

Delphi looks into diesel's future

Powertrain developers are facing a challenging future, with stringent regulations leading to the reduction of emissions in Europe, the U.S., and other major markets a continuing top priority. Governmental authorities commissioning construction projects or licensing mines are also increasingly requiring very high standards of environmental care, not only via low emissions but together with a raft of other aspects, including operator conditions, to make powertrains cleaner, quieter, and more refined.

The off-highway market already has a head start in CO₂ reduction because of the predominance of diesel powertrains. For medium-duty applications, **Delphi's** Multec DCR fuel-injection system (already used by **JCB**) incorporates fast servo-solenoid injectors that, Delphi claims, allow the smallest injection quantities and highest precision fuel delivery of any common rail system currently available, including those using first-generation servo-piezo injectors, to provide added power with lower emissions, plus fuel economy and refinement improvements.



Delphi's electronic unit injector can be integrated with engine and vehicle control software, sensors, and aftertreatment.



For use in selective catalytic reduction systems, Delphi's ammonia sensor measures ammonia levels in the exhaust gas, which allows for the precise dosing of urea.

For heavy-duty applications, Delphi has developed an electronic unit injector (EUI) with what it describes as a unique two-valve design that allows rate shaping and very fast multiple injection events. An electronic unit pump (EUP) derivative, with separate cam-driven pumps and "smart" electronically controlled injectors, provides additional packaging flexibility for engine designers. Both the EUI and EUP systems are extremely robust and hence suited to the variable fuel qualities and demanding operating conditions of the off-highway market.

At Delphi's laboratories in London, engineers are working on a new hybrid system that combines the best of both common rail and EUIs/EUPs to deliver even higher fuel injection pressures—potentially beyond 2500 bar (36 ksi). Delphi says its design is optimized to increase control of fuelling events, which would facilitate substantial reductions in noise and fuel consumption as well as lower NO_x emissions.

The London Technical Center is also working on a new high-pressure common rail system (HPCRS) for medium-duty engines that will initially operate at 2400 bar (35 ksi) and provide a high level of control over multiple injection events with enhanced hydraulic stability.

"Control is critical if we are to achieve low noise, low fuel consumption, and low emissions," said David Friday, Director of Delphi's diesel heavy-duty business unit. "A lot of our research is focused on how to manage ever tinier amounts of fuel in increasingly small time windows, and how to manufacture the fuel-injection systems to the exceptionally precise tolerances required to ensure accuracy and durability."

Delphi is also looking ahead to new areas of legislation. "With the growth of diesel vehicles using intensive selective catalytic reduction [SCR] to reduce NO_x, ammonia emissions represent a potential problem that we want to help our customers address before it becomes an environmental issue," said Guy Hachey, President of Delphi Powertrain and Vice President of Delphi Corp.

To answer that challenge, the company has developed what it claims as the world's first automotive ammonia sensor, a technology that enables direct closed-loop control of the SCR system. By measuring tail pipe ammonia, the sensor allows the injection of urea (an ammonia-rich compound required by the SCR system) to be optimized and ammonia emissions reduced. Control of urea injection is expected to become a rapidly increasing priority as SCR levels rise to meet new emissions regulations. Delphi has also recently launched a new type of oil condition sensor designed to "greatly extend" change intervals.

No matter how efficient an engine is, it is still dependent on its fuel, and increasingly this will have high bio content.

"In Europe, there is almost no use of the bio-ethanol fuels popular in North and South America, but a substantial and growing use of biodiesel, which is well suited to heavy-duty off-highway applications," said Julie Galante-Fox, a Delphi bio-fuels specialist. "Usually made from rapeseed, a 20% blend of bio and mineral diesel [B20] can reduce smoke and particulates by 10 to 20%, and carbon monoxide by up to 20%, again due to the relatively high oxygen content of the biofuel."

Figures such as these have encouraged the European Commission to issue Directive 2003/30/EC, which sets an indicative target of 5.75% renewable fuel (by energy) for transport applications by the end of 2010 and 8% by 2015. Biodiesel is biodegradable, so it is less environmentally damaging if spilled, but it has some minus elements, said Galante-Fox.

It can degrade very quickly in storage, particularly if held in moist or warm conditions. It is more susceptible than other fuels to the growth of bacterial content, and it can pick up water, which accelerates chemical degradation. It is also an excellent solvent—dissolving existing deposits from distribution pipes and tanks and carrying it into the tiny conduits of the fuel system.

Insoluble polymers and products of age-related degradation can lead to injector coking, filter clogging, and deposits in the fuel system, she explained. It also attacks many widely used materials groups, particularly the elastomers used in hoses, gaskets, and seals. Peroxides, an oxidation product formed when the biodiesel reacts with oxygen, can lead to embrittlement of some elastomers, which may also become soft or swell.

