Functional Prototypes for Car Components

3D Printing Shortens Development Times for Load-Bearing Parts under the Hood

Fiber-reinforced plastic components, including those for load-bearing areas, are established alternatives to metals in vehicle construction. It is not just their low specific weight that makes them interesting, but also their acoustic properties, which reduce noise transmission. As development cycles become ever shorter, the scope for protecting and coordinating components in their vehicle environment is becoming increasingly restricted. 3D printed prototypes, however, can help with acoustic assessments and optimization of engines or entire vehicles.

The engine support in a passenger car, together with the engine mount, is the most important vehicle component for reducing the transfer of structure-borne noise from the drive unit to the vehicle structure and ultimately into the cabin (**Fig. 1**). This applies to both internal combustion engines and electric drives. In addition to its actual function as a holder for the drive unit in the vehicle, the engine support plays a significant role in the targeted optimization of noise, vibration and harshness (NVH) within its chain of effects.

NVH Assessment of the Entire Vehicle

Fiber-reinforced plastics have proven themselves in injection molding over many years [1]. At the same time, there have been further advances in the scope for predictive simulations of vibration behavior over large frequency ranges [2, 3]. However, the complexity of both drive unit and vehicle architecture still necessitates an NVH assessment of the entire vehicle, especially where new technologies are concerned.

3D-printed functional prototypes offer an advanced way to accomplish this: not only can components be produced quickly, inexpensively and without tools, but also optimization cycles become much faster and mold costs are slashed. For this, the following three boundary conditions must be met:

- The 3D-printed prototypes must meet the thermal and mechanical requirements.
- The NVH properties must match those of the equivalent injection molded component.
- The NVH properties must lend themselves to simulation.

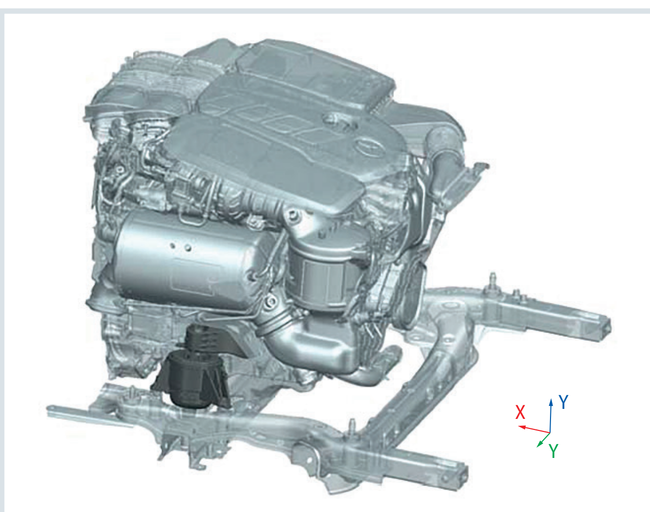

Fig. 1. Internal combustion engine and its connection to the vehicle structure via engine support and support (colored black) © Daimler

Materials Classification

The challenge on the materials side lies primarily in the high demands imposed on thermal and mechanical resilience: the plastics normally employed in the printing of 3D objects by laser sintering – PA11 and PA12 – fail to meet the mechanical and thermal requirements imposed by the application. Ultrasint PA6 MF is a mineral-filled polyamide 6 devised by Forward AM (a corporate brand of BASF 3D Printing Solutions GmbH, Heidelberg, Germany) that offers greater stiffness and is more resistant to heat.

With most filled laser sintering powders, the filler is added in the form of a dry mixture. However, Ultrasint PA6 MF utilizes in-particle filling (**Fig. 2, left**), which gives rise to more uniform filler distribution (**Fig. 2, right**), prevents potential segregation and thus supports enhanced processability on the materials side. When deployed in conjunction with a technology that supports production of finished components in a single day and thus fast development iterations, Ultrasint PA6 MF and laser sintering offer a constellation of materials and process that is highly conducive to rapid parts manufacture.

