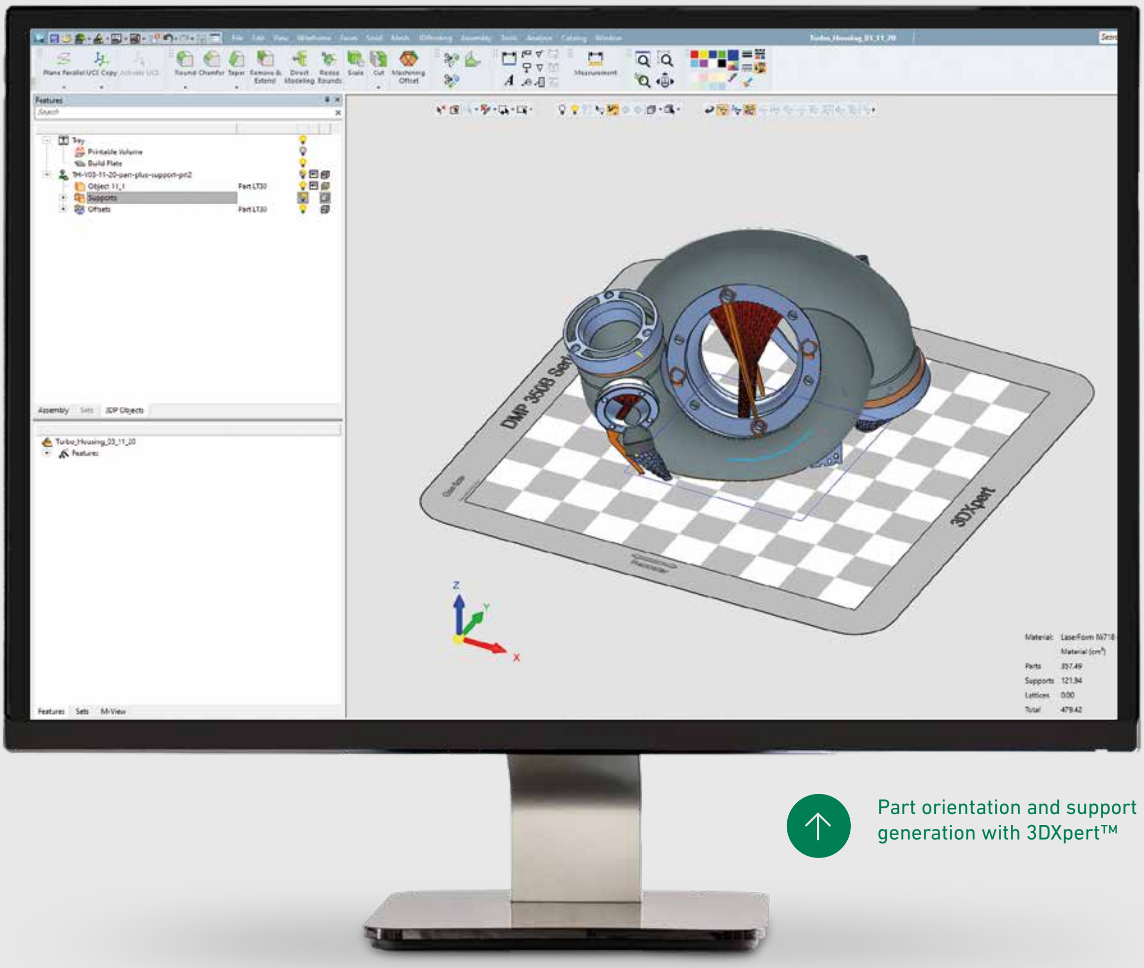
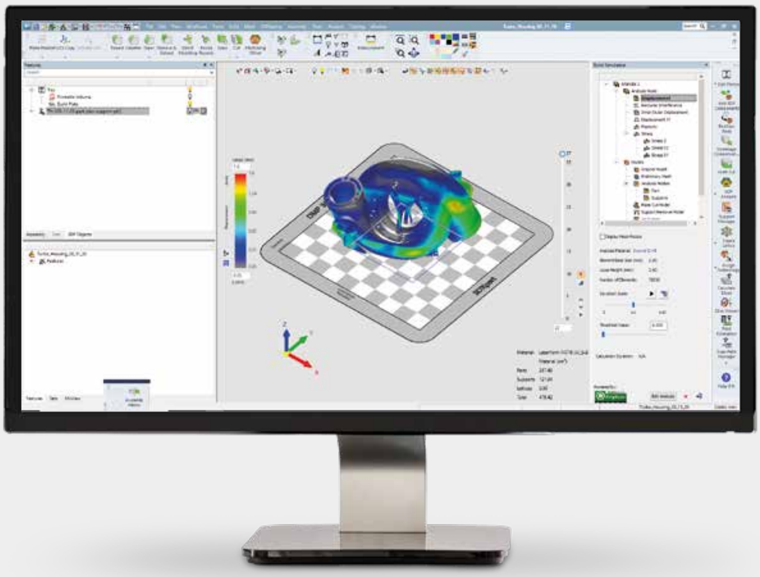


