TECH BRIEFS

SAE INTERNATIONAL

SPECIAL REPORT:
ENGINEERING THE C8 CORVETTE

Inside the design, development and technologies of Chevrolet's all-new mid-engine supercar

From the editors of SAE's *Automotive Engineering*

A Bespoke Transmission Custom Designed for a Super Car

TREMEC dual clutch technology delivers the efficiency of a manual transmission and speed of a racing gearbox. Lightning-fast and precise shifts allow for uniterrupted acceleration and the utmost in perfomance for the Chevrolet Corvette mid-engine masterpiece.

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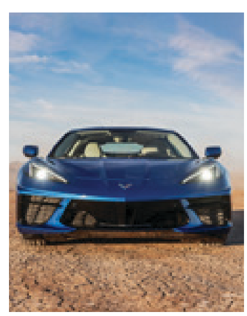
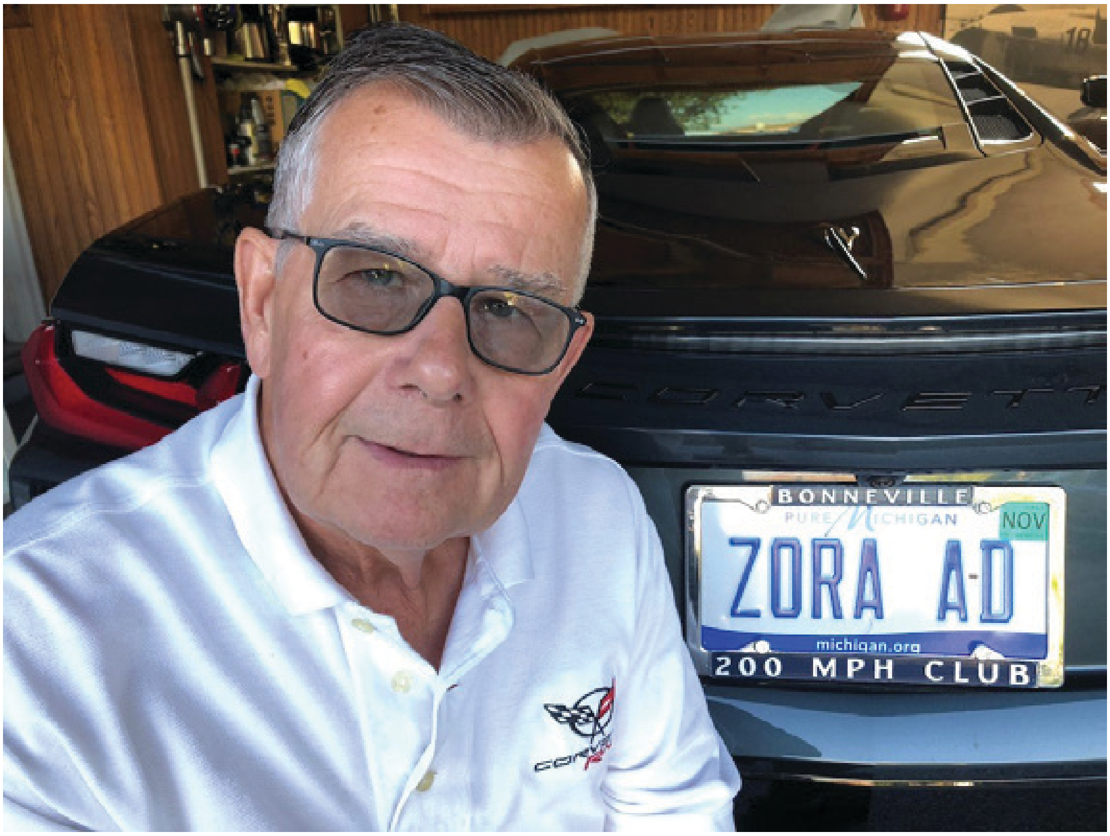


An engineering triumph and GM vision finally realized, the 2020 Chevrolet Corvette Stingray blends state-of-the art vehicle structure, materials and joining technology, chassis design and powertrain integration to create the world's most useful, accessible and affordable supercar. And it's a looker. (Chevrolet)

Realizing Zora's Dream



Don Sherman at home with his recently-purchased 2020 Corvette. The vanity plate's 'A-D' is Arkus-Duntov; its frame denotes Don's 238-mph land speed record, set at Bonneville in 1986 in a Mazda RX-7 Turbo. The record still stands in 2020.

CHERYL SHERMAN

In my 37 years of covering new-vehicle development and technology, few product launches have generated the high reader interest of the 2020 Corvette Stingray. That's no surprise. The eighth generation (C8) of GM's evergreen sports car finally realizes Corvette godfather Zora Arkus-Duntov's dream of a mid-engine architecture. The new layout puts 60.6% of vehicle mass over the rear tires, compared with the C7's roughly 50/50 weight distribution. The resulting dynamic performance and overall chassis balance have earned praise from road testers, racers and owners — more than 5,000 of whom have taken delivery (as of this writing) in this production-delayed, pandemic-wracked model year.

With the C8, Corvette executive chief engineer Tadge Juechter's team has delivered a rare benchmark: a ~200-mph supercar that can sprint from standstill to 60 mph (96.5 km/h) in less than three seconds, offers daily-driver utility, long-distance comfort, ample cargo space, head-turning style, ~30-mpg capability on the highway — and is priced at $60,000 in base trim. No Porsche, Ferrari or McLaren comes close to matching the C8's outstanding mix of technology, performance and value.

This Special Report, culled from our C8 Corvette coverage in *Automotive Engineering* magazine and SAE.org, highlights the hard work and innovations of GM engineers and their supplier partners in raising GM's sports-car icon to a new level. And for the bulk of that reporting, we thank veteran autowriter Don Sherman. Besides being the most experienced car-magazine road tester in the business, Don has been hot on the trail of the paradigm-shifting Corvette for years, steadily gathering intel on it well before the program officially kicked off.

Sherman's been an SAE member since 1970. He joined while a University of Michigan student, pursuing his MS in Mech. Eng. After earning his BS degree at the University of Iowa and joining Chrysler's Institute of Engineering in 1968, he was drafted into the Army. Thanks to Chrysler's efforts, he was assigned to the Yuma, Arizona, Proving Grounds, where he tested ammunition and assembled a Fiberfab Valkyrie GT kit car in the craft shop. This fiberglass-bodied, steel-framed, V8-powered concoction provided Sherman an early in-depth look at the virtues of positioning the engine midships, just behind the driver.

After earning his MS degree at Michigan in 1971, Don began an illustrious 49-year journalism career, including two memorable stints at *Car and Driver.* During that period Don's interest in Corvette development led to an illuminating interview with the retired Zora, who revealed his rationale for the mid-engine configuration. Nearly 30 years later, Zora's vision has landed in Chevrolet showrooms.

For us, there will be more C8 Corvette stories to tell. In the October *Automotive Engineering* and at SAE.org, we detail how Tenneco and GM collaborated on Corvette's sophisticated "smart" exhaust system. And even hotter C8s are in the pipeline, bringing new IC engines and electrification to the ever-evolving supercar.

Lindsay Brooke, Editor-in-Chief

Engineering the 2020 CHEVROLET CORVETTE

The eighth-gen (C8) Corvette is a creative mix of novel and traditional technical solutions unleashed at a shockingly low base price.

By Don Sherman

Veteran Corvette executive chief engineer Tadge Juechter unveils the long-awaited 2020 C8 in July 2019.

GM

Two days before the 50th anniversary of astronaut Neil Armstrong's leap for mankind and 10 years after General Motors emerged from bankruptcy, the camouflage was finally ripped from the eighth-generation (C8) 2020 Chevrolet Corvette. As widely anticipated, C8 now flaunts a mid-engine layout that ostensibly puts it on equal terms with the world's most venerated supercars.

After six decades of experimentation and concept-car teasing, GM acknowledged that the new Stingray will enter production before year's end. The truly shocking announcement is a base price of $59,995 including destination, only $3,000 more than today's front-engine C7. Along with moving the cockpit forward 16.5 inches (419 mm) to facilitate shifting the engine rearward, the new Corvette is an innovative mix of novel and traditional engineering solutions.

New V8 and DCT propulsion

GM's new 6.2-L LT2 fifth-generation small-block V8 may have roots extending back to 1955, but it brings a long list of new features to the party. Its aluminum block has revised oiling and venting arrangements in support of a dry-sump lubrication system with one pressure and three scavenge pumps. The sump casting is shallower to allow mounting the engine 1 in. (25 mm) lower in the car versus C7. The crankshaft nose is longer, to power revised accessory drives. There's an oil reservoir mounted at the top-left corner of the engine and the oil cooler's capacity is 25% greater than in C7 for more dependable operation during extreme (track or desert driving) conditions.

More aggressive valve timing and 11.5:1 compression along with new intake and exhaust manifolds raise output to an SAE-rated 490-495 hp (365-369-kW) at 6450 rpm (with and without the optional low-restriction exhaust system). Peak torque is rated at 465-470 lb-ft (630-637 Nm) at 5150 rpm. The LT2 is redlined at 6500 rpm. Cylinder deactivation remains to help enhance fuel economy.

Asked what kept GM from clearing the worthy 500-horsepower (373-kW) hurdle for the LT2, Jordan Lee, the global chief engineer for small-block engines, acknowledged, "Honesty stopped us at the level we were confident could be provided in all of the engines we'll build for the new Corvette. As the only naturally-aspirated V8 in the segment, this engine will deliver the visceral experience expected of a Corvette," he told *Automotive Engineering* during the car's unveiling in Tustin, California.