Theoretical Background and Simulation Approach

The mechanical properties of the injection molded material differ substantially from those of the material used in 3D printing (**Table 1**): lower stiffness leads to lower eigenfrequencies for the same mass and thus to inadequate NVH response by the engine support. Manufacturing the engine support by means of 3D printing while retaining the part geometry would therefore likely not bring about the desired results and the components would not be comparable. All the more reason, then, to compensate for the lower material stiffness by increasing the geometric stiffness in the corresponding direction. The eigenfrequencies of the engine support are directly proportional to the stiffness in the corresponding load direction. Since the first four eigenmodes are bending-dominated, stiffness under bending in the z-direction will serve in the following as a proxy for the estimated improvements resulting from optimization. Furthermore, there must be no change to the external dimensions if smooth installation on the test bench and the necessary connections to adjacent components are to be ensured.

	Orientation with regard to printing plane/flow direction	Ultramid A3WG10	Ultrasint PA6 MF
Modulus of elasticity	Parallel	16,800 MPa	6400 MPa
	Vertical	5760 MPa	5850 MPa
Tensile strength	Parallel	240 MPa	86 MPa
	Vertical	–	74 MPa
Density	–	1560 kg/m^3	1440 kg/m^3

Table 1. Materials data for Ultramid (injection molding) and Ultrasint (3D printing), dry

Source: BASF

The improvement in geometric stiffness is targeted by optimizing the topology of the engine support interior. To this end, the ribs typically associated with injection molding are eliminated to free up design space. This space is optimized for the instantaneous bending load on the basis of a target function with appropriate constraints. This approach fully exploits the advantages of the 3D printing process because it eliminates the restrictions on both demolding and wall thickness that arise in injection molding.

The mounting of the model reflects the installation conditions. The statics simulation examines a load case in which a force acts on the damper bearing in each of the x- and z-directions. This covers the "dead weight with dynamic loads" load case. For the eigenfrequency analysis, a point mass is attached at a distance **(Fig. 3, left)**.

Discussion of the Numerical Results

The interior geometry of the engine support resulting from the optimization, together with a numerical comparison of the flexural strength of different variants, are shown in **Figure 3 (right)** and in **Figure 4**. The optimized engine support (vari- »

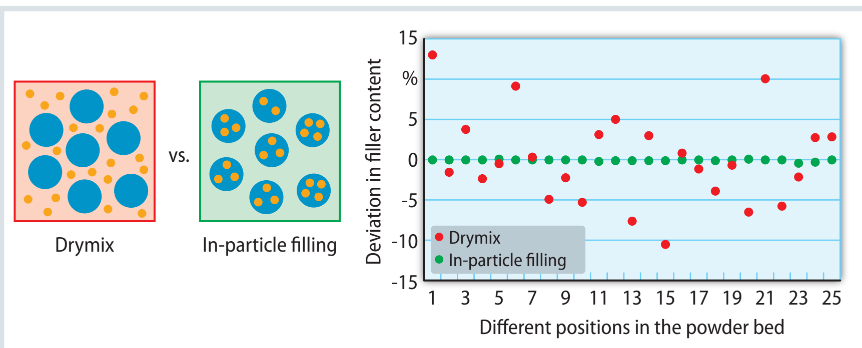

Fig. 2. Dry mix vs. powder bed mix (left) and filler content vs. powder bed position (right)

Source: BASF; graphic: © Hanser

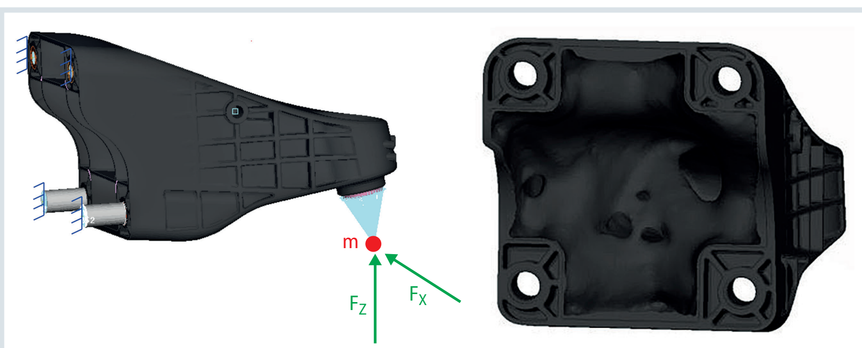

Fig. 3. Left: boundary conditions for the statics simulation (green) and the modal analysis (red). Right: the optimized engine support Source: Daimler/BASF; graphic: © Hanser

