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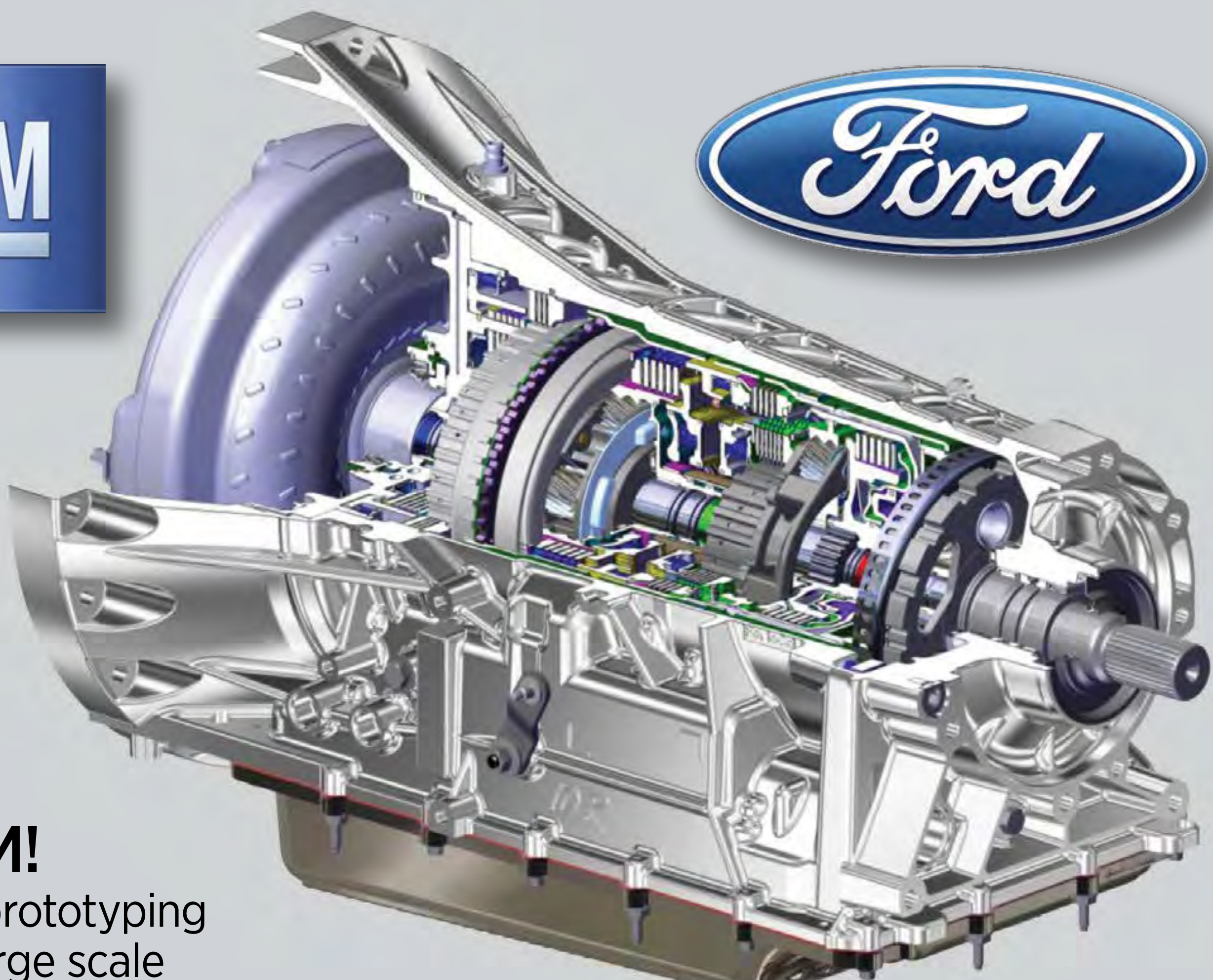
THE POWER OF 10

Arch rivals collaborate (again) on a triple-overdrive 10-speed automatic for cars and trucks



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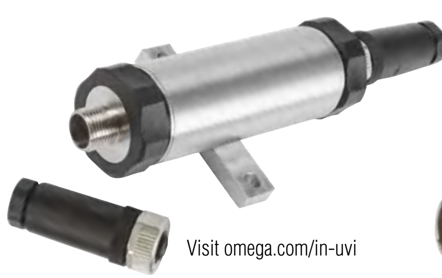

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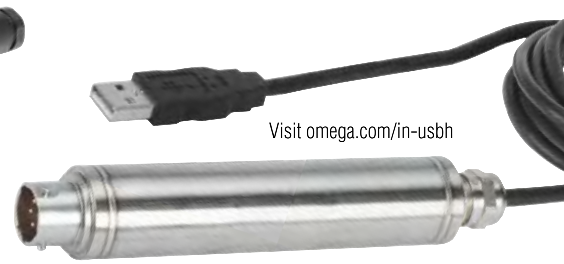

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CONTENTS

Follow us on social media

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VOLUME 3
ISSUE 2

3 EDITORIAL

4 WHAT'S ONLINE

6 TECHNOLOGY REPORT

INTERIORS
Quest for "new-car smell" dictates interior-materials changes

ELECTRONICS
New AUTOSAR platform: more freedom for vehicle electrical architectures

POWERTRAINS FEATURE
10 Doing it again—this time with 10
After a successful decade-long collaboration on 6-speed transaxles, Ford and GM partner again on an all-new 10-speed automatic. Here's a look inside the gearbox and the project.

MANUFACTURING FEATURE
18 Large-scale additive manufacturing for rapid vehicle prototyping
A case study from Oak Ridge National Laboratory bridges the "powertrain-in-the-loop" development process with vehicle systems implementation using big area additive manufacturing (BAAM).

30 GLOBAL VEHICLES
- Steel-intensive Mazda CX-9 sheds mass, debuts novel turbo setup
- Shell Oil shows radical city-car concept

36 PRODUCT BRIEFS
Spotlight: Composites

42 AD INDEX & UPCOMING

Disruption is one thing, but...

A late-spring brouhaha between **Tesla Motors** and an intrepid reporter blew over fairly quickly—but not before highlighting some unaccounted costs of car-making that the tech world tends to gloss over on the path to auto-industry disruption.

In uncovering Tesla's largely undocumented practice of expecting customers to sign non-disclosure agreements (NDAs) before the company would make certain repairs outside the standard warranty coverage, *The Daily Kanban*'s Ed Niedermeyer shed light on what could have been interpreted as Tesla's attempt to shield potentially faulty engineering from the increasingly scrutinous watch of the **National Highway Traffic Safety Administration.**

NHTSA found no evidence of Tesla Model S front suspension design flaws.

A swifter-than-expected NHTSA investigation found no evidence of intrinsic design problems with the Tesla Model S front suspension. But the evolving situation exposed uncomfortable realities behind Tesla's approach to being a mass market OEM.

There was a thin-skinned social-media tongue lashing that's become a hallmark of CEO Elon Musk's first response to detractors, including his accusation that Niedermeyer was in cahoots with Wall St. short-sellers. Mature car companies know better.

More telling to me was what the short-selling angle suggested about Musk—that his underlying concern was how the faulty-suspension story affected his company's stock price, rather than whether the Model S suspension design or a manufacturing execution was faulty. (Tesla did, as a result, modify the language of its NDAs.)

Musk seems to be immensely concerned about how negative news might affect his company's financial position. Such a worry, diesel-emissions cheating excepted, generally doesn't cause lost sleep for multinational auto companies and their asset-backed manufacturing and development empires.

And it's one of the starkest reminders yet of why even fabulously rich tech companies such as **Apple** and **Google** are unlikely to ever undertake the development and manufacture of entire vehicles.

Some disruptors understand the "cars aren't cell phones" adage and are working on how to profitably participate in automotive development—without taking over.

Others, like Musk, have ushered in wonderful slices of disruption. But taking over has costs even billionaires can't comprehend.

Bill Visnic, Editorial Director

VIDEO

SAE Eye on Engineering: Toyota's unique i-Road

One of the coolest new urban mobility solutions we've seen in a long time is the i-Road. In this episode of SAE *Eye on Engineering*, Editor-in-Chief Lindsay Brooke looks at the electric 3-wheeled concept car made by **Toyota**. The video can be viewed here or at video.sae.org/12178. SAE *Eye on Engineering* airs in audio-only form Monday mornings on WJR 760 AM Detroit's Paul W. Smith Show.

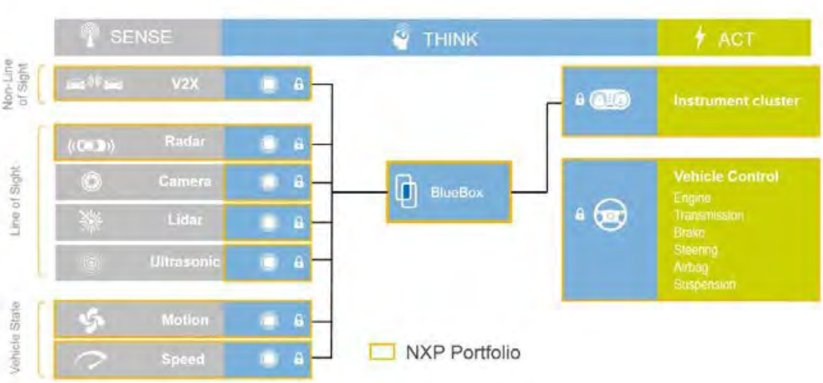
Access archived episodes at www.sae.org/magazines/podcasts.

WHAT'S NEW

New NXP system drives sensor fusion for autonomous vehicles

Silicon suppliers are stepping up to help facilitate progress in the road to autonomous driving. **NXP Semiconductors** has unveiled its BlueBox, which handles sensor fusion, analysis and complex networking.

NXP, which became the largest automotive semiconductor supplier last year by acquiring **Freescale**, provides all the silicon in the system. The module underscores chipmakers' growing focus on systems. Last year, **Renesas** teamed up with a number of partners whose sensors and other components augment its autonomous driving platform.



NXP's BlueBox system collects data from multiple sensors, combining inputs so safety decisions can be determined.

As safety systems that make decisions on braking and steering pave the way for more autonomous driving, central controllers collect input from multiple sensors and stitch it together so it can be analyzed. These controllers will typically classify vehicles, pedestrians and other objects, then determine whether and how these objects impact the vehicle's movement.

NXP's BlueBox utilizes two main processors to fuse inputs and make decisions. A networking device handles communications while a safety controller combines inputs from cameras, radar, lidar and vehicle-to-vehicle communications. The centralized controller, which includes significant RAM, has fairly low power requirements.

Read the full story at articles.sae.org/14837.