Tremec will supply a U.S.-made 8-speed dual-clutch automated-manual transmission with paddle

Uncloaked view of GM's new mixed-materials flagship shows extensively-webbed castings serving multiple structural roles, along with various aluminum sheet and extrusions. Note exhaust routing, fan location ahead of rear wheels, airbox design, and GM-Tenneco electronically-tunable exhaust outlets.

More 'Bedford' castings in C8's AL-intensive front structure. Note rear bulkhead and A-pillar construction, IP casting and coolant radiator location.

BOTH IMAGES: STEVE FECHT/GM

shift control. Along with the absence of a clutch pedal, a conventional shift lever is also a thing of the Corvette's past. Instead, two console-mounted pull toggles select Drive or Reverse while three buttons choose either Park, Neutral, or the Low/Manual modes. Executive chief engineer Tadge Juechter added, "Regardless of driving mode, our performance shift algorithms are so driver-focused they can sense spirited driving and hold lower gears longer for optimum throttle response."

Explaining the loss of the manual transmission selected by 20% of C7 buyers, Juechter noted, "With no interruption of torque delivery during upshifts, the DCT is the superior performance solution. Squeezing a clutch pedal into the foot box and shift linkage down the structural center tunnel would have posed design compromises we weren't prepared to make. And we know our customers will be thrilled with the sub-3-second zero-to-60 [mph] acceleration we've achieved with the Z51 [equipment] option."

To exploit the benefits of a mid-engine car's enhanced traction at the rear wheels, first gear provides more torque multiplication, while seventh and eighth are tall overdrive ratios for quiet and efficient highway cruising. The middle five gear ratios are closely spaced for optimum acceleration and track performance. Like a race car, the transaxle's input shaft is positioned below (versus above) half-shaft height to facilitate mounting the engine lower in the car. Electronic traction management and limited-slip differential controls are both available.

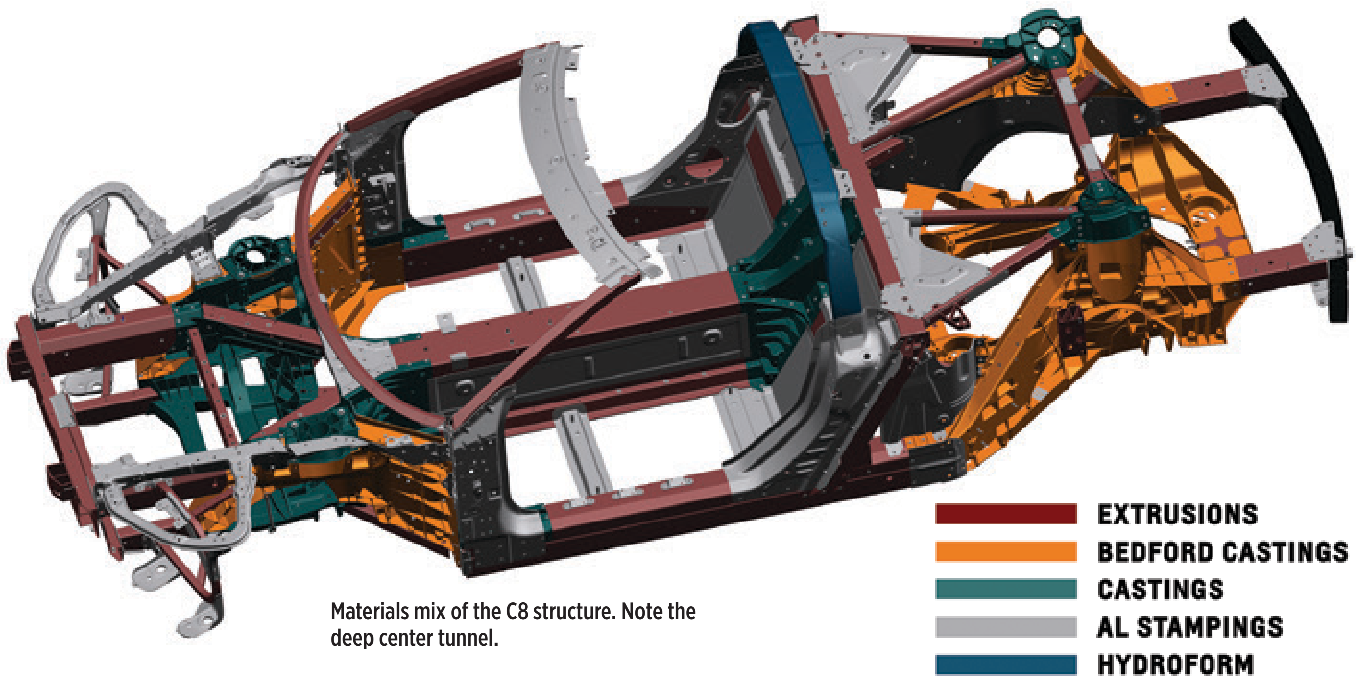
In addition to previous Weather, Tour, Sport and Track driving modes, two additional choices have been added to C8. MyMode is a configurable setting, and "Z mode" goes beyond MyMode to permit tuning of up to twelve engine, transmission, steering and damper performance variables.

Thermal-management challenge

Asked to name the greatest challenge faced during C8 development, Juechter doesn't hesitate to cite the cooling system. "With the engine and radiator up front, cooling air entering the nose sweeps through the heat exchangers, over the hot exhaust manifolds, out the fender wells and side gills, or under the car. That's straightforward," he explained. "The solution for the mid-engine Stingray we validated at 100-degrees F with a pro driver at the wheel is significantly more involved. There are two radiators in front and a third positioned in the left-side scoop, which also routes fresh intake air to the engine.

"Airflow has to bend abruptly toward the car's centerline before sweeping past the exhaust headers," he continued. "Then it slams into our huge rear trunk wall. Since there's no room for ductwork, we fitted large air outlet vents, aided by electric fans, in the rear corners of the car to cool the powertrain during sweltering traffic conditions." In addition, the cantilevered glass hatch has an open "mail slot" at its trailing edge to vent hot air. "The DCT's substantial cooling needs are satisfied using a lubricant-to-coolant heat exchanger mounted atop the transaxle and a dedicated flow loop," Juechter added.

Engineering the 2020 CHEVROLET CORVETTE



Materials mix of the C8 structure. Note the deep center tunnel.

Structure from experience

Like the C7, the new C8's structure is a bonded-and-welded-aluminum spaceframe built at GM's Bowling Green, Kentucky, assembly plant. This second-generation design consists of stampings, extrusions, castings, hydroformed tubes and six intricate die-cast aluminum assemblies aimed at improving torsional rigidity while also reducing the number of welds. Known as the 'Bedford Six,' these structural nodes are made at a GM Powertrain plant in Bedford, Indiana.

Thanks to its robust 12-in. (305-mm)-tall center tunnel, the new spaceframe is relatively light and claimed to be 10% stiffer than before to provide a solid foundation for steering, suspension and powertrain components. With no need for tall, wide rocker sections to supply the desired structural integrity, the C8's ingress and egress are exemplary.

Suspension control arms are cast- and forged-aluminum as before. In place of the fiberglass monoleaf springs long employed in Corvettes, C8 has conventional coil springs encircling a damper at each wheel location. GM's optional Magnetic Ride Control, which senses wheel motion and automatically adjusts the dampers using BWI's magneto-rheologic technology, has been retuned for improved ride and handling.

"No Corvette has ever felt so comfortable, nimble, and stable," Juechter exclaimed. "We're confident our customers will admire the strides we've achieved in ride quality. And now that the car's center of gravity is very close to the occupants' hip points, the feeling during acceleration and braking is analogous to riding at the center—instead of the ends—of a teeter-totter. There's practically no sense of pitch motion in the cockpit."

Moving the engine rearward also cleared a path for a straighter, stiffer connection between the steering wheel and the electrically-assisted rack-and-pinion gear. Less weight on the front wheels enabled quickening the steering ratio from 16.25:1 to 15.7:1 to sharpen agility. Michelin will continue as Corvette's sole tire supplier. Standard tires are Pilot Sport ALS (all season) radials while Pilot Sport 4S (summer) rubber is included with the optional Z51 performance package.

The 20-in. (508-mm) diameter rear wheels are an inch wider than before, while rear tire section width has been increased by 20 mm (0.8-in.) in keeping with the increased rear-axle loading. Brembo will continue supplying the four-piston fixed caliper, vented-rotor brake components but no longer delivers corner modules to the Bowling Green manufacturing plant. The brake booster is electrically powered.

New mid-engine packaging

Here the C8 bears little resemblance to its immediate predecessor. Except for a 2-in. (51-mm) loss of hip room, occupant space is unchanged. Rearward seat travel is an inch longer and the backrest recline angle is nearly doubled to better accommodate taller occupants. In spite of a more steeply angled hood and low cowl height, there's space available in the front cargo compartment for a carry-on suitcase and a briefcase.

