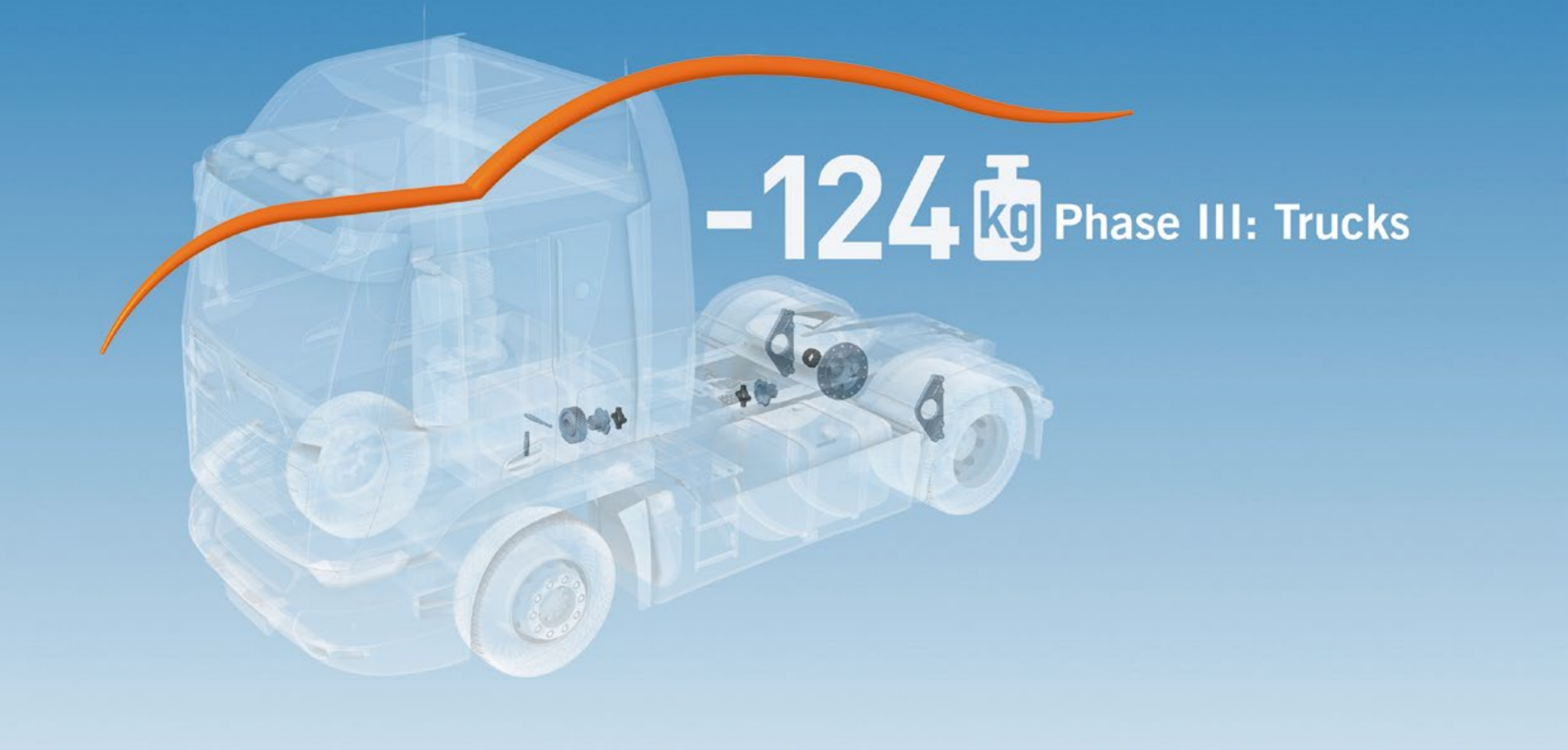

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Due to the constantly improved possibilities of material-flow simulation, increasingly complex components can be forged. In its third phase, the Lightweight Forging Initiative which now incorporates international partners, too, demonstrates the lightweight design potential in a split-axle hybrid car and in sub-systems of a heavy-duty truck. Following optimizations in material lightweight design, solutions based on forging concepts are described here. In commercial vehicles in particular, lightweight design measures on the brake carrier, transmission countershaft and propshaft flange, for example, resulted in a considerable weight reduction of 124 kg.