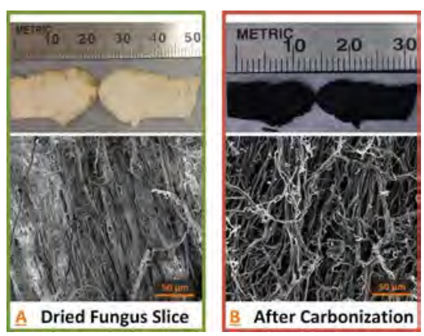
WHAT'S NEW

Fungus-inspired improvements in battery performance

Carbon fibers derived from a sustainable source, a type of wild mushroom, and modified with nanoparticles have been shown to outperform conventional graphite electrodes for lithium-ion batteries.

Researchers at **Purdue University** have created electrodes from a species of wild fungus called Tyromyces fissilis.

"Current state-of-the-art lithium-ion batteries must be improved in both energy density and power output to meet the future energy storage demand in electric vehicles and grid energy-storage technologies," said Vilas Pol, an Associate Professor in the School of Chemical Engineering and the School of Materials Engineering. "So there is a dire need to develop new anode materials with superior performance."



Microscope images of a type of wild fungus shows that it contains an interconnected network of fibers ideal for battery anodes. (Purdue University/Jialiang Tang)

The anodes in most of today's lithium-ion batteries are made of graphite. Lithium ions are contained in an electrolyte, and those ions are stored in the anode during recharging.

Pol and doctoral student Jialiang Tang have found that carbon fibers derived from Tyromyces fissilis and modified by attaching cobalt oxide nanoparticles outperform conventional graphite in the anodes. The hybrid design has a synergistic result, Pol said.

"Both the carbon fibers and cobalt oxide particles are electrochemically active, so your capacity number goes higher because they both participate," he said.

The hybrid anodes have a stable capacity of 530 mAh/g, which is one and a half times greater than graphite's capacity.

Read the full story at articles.sae.org/14851.

INTERIORS

Quest for 'new-car smell' dictates interior materials changes

Benecke-Kaliko's Xpreshn surface material accents a soft-touch feel.

The sensory elements of smell, touch, sound and sight are influencing material innovations for vehicle interiors more than ever.

Chinese buyers abhor certain new-vehicle smells. And with forecasters at **IHS Automotive** projecting annual light-duty passenger vehicle sales in China to reach 29 million by 2020, there are obvious financial motivations for ridding car and truck interiors of the objectionable odors associated with certain widely-used plasticizers and adhesives.

"That odor kind of goes hand-in-hand with VOC (Volatile Organic Compound) requirements—and China to a certain extent is going to lead how VOC limits are set," Rose Ann Ryntz, Ph.D., Vice President of Advanced Development & Material Development at **International Automotive Components** (IAC), said in an interview with *Automotive Engineering* at the 2016 **WardsAuto** Interiors Conference in Detroit.

Although it's unlikely that all OEMs will have the same VOC specification standards, moving to organic chemicals is on the industry's docket, said Ryntz, moderator of a materials innovation panel at the conference.

"We're moving away from VOC-laden PVC slush [programs] at IAC, and we're looking to do more with polymeric plasticizers for slush PVC as well as slush TPE-type [projects]. We're also looking at how the construction of vacuum formed bi-laminates are

This door bolster is made from kenaf, a natural material. Manufacturer IAC uses adhesives to build up the layers before the unit is assembled into a door panel. The company is looking at how the construction of vacuum formed bi-laminates are put together with adhesives since adhesives can be a source of VOC and odor.

put together with adhesives, since the adhesives can be a big source of VOC and odor," she said.

3M debuted a new line of low-VOC attachment tapes at the WardsAuto conference. These thin tapes are designed for armrests, center consoles, instrument panels, door bolsters, and other interior applications that require bonding and dimensional stability during lamination.

The recently launched Xpreshn Lux, a low VOC surface material in **Benecke-Kaliko**'s Xpreshn product line, gives a soft-touch sensation to instrument panels, door trims and other cabin locales, according to Dominik Beckman, the company's Global Director of Marketing and Innovation Management. Benecke-Kaliko is part of the **ContiTech** group.

"It has an ultra-soft lacquer coating, and the formulation is ultra-soft as is the foam layer. The whole construction is ultra-soft. It's more than just a soft foam, Beckman said about Xpreshn Lux.

Company officials claim that Xpreshn Lux, making its global debut in the Cadillac XTS sold in China, is up to 500% softer than Tepeo, Benecke-Kaliko's low-density polyolefin foil used in surface materials.

Xpreshn Lux is thermoformed and an up-level Xpreshn version is in the final stages of development.

The new version "will be cut-and-sew for a TPO-type of material, so that's definitely different than the traditional processing method of vacuum-forming," Beckman said.

Kami Buchholz

ELECTRONICS

New AUTOSAR platform: more freedom for vehicle electrical architectures

Because they require controllers that communicate with each other more randomly than the fairly dedicated links between current-day modules, advanced-safety, connectivity and autonomous features are altering vehicle electronic architectures. That's prompted the Automotive Open System Architecture (**AUTOSAR**) development partnership to devise a new standard that adapts to changeable communication patterns.

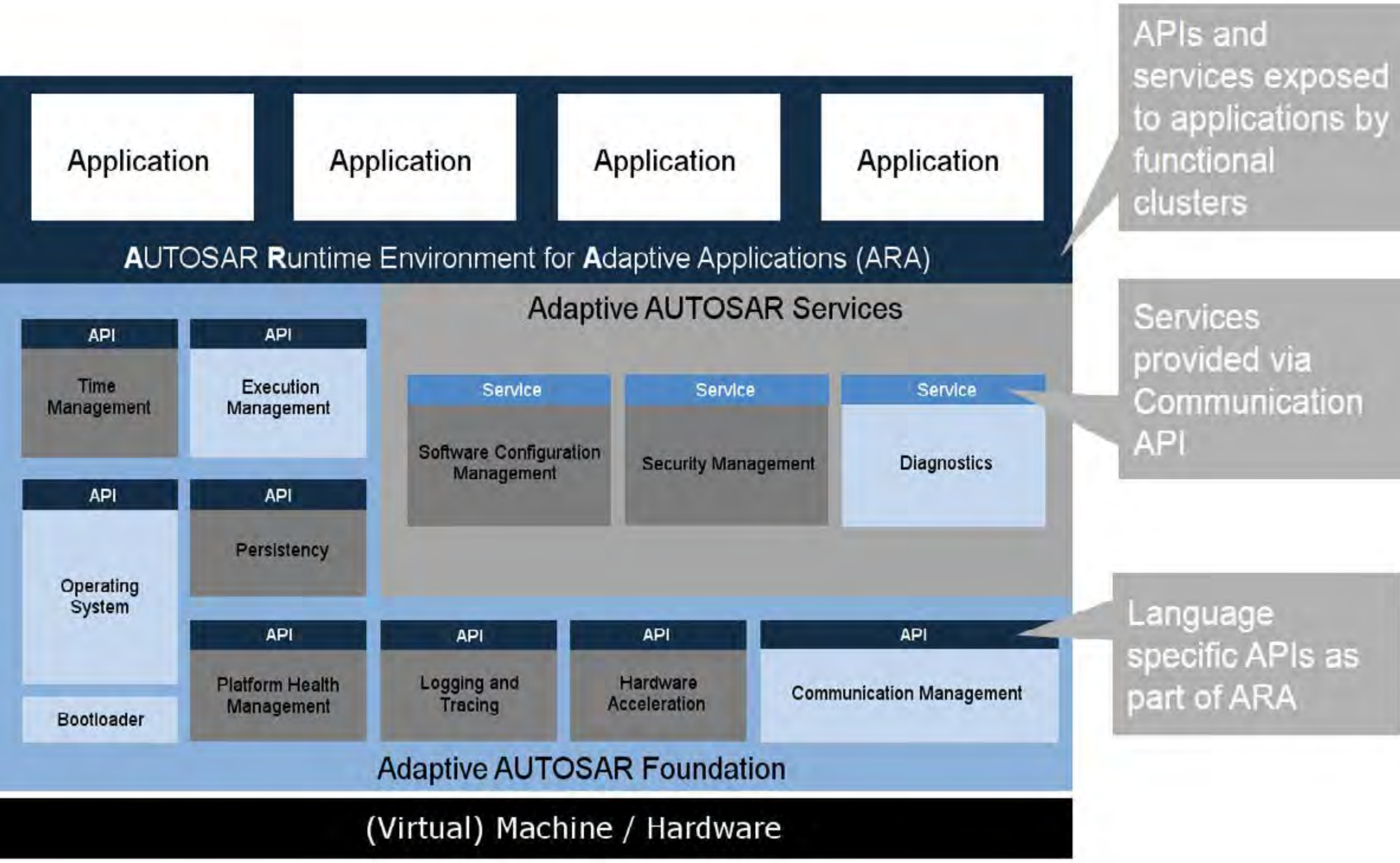
The AUTOSAR Adaptive Platform, currently targeted for completion in 2017, is designed to help engineers create more flexible electrical architectures. AUTOSAR Adaptive will provide a software framework for more complex systems and help engineers increase bandwidth by implementing Ethernet.

In forthcoming architectures as diverse as infotainment and advanced driver assistance systems (ADAS), increased and faster communication will be necessary to provide features and functions that can't be handled by dedicated modules alone. The rapid proliferation of electronic controls and communications has fueled growing acceptance of AUTOSAR and the new upgrade augments existing deployment of the standard.

"It's important not to think of AUTOSAR Adaptive as a replacement for AUTOSAR," said Alexander Much, head of software systems engineering for car infrastructure at **Elektrobit**. "Currently, vehicles have very static architectures where brake and steering modules send a lot of messages to nodes that 'know' who and where all the units are," he said. "Now, more dynamic things are coming, where nodes don't need to know where computers they are communicating with are located or when they're going to transmit."

"AUTOSAR Adaptive will concentrate a bit more on ADAS needs in the short term," said Kurt Krueger, North American Product Line Director for Embedded Software at **Vector CANtech**. "Highly automated driving systems must be dependable and have fail-safe operational capabilities. This can only be accomplished with high-performance microcontrollers, computing power, and high data transfer rates."

Designed to meet key requirements with regard to autonomous driving, the AUTOSAR Adaptive Platform comes with features such as high data processing



Set to debut in 2017, AUTOSAR Adaptive makes it easier for a range of different application programming interfaces (API) and modules to communicate randomly.