To further understand these challenges, Delphi has initiated a number of research programs. "Biodiesel presents a considerable list of challenges for fuel system engineers," said Detlev Schoeppe, Delphi Diesel Director of Engineering based in Paris. "We also have to accommodate considerable variation in both



Guy Hachey, President of Delphi Powertrain and Vice President of Delphi Corp.: "With the growth of diesel vehicles using intensive selective catalytic reduction to reduce NOx, ammonia emissions represent a potential problem that we want to help our customers address before it becomes an environmental issue."

physical and chemical characteristics as the fuel properties are heavily dependent on the production materials and the quality of delivery and storage." Currently all Delphi diesel fuel systems are compatible with B5 (5% bio content) and the company is developing injection systems compatibility with significantly higher biofuel contents.

"There is a long road ahead of us, starting with better versions of today's technologies and taking us through to engines running on new types of fuel, possibly with electric assistance so that kinetic energy can be captured," said Steve Gregory, Delphi's Business Line Manager, Medium-Duty Diesel Injection and Engine Management Systems. "The challenge is to provide the required improvements without compromising price or reliability. For Delphi, that means extracting more from proven technologies and only introducing innovative solutions such as piezo injectors when they bring benefits that cannot be achieved in a more cost-effective way."

Stuart Birch

Taking the next step in test plant integration

A.J. Martyr, Director of **AVL** UK, Leader of AVL Group System Integration, and surviving author of the third edition of *Engine Testing*, discussed some of the book's main themes and challenges facing the engine testing industry during April's **SAE** 2007 World Congress.

Martyr, who teaches subjects related to project control and test plant system integration, has designed test facilities all over the world in his 40 years in the industry. In *Engine Testing*, Martyr offers an updated view of the engine-testing landscape and provides today's engineers—who often have extremely specified skill sets—a complete view of the discipline.

In his remarks, Martyr brought to light many of the problems faced by engineers tasked with managing the construction or upgrade of test facilities.

He said the primary issue related to test-plant integration lies at the start of the process in the creation of the test-facility specification. As engineers have become more specialized and older engineers with a more complete view of the process have entered retirement, drafts of customer specifications have suffered.

"The first thing is, they lack a clear operational requirement," Martyr said. "I think this is evident because there's a lack of senior involvement. The task of writing specifications seems to get passed down through the chain."

According to Martyr, the specification often reads like a shopping list, which can be difficult to deal with due to incom-



A.J. Martyr, Director of AVL UK and Leader of AVL Group System Integration, discussed the problems associated with managing the construction or upgrade of test facilities at the SAE World Congress.

patibilities. "They will list the existing equipment they have, new equipment they want to get, etc. It provides you with a challenge," he said.

A trend has also developed for the lack of appreciation for the importance of integrating modern instrumentation in building services. This problem is often encountered when dealing with joint ventures of large companies in India and China.

Companies often also fail to realize the possibilities available with next-generation equipment and do not take advantage of the test equipment that they should.

"If you're spending \$1.6 million on a state-of-the-art highly dynamic engine testbed, you really ought to keep it running most of the time," Martyr said.

Matt Monaghan

Honda aims at growing backup market

Honda Power Equipment is making a play to gain market share in the rapidly growing market for portable electric generators, coming out with a line that is significantly smaller and quieter than its predecessors.

The EU6500is features reduced size and weight so it is easier to store and retrieve when it is needed. "We're offering a 33% smaller footprint and a 35% reduction in weight," said Dan Sherlock, Product Planning Director at Honda Power Equipment. At 253 lb (115 kg), it's a third lighter than its predecessor, the EX5500.



Honda's 6500-W generator is compact, cutting size and weight by about a third.



The generator provides both 120- and 240-V output.

The move is driven in part by rapid expansion of the market, which has surged since the advent of rolling blackouts in California and the lengthening of power outages caused by blizzards, hurricanes, and other storms. "Home backup sales have increased 26% in the last five years," said Sherlock.

While size was a key factor during the development cycle, quiet operation is perhaps the most significant aspect of the design. All aspects of the generator were examined to reduce noise generation.

"In the past, sound was deadened with heavy insulation. We've addressed it in many ways," said Sherlock.

Honda redesigned the intake chamber, exhaust, air intake, and other elements of the four-cylinder GX390 engine to lower noise. The intake is not generally considered a high noise factor, but engineers devised ways to reduce noise generation from incoming air, employing a triple chamber construction and burying both the intake and exhaust inside the unit.