CONTINUOUS FURTHER DEVELOPMENT

Following the in-depth analysis of measures for material lightweight design in its third phase on hybrid passenger cars and heavy trucks in ATZworldwide 3/2019 [1], the Lightweight Forging Initiative now discusses the lightweight design potential of new forging concepts.

Forging technology has undergone continuous further development over the past few years. The improved possibilities offered by material-flow simulation enable the forging of increasingly complex parts. The use of component-calculation FEM inside forging companies allows ever greater coordination of part design and the forging process, thereby helping to uncover and further exploit lightweight design potential. This is shown in the following using numerous examples from a split-axle hybrid car and – at the end of this article – on the basis of commercial vehicle parts.

LIGHTWEIGHT DESIGN POTENTIAL IN THE COMBUSTION ENGINE

The connecting rod in the spark ignition engine of the split-axle hybrid car is made of the micro-alloyed steel 3MnVS3, which has a tensile strength of 850 MPa. Here, there are new micro-alloyed steels on the market with a tensile strength of

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1160 MPa, thereby allowing a reduction in the shaft cross section and thus a weight reduction of 51 g, without compromising the safety factor. Modern bainitic steels with even higher tensile strength promise a weight saving potential amounting to an additional 20 g.

The camshaft is produced as a solid shaft made of cast iron material. Assembled solutions using forged cams represent the widespread state of the art, and this was also put forward as a lightweight proposal by Tekfor. The suggestion shown in **FIGURE 1** uses tube material which is shaped into a functional contour by means of internal high-pressure forming with multidirectional tool movements. A weight reduction of 400 % can now be achieved. The strength and wear resistance of the cams certainly still require more detailed analysis, however.

For the crankshaft, various suggestions for optimized steel materials were made: High-strength, micro-alloyed or bainitic steels which, like the current material, do not require any additional heat treatment following forging, or steels with a very high degree of purity due to a reduced sulfur content, should allow smaller dimensioning thanks to their longer service life.

At the same time, solutions based on design/forging concepts were also proposed. Hatebur suggests building the crankshaft from individual parts. This would allow pockets and boreholes to be forged easily into them. Schuler expands this idea by proposing the joining of the parts by means of a shrink fit. Trumpf takes it a step further, suggesting the use of hollow journals which are then joined by laser welding with the individual forged parts.

LIGHTWEIGHT DESIGN POTENTIAL IN POWER-SPLIT TRANSMISSION AND POWERTRAIN

The rotor shaft in the power-split transmission is designed as a two-part solution, **FIGURE 2**. The hollow shaft is joined with a press fit in the electric sheet stack carrier. Torque transmission inevitably requires a very thick-walled solution. The lightweight design solution here aims at guiding the bearing bending torque across a much larger diameter, namely the seat of the electric sheet stack, thereby achieving an overall mass reduction.

Further down the powertrain, there is a slide joint in the half shaft. The outer side of the joint (tripot, **FIGURE 2**) is round and turned on the outside. The lightweight proposal aims at forging an outside contour that follows the inner side. In so doing, the wall thickness remains sufficient for induction hardening on the inner side. Another source of lightweight design potential that has not yet been quantified is achieved by forging the part from the steel 50CrMnB5-3 (H50) 1.7136. This generates a higher core strength directly through cooling from the warm forging heat than that of the induction-hardened carbon steel used in the part. This could improve the load-bearing capacity of the surface and thus enable the joint to have a smaller design.

The connecting flange that connects the output of the differential transmission with the half shaft (this is fastened to the flange of the joint housing mentioned above) could likewise lead to a mass saving of approximately 10 %. Here, San Grato suggests a deeper cavity which can be produced cost-efficiently by means of forging.

In the analyzed vehicle the connection between the inner and outer side of the constant-velocity drive shaft is achieved by means of a solid shaft. In the weight-optimized proposal, the half shaft is produced as a hollow design by means of swaging a tube.