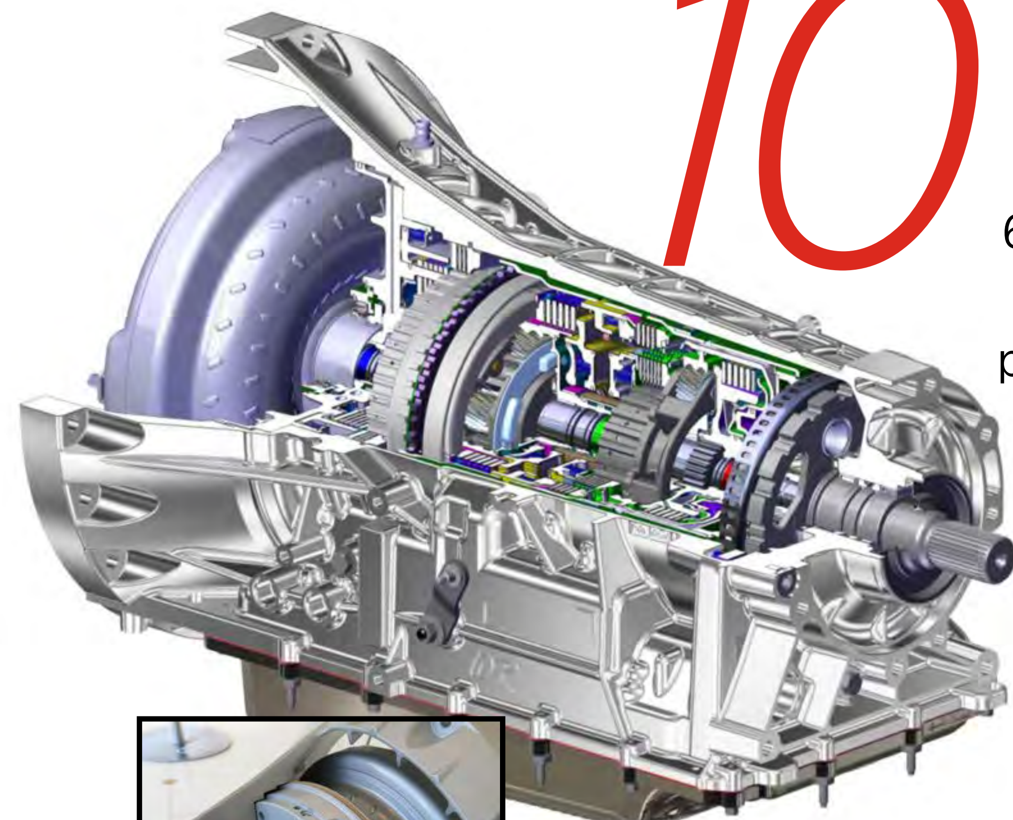
capacities, service-oriented communication and updates over the air, Rathgeber explained. He added that AUTOSAR strives to be a key enabler on the way to the self-driving car by making the new platform accessible to as many manufacturers, suppliers and developers as possible.

Among the development committee's goals is to create a dynamic system that includes middleware and supports complex operating systems using a Posix interface and multicore microprocessors. Its main communication approach is based on service-oriented communication and IP/Ethernet.

The platform will be capable of supporting adaptive software deployment while interacting with non-AUTOSAR systems.

Terry Costlow

DOING IT AGAIN— THIS TIME WITH 10



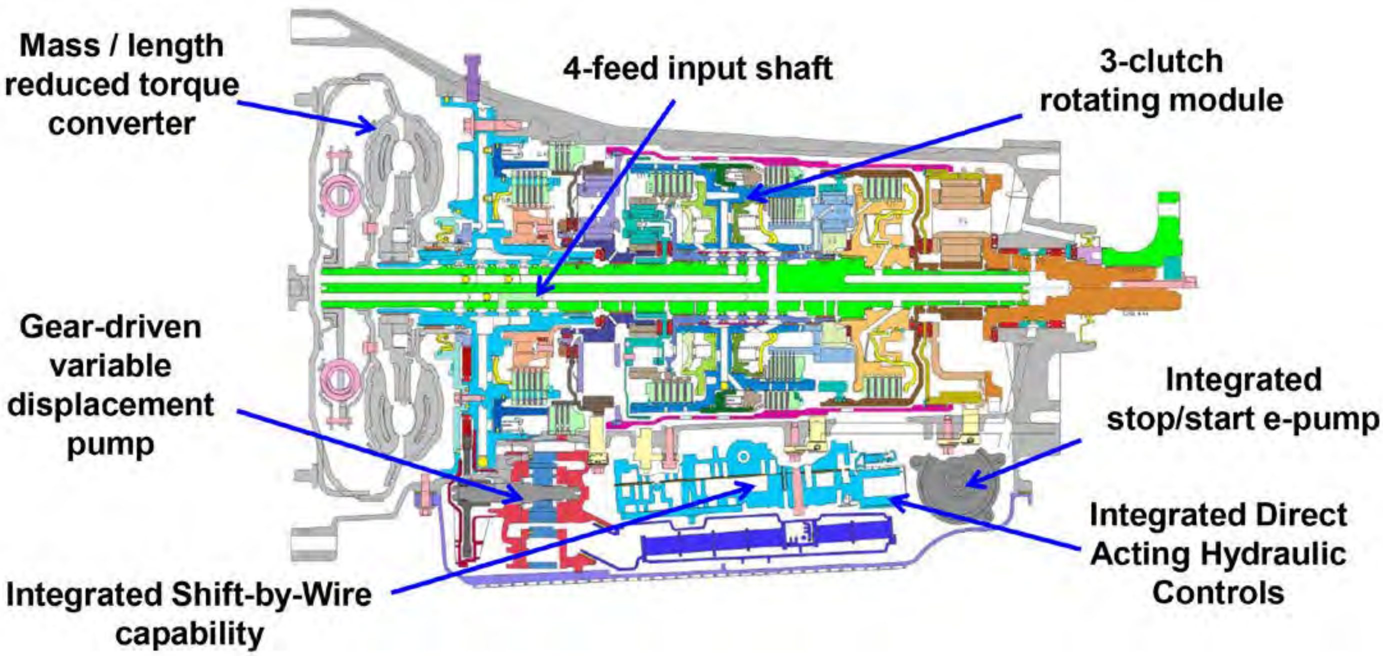
After a successful decade-long collaboration on 6-speed transaxles, Ford and GM partner again on an all-new 10-speed automatic. Here's a look inside the gearbox and the project.

by Bill Visnic

The new Ford and GM 10-speed automatic was developed from a clean sheet and contains a number of advanced features including compact, nested clutches (inset) and a weight-saving torque converter. Lightweight solutions abound in this unit; the 10R (shown) is the first Ford automatic that does not employ a single iron part. (Lindsay Brooke photo)

Almost exactly a decade after **Ford** and **General Motors** initiated production of 6-speed planetary-gear automatics derived from the two companies' first-ever transmission-development collaboration, the Detroit behemoths are at it again. In the coming months, each company will launch a specialty model showcasing an all-new 10-speed automatic that is ultimately earmarked for some of the respective companies' highest-volume products: full-size pickup trucks.

The new 10-speed automatic is the result of a four-year joint

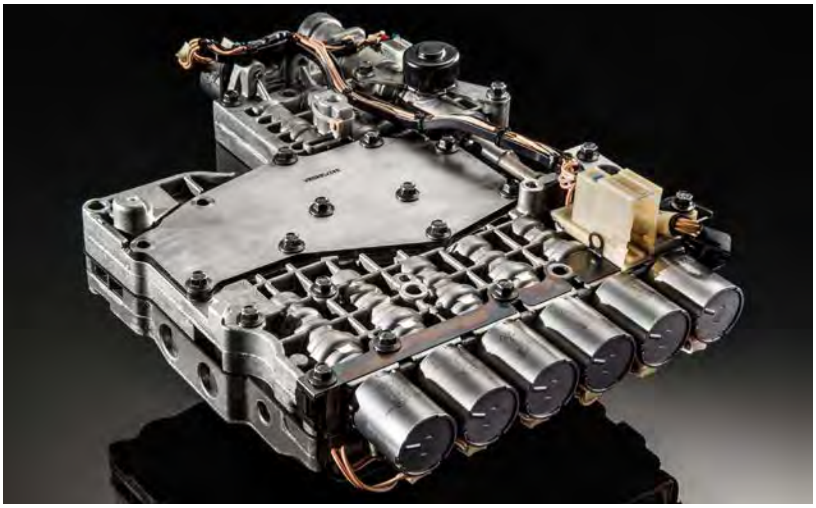


The new 10-speed automatic has essentially the same physical dimensions as existing 6- and 8-speed counterparts. It features a gun-drilled main shaft.

development program first confirmed in 2013 (see http://articles.sae.org/12015/). It is intended primarily for rear-drive or four-wheel-drive vehicles with longitudinally-mounted engines (see sidebar). The two companies' engineering teams concurrently developed a 9-speed automatic transaxle for front- or all-wheel-drive models with transversely-mounted engines; applications for that transmission have yet to be announced.

It is understood that Ford Powertrain led the fundamental engineering and development of the 10-speed while GM Global Propulsion Systems led that of the 9-speed unit.

Both transmissions were developed to wring yet more efficiency from the step-gear torque-converter automatics American drivers so avidly embrace, providing improved acceleration and enabling lower numeric axle ratios for improved highway and city fuel economy. They also address several of the performance and driveability foibles of current multi-speed automatics, Kevin Norris, Ford's manager of 10R transmission systems, told *Automotive Engineering* during an interview at the 2016 **CTI Transmission Symposium** where Ford presented details of the new 10-speed automatic.



Integrated electrohydraulic controls shown in the GM Hydra-Matic 10-speed automatic enable exotically quick shift times, engineers claim.

Incidentally, Ford has internally coded the transmission the 10R80, while a GM source said the company's Global Propulsion Systems unit has yet to apply an internal designation. Their version is currently referred to only as a Hydra-Matic but it is expected to be named 10L80 or 90, following GM's longstanding nomenclature.