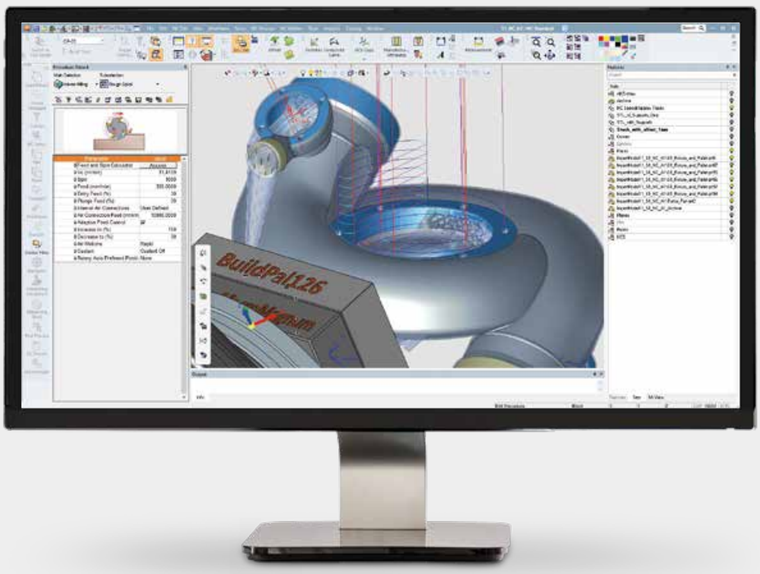
Part orientation and support generation with 3DXpert™

3DXpert™ also offers a range of tools aimed at simplifying part programming for metal AM. There are a number of AM-specific structures, geometries and print strategies that the software can apply automatically. In Cimatron™, this feature even provides advanced milling strategies during post-processing “in its design”, such as the trochoidal milling required to remove the tough Inconel supports that were used to hold up the part during and after the metal AM process.

Indeed, the software also helps manufacturers avoid risk with robust simulation capabilities. With parts such as the turbocharger, where expensive materials and a long build cycle create a high-value workpiece, getting the real-world process right on the first attempt is critical. Using 3DXpert™, multiple build iterations can be simulated to perfect build processes. As a result, potential issues like stress accumulation or elevated displacement can be addressed long before 3D printing begins.