LIGHTWEIGHT DESIGN POTENTIAL IN THE ELECTRIC REAR AXLE DRIVE

The first lightweight proposal in this application area aims at assembling six instead of four bevel gears in the differential, **FIGURE 3**. In this way, the torque transmission is distributed across double the number of gear flanks, and the entire system can be designed significantly smaller.

The input gear is fastened on the outside of the differential housing. Here, the proposal from Hirschvogel addresses material savings beneath the tooth root in the areas where less torque is transmitted to the teeth by design. Furthermore, by means of piercing during the forging process, it is possible to produce a contoured borehole which saves weight between the mounting holes. Here, too (as with the conrod), the case-hardening steel 16MnCrV7-7 (H2) 1.8195 with cost-efficient alloying elements for increasing hardenability could further raise the load-bearing capacity of the gears through higher tooth strength. For gear components, Daido recommends its DCDG steel, which demonstrates a 40 % higher pitting strength and a 20 % higher tooth

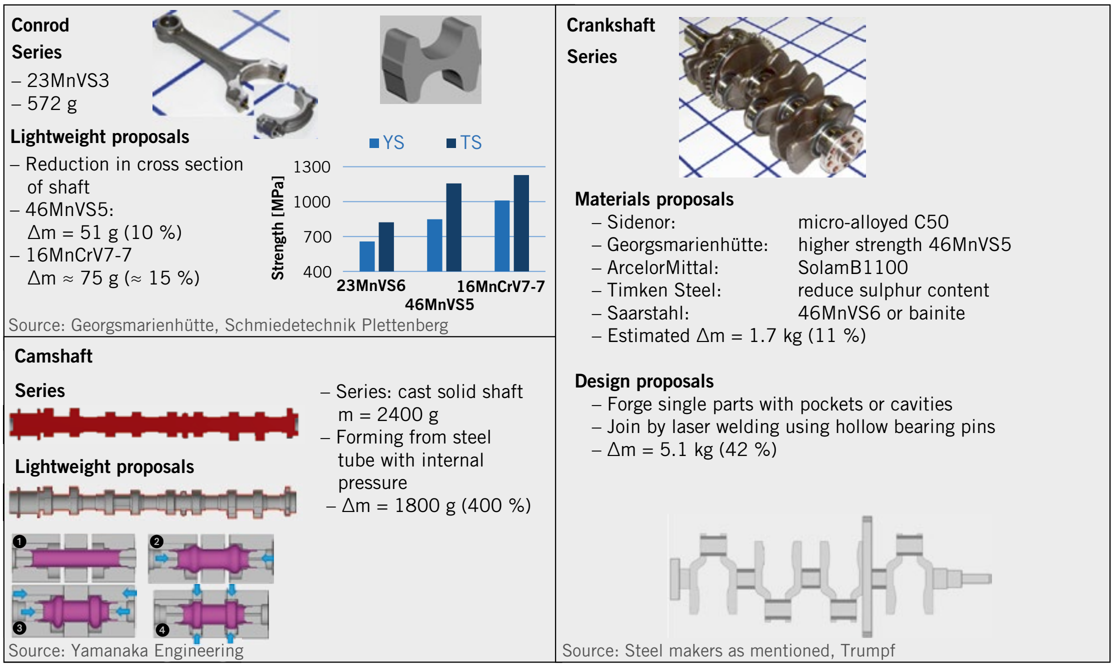

FIGURE 1 Lightweight design potential in the combustion engine of the split-axle hybrid drive (© Lightweight Forging Initiative)

root fatigue strength, thereby allowing smaller and lighter dimensioning.

Timken Steel provides quantifiable data in its lightweight proposal that can be applied to several power-transmitting components [2, 3]. One component, previously made from a case-hardening steel of the ME grade, can withstand loads on the flank that are 300 MPa higher when using ultraclean steels. Depending on the load state of the components, mass savings of 10 to 30 % are possible.

In the analyzed car, the input gear is joined to the differential transmission using several threaded fasteners. Trumpf proposes edge-to-edge laser welding, which would lead to a material saving of 1 kg.