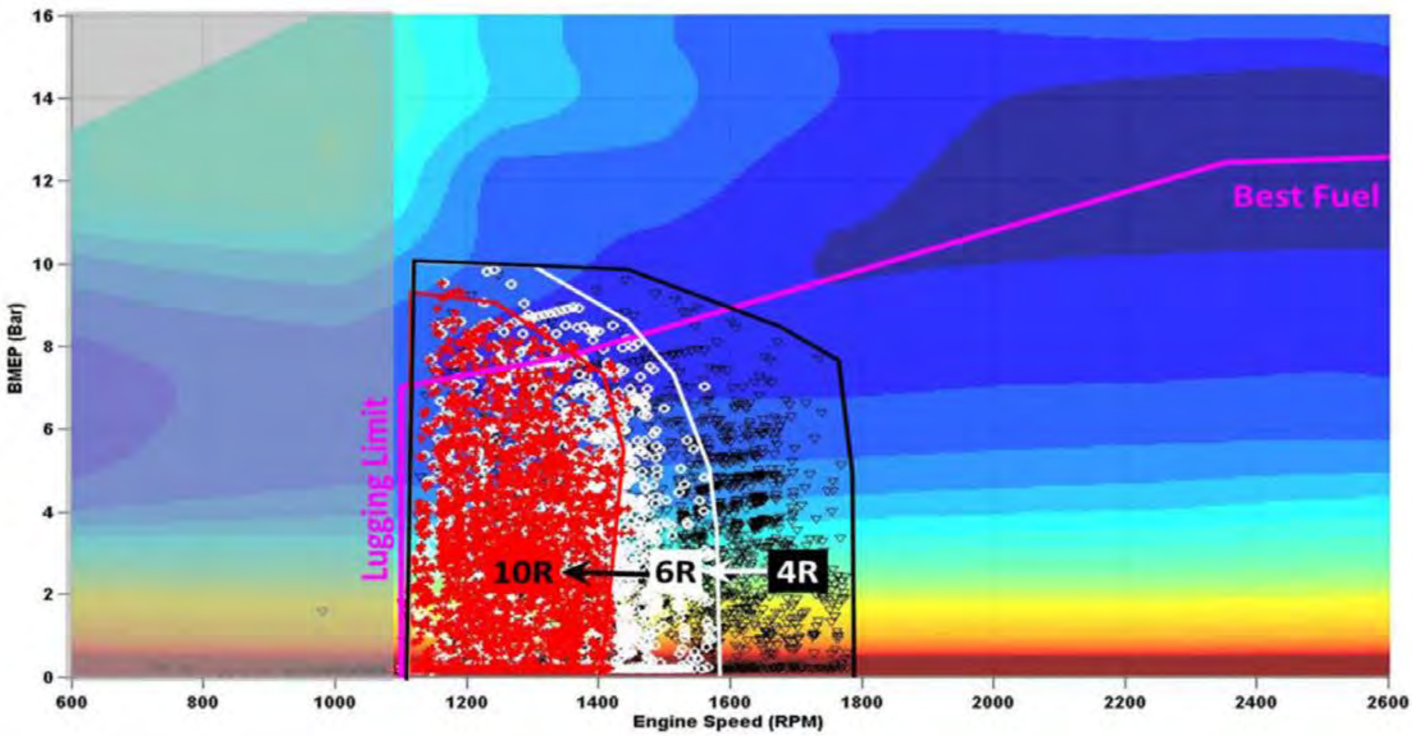
For GM, the 10-speed automatic launches in late 2016 in the ultra-performance 2017 **Chevrolet** Camaro ZL1. Ford's first application will be similarly severe-duty: the 2017 F-150 Raptor powered by a new 3.5-L Ecoboost V6. Although neither company has yet confirmed the transmission's application for mainstream full-size pickups, it's widely known that's the end game. GM has said the 10-speed will be used by 18 different models by the end of 2018.

Automotive Engineering has learned that Ford is investigating a 10-speed capable of handling 1000 lb·ft (1356 N·m) inputs, for use with Super Duty diesel trucks. GM is separately developing its own 10-speed for medium-duty applications, coded AB1V and expected to debut in late 2019, according to transmission-supplier sources.

Inside the box

For engineers starting with this clean-sheet design, expanding the physical package wasn't much of an option. The new 10-speed automatic needed to offer a hassle-free fit with existing-vehicle interfaces, so thousands of hours of CAE design generated key dimensions that effectively are the same as the 6- and 8-speed automatics currently used by both companies.

This was no mean effort and dictated a variety of clever space-saving solutions: an integrated turbine clutch saved 10 mm (.39 in) of axial space and chopped a kilogram (2.2-lb) of mass. A special triple-clutch assembly in the middle of it all is a primary enabler for packaging 10-speed content in the same [longitudinal] space as 6- and 8-speed automatics,



Transmission-schedule trace demonstrates that the 10-speed automatic keeps the engine closer to its optimum efficiency.

according to GM engineers.

The standard-equipment electronic pump that coordinates with the engine's stop-start functionality is integrated directly into the transmission, as are all the direct-acting hydraulic controls.

The new 10-speed (the top three ratios are overdrive) is housed in a one-piece aluminum case with an integral bell housing. The primary mechanicals consist of four planetary gearsets and six clutches—four clutches are rotating and two are brake clutches. Despite having two more forward ratios than the 8-speed automatic GM currently uses, the company said the new transmission adds just one more clutch. This helps minimize package size while reducing the spin losses the two companies' engineers identified as a primary target to improve efficiency.

The healthy overall ratio span of 7.4 also came as no accident, said Ford's Norris, as powerful kinematic search software helped engineers determine optimum ring and sun-gear ratios, gear speeds, spans and ratio progressions and even evaluate the hardware matrix in terms of cost and fuel-efficiency potential. And key for the customer, he said, was the focus on kinematics control which "really

How the arch competitors "meshed" on the new 10-speed program

When **Ford** and **GM** transmission engineers kicked off their alliance for the new 10-speed RWD and 9-speed FWD automatics, they were standing on a strong foundation: the highly successful 6F/6T program. The joint 6-speed automatic collaboration launched in 2006 has produced millions of high-quality transaxles and set an industry benchmark, in the view of *Automotive Engineering*, for arch competitors working together on a common product.

"We checked our egos at the door," Bob Vargo, GM's Assistant Chief Engineer, observed at the time. His Ford counterpart, Ram Krishnaswami (now Director, Transmission and Driveline Engineering) agreed.

The 10-speed program required structured program management processes with dozens of milestones. The joint teams use many common suppliers, deal with the same regulations and sell in the same markets—all of which helped enable the engineers "to generally reach agreement on common problems," noted Kevin Norris, Ford's Manager of 10R Transmission systems.

"Customers will routinely see 10th gear at highway speeds." —Ford 10R program manager Kevin Norris (Lindsay Brooke photo)

He said three key tenets from the 6F/6T program—maximizing common hardware and leaving software separate, avoiding producing GM- and Ford-specific parts and "putting our smartest people in the room to tackle any problems"—remained pillars of the 10-speed program. Norris's counterpart at GM, Assistant Chief Engineer Jim Borgerson, added that "having a clear division of responsibilities, holding good to timing commitments, trust and respect for areas of expertise" played an important role.

From the onset, the teams established a strong cross-functional structure, meeting regularly at the system and key-subsystems levels. There are also oversight teams for manufacturing and purchasing as well as others "to have solid agreement in these important areas. Again, continual communication is key to success," Norris asserted.

Because controls and calibration are the key

helped us to improve dynamics and responsiveness."

The 7.4 ratio spread is about the maximum current research says is usable on the road, Norris added. So, too, for the 10 forward ratios. "Beyond about 7.5 (overall ratio), we see little gain," he said. And while analysis indicated opportunity for gains at more than eight ratios, beyond 10 ratios "we see the benefits start to decline." Design software determined the transmission's overall component count also was optimized at ten speeds.

Transmission junkies will be interested in the "return" of a product differentiators between Ford and GM applications, the program's software engineering and "cal" teams were kept distinct, the engineers noted, unless specific experts were drawn in for problem solving.

Regarding dyno and road testing, unique Ford and GM engines, vehicles and software meant that each company performed its own separate validations and testing. Some supplier testing was commonized. Base transmission validation was leveraged by both companies.

To handle joint ownership of problems, the partners pulled technical experts from both sides as needed to drive a solution as quickly as possible. "Both companies respect where the expertise resides and relied on the decisions-making process," said Borgerson. "This involves very good communication in respect to design and experience."

As powertrain engineers know well, failures are a normal part of transmission development. The partners maintained what Norris calls "full transparency" on any failures to speed issue resolution. When issues surfaced in either company, joint reviews were held to quickly develop solutions, Borgerson noted. "We also had a structured issue-elevation path, leading up to our respective vice presidents," Norris explained, but he said the teams worked so well together that this path was rarely used.

"Both companies respect where the expertise resides and relied on the decisions-making process." —GM Assistant Chief Engineer Jim Borgerson

After production begins, Ford and GM will continue to try to maintain the common component set to optimize economies of scale. As such, they will coordinate further changes going forward.

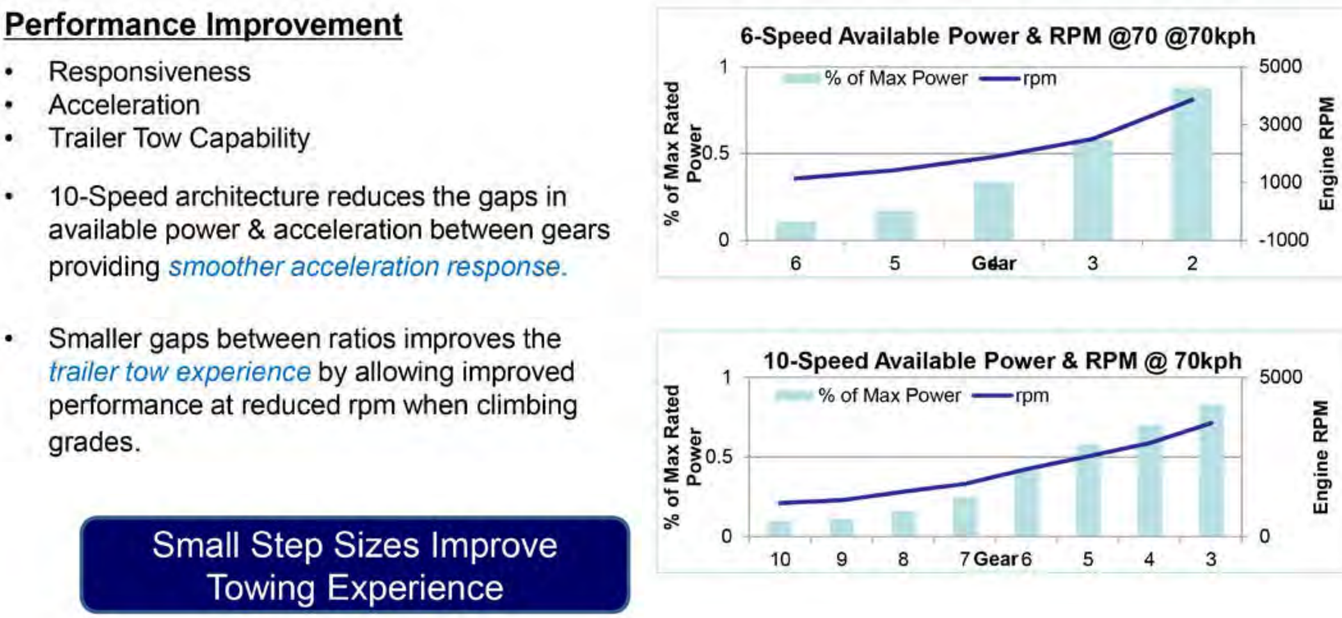
What would the collaborators do differently next time around? "Continue to bring the learnings from the previous programs forward," said Norris. "Should there be another we will certainly build on strengths developed this time around," Borgerson added.

"This program has allowed us to understand the processes and people much better," he said, "which we believe has resulted in a superior product."

Lindsay Brooke

roller one-way clutch, a bit of a throwback in transmission design. The one-way clutch is an important "schedule enabler" for shift programming to mitigate driveline lash and Norris claims it also eradicates the lazy-feeling low-speed throttle tip-in that plagues many multispeed automatics.