The rear trunk will swallow two sets of golf bags or the standard removable roof panel. An entertaining view of the well-dressed LT2 V8 is available through the hatch glass, which has an unsealed trailing edge to vent heat. Key dimensions are larger: 0.5-in. (12.7-mm) of increased wheelbase; 5.4-in. (137-mm) longer overall length; 2.2-in. (55.9-

BOTH IMAGES: GM

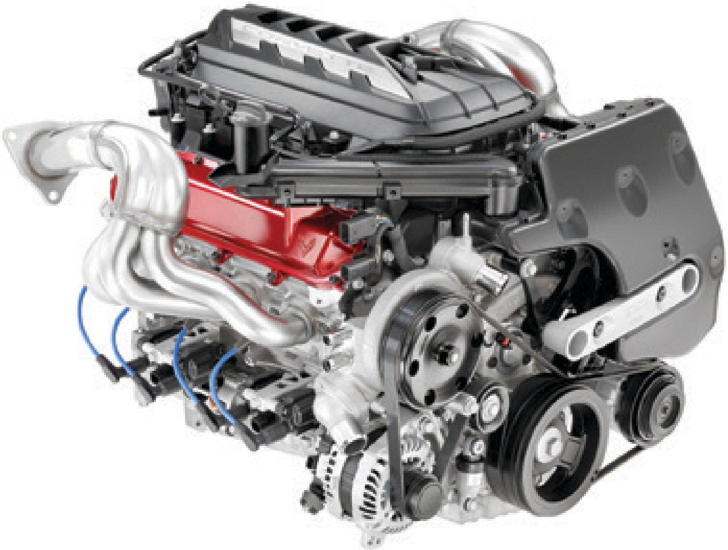
mm) more width and a 1.4-in. (35.5-mm) wider front track. Height is reduced by 0.2-in. (5 mm).

Curb weight is inconveniently increased by roughly 200 lb. (90.7 kg) versus C7's base weight. Program engineering manager Josh Holden explains why: "While we spent more on weight-saving measures, there is significant added equipment in the base C8: the automatic transmission and dry-sump lubrication system for example. The substantial spaceframe anchor points for the coil springs, larger rear tires and wheels and a more-complex cooling system also increase mass."

The skin – and underneath it

Two key C7 body-systems suppliers return to C8. According to GM engineers, Continental Structural Plastics supplies the primary molded-SMC exterior panels, while the car's triangular engine-bay trim panels are sourced from Plasan Carbon Composites (see sidebar). The exterior fascias, in TPO, are from Magna, as is the Stingray's removable roof panel. The rear bumper beam is a carbon-fiber pultrusion to save weight. A large front air splitter, in collaboration with a combination spoiler and airfoil on the rear deck, contribute 400 lb. (181 kg) of downforce at speed. Relocating the exhaust outlets to the rear corners of the car clears space for a trunk capable of stowing the roof panel or two golf bags.

BOTH IMAGES: GM



Dry-sump LT2 carries its lubricant in the black tank shown at right. Note ignition coils moved from top of rocker covers to new location low on block, underneath the exhaust ports.

Inside, attention to detail is evident in the standard leather seat and dash trim adorned with contrasting color stitching. Instead of molded plastic door and console surfaces, aluminum or genuine carbon-fiber panels are fitted. Speaker grilles are stainless steel.

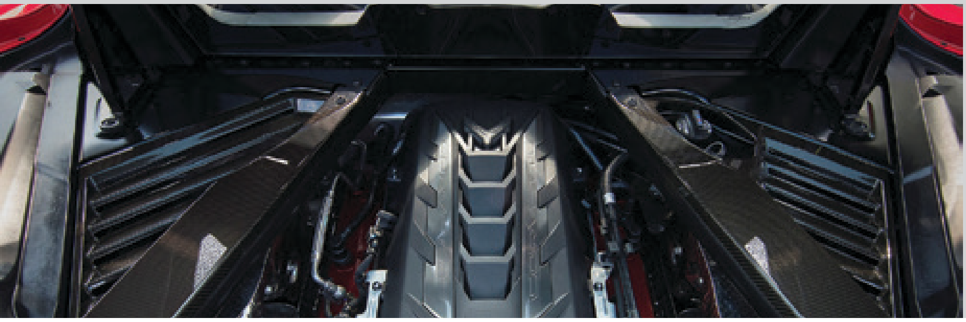
Plasan's classy carbon fiber

The new Stingray's engine compartment brims with visual delight. Its centerpiece, of course, is the mighty LT2, but equally fetching are the two pieces of "eye candy" flanking the V8: beautiful carbon-fiber trim panels supplied by Plasan Carbon Composites (PCC). The triangular panels' deep gloss and exposed-weave design are as likely to draw a crowd as the 495-hp heart beating between them.

"Class-A was GM's goal with those parts," explained Robert Murch, R&D principle engineer at PCC. "And while we're not in the styling business, we are in the business of making the stylist's dreams come true."

PCC is well versed in the art of lightweight, functional aesthetics for Corvettes. The Walker, Michigan-based company supplied the exposed-weave hood and roof panel for the sixth-generation ZR-1 and reprised it on the base and Z06 C7 by adding CFRP rockers and splitters.

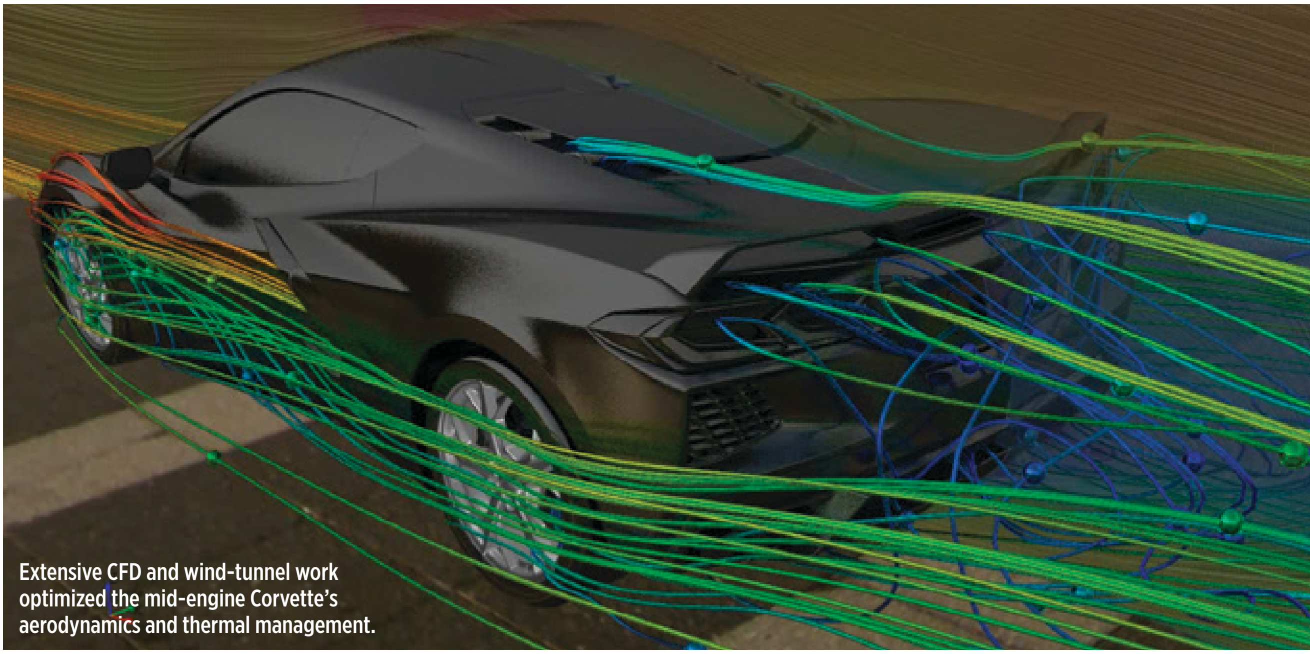
The C8's panels "are constructed from the same family of carbon-fiber epoxies that we've worked with on past Class-A woven cosmetics," Murch told *AE*. "The twist to these is there is a bit more temperature requirements due to their [engine compartment] location. We had to meet a minimal 150C thermal requirement, but we know the material can take a lot more than that." Murch has high praise for Chris Basela, who as the BFO (global bill-of-material family owner) for carbon fiber components at GM, served as PCC's interface on the program. "Chris was key in working with us and with the engineering team at GM to ensure that the proper robustness was applied to those components," Murch said.



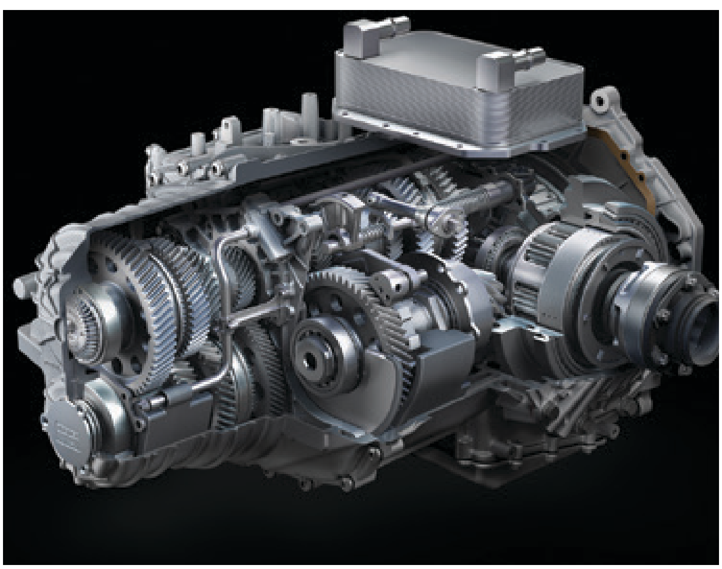
The PCC development team took a traditional approach in using one-sided steel autoclave tooling, with manual lay-up "primarily due to the detail that goes into these components," Murch explained. "Each ply is hand placed into the tool, with careful consideration to the processes to ensure proper grain direction of the weave—it's an opposing pattern from left-hand to right-hand sides on those covers. That's GM's intention that we match that appearance part to part." Nest tooling allows the panels for each Corvette to be molded in vehicle pairs.