The carrier which connects the differential to the chassis frame is made of cast iron and weighs 6.56 kg. Bharat Forge, Hammerwerk Fridingen, Hirschvogel and Lasco suggest weight-optimized versions here, which could achieve a weight saving of 10 to 20 %.

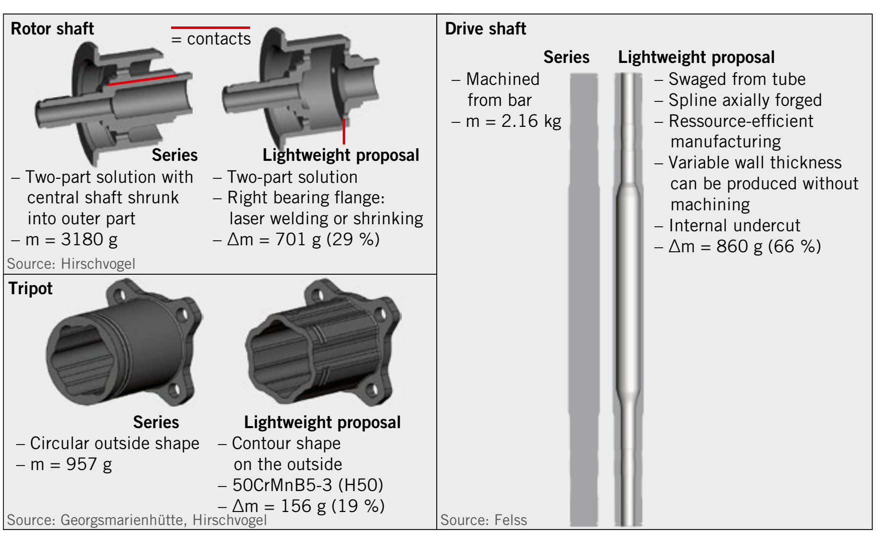

FIGURE 2 Lightweight design potential in the power-split transmission and in the downstream powertrain (© Lightweight Forging Initiative)

Hirschvogel and Leiber propose switching to forged aluminum, which should lead to a mass saving of 30 %.

LIGHTWEIGHT DESIGN POTENTIAL IN THE CHASSIS

One suggestion concerns the stabilizer, **FIGURE 4**. In the vehicle this is a bent tube with a constant wall thickness. Benteler suggests using a tube with variable wall thickness as a starting material. In this way, the highly loaded arc areas demonstrate a larger wall thickness, while those parts subject to fewer loads have a thinner one. With this load-oriented design, 1.55 kg of weight could be saved in the stabilizer. Voestalpine proposes using a high-strength spring steel for this part in order to render it more lightweight.

The damper strut bearing in the analyzed vehicle is a complex assembled part comprising several joined steel sheets. Here, switching to an aluminum forged part could lead to a weight saving of approximately 200 g.

The direct connection of the chassis to the driver, the steering system, likewise offers lightweight design potential. Here, Yamanaka Engineering suggests forging the steering rack over a mandrel using a tube as raw material. The forging group of Nissan agrees with this approach, but without the