"The air comes in from the bottom and the intake chamber has a smooth surface for lower noise," said Sherlock. The exhaust chamber is housed in the body of the generator so it is not exposed, improving safety while reducing noise, he added.

Developers also lined doors and other openings with rubber gaskets to dampen sound, augmenting door seals with spring-loaded locks. "This is only 60 db; that's a conversational level," Sherlock said. That is a reduction of 5 dB(A) at rated load.

The EU6500is provides 6500 W of commercial grade electricity with a wave form distortion factor of less than 2.5%. A voltage selector switch makes it simple to switch between 120- and 240-V outputs, which are protected by internal circuit breakers.

This clean output comes without burning a significant amount of fuel. Honda's Eco-Throttle technology and a high-efficiency inverter design combine to reduce fuel consumption by 30% at ¼ loads when compared to the EX5500. It can operate for 14 h on 4.5 gal (17 L) of gasoline.

The generator requires minimal upkeep. "The cost of ownership is low," said Sherlock. "There's no oil filter, no radiator, and we've got a maintenance-free battery that's smaller than previous models."

Terry Costlow

Off-highway meets F1

Most aftertreatment systems rely not on chemical dosing but on a chemical reaction taking place at high temperatures. That fact can pose a significant problem for off-highway applications in which periods of idle or low-load operation allow catalysts to cool below their effective operating temperature.

"We've already started to look at [that problem], using whole-vehicle drive cycle simulations in our Variable Temperature Emissions Chamber," said Mark Coverley, Deputy Managing Director of European test specialist **Millbrook**. "We are ready to apply solutions developed for bus operators, which face similar problems, but there is increasingly a need for a new approach."

One possible answer is a ceramic coating originally developed for the British nuclear energy program. Applied by high-temperature plasma spraying, it provides a thermal barrier that keeps heat within the exhaust system. According to Andy McCabe, Technical Director at process developer **Zircotec**, the technique had been proven in the demanding

environment of Le Mans racing and **Formula One** and is now available for wider application.

"As aftertreatment systems stack up, close coupling becomes more difficult and efficiencies can decline," he said. "The efficiency of particulate traps may suffer if their temperature is not kept very high, which can be an increasing problem as more and more particulate filtration is required to accommodate growing use of high EGR [exhaust gas recirculation] ratios. Zircotec's plasma-sprayed ceramics provide a durable, affordable thermal barrier that keeps the heat where the designers need it, allowing the most efficient working temperatures to be maintained and possibly even a reduction in the precious metal content of some catalysts."

Such programs indicate the shift in emphasis and the increase in sophistication now required for successful powertrain engineering. At Millbrook, Coverley sees this trend via test and development work.

"Our off-highway activities have traditionally focused on

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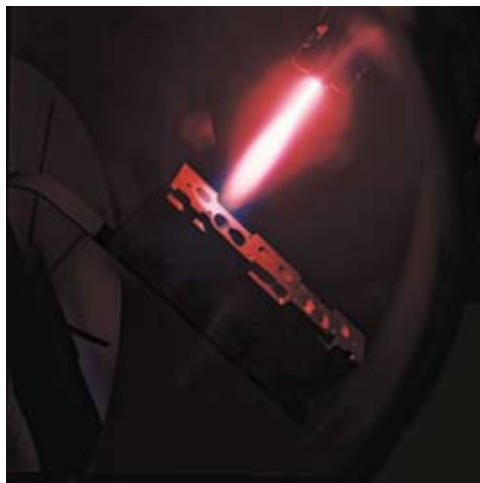
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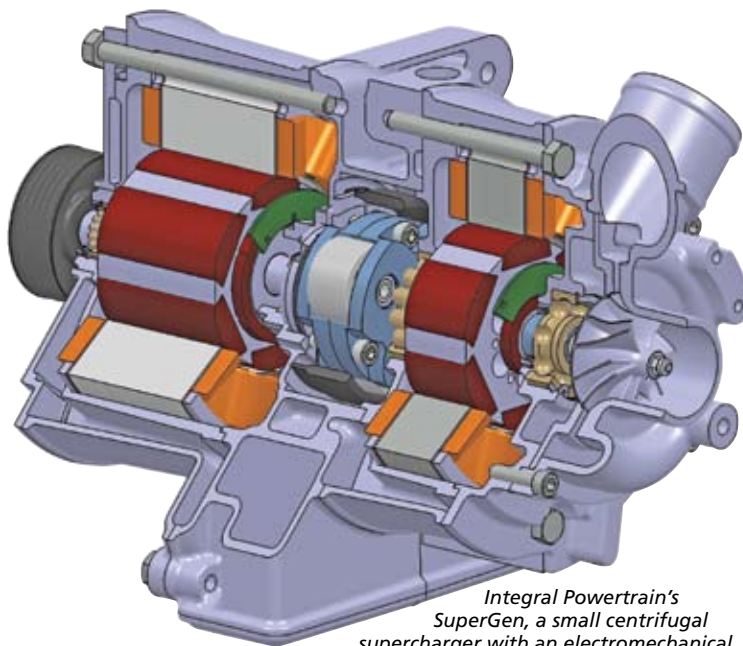
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Zircotec's plasma spray process could be used to provide a durable thermal barrier that keeps heat with an exhaust system.