"In each generation of Corvette, GM has upped the ante of where they want to put carbon-fiber material," Murch noted. "To date, these [the C8 panels] are the most challenging and rewarding at the same time."

Lindsay Brooke



Extensive CFD and wind-tunnel work optimized the mid-engine Corvette's aerodynamics and thermal management.



A look inside the new Tremec 8-speed DCT. The transaxle's input shaft is positioned as on a racecar, below half-shaft height to facilitate mounting the engine lower in the car.

Vertically-oriented vents and climate controls help reduce the height of the instrument panel, enhancing the feeling of spaciousness.

C8's small-diameter, two-spoke steering wheel is flattened top and bottom to avoid obscuring the view of the 12-in. (305-mm) reconfigurable instrument cluster. There are three seat choices to balance comfort and support under aggressive (racetrack) driving conditions, six interior colors, two optional upholstery stitch choices and six seatbelt colors. Add to that two wheel designs and an unprecedented 12 exterior colors. The options list includes a wireless phone charger, 14-speaker Bose audio system and a high-definition performance data recorder. One thoughtful feature is a traditional round volume knob on the center console's touchscreen.

More engineering highlights

GM's new Global B electrical architecture provides quicker subsystem communication, fewer wires, enhanced display screen resolution, greater security measures and the ability to update the Corvette's software over the air via WiFi. The low-profile headlamps are lit by projector beams and the taillamps are LED.

For the first time, Bowling Green will manufacture Corvettes with right-hand drive to better serve foreign markets. A new proprietary glass-reinforced resin material trims weight from the instrument panel and trunk moldings. To reduce the likelihood of scraping the car's chin over driveway verges, an optional lift system increases front ground clearance by 40 mm (1.6 in.) in 2.8 s. That equipment can be programmed using GPS data to remember thousands of raise-the-chin locations.

Considering the revolutionary design, engineering and development invested in C8, it's evident why this latest Corvette was a long time coming. Now that this Ferrari-for-working-stiffs is here, the anticipation will begin concerning more powerful editions, a potential Cadillac-branded version of the Stingray and how electrification might stretch Corvette's appeal into unexplored territory. ■

BOTH IMAGES: GM

Long time coming

Aerovette was perhaps the most exquisite of all mid-engine Corvette concepts—and Zora's favorite.

After six decades of teasing enthusiasts with intriguing concepts, Chevrolet is launching an all-new Corvette with its engine located where Zora intended—behind the driver.

By Don Sherman

In the Spring of 1957, while pondering the demise of Chevrolet's Corvette Super Sports racer at Sebring's 12-hour endurance race, legendary Corvette godfather Zora Arkus-Duntov concluded, *"Heat source must be behind driver."* The official explanation offered for dropping out after 29 laps was a failed rear-suspension bushing—but the actual show-stopper was that driver John Fitch's feet were being cooked by the exhaust-header pipes snaking around the SS's sheet magnesium 'firewall.'

Sixty-two years later, the Corvette development trek initiated by Arkus-Duntov's brainstorm reached New York's Times Square, when a camouflaged prototype (see cover image) driven by chief engineer Tadge Juechter and with GM CEO Mary Barra as passenger, finally confirmed that the 2020 Corvette will have its engine located behind the driver.

The 7-18-2019 date prominently displayed on both sides of the prototype car is when GM will reveal details about the mid-engined Corvette, exactly fifty years after the Apollo 11 mission to the Moon. Until then, we have but history and speculation—supported by interviews with five Corvette chief engineers and one retired GM vice chairman—defining the signposts and sidetracks leading to the revolutionary Corvette.

Superior vehicle dynamics

Arkus-Duntov, born in Belgium in 1909 to Russian parents, earned a mechanical engineering degree at the Charlottenburg Technical University (now the Technical University of Berlin), in 1934. In his teens, he graduated from two to four wheels as his preferred means of rapid transport. In 1941, after relocating to the U.S., he adopted the surname Arkus-Duntov out of respect for his father and step-father, both of whom shared a home with his mother and brother Yura in Leningrad, Russia.

Arkus-Duntov's fascination with speed made him practically an eyewitness to Adolf Rosenberger's 1924-25 racing victories with the mid-engine Benz Tropfenwagen. The next decade, the fearsome V16 mid-engine Auto Union cars conceived by Dr. Porsche's budding design office often trumped Mercedes' traditional front-engined Grand Prix racers. In the year of Arkus-Duntov's epiphany (1957), F1 driver Jack Brabham's mid-engine Cooper showed promise at the Monaco Grand Prix. Two years later, the Cooper team won the World Championship, rendering front-engined racecars obsolete.

His engineering education gave Arkus-Duntov a clear understanding of the physics underlying mid-engine car design. This is the preferred configuration for rear-driven sports cars and all race cars (rules permitting) for the following reasons: Traction while accelerating from rest and exiting turns is maximized with the engine located as closely as possible to the drive wheels. The load transferred forward during aggressive braking helps

Corvair Monza GT concept of 1962 used a mid-mounted flat six.

Zora Arkus-Duntov: his mid-engine focus was influenced by Auto Union's pre-WWII Grand Prix cars.

all four tires produce nearly equal stopping forces. A central-mounted engine also minimizes the vehicle's polar moment of inertia about its vertical axis; as a result, initiating and arresting yaw motion (turning) is easier with the engine in the middle.

Bottom line: Mid-engine cars deliver quicker acceleration, superior braking and more agile handling.

Arkus-Duntov joined Chevrolet R&D in 1953. When a rear-mounted transaxle was under consideration for GM's 1960 mainstream models—beyond those used in the Corvair and compact Pontiac Tempest—he realized that this component might enable a mid-engined, second-generation Corvette. Design studies revealed that the driver's forward visibility and the car's center of gravity would both benefit from moving the engine rearward. Unfortunately, problems with the transaxle resulted in its cancellation and the mid-engine C2 was stillborn.

The consolation prize was approval to build an experimental single-seater with Indy 500 potential, the first of thirteen GM mid-engine concept and show cars. Dubbed a Chevrolet Engineering Research Vehicle (CERV), this 1960 concoction had a 500-hp (373-kW) small-block V8 yielding a top speed over 200 mph (322 km/h) at the Milford Proving Grounds. Its independent rear suspension made the leap to the 1963 Sting Ray (C2) production model.

When GM politics forbade Arkus-Duntov to go racing, CERV was 'loaned' to a west-coast museum for display. Retrieving this stunning heirloom ended up costing GM $1.32 million at a 2017 auction.

GM Design boss Bill Mitchell joined the mid-engine game in 1962 with the Corvair Monza GT coupe, constructed with the production model's flat-six engine relocated from behind the rear axle to the middle of the car. Driver and passenger climbed aboard by hinging the unified doors and windshield assembly up and forward in one dramatic sweep.

Responding to Ford's ambitious GT40 international endurance racing effort, Arkus-Duntov yanked another experiment out of his sleeve. The 1963 CERV II had a centrally mounted 7.0-L big-block V8 with a transmission at each end of its crankshaft to provide four-wheel drive. Top speed climbed to 214 mph (344 km/h) in testing. Finding favor with this twin-transmission arrangement, Ferrari adopted a version of GM's creation for its 2011 FF GT (now called the GTC4Lusso).

Alas, GM's management chose to support Chaparral Cars in the Can Am race series instead of assaulting Ford at the 24 Hours of LeMans, so CERV II was also shelved. It too slipped from GM's grasp, selling at a 2013 auction for $1.1 million.

Tantalizing concepts

After Ford finally won LeMans in 1966, GM's Design and R&D departments teamed up to build the stunning Astro II mid-engine concept for the following year's New York auto show. *Road & Track*'s cover coyly queried, "A Chaparral for Production?" Still lacking a suitable transaxle, GM answered 'no.'

R&T again swallowed the bait two years later when another GM prototype stole the New York show, exclaiming, "We'll stake our reputation on this being the Corvette of the future." Called simply a Corvette Prototype (internal code XP-882), this mid-engine mirage combined a transverse small-block V8 with an Oldsmobile Toronado transaxle to drive both axles. The Ford Pantera, Mercedes-Benz C111 and AMC AMX/3 ironically all seconded the mid-engine motion at the same show. Arkus-Duntov was ready to serve this car to the Corvette faithful—but when Chevy boss John DeLorean denied that wish, he threatened to resign.

BOTH IMAGES: GM HISTORICAL ARCHIVES

Long time coming

CERV II: midship V8, two transmissions, four-wheel drive.

Astro II concept from 1966: still no suitable transaxle.

BOTH IMAGES: GM HISTORICAL ARCHIVES

Mitchell's next move was the 1969 Holden Hurricane concept car, constructed in Australia with a mid-mounted 253 cu. in. (4.1-L) V8 driving the rear wheels through an experimental transaxle. Mimicking the Monza GT, this two-seater's canopy was lifted by servo motors for entry. Advanced features included one of the first back-up cameras and oil-cooled disc brakes.