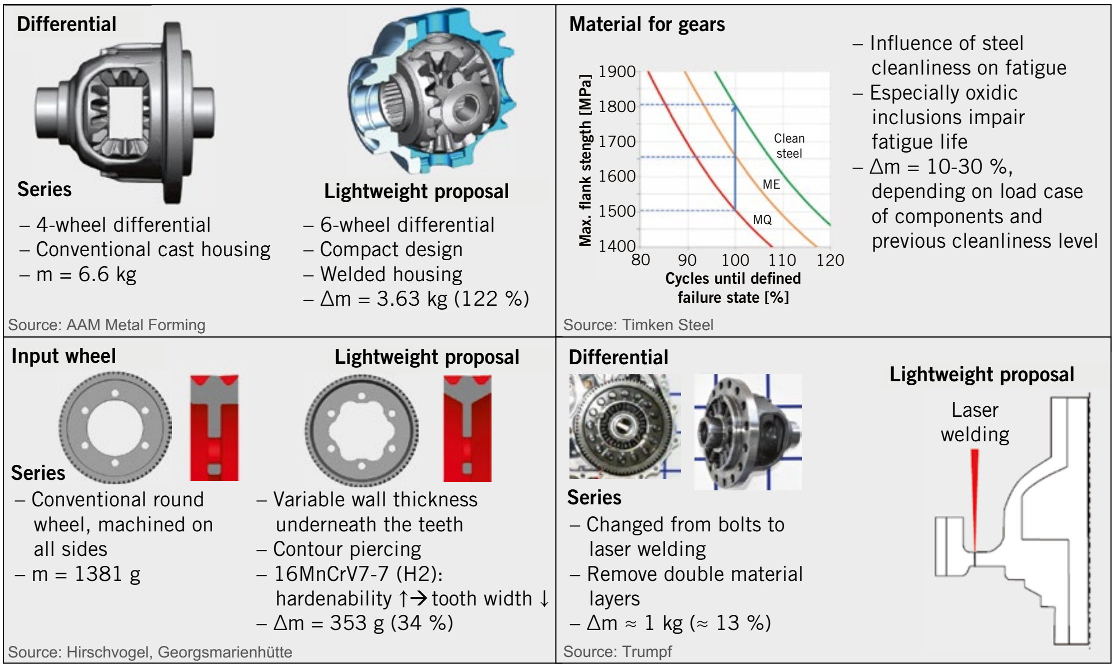

FIGURE 3 Lightweight design potential in the electric rear axle drive (© Lightweight Forging Initiative)

supporting mandrel. Hollow forging processes for such components are already in use. JFE suggests using a high-strength steel in the gears in order to achieve smaller and thus lighter overall dimensioning.

Steering knuckles and wheel carriers made of cast iron, **FIGURE 5**, can be replaced by forged aluminum with barely any geometrical changes, as very similar strength values are achieved. Depending on requirements, small adjustments to the geometry may be necessary in order to achieve the same stiffness values in the part. From a forging standpoint, a geometrical optimization of the components would be beneficial for increasing quality.

The rear transverse strut can also serve as a lightweight design example. Switching from a welded steel sheet design to a forged aluminum solution generates greater flexibility when it comes to stiffening elements, so that in spite of the lower Young's modulus, a weight saving can be achieved while attaining increased longitudinal stiffness.

In the case of the wheel hub, several suggestions based on the rotationally symmetric part aim at removing material from the round outer side. Cotarko suggests piercing openings in the flange, an operation which can also be carried out on the forging press. Lightweight proposals based on design concepts were also put forward: Replacing the connecting pot of the brake disk with the star-shaped arms of the wheel hub not only offers assembly space savings across the width but also a significant lightweight design potential.

LIGHTWEIGHT DESIGN POTENTIAL IN A HEAVY-DUTY COMMERCIAL VEHICLE

During the third phase of The Lightweight Forging Initiative, the heavy-duty truck segment was also analyzed in order to demonstrate the lightweight design potential offered by forging in this application area, too. Based on the transmission, a propeller shaft and a rear axle, numerous mass saving possibilities are revealed. Here, the rear axle is a welded design comprising a central cast part, a brake carrier and a hollow axle stub.

The brake carrier at the rear axle used in this assembly is a very planar forged part. The lightweight proposal shown in **FIGURE 6** aims at concentrating material on the load paths only. Piercings and indentations as well as filigree structures can be introduced during forging without any great effort, so that a considerable mass reduction of 29 % is achieved for a component with a series mass of 10.32 kg.

The connecting flange of the propshaft is largely designed as a rotationally symmetric part. From a forging standpoint, it is easy to remove material areas subject to less load in order to thereby generate a lighter part.

Even when retaining the rotational symmetry it is still possible to achieve clear weight savings in the transmission area, as the countershaft application shows. Here, Linamar Seissenschmidt proposes switching from a solid to a hollow shaft. Starting with tubular material, a hollow form can be produced by means of swaging. Richard Neumayer suggests generating mass savings in direct proximity to the shafts by means of more pronounced contours on the gearwheels in the transmission.