According to supplier sources related to the 10-speed program, GM and Ford are licensing certain elements of the 10-speed clutching system from **ZF TRW**, due to the German driveline supplier's broad clutch-technology patents.



Tightly-spaced ratios, and more of them, mean more engine power is available in most gears, but particularly in higher gears, smoothing the acceleration experience.

Of spin losses and shift times

Although the 3-4% improvement in fuel economy compared to 6-speed automatics (an up to 2% gain versus GM's 8-speed) was the primary raison d'etre for Ford and GM's 10-speed automatic, the clean-sheet opportunity was used as a springboard to address performance, refinement and driveability concerns some find with existing multi-speed automatics. GM and Ford engineers concede, however, that most incumbent multi-speed automatics generally operate with laudable refinement.

Norris adds that the quality of shifts is on a similar high level and that this transmission in all its applications, unlike some other multispeed automatics, will use all its gears.

"Customers will routinely see tenth gear at highway speeds," he promised.

Moreover, the transmission's small steps and intense shift-schedule optimization mean the crucial 9-to-10 step is virtually unnoticeable. Said Norris: "We've reached the point where that's really an imperceptible shift."

Then there are the outright performance advantages of 10 tightly stacked ratios. Data developed by GM indicates the 10-speed automatic delivers upshift times that are markedly quicker than **Porsche**'s benchmark dual-clutch PDK automated-manual transmission.

"With shift times on par with the world's best dual-clutch transmissions and the refinement that comes only from a true automatic, the 10-speed delivers incomparable performance on and off the track," said Dan Nicholson, Vice President, GM Global Propulsion Systems, in a statement.

Norris said those towing with a 10-speed equipped vehicle also will be similarly impressed: "Overall, the trailer-tow experience is more comfortable and competent." The closely spaced ratios enable lower-rpm shift speeds at wide-open throttle (WOT) and make more of the engine's power available in the higher gear ratios—enhanced performance that should be apparent in nearly all driving situations.

Although Ford has not yet released individual gear ratios for the 10-speed automatic as installed in the 2017 F-150 Raptor, GM Global Propulsion Systems did detail gear ratios compared with its 8-speed automatic. The numbers indicate a first gear ratio of 4.70:1 for the new 10-speed compared with 4.56:1 for the 8-speed, while direct drive occurs in sixth gear for the 8-speed automatic and seventh gear for the new 10-speed. The 8, 9, and 10 overdrive gears have respective ratios at 0.85, 0.69 and 0.64.

Additional innovations

The two companies' transmission designers baked in a few other advanced features, most aimed at improving efficiency. A variable-displacement vane pump is offset-mounted, cutting torque losses and simultaneously improving high-speed NVH. New ultra-low-viscosity transmission fluid (surprisingly, not fully synthetic) delivers the expected benefit of any lower-viscosity fluid, but also cuts the tendency for "squawk."

An internal thermal bypass hastens warmup, bringing the 10-speed more quickly to normal operating temperature, which enhances fuel economy. And in addition to the integrated e-pump for ideal collaboration with engine stop-start functionality, the new automatic also is designed with integrated capability for shift-by-wire control.

In a few months, journalists will have the first on-the-road impressions in the 2017 Camaro ZL1 and F-150 Raptor. But you don't have to wait for the verdict: Ford's Norris, with as little bias as is possible from the person leading his company's development team, is certain the all-new 10-speed automatic won't disappoint.

"It's really exhilarating," he promises. ■

Large-scale additive manufacturing for rapid vehicle prototyping

A case study from Oak Ridge National Laboratory bridges the "powertrain-in-the-loop" development process with vehicle systems implementation using big area additive manufacturing (BAAM).

Cobra frame being printed on the BAAM system. The computer-controlled extruder follows instructions for path and deposition rate.

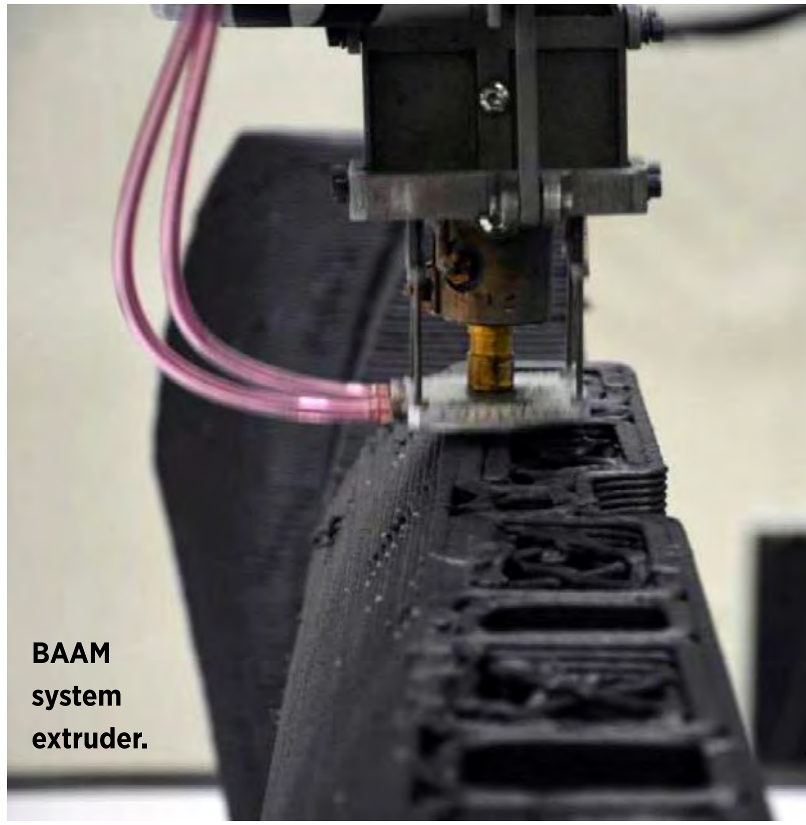
The final product.

In model-based development of vehicle powertrains, through hardware-in-the-loop (HIL) to mule integration, a new enabling design tool is emerging from recent advances in large-scale additive manufacturing (AM) that has become known as big area additive manufacturing (BAAM). AM creates components directly from a computer model and is well-suited for rapid prototyping as it is extremely flexible and enables the rapid creation of very complex geometries with minimal waste. This technology could be transformative for many sectors including automotive.

Until recently, AM processes were constrained to relatively small scales for both polymers and metals. The polymer AM processes used in these applications and studies have been limited in scale due to the constraint of needing reduced oxygen and constant heat environments. In addition, there are some issues with residual

Extruder Type	Single Screw
Fill Rate	40 lb/hr
Extruder Temperature	350 ° C
Bed Temperature	120 ° C

BAAM system extruder characteristics.



BAAM system extruder.

stresses during the AM process with both metals and polymers that have made larger-scale printed parts difficult to produce with precision and dimensions needed for automotive applications.

Recent advances in BAAM with polymers and composites have enabled larger scales. Conventional polymer additive systems are capable of producing workpieces in the size range of less than a few cubic feet in volume. The BAAM systems from **Cincinnati** Inc. now have the ability to print pieces on the order of 1000 ft^3 (28.3 m^3). The initial BAAM systems were the result of co-development by **Oak Ridge National Laboratory** (ORNL) and **Lockheed Martin**.

The ability to directly print a large, complex working part directly from a CAD file with these BAAM systems allows for direct generation of parts such as welded tube frames and body-in-white as opposed to conventional mule manufacturing processes. To date, however, there have only been limited efforts to use large-scale AM for vehicles. For example, in 2014, ORNL, Cincinnati and **Local Motors** printed a vehicle named the Strati at a trade show using a BAAM system.

This article focuses on the combined use of a BAAM system and HIL for rapid vehicle prototyping. HIL is deployed to develop the powertrain and its controls with the same accelerated time frame achieved by BAAM to create the vehicle chassis. Opportunities and challenges associated with the use of BAAM for rapid prototyping of vehicles are

Printed Cobra traction motor installed in ORNL component test cell in the NTRC loop laboratory.

documented, using a printed Shelby Cobra replica as the case study.

BAAM for printed vehicle prototype

The new BAAM system is able to print polymer components at speeds 500 to 1000 times faster and 10 times larger than is possible with current industrial additive machines. These systems are able to produce very large components, including those on the order of a vehicle frame, from pellets and provide a unique resource for rapid vehicle prototyping.

The BAAM system used for this project was a polymer-extruded nozzle fitted to a multi-axis computer-aided servo system. Other key features include the use of a 0.2-in (5-mm) diameter nozzle, resulting in a 0.03-in (0.76-mm) surface variation. The BAAM system was capable of deposition rates of about 20 lb/h. In addition, the pellets used for printing were relatively inexpensive, typically under $5/lb.

Additive Manufacturing webinar

Additive manufacturing is gaining steam in the automotive industry, and not just for prototyping parts. 3D printing processes increasingly are being evaluated for production components, with their promise of shorter development times, lower tooling costs, parts consolidation, more dramatic part shapes and sizes, among other benefits. During this free one-hour **SAE** Technical Webinar, scheduled for late September, experts will discuss these benefits as well as implementation challenges, detail current additive-manufacturing technologies and applications, and offer a vision for what the future could hold for 3D-printed parts in production vehicles. To register, visit www.sae.org/webcasts.
Sponsor: **Stratasys**

A carbon-fiber-reinforced ABS plastic was used. Previous experiments had determined that a blend of carbon fiber higher than 15-20% led to significant reduction in warping out of the oven. This behavior makes the addition of carbon fiber an enabling technology for large printed workpieces and can eliminate the need for additional ovens to prevent curling.

The mechanical design of the vehicle body and frame was driven by the drivetrain, suspension and battery components already selected and by the special requirements of 3D printing with the carbon-fiber-reinforced ABS polymer. A number of different body styles were considered before settling on the classic Shelby Cobra roadster shape. **Dassault Systèmes SolidWorks** design software was used for all mechanical modeling.

The vehicle frame was designed specifically for 3D printing that keeps stresses below 1000 psi (6.9 MPa) and provides fasteners to prevent possible delamination between the

Effect of carbon fiber addition to ABS on workpiece curl.

horizontally printed layers. FEA shows that with the frame loaded to 2000 lbf (1000 lbf per side), near mid-span the stress is under 600 psi (4.1 MPa), and maximum deflection is under 0.35 in (8.9 mm). The polymer frame mass is about 260 lb (118 kg).

The polymer frame could not be designed with sufficient torsional stiffness within the envelope restrictions, so a metal torsion bar was added between the firewall and rear of the cockpit. The vehicle body consists of front, middle, and rear deck single bead (0.22-in thick) sections with multiple bonded stiffeners and internal supports. The front and rear sections are removable for maintenance access. All of these body panels were printed using the BAAM system and have a combined mass of about 430 lb (195 kg).