The next stage of XP-882 development was a thorough redesign in collaboration with Reynolds Metals to shed weight. The new aluminum unibody trimmed 500 pounds (227 kg) for the 1972 prototype code-named XP-895, but its spot-welded-and-adhesively-bonded structure was deemed prohibitively expensive for production. Result: another dead end.

Most Corvette aficionados consider the most tantalizing mid-engine experiments to be the high visibility part of GM's ill-fated rotary- engine gambit. The XP-987 GT bowed at the 1973 Frankfurt motor show with GM-designed, Pininfarina-crafted coachwork over a Porsche 914 chassis and an experimental two-rotor engine in the middle. At the Paris salon later that year, Arkus-Duntov pulled out the stops with his awesome Four Rotor: two rotaries in series, under a stunning body fitted with folding gullwing doors.

When GM's rotary engine work ceased soon thereafter, a conventional V8 was transplanted under deck and the car was rechristened Aerovette. After he retired, Arkus-Duntov told anyone who'd listen that this was his all-time favorite mid-engine design.

Gib is the Engineer's engineer

He was known as Zora's problem-solver and kindred spirit, and now Gibson "Gib" Hufstader is delighted to see Arkus-Duntov's mid-engine dream hit the streets.

Hufstader, 88, became an SAE member in 1957, the year he joined General Motors R&D following studies at the General Motors Institute (now Kettering University) and military service at the Army's Aberdeen Proving Grounds.

During his 45-year GM career, Hufstader earned seven patents for driveline-related innovations. His passion for motorsports born in 1959 persists. In the 1960s, he assisted Corvette and Camaro teams, including Roger Penske's, in both endurance and Trans-Am events. Co-driving the Owens-Corning Corvette at the 1969 12 Hours of Sebring, he scored second in the GT class and 14th overall.

Hufstader joined the Corvette group in 1964. During that time, efforts to engineer a viable mid-engine production design persevered at what he describes as the 'hobby' level.

"Zora would ask me to sketch layouts, initially with the Hewland transaxle, then with other arrangements to reduce length," Gib recalls. "A transverse layout using parts of an Oldsmobile Toronado automatic transmission with all-wheel drive capability earned Zora a patent in 1971." The patented mid-engine powertrain layout works as follows:

- Engine transversely positioned behind cockpit with west-east orientation.
- Crank-mounted torque converter drives transverse automatic transmission located ahead of engine via Morse chain.
- Bevel-gear box at transmission's output end drives shaft passing through engine oil pan to rear axle final drive differential.
- (Optional) shaft forward from bevel gear to front-axle final drive differential.

Gib Hufstader in 2019.

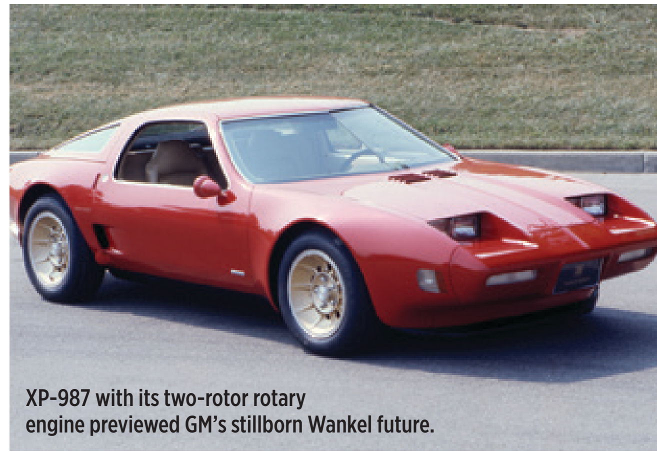
LINDSAY BROOKE

Hufstader's most memorable project was the Four-Rotor Corvette constructed for the 1973 Paris Salon. "While that three-month effort didn't venture beyond the show car," he noted, "it had ample potential for further development."

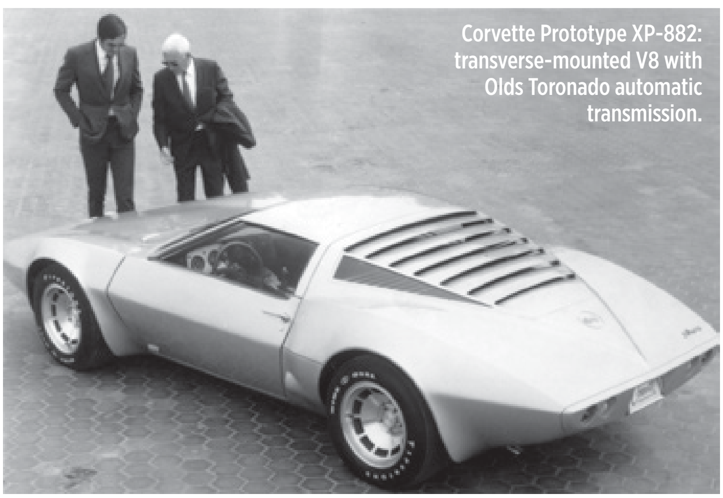
Today, Gib's hobby fleet consists of the '67 427 Corvette he campaigns in vintage road racing, an aerobatic Steen's Skybolt biplane, and eight motorcycles—including a 1952 Vincent Black Shadow, a 1974 Ducati 750 Super Sport and a 1956 Triumph 650 Trophy. Look up 'engineer's engineer' in the dictionary and you'll see Gib Hufstader, wearing an engaging smile.

D.S.

The XP-895 concept featured a Reynolds Aluminum body.



XP-987 with its two-rotor rotary engine previewed GM's stillborn Wankel future.



Corvette Prototype XP-882: transverse-mounted V8 with Olds Toronado automatic transmission.

2009: 'The patient is dead'

When he left the building in 1975, Arkus-Duntov's parting words to his successor were "Dave (McLellan), you must build the mid-engine Corvette." That wouldn't happen in the 20th century, though there was sufficient interest in the layout to create another ambitious experimental called CERV III (also Corvette Indy). This 1986 GM design study was modeled in Italy and built in England by Lotus with electronic features galore. Active suspension, four-wheel steering, drive-by-wire and advanced navigation gear were packed into a molded-composite chassis. The 4.3-L V8 was initially a version of the engine supplied to Indycar racers. In 1990, that power source was supplanted by a twin-turbo version of the Lotus-designed LT5 5.7-L DOHC V8.

Acknowledging the benefits of moving mass rearward, McLellan did shift the transmission aft for the comprehensively redesigned 1997 fifth generation (C5) Corvette, introduced shortly after Arkus-Duntov's passing at 86 on April 21, 1996. Like the original CERV, C5's manual and automatic transmissions were located just ahead of the differential, where they remained through today's C7.

The most recent official ray of hope that Arkus-Duntov's mid-engine dream was not dead was Cadillac's Cien concept shown at the 2002 Detroit auto show. Key features were a magnificent exterior shape inspired by the F-22 Raptor fighter aircraft, scissors-hinged doors, a chassis made of Aerogel composite and a 7.5-L 750-hp (559-kW) V12 with direct fuel injection and cylinder deactivation. In the 2003 through 2009 model years, Cadillac leveraged the Corvette C5 and C6 platforms for its XLR luxury roadster.

For Cadillac fans, hope springs eternal that the brand will again offer a two-seater—this time a BEV with a mid-mounted motor. Our circumstantial evidence is that a new two-seat Cadillac sportscar design was wind-tunnel tested a few years ago.

McLellan's successor Dave Hill, who coincidentally came from Cadillac, focused on ridding Corvettes of quality flaws, especially squeaks and rattles. He was tempted to use Cadillac's Northstar DOHC V8 but found it too bulky. Instead, the 2006 C6 Z06 he created brought 505 hp (377 kW) and 7,000 rpm to the party with a 7.0-L OHV small block at the front atop an aluminum space frame. In 1993, Hill hired Tadge Juechter as his assistant, whom he describes as "a wonderful engineer, team leader, and GM executive."

Tom Wallace succeeded Hill as Corvette chief engineer in 2005. After the redoubtable 2009 Corvette ZR1 was bumped to 638 hp (476 kW) with an Eaton supercharger and intercoolers, the inevitable, 'what's next?' question was asked. It was answered with 'mid-engine' as the most practical means of improving performance.

Juechter was the first hand-raiser, and Wallace quickly seconded the mid-engine motion, in part because of his years of amateur road racing. Chevrolet's marketing department, realizing this might be an excellent means of attracting younger buyers, also was enthusiastically on board. GM vice chairman Bob Lutz was skeptical at first, but he was soon convinced.

ALL IMAGES: GM HISTORICAL ARCHIVES

Long time coming

CERV III experimented with composite chassis, advanced electronics.

The engineering team then satisfied CEO Rick Wagoner that a mid-engine Corvette would earn a return on investment with a modest price bump over the then-$47,895 base model. Unfortunately, cash and time ran out before the mid-engine cause advanced beyond full-size clay models and test drives in reference Porsches and Ferraris.

In October 2008, boss Lutz returned from a board meeting to report, "The patient is dead. No new Corvette capitalization is available and I don't know the foreseeable future." The following year, Wallace took early retirement at age 62 to avoid placing Corvettes on life support with new decals and color schemes.

Succeeding Zora as Corvette chief engineers from 1975 to 2008 were Dave McLellan (center), Dave Hill (left) and Tom Wallace.