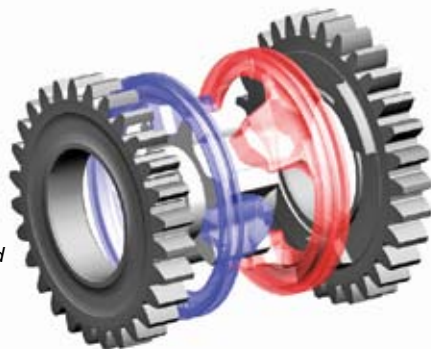
Working hard for reduced emissions

At UK engineering consultancy **Integral Powertrain**, specialists in boost systems, Technical Director Luke Barker says there had been an increase in the use of twin-stage forced induction systems to improve both range and response in high exhaust gas recirculation applications, where lower exhaust tempera-



Integral Powertrain's SuperGen, a small centrifugal supercharger with an electromechanical drive system, is placed in series with a conventional turbocharger.

A pair of interlocking rings, each incorporating the three drive elements in a single forged component and operated by new, lightweight shift forks are at the core of the Zeroshift transmission.



safety and capability assessment, but we are now seeing rapid growth in emissions testing, noise reduction, and fuel consumption optimization," he said.

Millbrook can measure emissions in the field, with a whole vehicle in its Variable Temperature Emissions Chamber, or by simulating the vehicle and drive cycle on its engine test dynamometers.

Also significant is the increased emphasis placed on care of employees. "This year, we are seeing substantial growth in the analysis and reduction of NVH," he said. "Duty of care and new European legislation dealing with vibration at work, is focusing the users' attention on providing a working environment for drivers that is not just safe in an impact or rollover, but also provides long-term protection for the driver's health."

At the heart of these requirements is the propulsion system. But performance and overall engine output and efficiency are also musts.

Stuart Birch

tures mean there is less energy available to the turbine. "However, some customers are looking for boost response times in the order of 0.1 to 0.3 seconds and for this we have to look at a different approach."

The company's solution is a boost-assist device to decrease response times. Now under development, SuperGen, is a small centrifugal supercharger with an electromechanical drive system that is placed in series with a conventional turbocharger.

Another solution to reducing emissions and improving fuel consumption is to keep the engine working hard, at its most efficient operating point, by downsizing to a smaller but more efficient unit. This feat can be achieved without reducing performance by either increasing engine efficiency—one of the solutions being developed by Integral Powertrain—or by making more efficient use of the available torque. Replacing a manual or automated manual transmission (AMT) with a fully automatic transmission allows gear changes without torque interruption, which can provide a worthwhile improvement in performance to provide added acceleration or reduction in fuel consumption.