Kamax sees lightweighting potential in the heads of fasteners through the use of an internal hex, which can also bring advantages during assembly, too. Significant weight savings can also be achieved by using a high-strength material with a strength class of 15.9U, taking into account all boundary conditions (for example hydrogen resistance). Lightweight design potential achieved with high-strength fasteners is also seen by steel manufacturer Nippon Steel through the use of a steel with good resistance to hydrogen embrittlement. Overall, the study identified a lightweight design potential of 124 kg for the heavy-duty truck.

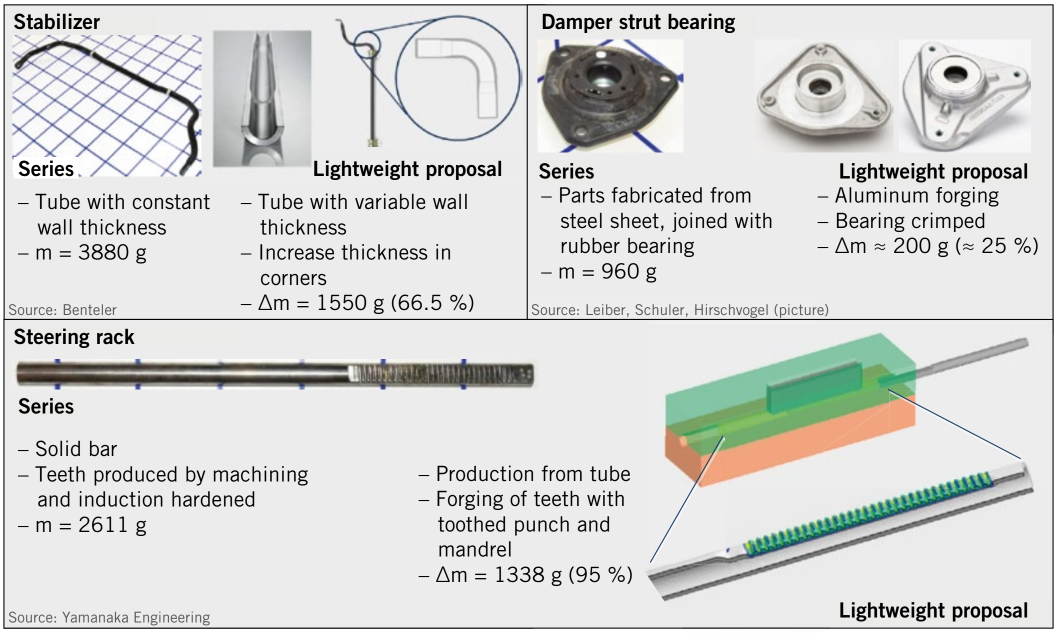

FIGURE 4 Lightweight design potential in the chassis – stabilizer, damper strut bearing and steering rack (© Lightweight Forging Initiative)

OVERALL CONCLUSION

Even though forging is the oldest metal production technology, the industry continuously works on creative further developments – ones that can also be used for achieving optimizations in the area of lightweight design. This applies both at industrial level, as shown by the numerous examples outlined here, as well as in academic contexts. The latter is demonstrated by the "Lightweight Forging" Research Network, which was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) for a duration of three years (from 2015 to 2018) [4].

Through the interplay of improvements achieved by means of material and production technology concepts and the involvement of all process chain partners, it is possible to generate significant lightweighting advances, as shown impressively in the examples. The companies of the steel and forging industries can accompany their customers in mastering these challenges.