CAD files were transformed into STL files and input into a slicing program that transformed the 3D geometry to machine tool path commands. Printing the frame was completed in one process taking approximately 12 hours. This rate is 500 times above that normally associated with polymer AM processes. It should be noted that a newer BAAM co-developed by ORNL and Cincinnati is capable of printing larger pieces at a maximum deposition rate of 100 lb/h.

3D printing machines can't be built fast enough

As Deposition Science and Technology Group Leader at **Oak Ridge National Laboratory** (ORNL), Ryan Dehoff facilitates the development of additive manufacturing of components, utilizing various techniques including electron beam melting, laser metal deposition and ultrasonic additive manufacturing. He is developing processing techniques and exploring new materials via additive manufacturing to improve energy efficiency during component production, decrease material waste and improve material performance. We recently spoke with Dehoff to learn more about these innovations and industry trends.

"The big challenge with additive is it may be difficult to actually qualify and certify parts with a conventional mind-set," said Ryan Dehoff of Oak Ridge National Laboratory.

What are some of the new applications where additive manufacturing could potentially be used?

A couple of examples I've seen in the automotive industry are things like utilization of metal powder bed systems to make injection mold tooling. That's a really big application for additive manufacturing because you don't necessarily have to certify and qualify an end-use part, but it can dramatically increase the cycle time of injection molded components and therefore lead to decreased cost of producing that component. People are also looking at utilizing additive technologies to build prototype engines that they might want to go into production in the future. So they're trying to make those engines more efficient and more cost-effective through design optimization, and additive gives them a valuable tool to be able to go through and look at those designs prior to going into the casting or production process.

Where is the 3D printing standards discussion at currently?

The standards that are being developed, I think, are a good first step in implementation of additive into different industrial applications. But I think the big challenge with additive is it may be difficult to actually qualify and certify parts with a conventional

The skins took about 8 hours, and the supports 4 hours to print.

As with any layered process, BAAM exhibits anisotropic mechanical properties. The carbon fiber aligns with the tool path direction, providing manufacturing-controlled strength and stiffness. The weakest direction of the parts was between layers. To help with the integrity of the frame, drivetrain components were attached with threaded rods that put the layers in compression.

The Department of Energy's Manufacturing Demonstration Facility at ORNL is now home to the world's largest polymer 3D printer. The new BAAM (Big Area Additive Manufacturing) machine is another result of ORNL's yearlong collaboration with Cincinnati Inc.

mind-set. There are a lot of different groups; I know there are several different standards organizations and they all have efforts in additive manufacturing ongoing. Some of the government standards organizations also have some fairly large efforts going on in how to certify and qualify additive. It would be good to make sure as we go through and start trying to develop those standards that it's not only the aerospace community that's involved in standards development, but it's also automotive and other industrial sectors that are also involved with that development work.

How do you see the automotive industry embracing additive manufacturing?

There's a lot going on behind the scenes that a lot of people aren't necessarily talking about. Because it does have the potential to revolutionize people's business cases. Right now, most of the additive manufacturing are niche applications, especially in the automotive industry. We have a tendency for additive parts to focus on customization. An example of the potential for customization is something like Jay Rogers from **Local Motors**, and what he's trying to do is make a micro-factory where you may come in and design your car. At the same time, we see that going down into mass customization for the tool and die industry where you can start getting into very low-volume production as well, which is a little bit unique and a niche market. Eventually it may be adopted well beyond that also.

Is the aerospace industry much farther along in terms of adopting additive manufacturing?

The general trend that I've seen in the industry over the past decade is that aerospace seemed to be the

HIL development and integration of hardware

While the entire frame and body of this vehicle were printed, the powertrain, suspension and components were conventional. Vehicle systems simulations were used for component sizing for the Cobra's electric powertrain. Electrical consumption over multiple drive cycles was used as the baseline to determine the required energy storage system (ESS) capacity. Due to the accelerated

main driver because it had huge payoffs associated with making components lighter and making components more efficient. What we're starting to see in the additive world is that the costs of components are dropping, the technology is becoming more reliable, you can get parts fabricated faster and that's allowing different industries to adopt additive technologies like the auto industry. There are some unique things that I know **Cummins** has done where they've been able to increase the efficiency of their engine through additive technologies. I don't know if it's being bulk adopted for 3D printing of car frames or bumpers; that's probably not where we're going to be any time soon, but on specific applications in turbochargers, water pumps and engine housings, those types of things may be a reality sooner than we think.

What are some of the materials being considered for additive?

Holistically, most of the materials that are being developed are materials that we currently use today in castings or machine forms. I think we're limiting ourselves a little bit when we do that. What we're starting to see a general trend in is the development of new materials specifically designed with the very harsh thermal environment during the processing condition. We get a lot of thermal transients during building. Those thermal transients can be very hard on conventional materials, but if we're developing materials specifically in mind of being processed with additive we can actually make better material than we can today with other processes. In the next 10 years you'll start to see customized materials specifically for additive manufacturing.

What are some of the challenges yet to be overcome?

One of the things that I see as a unique challenge in additive manufacturing is as these technologies show promise the additive manufacturing community is growing at a tremendous rate. If you look at some of the reports by Terry Wohlers [of consulting firm **Wohlers Associates**], there's a huge compound annual growth associated with additive manufacturing. In some cases, we can't actually build machines fast enough. There are a lot of companies out there that are machine vendors where if you order a machine today, you may have to wait a year until that machine arrives at your factory, there's that much demand on the industry.

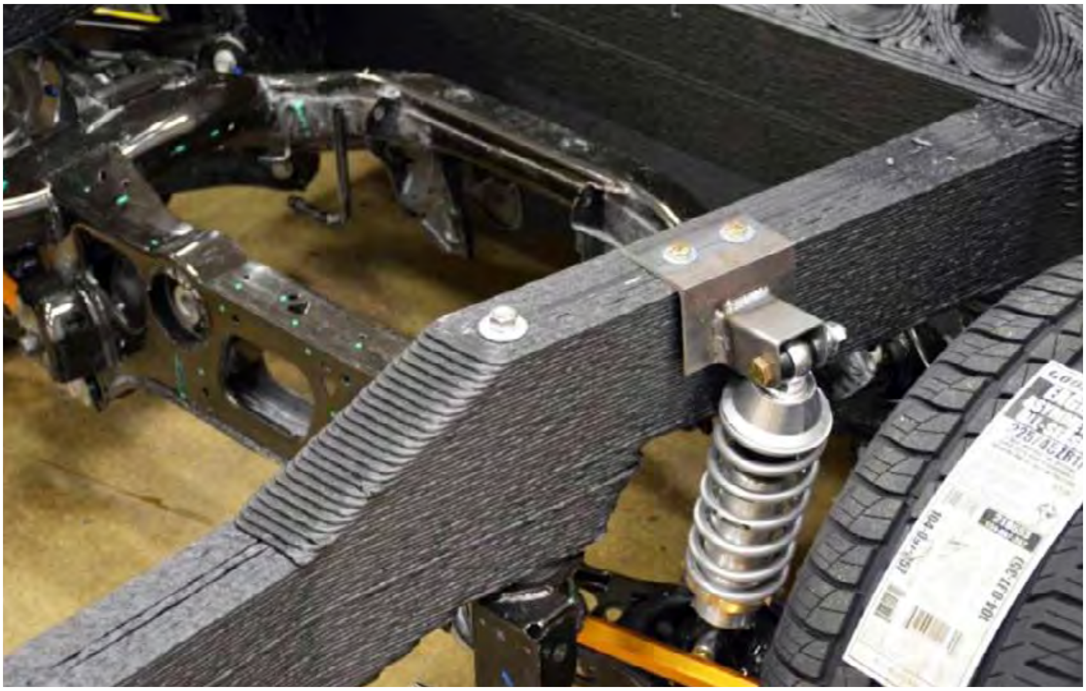
Matthew Monaghan

nature of the project, components under consideration were limited to commercially available powertrain components using CAN communications.

The capabilities at ORNL's National Transportation Research Center, where vehicle modeling and testing were performed, include powertrain test cells with two 500-kW transient dynamometers suitable for Class 8 truck powertrain testing and a component test cell designed to handle smaller, individual components such as engines or traction motors. They share a 400-kW ESS and each is equipped with a **dSPACE** HIL real-time platform.

Following the simulation study and component selection, as components became available they were installed in the component test cell. At the same time, yet-to-be-procured vehicle components and the vehicle chassis were modeled on the HIL real-time platform.

The next phase was powertrain-in-the-loop testing, where all electric drive components were physically installed in the dynamometer cell. This included the motor, inverter, battery pack, dc-dc converter, high voltage distribution box, vehicle supervisory controller, driver interface and onboard charger. The real-time platform emulated



Mechanical fastening using cross-drilling through frames with conventional bolts and brackets being used.

the rest of the vehicle (transmission, driveline, wheels, chassis, driver and drive cycle) and controlled the dynamometer to subject the motor and electric drive to real-world speed and loads based on the vehicle model. The powertrain-in-the-loop provided a safe and controlled environment to design, construct, debug and validate the system.

The powertrain system was then moved out of the test cell and installed in the actual vehicle, allowing for immediate operation—i.e., the vehicle was fully operational at completion of the wiring.

The front suspension was modified from a commercially available aftermarket suspension kit. The rear suspension was modified from a rear-wheel-drive passenger vehicle. Modifications to the rear suspension included adding shock mounting points and a cradle for the traction motor and gearbox, which were integrated into space originally occupied by the rear differential. All structural modifications to both the front and rear suspension were done through welding of carbon steel. An aftermarket brake system was used.

Mounting was made directly to printed parts. The frame was cross-drilled with conventional drill bits for bolt-on pieces. Care was taken to avoid melting polymer during the cross-drill process. Fasteners were used for all of the polymer-to-metal interfaces.

In addition to mechanical attachments, bonding was used extensively on the printed Cobra. For polymer-to-polymer bonding, **Valvoline** Pliogrip was used. Some examples include bonding the nose piece of the printed Cobra to the hood, the hood to the fender well section, and the tailpiece to the rear deck lid section. The door

Printed Cobra components before final assembly (not shown are front nose cone or rear cap).

skins were bonded to the A-pillar sections, as were a number of smaller support pieces. Bonding was also used for repair of partial delamination and for filling voids.

Additional surface finishing through machining, sanding, filling and polishing allowed for the body of the printed vehicle to be painted with an automotive-grade paint to near Class A finish. **Tru-Design** helped with this process. Finishing the vehicle consisted of sanding to remove loose fibers followed by a surface prep and coating to fill the ridges created by the printing process. The carbon-fiber-reinforced ABS plastic is a new material, requiring investigation of finishing and painting, and the effects of temperature swings and long-term use are still unknown.