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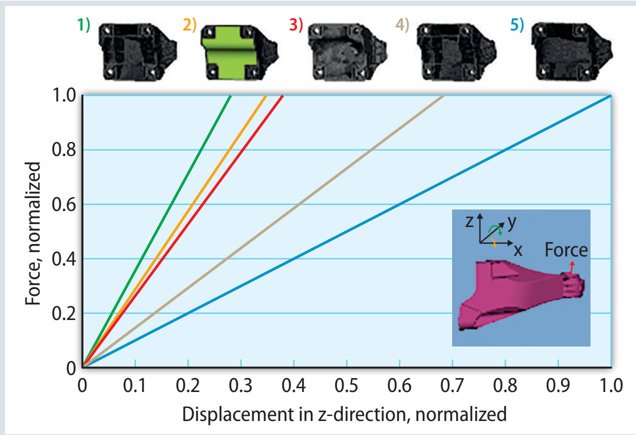

Fig. 4. Numerical comparison of the flexural strength of the geometrical variants 1–5 Source: BASF; graphic: © Hanser

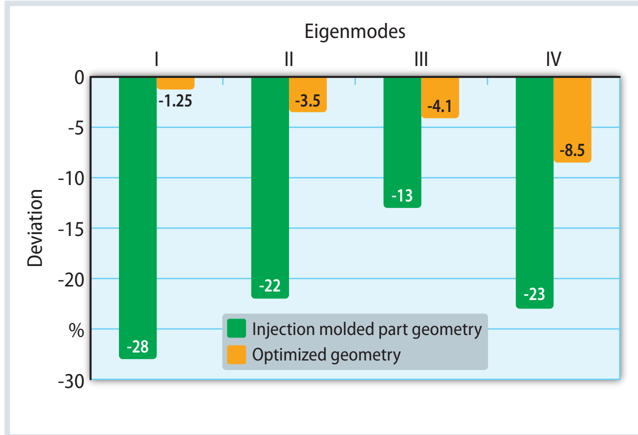

Fig. 5. Deviation in eigenfrequency: comparison of the simulated eigenfrequencies of variants 4 and 3 (each made from Ultrasint PA6 MF). Reference (0 %) is the engine support molded from Ultramid A3WG10 Source: Daimler; graphic: © Hanser

ant 3) is compared with four other variants. Variant 1 is the molded engine support, variant 4 is a 3D-printed engine support with the same geometry as the molded component, and variants 2 and 5 are 3D-printed engine supports with completely filled and totally empty design space, respectively. Variants 2 and 5 represent the upper and lower limits of attainable component stiffness in 3D printing.

Numerical comparison of the variants shows that the optimized engine support is a very close match for variant 2 in terms of stiffness and markedly outperforms the 3D-printed geometry of the molded part (variant 4). The relevant simulated eigenfrequencies of the optimized engine support very closely match those of the molded mount and are substantially better than those of variant 5 (**Fig. 5**).

By virtue of the manufacturing process, 3D-printed materials in most cases possess transverse isotropic strength in addition to possible anisotropic stiffness (**Fig. 6, right**). For this reason, the alignment of the geometry in the printing chamber is hugely important.

Given that the bending load about the y-axis dominates and so the highest stresses arise in the x-direction, the z-direction proves to be the optimal printing direction, as shown by a simulation carried out on Ultrasim [4] (**Fig. 6, left**).

The geometrical accuracy is verified by conducting a 3D scan on the laser-sintered component and then comparing the scan with the CAD file. Minor deviations outside the specified tolerances – especially where extreme accuracy is required, such as for engineering fits – are mechanically reworked.