Mid-engine debut

On June 1, 2009, GM filed for Chapter 11 bankruptcy. Juechter, as the last Corvette engineering chief standing, continued working on a seventh-generation car for a 2014 model year introduction. Since this was hardly the opportune time to launch a flashy Corvette with a revolutionary powertrain layout, Juechter kept team heads down. They focused on launching well-received Z06, Grand Sport and the recent 755-hp (563-kW) ZR1 editions while, behind the scenes, work intensified on the mid-engine C8 due for the 2020 model year.

Pre-July 18 speculation calls for a base LT2 6.2-L small-block V8 producing more than 500 hp/373 kW (up from C7's 455 hp). An 8-speed dual-clutch, paddle-shifted automatic supplied by Tremec and Fassler will be the sole transmission. Later in C8's life, hotter LT-series V8s will be introduced, some with flat-plane crankshafts, others with DOHC. A top-spec twin-turbo V8 will eventually deliver over 800 hp (596 kW). "ZERV" and "ZORA" nameplates have been copyrighted by GM along with various reactive aerodynamic devices.

Three removable targa roof designs will be offered at launch and a convertible will follow later. C8's foundation will be a hydroformed aluminum space frame as before, with composite body panels supplied by Plasan and others. Expect a shift to rear coil springs (away from today's transverse composite leaf springs) along with 245/35ZR-19 front tires and 305/30ZR-20 rear rubber by Michelin. As before, Brembo will supply conventional and carbon-ceramic brake components.

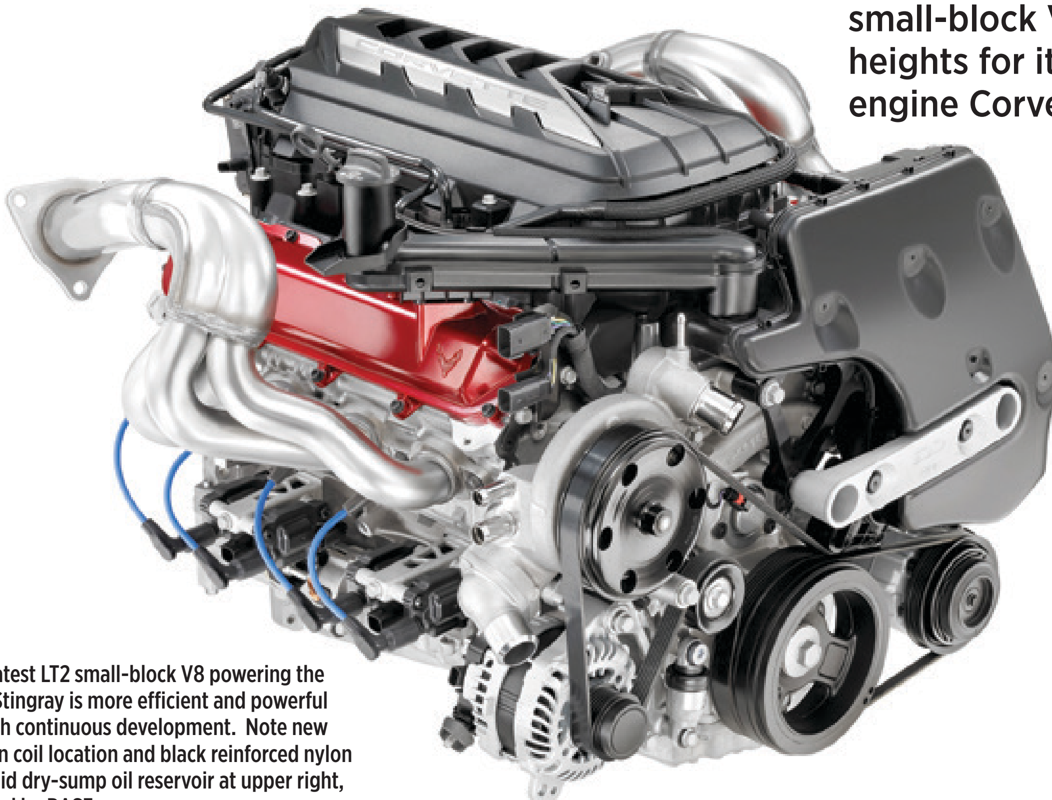
The announced June 28 auction for charity of the final C7 Corvette suggests that the previously expected generational overlap will not happen. Production of C8s for publicity and engineering use is underway at GM's Bowling Green, Kentucky, assembly plant and customer deliveries are expected to commence well before the end of 2019. Expect an attractive base price to maintain Corvette's longstanding value proposition, with subsequent six-figure future editions capable of slaying hypercars wearing Bugatti, McLaren, Ferrari, Lamborghini, and Porsche badges. ■

FROM TOP: GM HISTORICAL ARCHIVES; NATIONAL CORVETTE MUSEUM

More sting for the STINGRAY

GM Propulsion engineers elevate the evergreen small-block V8 to new heights for its mid-engine Corvette mission.

by Don Sherman



GM's latest LT2 small-block V8 powering the 2020 Stingray is more efficient and powerful through continuous development. Note new ignition coil location and black reinforced nylon Ultramid dry-sump oil reservoir at upper right, supplied by BASF.

Instead of heaving decades of small-block V8 expertise out the window, GM Propulsion engineers led by chief engineer Jordan Lee leveraged past success to create a new-for-2020 V8. Known as the LT2, the 6.2-L V8 gives Chevy's all-new, eighth-generation 2020 Corvette more power (the most yet in the base Stingray), stirring response, and competitive fuel efficiency compared with the outgoing C7.

And the small-block, with its single camshaft in block and two valves per cylinder, remains unmatched versus its rivals in three key metrics: bill of material, package efficiency, and the power-per-dollar quotient. It's the payoff for 65 years of continuously refining (and never giving up on) a brilliant original design.

While the eighth-generation Corvette is revolutionary in scope, its LT2 ingeniously blends innovation with traditional design features.

Cylinder block

While it continues the small-block's classic 4.40-inch (111.8-mm) bore spacing, the LT2 cylinder case is a fresh design with key features related to Corvette's move to mid-engine architecture. To facilitate mounting the engine as low as possible in the chassis for optimum performance, dry sump lubrication is standard equipment.

Lubrication and ventilation systems are thoroughly revised to assure reliable oiling across the full operating range (6600 rpm redline). That includes flat-out driving conditions with ambient temperatures up to 100-deg.F, and while loaded to 1.2-g in all three directions.

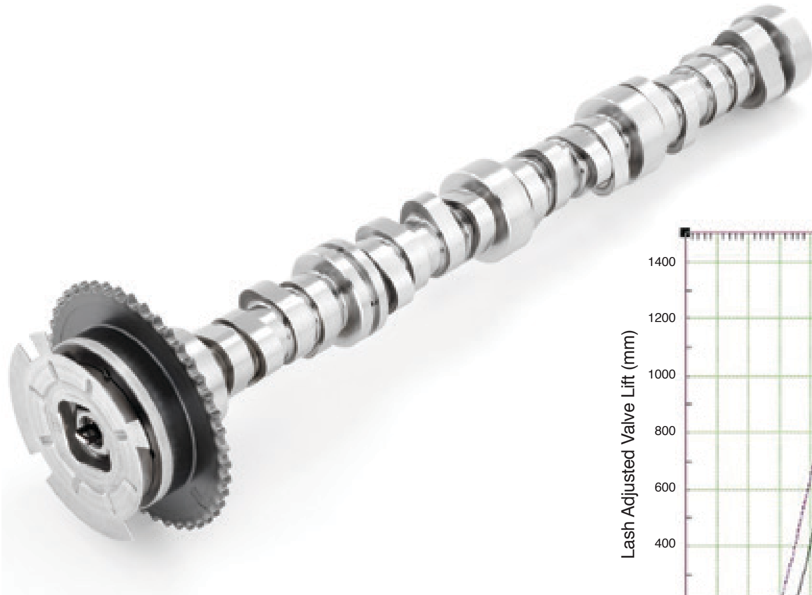
To prevent oil from draining from the cylinder heads and valve lifters into the crankcase, the LT2's valley compartment between the cylinder banks is sealed at its bottom. According to Lee, this arrangement (an all-time first, *Automotive Engineering* believes) greatly diminishes aeration of the lubricant by the crankshaft and windage losses caused by the crank whirling in a mist of oil droplets. A gerotor pump, driven by the camshaft via chain, scavenges oil from the valley, returning it to the 7.5-quart (7-L) injection-molded reservoir mounted to the left front corner of the engine.

The new deep skirt block is A319-T7 cast aluminum, as before, with cast-iron bore liners and cross-bolted nodular-iron main bearing caps to help secure the crankshaft. The block's flanks feature new ribbing, engine mount bosses and attachment points for the eight ignition coils. The 4.065-in (103.25-mm) bore, 3.622-in (92.0-mm) stroke, and 9.24-in (234.7-mm) deck height are carried over from the LT1 V8.

