Driving Towards The Sustainable Car Engine Of The Future

By Mark Stephenson, MAHLE Powertrain Ltd.

MAHLE Powertrain's 3-cylinder, 1.2 liter, extreme-downsized, demonstration engine (I3) has been installed in two VW Passats for test driving. The 50-percent downsized unit generates 160 hp, gets 49 UK-miles-per-gallon, meets EU6 CO_2 standards, has CO_2 emissions of only 135 g/km, and was designed with the aid of an extensive suite of simulation software tools.

Stricter standards for fuel consumption and emissions are leading all of us in the automotive industry to go beyond what we have done in the past. At MAHLE Powertrain Ltd., for instance, our R&D effort now includes both extreme-downsized internal combustion engines and range extenders for electric vehicles. Yet pushing the creative envelope in such new areas can bring its share of design challenges.

As a Tier 1 automotive supplier that designs and develops engines, MAHLE must always meet the expectations of our OEM customers. We do this while balancing a variety of tradeoffs such as the underlying regulatory, cost, production, and business hurdles of weight, durability, friction, emissions, and efficiency. Plus, we have to meet time-to-market demands. Our go-to toolset in balancing all of these targets efficiently is computer-aided engineering (CAE), the main design driver that underscores our entire development process.

Simulation up front

We start every product development program with a cycle simulation to determine exactly what engine configuration and technology our customers are looking for. Moving to CAD, we turn to concept-level models for information on package volume, costs, and weight. Once a concept is chosen, we manage the models using Product Lifecycle Management (PLM). For fluid studies, we utilize several 1-D tools to help avoid and reduce pressure losses in the oil and cooling systems. To guide design of the combustion chamber and related systems, we employ Computational Fluid Dynamics (CFD) for insight into very complex 3-D behavior.

We incorporate structural analysis of our conceptual ideas early on in the development process, using Abaqus Finite Element Analysis (FEA) as the main workhorse for our thermal and stress queries. These studies help us investigate ways to reduce weight and friction of components, such as the crank train, connecting rods, bearing panel, and bearings. For preprocessing, fatigue analysis, and crank train dynamics, we are able to couple other tools seamlessly with Abaqus without worrying about integration, as they can all use or generate native Abaqus data.

Each tool in our extensive library of software is hand-picked for its specific complementary capabilities, and our team of designers and analysts is cross-trained for maximum flexibility. Our design engineers are capable of using numerous CAD programs—virtually whatever our customer uses.

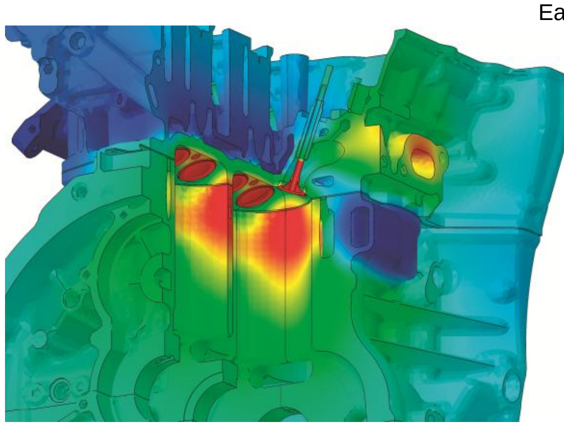
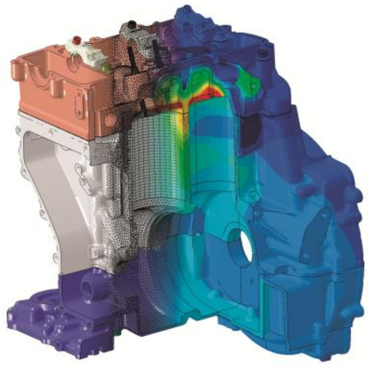
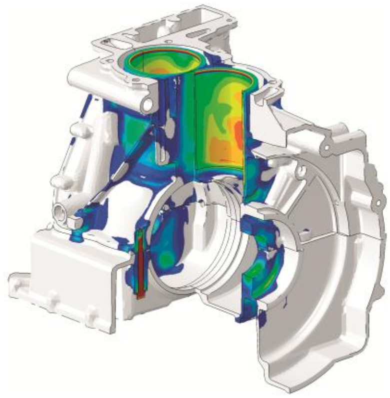


Figure 1. The 3-cylinder design for MAHLE's downsized engine (shown here in cross section on left) generates the power of a 6-cylinder engine, necessitating the need for structural and thermal optimization (right) to ensure that the engine can sustain the stresses of running at higher loads.