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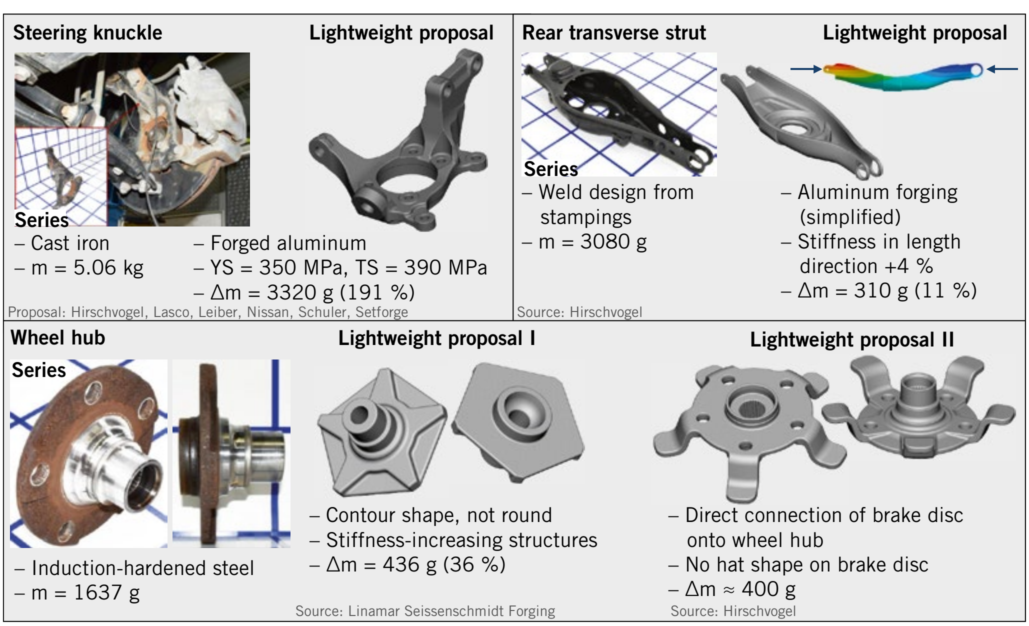

FIGURE 5 Lightweight design potential in the chassis – steering knuckle and wheel carrier, rear transverse strut as well as wheel hub (© Lightweight Forging Initiative)

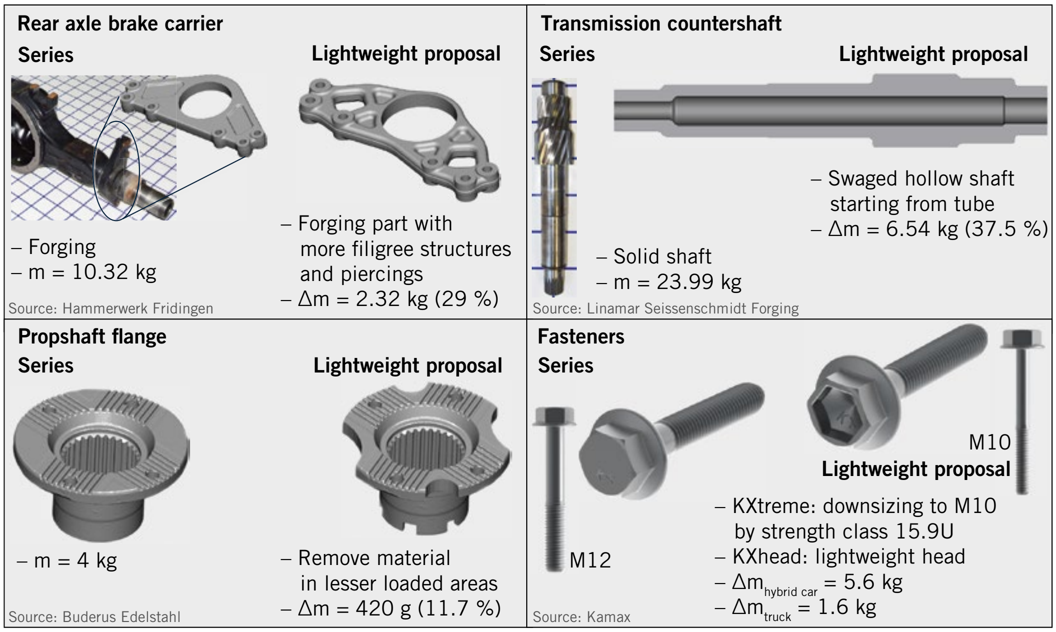

FIGURE 6 Lightweight design potential in the heavy-duty commercial vehicle powertrain – rear axle brake carrier, transmission countershaft, propshaft flange and fasteners (© Lightweight Forging Initiative)