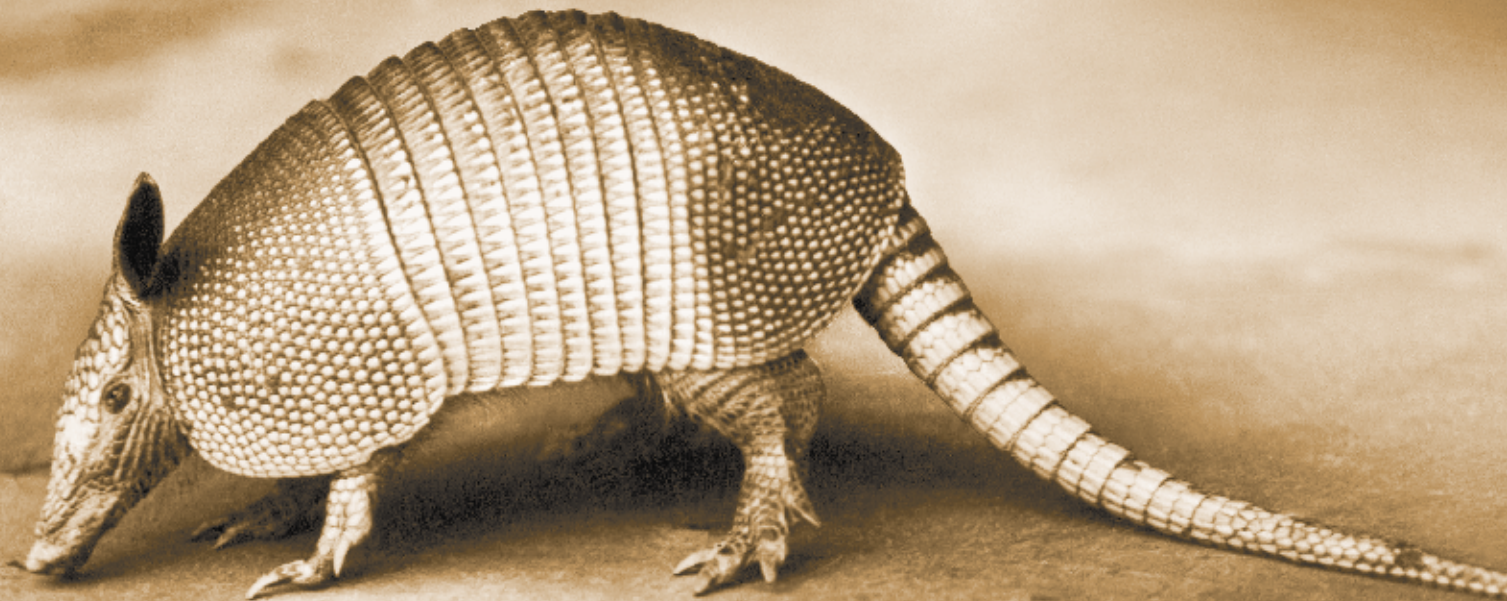
"We predict that our technology will allow significant downsizing of heavy-duty off-highway engines," is the confident statement of Bill Martin, Managing Director of **Zeroshift**, a UK company that is developing a new transmission that combines the compactness and cost benefits of an AMT with the smoothness of a conventional planetary automatic. "It will generate a fuel economy saving of at least 7%, with a comparable reduction in CO₂ emissions."

The first-generation Zeroshift transmission was pneumatically operated and used six drive elements—specially contoured metal "bullets"—to engage and disengage the drive gears in a similar manner to dog clutches, replacing the synchromesh found in a conventional manual gearbox. In the second-generation system, launched with a paper delivered at the 2007 **SAE** World Congress, these have been replaced by a pair of interlocking rings, each incorporating the three drive elements in a single forged component and operated by new, lightweight shift forks. The control system, also developed and calibrated by Zeroshift, coordinates gearshift actuation, engine management, and clutch operation to provide full control over the driveline during gear shifting.

Stuart Birch



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EPA official focusing on smooth implementation

Much progress has been made in terms of vehicle emissions, but more needs to be done—via regulation or otherwise. That roughly sums up the multifaceted answer given by the Director of EPA's Office of Transportation and Air Quality (OTAQ) to the question, "Has the U.S. reached the point of diminishing returns as it applies to vehicle emissions regulation?"



A frequent figure at the SAE World Congress, the EPA's Margo Oge has been Director of the Office of Transportation and Air Quality for 12 years.

Margo Oge began a discussion of diminishing returns by pointing out that in her 12 years as Director of OTAQ, the EPA has put into place three major vehicle emissions regulations that, combined, have brought about \$170 billion in health care benefits nationwide at an annual cost to industry of \$8 billion to \$10 billion. Those regulations include one that limits emissions for light vehicles, one that limits emissions from heavy

trucks, and another that limits emissions from nonroad diesel-fueled equipment.

Regarding one of the major pollutants, NO_x, there are no current plans to reduce allowable levels, according to Oge, who has an engineering degree. But with changeover in the Congress and a presidential election coming up, "I cannot speak about future initiatives that this office will take."

Action on particulate matter is more likely, as recent research has revealed that the amount of that pollutant emitted by gasoline-fueled vehicles is higher than suggested by modeling, said Oge. "Well, what does that mean? We don't know what it means. So we are in the process of talking to the car companies and the oil industry" to assess the problem and develop a strategy for solving it.

Her priority for now is making sure that the Tier 2 light-vehicle emissions program is fully and smoothly implemented through the rest of its phase-in, "Because having clean cars when they are new is one thing, but making sure that cars stay clean for their useful life is what we all care about," said Oge.