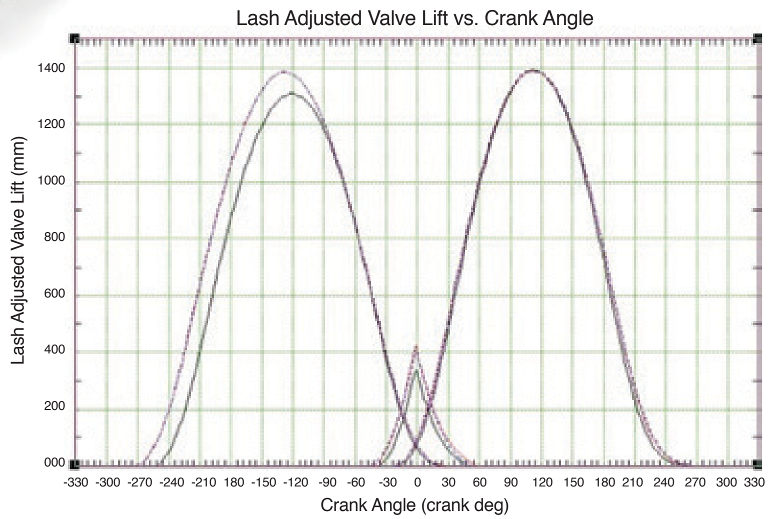
Block bottom cover

The low-profile bottom 'pan' is a high-pressure aluminum die casting with 3.5-mm (0.13-in) wall thicknesses. Two distinct bays collect oil draining

ALL IMAGES: GM



A new, more aggressive camshaft design and a phaser with greater authority conspire to increase the LT2's volumetric efficiency.



from piston-cooling jets and the crankshaft and cam bearings; each bay is scavenged by a crank-driven gerotor pump. A molded plastic scraper peels oil clinging to the crankshaft counterweights. An external oil-to-coolant heat exchanger bolted to the side of the oil sump is rated at 23 kW, 28% greater cooling capacity than the LT1's oil cooler. The oil filter mounting boss is integral with this component.

Lubrication and ventilation

The LT2's 450-mm x 370-mm x 195-mm (17.7-in x 14.6-in x 7.7-in) plastic dry-sump oil tank, supplied by BASF, is 30% glass-filled PA66+PA6, known as Ultramid. It also handles centrifugal separation of the inbound oil and vapor. Attaching the reservoir directly to the engine trims mass, complexity, and flow losses inherent to external lines, Lee explained. A crank-driven vane pump provides low and high lubrication outputs to minimize parasitic losses below the 5,500-rpm switching point. Vent lines run from the reservoir to the cylinder-head covers which are in turn plumbed to the intake manifold so no oil vapor escapes to atmosphere.

In the LT1 V8, up to three quarts (2.8 L) of lubricating oil can be trapped in the engine during harsh operating circumstances, increasing the likelihood of momentary pressure pump starvation. In the LT2, less than one quart of the Dexos 2 0W40 synthetic oil is in use at redline. Lee claims this greatly enhances the new lubrication system's reliability and facilitates a 2.2-quart reduction of the V8's oil supply, compared with the LT1. That trims 3.7-lb (1.7-kg) of mass and reduces the cost of each oil change.

Crankshaft

A switch to S38 alloy steel improves the strength of the LT2's forged crankshaft vs. the LT1. A longer nose extension drives the three stacked oil pumps. The front damper has an aluminum hub and steel inertial ring equipped with a ribbed outer surface to drive accessories via rubber belts. A second damper at the rear of the engine connects the crankshaft to the dual-clutch automatic transaxle. This device diminishes torsional vibration, a concern while switching to the LT2's fuel-saving Active Fuel Management four-cylinder operating mode.

The rear damper is small in diameter because no flywheel or torque converter is required with the new automatic transmission. Extra effort was invested in locating the new transaxle's input shaft below its output shafts to facilitate the lowest possible engine mounting and center of gravity.

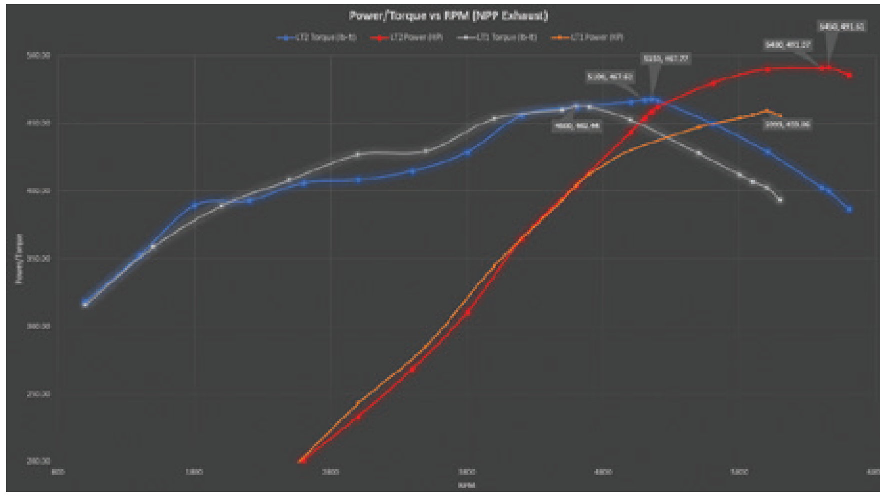
Intake, exhaust and Tenneco downstream

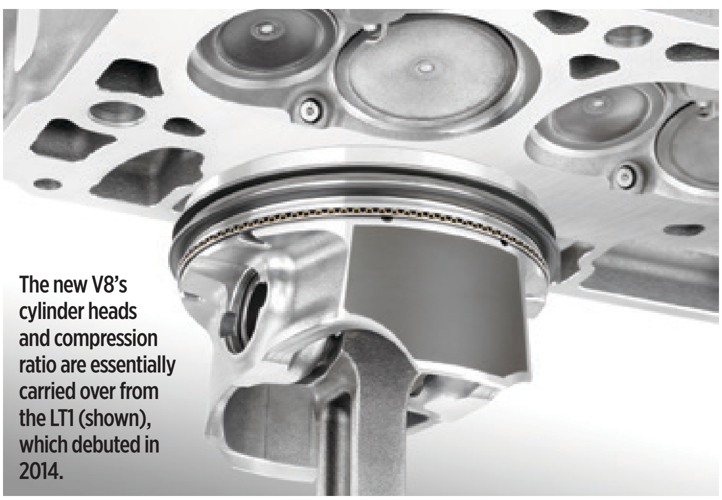
A key advantage with the mid-engine layout is more space and flexibility in the design of intake and exhaust systems. Chief engineer Lee acknowledges that there's nearly three more inches (76-mm) of height available for a larger intake plenum—with its internal volume increased from 13.5- to 16.0 L and more efficient runners—because there's no risk of the engine blocking the driver's view of the road ahead. While the LT1 had six 225-mm-long runners and two 185-mm runners (due to space limitations), the new LT2 intake provides eight runners all of which are 210 mm in length.

The intake manifold consists of four 'shells' made of injection molded PA66. These pieces are welded together using a vibratory friction process that temporarily melts mating surfaces. The eight runners are 210 mm (8.27-in) long. The 87-mm (3.42-inch) throttle body, now aimed toward the rear of the car, is the same diameter as the LT1's. Since the black plastic intake manifold isn't particularly attractive, designers hid it beneath a molded plastic cover textured to coordinate with the Corvette's rear body surfaces.

More sting for the STINGRAY

The Corvette V8's SAE J1349-certified 495 hp peak represents a 35-hp gain over the LT1.





The new V8's cylinder heads and compression ratio are essentially carried over from the LT1 (shown), which debuted in 2014.

GM designers also collaborated with powertrain engineers to perfect the routing and surface finish of the LT2's stainless-steel exhaust headers. The classic four-into-one layout has tubular runners, a brass-colored hue, and gently tapered collectors feeding a single-volume, close-coupled catalyst per side. Each cat is 132.1-mm in diameter x 140.0-mm long, yielding 1.9 L of internal volume. The ceramic bricks are drilled for O2 sensor clearance.

Lee's engineering team took full advantage of the newfound volumetric efficiency with a more aggressive camshaft design. Exhaust valve lift was increased from 13.5-mm (0.53-in) to 14.0-mm (0.55-in) and duration was upped a significant 18-deg. over the LT1's exhaust-valve timing. Intake duration was increased by 4-deg. While these changes sacrificed some power and torque in the mid-range (2800—4500 rpm), there are significant gains in both above 5000 rpm. Claimed peak torque of 465/470 lb-ft (637 N-m, with/without the optional performance exhaust system) is attained at 5150 rpm. The SAE J1349-certified 490/495 hp peak (365/369 kW; a 30/35 hp gain over the LT1) arrives at 6450 rpm.

The LT1's variable valve timing system providing up to 62 degrees of cam phasing authority and GM's AFM cylinder deactivation system both carry over in the interests of cruising serenity and fuel efficiency. Engine control is via GM's 32-bit E99 ECU.

Owners and bystanders will revel in C8's sonorous exhaust note. Reprising their work on C7, Tenneco engineers helped the C8 team create an electronically-controlled muffling system that switches tone and volume with the car's Sport and Track driving modes.

Cylinder heads

Cast in A319-T7, these components are largely unchanged from the LT1 designs. The 59-cc combustion chambers, valve sizes (2.13 in / 54 mm intake, 1.59 in / 40.4 mm for the sodium-filled exhaust), and 11.5:1 compression ratio carry over. Like the LT1, the new LT2 employs direct fuel injection, operating at 2,175 psi (15 Mpa) maximum pressure.