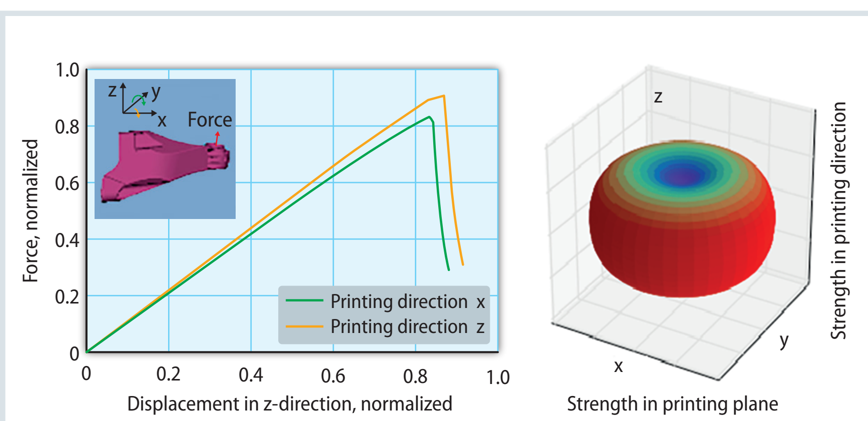

Fig. 6. Influence of printing direction on component strength, simulated with Ultrasim (left), and schematic representation of directional strength in all spatial directions Source: BASF; graphic: © Hanser

Validation of the NVH Profile

For the purpose of verifying component failure, statics tests were performed on the component in the z critical load direction under real operating temperatures. **Figure 7** confirms that the strength requirements in the NVH-relevant load profile are met with an appropriate margin of safety (below the red line). 3D-printed components can therefore be installed in the engine-transmission assembly and in the entire vehicle. In the NVH-relevant load range (below the blue line), the engine supports also exhibit a comparable level of stiffness, a fact which, to a first approximation, suggests comparable NVH performance.

The NVH profile is validated by performing modal analysis on the component at different temperatures and in comparison to the injection molded part and the geometrically identical 3D-printed part. In addition, overall engine evaluations were carried out under operating conditions. Over the duration of the test period, no thermally or mechanically induced component changes occurred, a fact which also confirms the application potential of the material employed.

Figure 8 shows the differences in the first four eigenfrequency positions at room temperature and operating temperature, as determined by measurements. As expected, the non-optimized geometry of the 3D-printed part deviates extensively from that of the injection molded component. The material and process-related lower component stiffness inevitably leads to markedly lower resonant frequencies. The geometry-optimized mount, on the other hand, exhibits almost the same transfer behavior, with a frequency difference in each case of less than 6%.

The relevance of geometry optimization is even more evident from the measurements performed under operating conditions. **Figure 9** shows the comparison in a format analogous to that for the component test. The markedly lower resonant frequency of the geometrically identical printed part reduces the information value in the overall chain of effects, therefore ruling out any benefit in respect of NVH optimization. The transfer functions of the molded component and the geometry-optimized support, on the other hand, are almost identical over the frequency range under consideration.

Conclusion and Outlook

The method described here will render it possible in the future to make components for hardware tests available quickly, cost-effectively and without molds, for the purpose of NVH optimization or technology testing. The various aspects addressed here reveal the importance of creating a digital description of component behavior, both for the design of the individual component and for the optimization of complex systems. Thanks to structural dynamics simulation, this area is already venturing beyond classical mechanical design. In automotive construction, digital structural optimization supports targeted improvements in NVH behavior or service life.

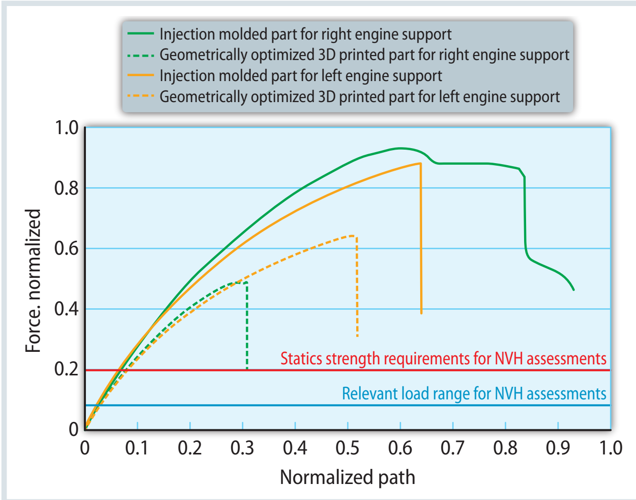

Fig. 7. Requirements profile and results of the statics component test performed on the left and right engine support under operating temperatures for the critical load direction z Source: Daimler; graphic: © Hanser