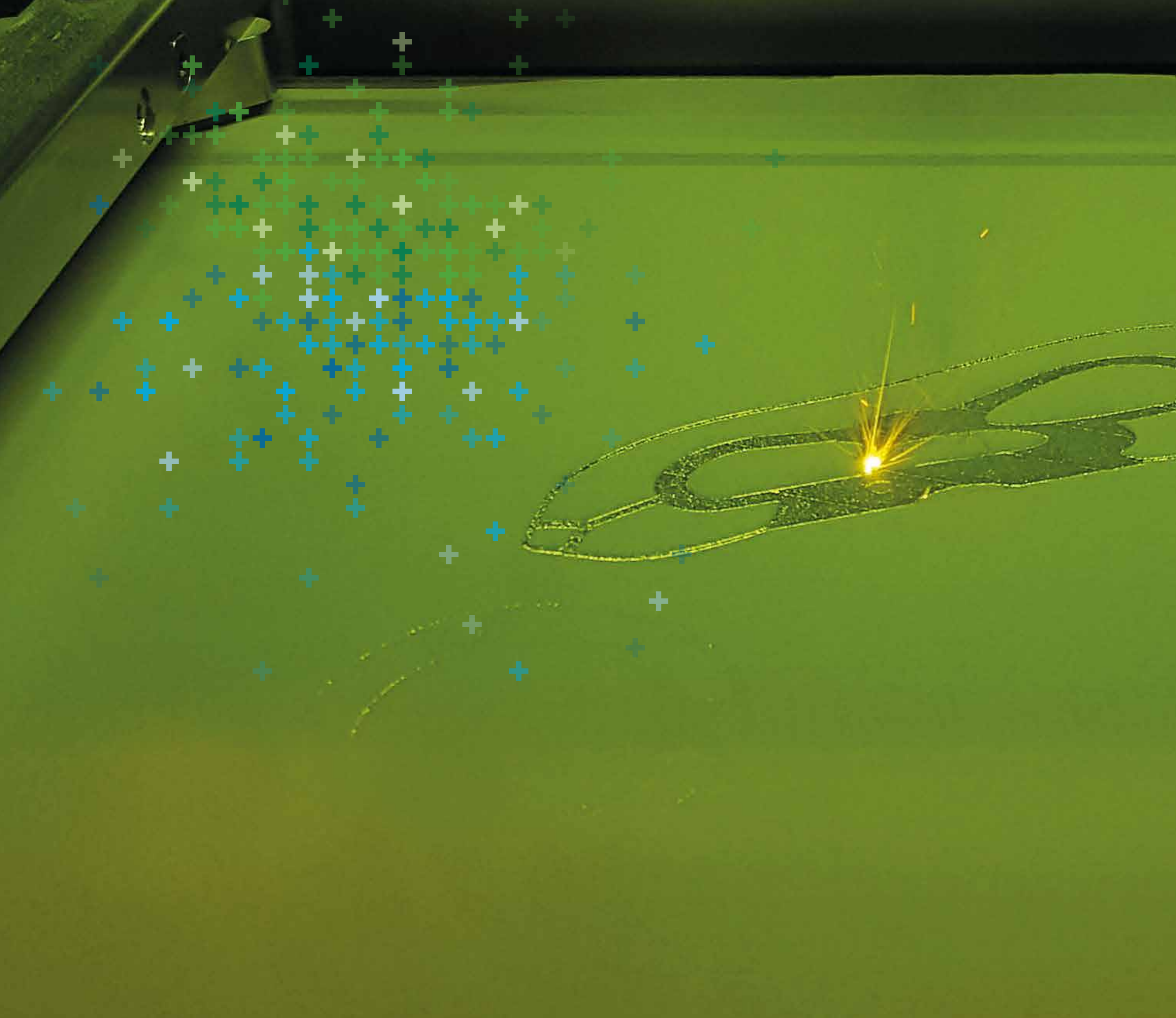
Simulation stages with 3DXpert™



AM supports are considered for post-processing operations thanks to data exchange between 3DXpert™ and Cimatron™