The use of the HIL platform meant that for this case study the powertrain controls were completed in a parallel process to the printing and integration of the vehicle hardware.

Challenges and opportunities

The ability to go from CAD directly to part with minimal or no additional machining operations holds great promise for BAAM to be used in vehicle prototyping. This case study has demonstrated that as an extension of HIL powertrain development, BAAM can accelerate design to integration for prototyping vehicles. The combination of BAAM plus the HIL development cycle demonstrates the ability to use parallel processes in vehicle prototyping as opposed to more serial processes.

The ability to use BAAM in the HIL development cycle has not been fully explored here, but the potential to integrate design iterations with printing revised components shows promise. A follow-up effort to this project has been completed in which an extended-range hybrid powertrain was developed on the framework described here. Current research is focused on integrating an advanced heat engine with additively manufactured parts into the printed car to study the generation of power for vehicles and buildings.

Industry has been involved in the AM development process, and recently **Local Motors** indicated an interest in using the BAAM process for low-volume production of neighborhood electric to highway vehicles in local microfactories. However, the ability to directly produce complex parts through AM processes has not been fully exploited in the vehicle space.

Carbon-fiber-reinforced ABS plastic would not be considered an engineering material for direct use in a printed vehicle for the commercial market. The material is not nearly stiff enough to be used alone in the creation of a vehicle frame. It does not take point loads well and cannot be used like steel; hence, the torsional bar system for added support. Researchers at ORNL and elsewhere are investigating other polymer formulations that would be suitable as engineering materials for large-scale printed components, including vehicles.

Printed Cobra on the ORNL chassis rolls laboratory.

No documented delamination occurred after final assembly, and no significant distortion in the frame or body has been observed in more than six months of operation. This is notable considering the chassis dynamometer testing and significant on-road driving time.

This study did not focus on meeting specific vehicle performance targets or address crashworthiness, vehicle lightweighting or any other consumer acceptability issues. Studies investigating the crush performance of carbon-fiber-reinforced ABS plastic are ongoing at ORNL. ■

This article was adapted from: Curran, S., Chambon, P., Lind, R., Love, L. et al., "Big Area Additive Manufacturing and Hardware-in-the-Loop for Rapid Vehicle Powertrain Prototyping: A Case Study on the Development of a 3-D-Printed Shelby Cobra," SAE Technical Paper 2016-01-0328, 2016, doi:10.4271/2016-01-0328.

Steel-intensive 2016 Mazda CX-9 sheds mass, debuts novel turbo setup

Other than its aluminum hood, the 2016 CX-9's structure and exterior panels are in various steel alloys. Finally Mazda has arrived at a handsome exterior design language that doesn't resemble origami.

For a mainstream unibody SUV, the 2016 **Mazda** CX-9 pulls off a neat trick—it adds premium content and features while losing weight compared with its predecessor. The design and engineering solutions behind this achievement go beyond expectations for vehicles in this segment and include first use of an all-new, direct-injection turbocharged 4-cylinder gasoline engine with cooled EGR.

For this second-generation CX9, the changes start with a shift away from the previous CD3 platform shared with former partner Ford. The new seven-passenger CX-9 adopts the same large-Skyactiv platform used by the Mazda3 and Mazda6 sedans, as well as the CX-5 compact crossover. At 199.4 in (5065 mm) long, the new CX-9 is 1.2 in (30 mm) shorter than its predecessor, but its wheelbase has been stretched 2.2 in (55 mm), providing more passenger legroom and easier entry and egress to the rear compartment.

Contributing to the new model's more-distinctive and better-proportioned design are reduced overhangs—2.3 in (59 mm) shorter in front and 1 in (25 mm) shorter in the rear. In addition, the A-pillars are moved 3.9 in (100 mm) rearward.

The CX-9's other big change is a switch from **Ford**'s 3.7-L V6 to Mazda's first use of a turbocharged version of its Skyactiv 2.5-L 4-cylinder—the sole powertrain offering for CX-9 and rare among three-row crossovers typically fitted with V6s. But according to Mazda vehicle development engineer Dave Coleman, both platform and powertrain changes bring significant weight reductions—198 lb (90 kg) total in the front-drive version and 287 lb (130 kg) in AWD models. Nearly half of that reduction comes from the powertrain switch.

"We improved the strength-to-weight ratio without resorting to materials other than high-strength steel," Coleman told *Automotive Engineering*. While the car's hood is aluminum, the development team "shied away from more extensive use of aluminum because of its high cost in Japan," he explained.

The weight savings in turn allowed Mazda to increase use of NVH dampening material—53 lb (24 kg) in the CX-9, compared to 5 lb (2.23 kg) in the CX-5. Combined with the use of acoustic glass (window thickness is increased to 4.8 mm/1.9 in), the changes reduce interior noise levels by a claimed 12%.

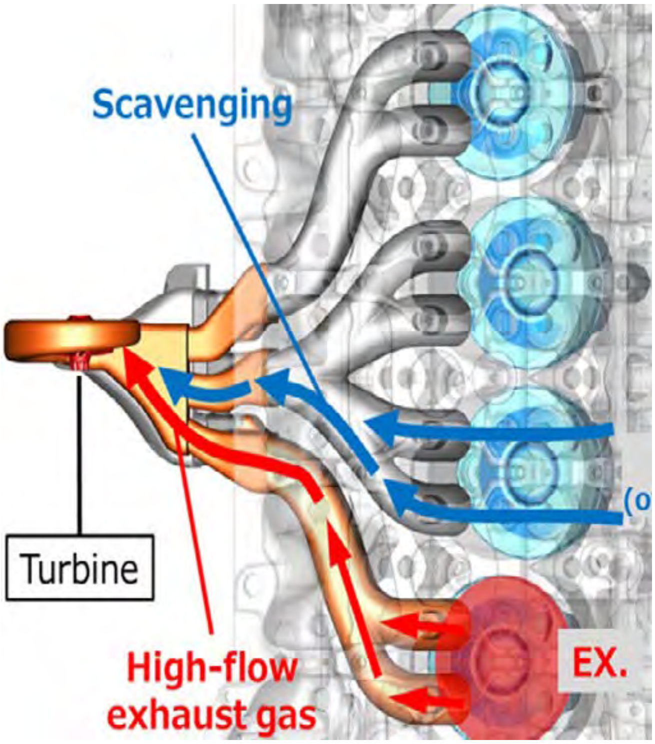
Equally notable is the powertrain transformation. Shifting to a 4-cylinder-only strategy is potentially risky in a segment where buyers are conditioned to expect a V6, but Mazda's research found that "in real-world conditions consumers are less concerned with 0-60 mph times than they are with drivability at lower engine speeds," Coleman noted.

High compression, cooled EGR

This data drove development and tuning of the turbocharged 2.5-L. Addressing the traditional drawback of turbo lag, Mazda engineers developed a new "dynamic pressure" turbocharger layout. This design locates the turbo just one inch from the engine block, connected with a novel 4-into-3 exhaust manifold that pairs the output of cylinders two and three.

At low rpm, the exhaust routes through

Top-range CX-9 cabin reveals use of premium materials including genuine aluminum. Note central rotary control module in center stack.



Strategic exhaust gas flow in Mazda's all new turbocharged DI 2.5-L gasoline engine.

separate smaller ports to accelerate the gas pressure and more quickly bring the turbocharger to its maximum boost of 1.2 bar (17.4 psi). At higher rpm, valves open to allow exhaust flow through the three larger ports.

Pairing the center ports encourages better exhaust gas scavenging, thus raising the knock limit and allowing for a high compression ratio.

Mazda claims the engine's 10.5:1 compression ratio is one of the highest of any production-vehicle turbocharged engine and is enabled in part by use of cooled exhaust-gas recirculation (EGR). Mazda's EGR design cuts exhaust gas temperatures by as much as 212°F (100°C), using EGR rates up to 15%.

The engine produces a claimed 310 lb·ft (420 N·m) at just 2000 rpm. Claimed power is 250 hp at 5000 rpm on 93-octane fuel and 227 hp on 87 octane.

EPA fuel economy figures are 22/28 city/highway mpg for the fwd CX-9 and 21/27 mpg for the AWD versions.

Bucking the industry trend to 8- or 9-speed automatic transmissions, the CX-9 makes do with a 6-speed unit. According to Coleman, its ratio spread is well-matched to the engine's torque characteristics and avoids the "ratio hunting" issue that afflicts some transmissions with more gears.

Inside, the new CX-9 adopts and expands on the range of infotainment and driver-aid features found in the CX-5. The flagship CUV also offers greater use of upscale materials including, for the first time for Mazda, aluminum, real wood and Napa-quality leather trim.

The latter is featured in the new range-topping Signature edition, which sits above the Grand Touring version and starts at $44,015.

The base CX-9 Sport model starts at $31,520.

John McCormick

Shell Oil shows radical city-car concept

Access to the Shell Concept Car involves a single canopy.

Oil companies typically don't announce concept city cars, but a very non-typical vehicle has altered conventional thought at **Shell**. Its 2016 collaboration with **Gordon Murray Design** and **Geo Technology**, called the Shell Concept Car, is a showcase for bespoke lubricants, engine friction reduction, radical downsizing and super efficiency.

Described by Shell as a "total rethink" of Murray's T.25 city car shown in 2010, the Shell Concept Car has emerged from the Project M (for Mobility) previously revealed (see http://articles.sae.org/14478/) as an ultra-compact and extremely frugal 3-seat, single-canopy access city car.

A salient figure quoted in a statement by Shell is that "independent testing and a rigorous lifecycle study shows that Shell's Concept Car would deliver a 34% reduction in primary energy use over its entire lifecycle when compared to a typical city car available in the U.K."

Regarding the car's efficiency, Shell states that its gasoline consumption has been measured using a range of testing protocols. Sample test results issued so far include a steady state figure of 2.64 L/100 km [89.1 mpg U.S.] at 70 km/h from

Interior of the Shell Concept Car follows the configuration of the Gordon Murray Design T.25 and of the Project M.

the use of bespoke lubricants, equivalent to a 5% improvement in fuel efficiency (and consequent improvement in emissions) compared to standard lubricants available in the U.K.

No urban or combined fuel consumption figure has been released but an aspirational Project M target was a combined figure of 2.8 L/100 km.

Just 8-feet long

The 2.5-m-long (8.2-ft) Shell Concept has a potential top speed of 156 km/h (97 mph), higher than the anticipated speed of 130 km/h/81 mph). Currently the design is restricted to 145 km/h (90 mph) and is claimed to reach 100 km/h (62 mph) from standstill in 15.8 s. The engine is a **Mitsubishi** 660cc 3-cylinder, all-aluminum 4-valve unit with variable valve timing. Claimed power output and peak torque are 33 kW (44 hp) and 64 N·m (47 lb·ft), respectively. The engine drives through a 5-speed semi-automatic sequential gearbox.

The Concept Car weighs 550 kg (1213 lb) and makes extensive use of recycled carbon fiber (wherever *that* comes from).