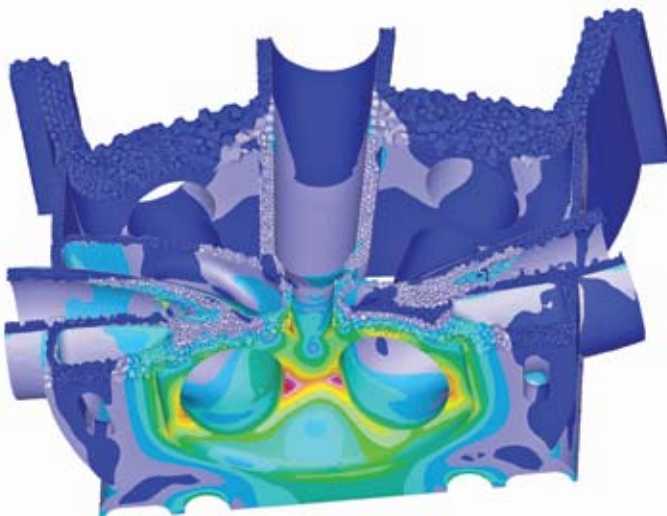
Number two on the priority list is the particulate matter situation. Third is the promotion of renewable fuels via "optimizing both cars and fuel so you don't have unintended impacts on criteria pollutants," Oge said. She noted that "climate change and energy security when it comes to the transportation sector go hand in hand." She also offered that "the pathways to improving the efficiency of the engine and increasing use of low-carbon fuels are not mutually exclusive."

The debate on climate change is no longer about whether it is happening; it is, Oge believes. And with a new Congress, "I strongly believe—and this is my personal view—that something is going to happen as far as figuring out strategies," be they focused on incentives or regulations, she said.

Patrick Ponticel

Flow, thermal, and stress simulation for engine cooling

Numerical flow simulation has long since displaced experimental flow visualization as the principal means of analyzing the coolant flow through prospective engine designs. Deployed early in the design process, CFD analysis now plays a critical role in defining the cooling concept for almost all engines.



Thermal stresses predicted in engine cylinder head.

Used effectively, CFD helps to improve the durability of the engine (by minimizing the influence of thermal stresses), demonstrate its thermal efficiency over the full range of operating conditions, and help to prevent knock.

However, despite its extensive use in engine design, the simulation techniques adopted by many practitioners to model an engine's thermal management remain relatively unsophisticated, either neglecting important physics or requiring extrapolation and mapping to structural analysis software to deliver temperature fields and thermal stresses.

Historical difficulties in creating a computational mesh for the complex solid geometries of the cylinder head and engine block mean that many water-jacket simulations are performed "cold," simulating only the flow of the coolant without directly simulating the actual heat-transfer process.

Deployed in this mode, CFD can be effective in ensuring that the flow throughout the coolant-jacket is balanced, with enough coolant being delivered to critical areas of the engine, such as around the cylinder liners and the exhaust valve bridge. Since the fluid volume of the coolant-jacket is particularly amenable to automatic meshing, designers are able to rapidly evaluate the effectiveness of a given cooling concept, over a full range of operating conditions, with little manual effort. Local flow deficiencies can be identified and the coolant-jacket design can then be adjusted accordingly.



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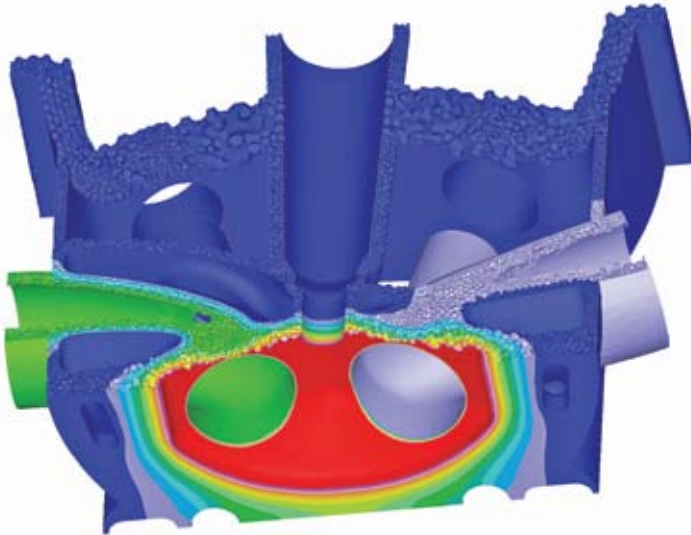


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Temperature contours predicted in engine cylinder head; not the polyhedral mesh.

Although thermal effects are not accounted for directly using this approach, the flow-field predicted in the cold simulation can be used to determine convective heat transfer coefficients, which are either interpreted directly, or passed as a boundary condition to a structural simulation of the engine, from which a temperature field and thermal stresses can be evaluated.