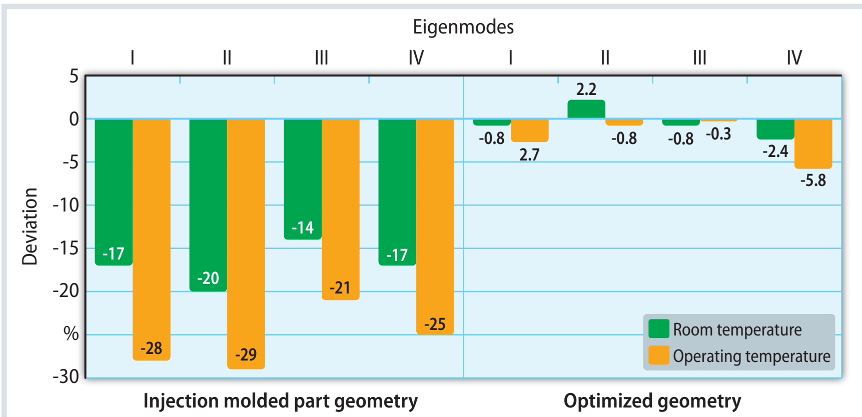

Fig. 8. Differences in 3D printed parts in the first four eigenfrequency positions, relative to the injection molded reference part, as measured on the component test rig Source: Daimler; graphic: © Hanser

In its current state of development, 3D printing already possesses huge potential: it can be used to make targeted geometrical changes throughout the entire development period – agilely, efficiently and cost-effectively. With this combination of digital design and component creation, it is now possible to extend the use of plastics printing to functional prototypes.

Replacing injection-molded prototypes can shorten production times and reduce costs for molds and moldings. The method could also conceivably be transferred to other applications in the automotive and other industries. ■

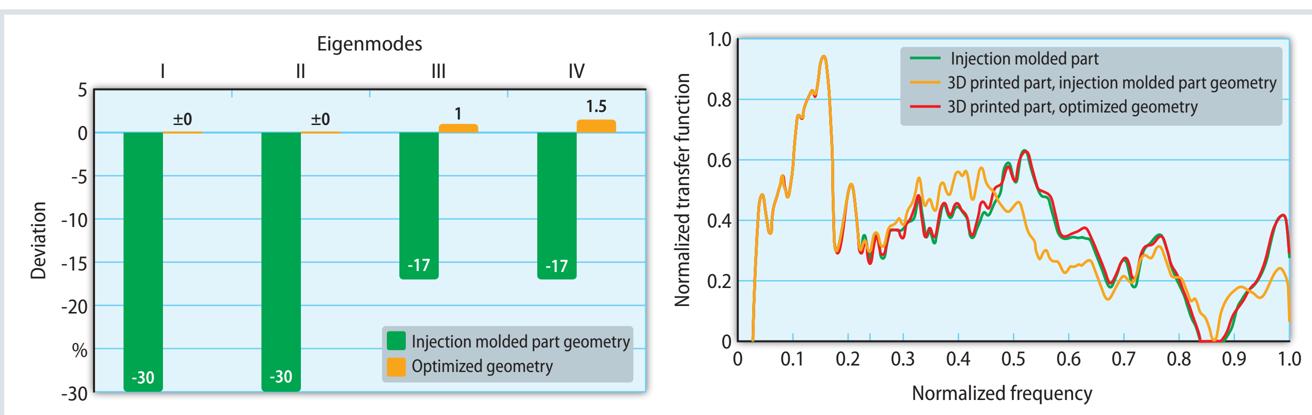

Fig. 9. Measurements under operating conditions: measured differences in the first four eigenfrequency positions under operating conditions, expressed in terms of the injection molded part (left) and the transfer functions Source: Daimler; graphic: © Hanser