Shell Global Lubricants' Vice President, Mark Gainsborough, noted the project's value in energy saving R&D: "This is a significant automobile engineering milestone. Insights gained from this project could be transformed in terms of how we address energy use in the road transport sector," while noting "the powerful role that lubricants can potentially play in helping achieve CO_2 reduction targets."

Stuart Birch

UPCOMING WEBINARS

FROM THE EDITORS OF SAE: CYBERSECURITY FOR THE LIFE OF THE CAR

Thursday, July 14, 2016 from 12:00 pm - 1:00 pm U.S. EDT

During this webinar, industry experts will address design, development, and implementation of security-critical cyber-physical vehicle systems; implementation strategies, process, and lifecycle management; and cybersecurity assurance verification and validation practices.

Speakers:

Mike Ahmadi
Synopsys Software Integrity Group

Alon Atsmon
HARMAN

Craig Smith
Open Garages

Lisa Arrigo
SAE International

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For additional details and to register visit: www.sae.org/webcasts

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ACTIVE SAFETY SOLUTIONS FOR NEXT GENERATION AUTOMOBILES

Tuesday, July 19, 2016 from 1:00 pm - 2:00 pm U.S. EDT

As automotive technology advances, so do the number and complexity of electronically controlled “safety critical” functions inside of a car. The challenge and risk that all designers face is that of a critical failure occurring and safety critical functions not working as intended. This webinar discusses the relevant quality standards, as well as detailed ASIL failure ratings and solutions to mitigate these challenges.

Speakers:

Lance Williams
ON Semiconductor

Lisa Arrigo
SAE International

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For additional details and to register visit: www.sae.org/webcasts

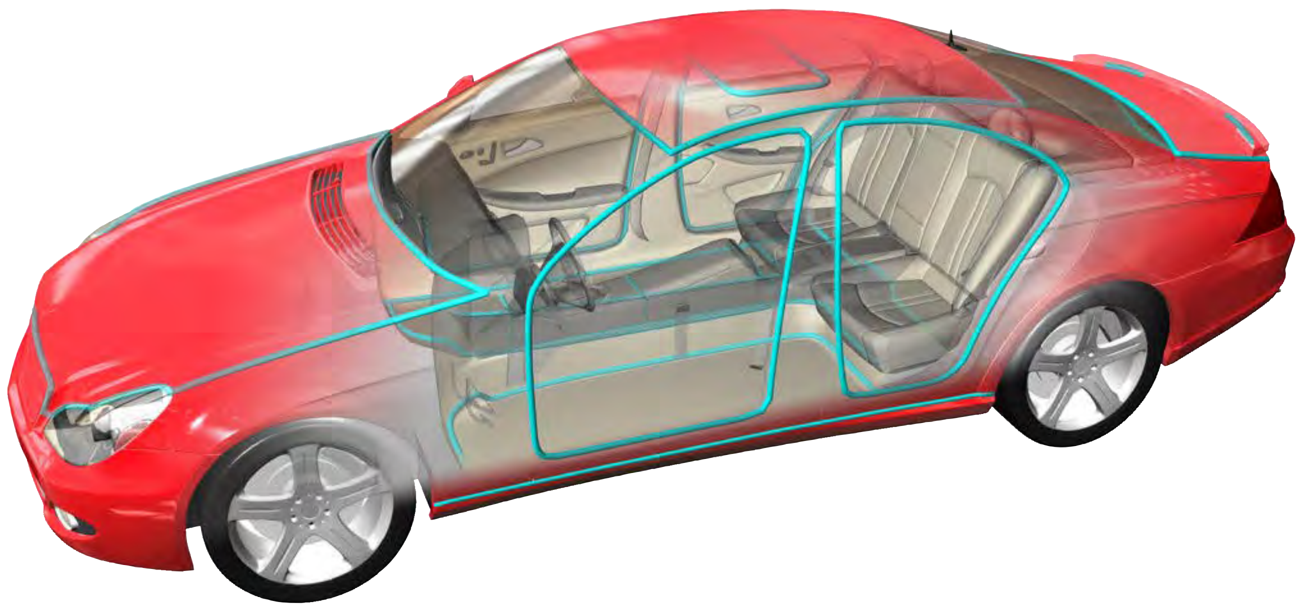
SPOTLIGHT: COMPOSITES

Rapid-cure resin for carbon-fiber blanks

Solvay recently launched its new rapid cure thermoset resin system MTR 760, which **BMW** selected to manufacture the CFRP (carbon-fiber-reinforced plastic) hood of its new M4 GTS. The new resin system was specifically developed to manufacture resin impregnated carbon-fiber blanks through processes such as filament winding. It is said to offer very good processing properties with rapid cure, a DMA onset Tg of 135°C (275°F), enhanced toughness and excellent dynamic loading characteristics. The surface finish of the resin allows a Class-A paint finish. MTR 760 filament wound prepregs have been selected for this application. Solvay's engineering team worked closely with **C-Con** (development, tooling and system supplier) and **Läpple** (pressing and bonding) from the start of the vehicle program to ensure that the material and manufacturing process were optimized. The press molded hoods are manufactured using a Double Diaphragm Forming process with tailored composite blanks. Diaphragm forming offers multiple advantages including blank support during the pressing process, which eliminates the need for preforming as well as more cost-effective, simplified tooling. The films used for this process are proprietary to Solvay and are matched to the resin system to offer the right level of conformability to the tool geometry. For more information, visit **www.solvay.com**.

SPOTLIGHT: COMPOSITES

Composite bonding adhesive



Dow Automotive Systems has introduced customized structural bonding solutions for weight reduction in high-end multi-material performance vehicles. Among the manufacturers using specially formulated adhesive solutions based on Betaforce composite bonding adhesives are **Audi** for the R8 and **Lamborghini** on the Huracan. Betaforce composite bonding adhesives are designed to support hybrid constructions such as lightweight solutions. Audi and Lamborghini are utilizing carbon fiber and bonding of structural parts including pillars or tunnels with coated aluminum. Structural adhesives also provide processing benefits, including the pre-treatment-free joining of carbon fiber, optimized open times and balanced mechanical properties regarding optimal stiffness and driving properties. The decision to apply the adhesive solutions from Dow Automotive was made after comprehensive trials. Image shows typical application areas for Betaforce composite bonding adhesives, including structural roof, assembly and attachment, tailgate/liftgate, trunk lids/hoods, spoiler, door modules, body closures and passenger cells. For more information, visit **www.dowautomotive.com**.

Closed-loop control for metal 3D printing

Sciaky, Inc., a subsidiary of **Phillips Service Industries**, Inc., is highlighting its patented IRISS closed-loop control, which powers its Electron Beam Additive Manufacturing (EBAM) systems. IRISS, which stands for Interlayer Real-time Imaging & Sensing System, provides consistent process control for part geometry, mechanical properties, microstructure and metal chemistry for large-scale 3D printed parts. The technology, exclusive to Sciaky EBAM systems, monitors the metal deposition process in real time and makes adjustments to the process parameters that compensate for variation throughout the build process. EBAM systems utilize wire feedstock, which is available in a variety of metals such as titanium, tantalum, niobium, tungsten, molybdenum, Inconel, aluminum, stainless steels, nickel alloys and more. Widely scalable in terms of work envelope, the EBAM systems can produce parts ranging from 8 in (203 mm) to 19 ft (5.8 m) in length, but can also manufacture smaller and larger parts, depending on the application. EBAM is also the fastest deposition process in the metal additive manufacturing market, the company claims, with gross deposition rates ranging from 7 to 20 lb (3.2 to 9.1 kg) of metal per hour. With a dual wirefeed option, two different metal alloys can be combined into a single melt pool to create "custom alloy" parts or ingots. For more information, visit **www.sciaky.com**.

Climatic wind tunnel

T/CCI Manufacturing's Climatic Wind Tunnel in Decatur, IL allows customers to simulate any real-world condition by controlling humidity, wind, temperature, solar and road conditions up to 100 mph (161 km/h). Because the system can test from bitter cold to stifling heat, at a specified range of temperature and humidity and solar capability between 100-1400 W/m^2, customers can fully understand the effects of the sun, ambient and road conditions. For more information or available tunnel time, contact Matt Wilson at **mwilson@tccimfg.com**.

Diesel injector-seat cleaning kit

A 17-piece kit from **IPA Tools** is designed to clean injector seats and bores on most light-, medium- and heavy-duty diesel engines. The kit is suited for removing carbon, rust and other debris from injector seats, bores, and cups. It includes helix brushes for deep seat cleaning, two-stage brushes for seat and inner seat hole cleaning and bore brushes for bore and tube-wall cleaning. The driver handle features a spring-loaded, quick-lock coupler that allows for quick interchange of brushes, drivers, extensions and the use of low-speed drills. Also included are 400 assorted low-lint, flexible, industrial-grade SWAB-EEZ ranging from 5 mm to 20 mm in diameter. For more information, visit **www.ipatools.com**.

Lightweight thermal camera core

Boson from **FLIR Systems** is a small, lightweight, high-performance uncooled thermal camera for OEMs. Boson is claimed to be the first thermal camera core to incorporate a sophisticated, low-power, multi-core vision processor running FLIR XIR expandable infrared video-processing architecture.

The camera features a 12-µm pixel pitch detector for high-resolution thermal imaging. It offers several levels of video processing with inputs and processing for other sensors, including visible CMOS imaging sensors, global positioning systems and inertial-measurement units. Additionally, the device provides a suite of advanced image-processing features including super resolution algorithms, sophisticated noise reduction filters, local area contrast enhancement and image blending. For more information, visit **www.flir.com/Boson**.

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Company Description

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AD INDEX

ADVERTISER	PAGE
Omega Engineering	1, 40
Phillips Screw Company	25, 41

RESOURCE LINKS

- Sales Team
- Contact Us
- Archives
- SAE Board of Directors
- SAE Membership

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UPCOMING

FROM THE EDITORS

JULY 7
Aerospace Engineering
Technology eNewsletter

JULY 12
Off-Highway Engineering
Technology eNewsletter

JULY 19
Automotive Engineering
Technology eNewsletter

JULY 27
Vehicle Engineering
Technology eNewsletter (all markets)

AUGUST
Automotive Engineering
Print Magazine
- Special Lightweighting Issue
- Vehicle lightweighting: What's beyond 2025?
- Composites product spotlight

AUGUST
Off-Highway Engineering
Print Magazine
- Advanced emissions strategies
- Thermal management
- Aerodynamics for over-the-road
- 3D printing
- Hydraulic Components product spotlight

AUGUST 2
Aerospace Engineering
Technology eNewsletter

AUGUST 9
Off-Highway Engineering
Technology eNewsletter

AUGUST 16
Automotive Engineering
Technology eNewsletter

AUGUST 29
Automotive Engineering
Technology eNewsletter

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