While this approach has some merit—and has formed the staple of engine cooling analysis for the last decade or so—it also has some serious shortcomings. As a consequence of highly rated downsized designs and structures with a low thermal inertia for emissions reduction, many modern engines either boil or are close to boiling in regions of the cylinder head. While controlled nucleate boiling can be desirable in increasing heat transfer rates, uncontrolled vapor generation and film boiling can lead to catastrophic failure or other engine damage. Simple “fluid-only” coolant-jacket simulations are incapable of reliably predicting where nucleate boiling might occur and, when it does occur, the influence it has on the flow distribution through the coolant passages.

Even when thermal effects are simulated, phase-change is typically not modeled directly. Boiling effects, if accounted for at all, are usually modeled using ad hoc modification of the wall heat transfer coefficient based on estimated local metal temperature—an approach that can significantly underestimate the actual heat-transfer to the coolant and lead to over-conservative (and thus less energy-efficient) design.

By far the largest obstacle to performing conjugate heat transfer (CHT) simulations of engines has been creating a computational mesh that accurately represents the complex geometry of the cylinder head, engine block, and coolant-jacket, and is suitable for simulation, resolving the many small passages and small features that define a typical engine. Although, out of necessity, a number of semi-automatic processes for meshing the complete geometry have evolved, until now none have been able to duplicate the rapid turnaround times typically achieved for coolant-only simulations, and thus have been reserved for a smaller number of “benchmark.”

To overcome this obstacle, and to enable routine CHT engine simulation, **CD-adapco** has invested heavily in developing a robust meshing methodology that allows users to automati-

cally generate a polyhedral mesh of both the liquid and solid geometries. This approach ensures that a conformal mesh is maintained at solid-fluid interfaces, guaranteeing one-to-one connectivity between cells at either side of the boundary, and removing the need for mapping or interpolation between the physical domains. To facilitate accurate resolution of flow and thermal gradients close to the interface, prismatic cells are automatically generated on the fluid side of the interface, and, if required, optionally on the metal side.

The input required from the user is minimal and, although the process is fully customizable, local modifications can be stored as a template, ensuring consistency with previous and future simulations. By adopting this approach, users are routinely able to perform a complete thermal simulation of the engine, specifying boundary conditions only at the inside of the cylinder liner and on the external surface of the engine.

The advantage of a fully coupled thermal simulation is that the temperature field, in both fluid and solid-domain, is updated on an iteration-by-iteration basis. Not only does this allow designers to immediately assess the influence of a change in cooling strategy on the temperature of the engine, but also the availability of coolant passage wall temperatures means that the CFD solution can also now include the influence of boiling.

Rather than rely on ad-hoc modification of wall heat-transfer coefficient, CD-adapco’s CFD solvers account for boiling explicitly, using a robust and validated model for sub-cooled nucleate boiling that models both the heat-transfer process and generation, transport, and destruction of vapor. Using this approach, powertrain designers are able to predict not only the onset of nucleate boiling (and the operating conditions under which it occurs), but how the cooling concept reacts boiling, both in terms of its influence on the flow-field and on the metal temperatures in the engine.

With the ability to accurately model the temperature distribution in the solid parts of the engine, in response to different cooling strategies and accounting for the influence of boiling, the only missing element is the ability to predict thermal-stresses.

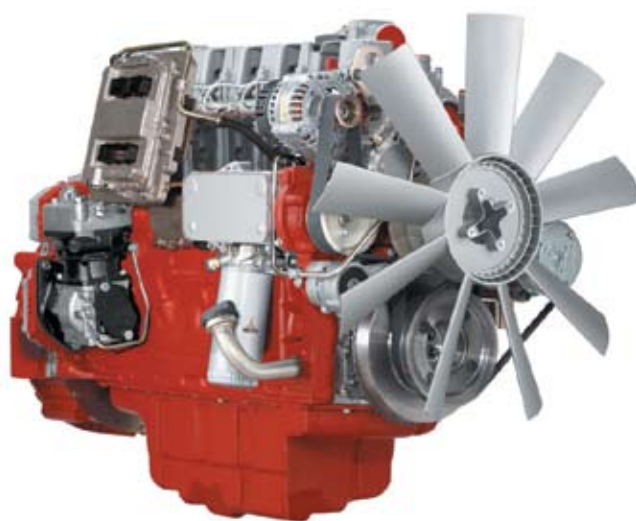
CD-adapco introduced the capability to perform finite-volume structural analysis within the CFD solver, allowing designers to calculate thermal stresses within the engine structure, without the need to map to a finite-element package.