Part building

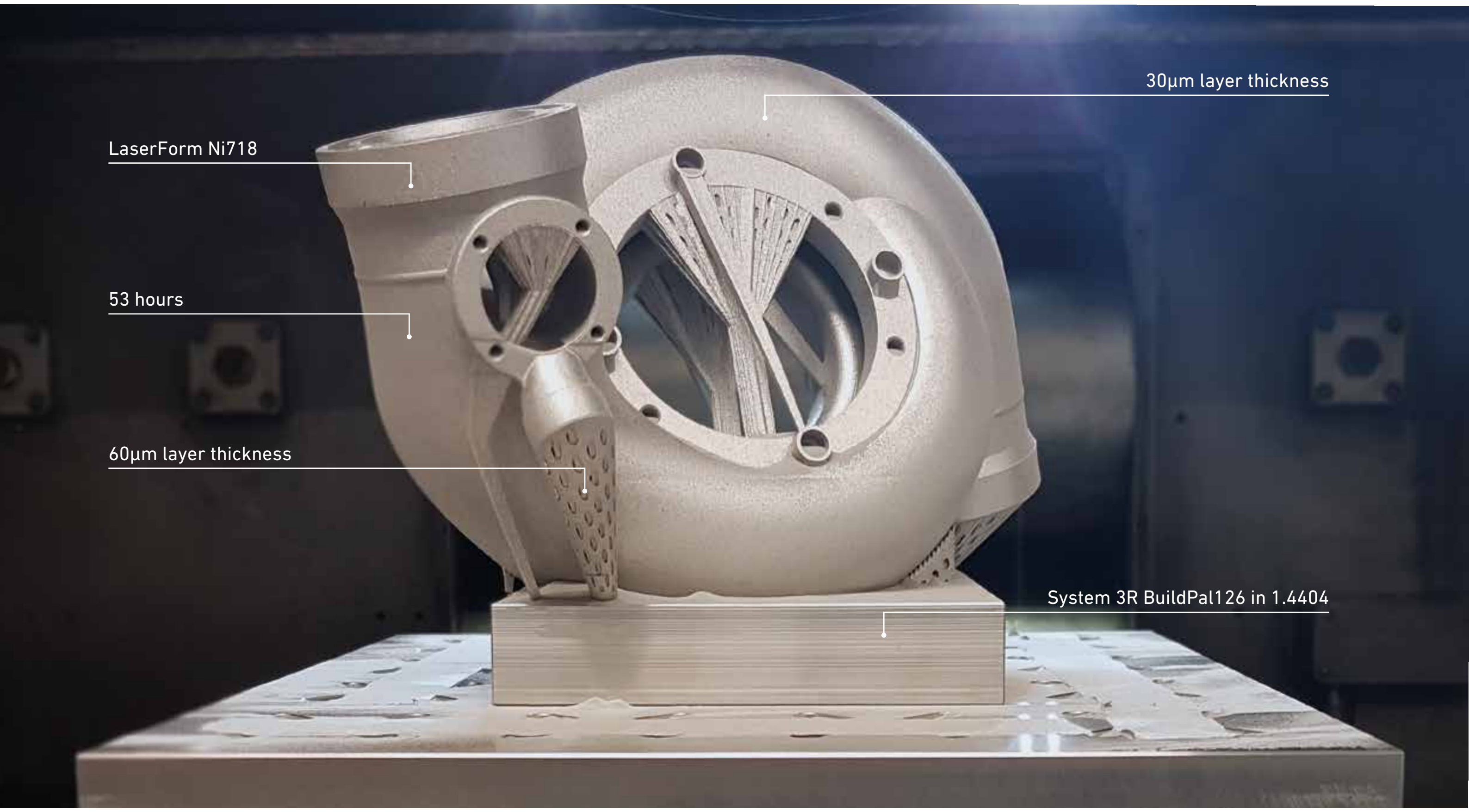
An additive workflow will naturally be built around its AM system, and GF Machining Solutions offers industry-leading selective laser sintering technology through its Direct Metal Printing (DMP) series of machines. A versatile, thoroughly proven AM solution designed for the utmost in simplicity and speed, the DMP Flex 350 acts as the center of the workflow for the turbocharger demonstration. System 3R tooling provides the connections between other machines and the DMP Flex 350 to ensure full additive scalability and easy access to automation.