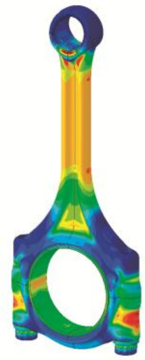


Figure 2. Abaqus FEA was employed extensively for structural and thermal analyses during the design of MAHLE's range extender (REx) engine for electric vehicles. Pictured is the engine assembly finite element model and temperature distribution (left), stresses on the engine block and crankcase (center) and connecting rod stresses due to combustion pressure (right).

Meeting the performance and efficiency challenge

In our downsized engine program (which started about four years ago), if fuel efficiency had been the only engineering challenge, finding solutions would have been much simpler. But car buyers everywhere refuse to give up performance, so our team was forced to find ways to deliver both horsepower and fuel efficiency. For boosting power in a small engine, direct fuel injection and turbocharging were critical add-ons. To cut fuel consumption, both weight and friction were methodically reduced wherever possible. Since nearly every manufacturer is investing in downsized options—shrinking their engines typically about 20 to 25 percent—we decided to go to the extreme to show what's achievable. Working with Bosch-MAHLE Turbo Systems as a partner, and relying on extensive trade-off studies and design iterations, we developed a 3-cylinder (I3), heavily-boosted, 50-percent downsized engine with the same horsepower as a 6-cylinder one [see RSN, Issue No. 9, January 2010, pages 16-18.] With power gains like this, structural FEA was key for ensuring durability of components, such as the crank train and bottom end of the engine. And thermal optimization was vitally important as well for an engine running at such high specific loads (see Figure 1).

Even now with working prototypes of the I3 in demo vehicles on the road, we continue to refine our downsized concept, investigating a long list of additional friction-reducing technologies: a lower-friction valve train; improved pistons, ring packs, and bearings; a variable displacement oil pump; cooled exhaust manifolds; and enhanced boosting and intercooling. We are also looking at variable valve timing, variable valve lift, and exhaust gas recirculation. In every case, we rely on simulation to measure and evaluate the benefits of these technologies.

Extending the range of electric vehicles

A more recent design effort has involved the development of an engine for electric vehicles that addresses the common issue of insufficient range. Range extenders (REx)—in which a small gas engine is used to recharge the battery—provide a good alternative to the traditional electric hybrid model. In these designs, extender size and thermal issues (since the engine is typically positioned directly under the passengers' seats) are the crucial areas that our engineers are focusing on.

Figure 3. MAHLE's REx is a gasoline-powered engine that is used to recharge the batteries of a more traditional electric-powered vehicle. To arrive at a durable, lightweight carry-on-luggage-size footprint, designers used extensive structural and thermal simulation in conjunction with optimization studies.

For the REx engine, the primary challenge has been one of balancing size and weight with durability and cost. Structural analysis has played a major role in this optimization (see Figure 2), with simulation helping us choose cost-sensitive, lightweight-yet-durable materials for components such as the crankshaft and block. The end result is an extremely compact, carry-on-luggage-size internal combustion unit that can be integrated into a more typical electric vehicle (see Figure 3).

The fundamental value of simulation can be plainly seen in the specifications of our new designs. Our REx has met target performance on the test-bed with a theoretical range of 400 miles (650 km) on 8.8 UK gallons (40 liters) and promises to provide an alternative to most market-ready hybrids. The I3—currently installed in two demo VW Passats for test driving—meets EU6 legislative requirements with 49 UK-miles-per-gallon (30 percent savings), CO_2 emission of just 135 g/km, and a responsive 160 horsepower, garnering interest from customers and industry alike.

Meeting market demands

In engine R&D, technology targets are all important. However, as in most industries, so are development deadlines. For the REx, we took only 12 months from a clean-sheet-of-paper to the building of the first prototype. For the I3, it was an even more aggressive nine months. Just five years ago, before we adopted simulation, those times would easily have been almost double. If we weren't fully invested in the software tools and were trying to solve these engineering puzzles with prototypes alone, we wouldn't stay competitive.

Already, CAE and simulation are helping us push the limits of engine technology and move toward a more energy-efficient automotive fleet—with aggressive downsizing, improved fuel efficiency, and lower CO_2 emissions. In the future, standards will only get tougher, and simulation will be even more essential as engine developers work hard to stretch technology boundaries in creative and exciting ways.

About Mark Stephenson

Mark Stephenson is responsible for the analysis team at MAHLE Powertrain Ltd.(Northampton, Great Britain), one of the world's leading automotive powertrain consultancies and part of the MAHLE Group. He oversees a department of six dedicated analysis engineers that carry out structural, thermal, dynamic, and fluid flow analyses on all aspects of the engine and its components.

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