Using this finite volume methodology, CD-adapco’s software can now solve linear and non-linear stress analysis problems using the same level of mesh density that has become common practice in fluid flow. This has been achieved using fast, scalable-parallel, iterative solvers and the polyhedral meshing technology that CD-adapco pioneered. One major advantage of using multi-million cell structural models is that it obviates the need to generate a multitude of local models to resolve detail in critical areas.

Using this approach, CD-adapco has recently performed a non-linear stress analysis of an engine structure containing over 4 million polyhedral cells (around 13 million degrees of freedom) in just 15 minutes, using a 32 processor Linux cluster—something that would be unthinkable using a traditional FEA approach.

Stephen Ferguson, Technical Marketing Manager, CD-adapco, wrote this article for *SAE Off-Highway Engineering*.

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Trucks get boost from copper motor rotors

Four 140-hp (104-kW) electric motors help power the latest generation of **U.S. Army** severe-duty trucks. The ac induction motors use die-cast copper rotors on each of four axles. The new rotors are considered a breakthrough in motor technology developed by the **Copper Development Association** (CDA) and delivered under the Copper-Based Casting Technology (C-BCT) program.

For large automotive vehicles, this is the first such application of a copper rotor, according to Ken Geremia, Communications Manager for the CDA. But the technology has already appeared in some passenger cars, including in the electric motor of the **Tesla** Roadster, which was announced last summer. Geremia noted that **Siemens** introduced several lines of integral motors in the U.S. last spring, and that other companies have sold them in Europe for the past couple of years.

In the Army trucks, the 520-V motors are powered by a 400-hp (298-kW) diesel engine, resulting in a hybrid drive system that can move the 35,000-lb (15,875-kg) vehicles and run a 335-kW generator to operate field hospitals, command centers, or airstrips.

Called ProPulse by **Oshkosh Truck**, the hybrid-electric

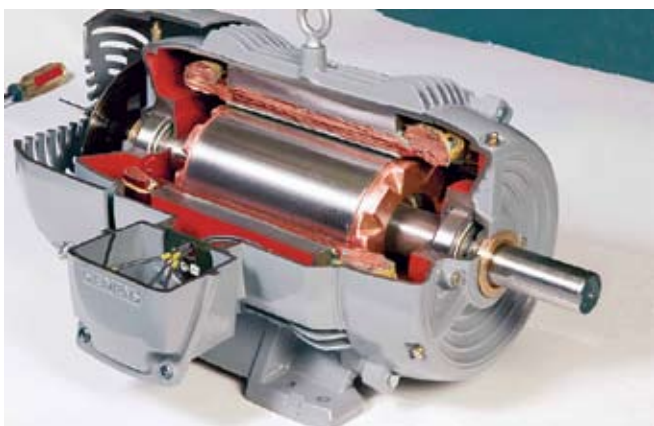
drive system is said to decrease emissions and increase fuel economy by as much as 40%. Aside from several configurations for the military's 8x8 HEMTT-A3 (Heavy Expanded Mobility Tactical Truck) series, the drive system is also configured for commercial use with refuse vehicles. Oshkosh says the new drives will lower life-cycle costs as well as lower interior and exterior noise profiles.

The electric motors were manufactured by **Reliance Electric**. Reliance's Director of Advanced Technology, Rich Schiferl, said in a statement that "using the die-cast copper rotor technology was the only way we could meet the rigorous military requirements for weight, size, and performance." According to Schiferl, the CDA-developed process for die-casting the rotor now enables cost-effective production of such rotors on a large scale for motors in this type of application.

It is known that a copper rotor is more efficient than a traditional aluminum rotor, said Schiferl, because copper is a better conductor of electricity and has lower resistance. Because of that, motors with copper rotors can be smaller and run cooler. "The result is an induction motor with the highest power density possible today," he said.



Oshkosh's third-generation Heavy Expanded Mobility Tactical Truck features a diesel-electric drive system that makes use of copper rotors for the ac induction motors.



Siemens introduced several lines of integral motors in the U.S. last spring. Shown is a cross section of a copper rotor in an electric motor.

Copper's "primary physical attribute is superior electrical conductivity, which enables greater efficiency," Geremia agreed. When asked about the cost of a copper rotor vs. an aluminum rotor, Geremia said that manufacturers and buyers find them cost-effective, but he could not provide specific numbers.

The C-BCT research program is sponsored by the **Army Research Laboratory** and is tasked to develop, demonstrate, and deploy applications of copper-based alloys to make significantly lighter, more efficient ac induction motors for use in defense and industrial systems.

The CDA helped organize a technical session titled Copper Alloys at April's **SAE** World Congress in Detroit. The session explored the use of copper alloys in electric motor technology, electrical and electronic connectors, HVAC systems, and other potential automotive applications.

Ryan Gehm

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