DMP Flex 350

Designed to offer the highest level of repeatability, throughput and cost-effectiveness, the DMP Flex 350 possesses a build volume of 275 x 275 x 420 mm and is compatible with a wide range of materials. High printer utilization and a consistently low-oxygen environment (fewer than 20 parts per million), as well as fast, bidirectional material deposition, makes it easy to achieve outstanding AM throughput.

The DMP Flex 350 also offers a number of features that simplify the turbocharger workflow. The DMP software suite includes DMP Inspection, which uses powder-bed images and meltpool data to identify defects such as warping, lack of fusion, rough surfaces, or poor deposition quality. The software also helps users identify the root causes of any issues and correct them within 3DXpert™. This allows shops to minimize the costs of post-build processing and part validation at the same time they prepare data for toolpath generation in their CAM systems.



BuildPal 126

Virtually all workholding moved between machines shares the same two goals: clamping the part and preserving reference and coordinate points. System 3R offers significantly more with its BuildPal and AMCarrier system, which connects every machine in the GF additive workflow. The system's thin build plates and clever design maximizes the available printing area, while the palletized design allows for easy integration with other System 3R automation for even greater productivity and post-processing speed.

The AMCarrier system is designed for exceptional clamping flexibility, with multiple sizes of BuildPals that can be clamped to the carrier to allow programmers to have maximum flexibility on part size and number per build cycle. For its turbocharger demonstration, GF used the BuildPal126, a 126-mm square build plate, four of which can fit on the AMCarrier at one time. at one time. The palletized system allows then for completely automated post-processing operations.

3D Printed turbo housing before post-machining stages

Part separation and post-build machining

Following a quick de-powdering process, post-machining can begin. Typically, an additional step is required – most additive processes require operators to remove AM support structures manually. However, thanks to the unified software ecosystem (3DXpert™ & Cimatron™) and palletized reference preservation, this step can be handled automatically as part of post-processing. Even without robotic assistance to handle pallets, as part of post-processing, as the BuildPal units themselves maintain the physical data chain across the entire process.

For parts such as a F1 turbocharger that includes functional elements that must be precisely refinished, keeping the part on the BuildPal maintains the same coordinate system for machining reference surfaces and holes with the highest possible precision. These same references can be used when re-clamping a difficult-to-align part such as a turbocharger for post-separation machining. For part separation, GF Machining Solutions' additive workflow uses the AgieCharmilles CUT AM 500, an innovative horizontal wire EDM machine, while all functional surfaces plus the pre and post-separation processing steps are carried out with a Mikron MILL E 700 U.

MILL E 700 U

The MILL E 700 U is a high-value, efficient solution for 5-axis simultaneous machining. Large guideways, a double-side-supported direct drive rotary table and optimal chip removal rates allow this machine to easily handle a wide range of milling applications. These features, as well as its capacity for advanced milling strategies through Cimatron™ software and its flexible, automation-ready design make it an ideal machine for demanding AM parts' post-processing needs.

CUT AM 500

Designed around a unique tilting table that reorients AM parts for a horizontal-wire EDM process, the AgieCharmilles CUT AM 500 is the fastest, most effective method for AM part separation. The EDM-level surface quality and small-diameter molybdenum wire allow for high-quality surface finishes. The machine's layout is also specifically designed for the integration of the AMCarrier automation-ready clamping system for the lowest risk of part damage.

Conclusion

From one race's podium finish to the next one's qualification laps, manufacturers serving the motorsports industry must act quickly to provide the high-performance components required for competitive race cars.

3D metal printing, when incorporated as part of an end-to-end manufacturing solution, offers significant time and cost savings compared to investment casting for parts like F1 turbocharger housings. An increasing number of high-end automotive manufacturers are integrating this technology, and many are partnering with GF Machining Solutions to achieve fast, reliable results. From industry-leading design and production software to the additive, milling and EDM equipment required for part production excellence – and the turnkey AM workflow that links it all together – GF can provide everything required for additive success.

GF Machining Solutions

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