Engine testing

Proving the new Corvette's speed and stamina required countless laps around the Milford (Michigan) Road Course, the Nurburgring's grueling Nordschliefe, Virginia International Raceway, and the Papenburg (Germany) 12.3-km (7.6-mile) banked oval. Tilt-stand tests in GM Propulsion's Pontiac technical center verified that the lubrication system was capable of maintaining pressure when subjected to a simulated 1.2 g in every direction.

Manufacturing

The LT2 is manufactured at GM's Tonawanda, NY, engine plant using contemporary CNC flexible machining centers in lieu of transfer lines. Built in 1937, Tonawanda has been the small-block V8's home since its 1955 inception. While the plant established a world record building 8,832 engines in one day, current small-block production is 2,200 units/day. LT2 output for the new Corvette is slated at 170 engines/day. ■

BOTH IMAGES: GM

Chevy reveals 2020 Corvette Stingray convertible, C8.R racer

by Bill Visnic

The 2020 Corvette Stingray convertible's folding hardtop and associated hardware add approximately 77 lb.

Reinforcing the Corvette's long association with astronauts, Chevrolet unveiled the convertible version of its all-new, mid-engine-layout 2020 Corvette Stingray in Cape Canaveral in October 2019. Executive chief engineer Tadge Juechter, underscoring the car's no-compromises performance and comparatively affordable price, called it a "no-lose proposition" for enthusiasts considering the new Corvette but also seeking an open-top driving experience. When it went into production in the first quarter of 2020, the Corvette Stingray convertible's base price started at $67,495 — just $7,500 more than the 2020 Stingray coupe, which was widely celebrated for its aggressive $59,995 base price.

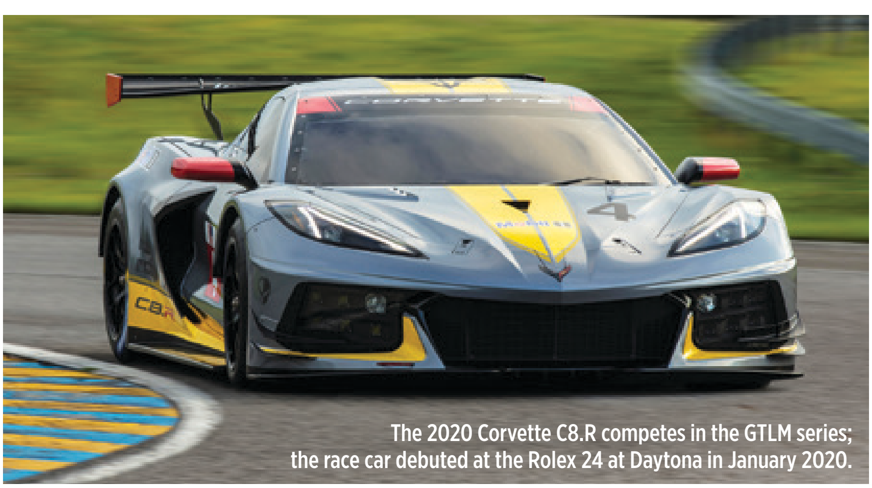
Although called a convertible, there is no fabric to be seen: the 2020 Corvette Stingray convertible uses a folding-hardtop design in which the center roof section folds in two pieces and stores above the rear-mounted engine. From some angles the new Corvette convertible will be difficult to distinguish from the standard Stingray coupe, even with the roof open. The giveaway is the glass rear hatch on the coupe that exposes the engine to view. The convertible does without this glass cover, but uses an upright section of glass behind the driver flanked by pronounced buttresses. The bodywork covering the engine is solid, with a rear-opening section that more closely resembles a conventional trunk.

A one-button actuation causes the folding section to raise or lower in about 16 sec, said Josh Holder, program engineering manager for the 2020 Corvette Stingray convertible. The new glass windblocker behind the driver can be power-adjusted to any position, including open even when the roof is in place. The roof can be actuated at speeds up to 30 mph (48 km/h).

Balancing mass vs. air flow

Holder told *Automotive Engineering* that the Stingray convertible is approximately 77 lb (35 kg) heavier than the conventional 2020 Stingray, but there is no additional stiffening required for the standard Corvette structure: he noted that the conventional Stingray was designed to incorporate its own removable roof section. Holder said spring rates and magnetorheologic-damper tuning for the standard 2020 Corvette's chassis are adjusted for the convertible to generate the same performance. The folding hardtop system uses six electric motors and was developed by sunroof and convertible specialist Webasto, which engineered the convertible top for the seventh-generation Corvette.

Apart from visual differences, Holder said perhaps the most meaningful change for the Stingray convertible is the incorporation of composite panels and heat shields that form the compartment for the folded top to protect it from excessive engine heat. And with the folded hardtop sitting atop the engine, the convertible uses revised engine-compartment cooling that directs airflow through the engine compartment in a different fashion than the standard Stingray. "The solution [to the stored roof pieces riding atop the engine] is airflow," Holder told *AE*.



The 2020 Corvette C8.R competes in the GTLM series; the race car debuted at the Rolex 24 at Daytona in January 2020.

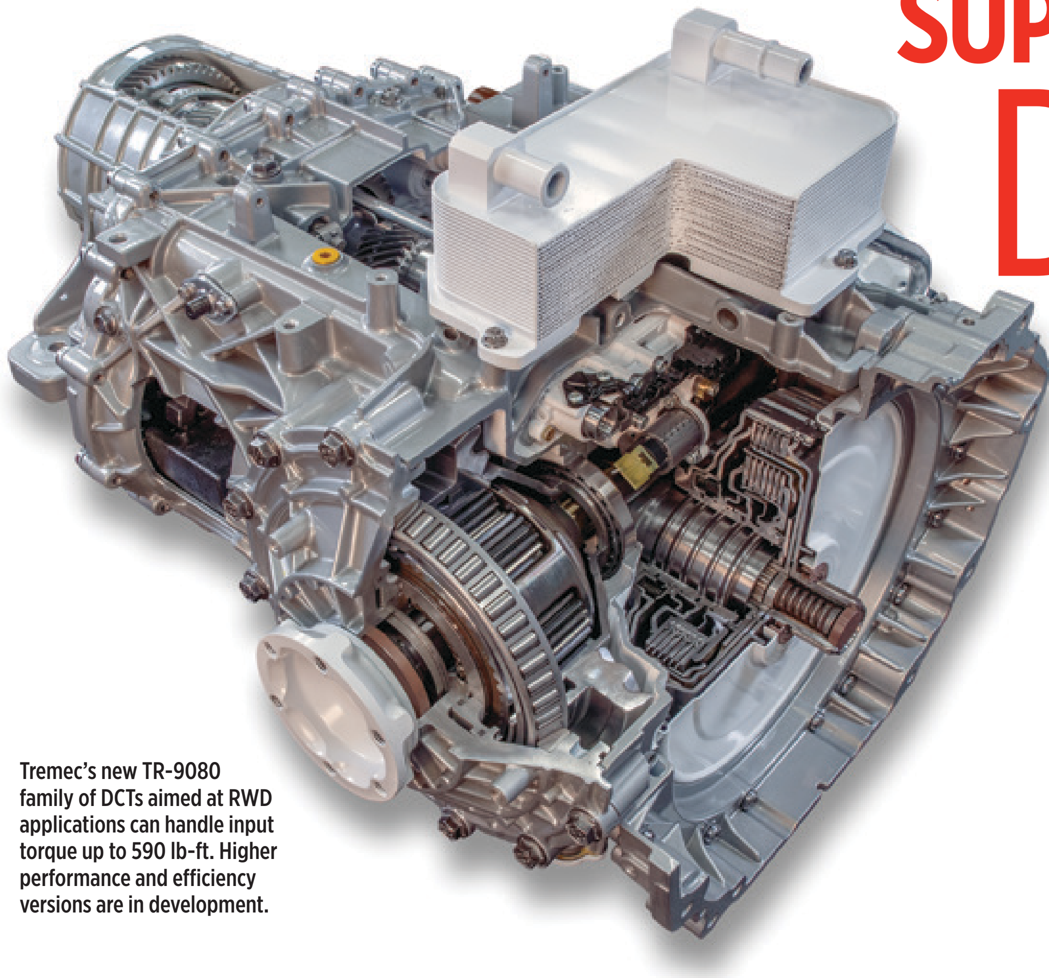
BOTH IMAGES: CHEVROLET

Racer ready

Chevrolet also used the occasion to unveil the 2020 C8.R race car which will compete in the GTLM endurance series, beginning with the Rolex 24 in Daytona, in January 2020 and including the iconic 24 Hours of Le Mans.

The C8.R was designed and built by longtime GM race partner Pratt & Miller Engineering of New Hudson, Michigan. It is powered by a new GM-developed 5.5-L DOHC V8 that uses a flat-plane crankshaft. ■

Inside Tremec's SUPERCAR DCT



Tremec's new TR-9080 family of DCTs aimed at RWD applications can handle input torque up to 590 lb-ft. Higher performance and efficiency versions are in development.

To polish the 2020 mid-engine Corvette's driving prowess, GM and Tremec engineers joined forces to create a new and better automated transaxle.

By Don Sherman

Explaining Corvette's move to one transmission for all buyers, global chief engineer Tadge Juechter notes, "Our customers began requesting a dual-clutch automatic transmission [DCT] several years ago. Following the introduction of the C7 Corvette in 2014, our take-rate for sticks [manual gearboxes] fell from 50 percent to less than 20 percent this year." Searching the globe – read Europe – for a suitable DCT, Juechter's team found none with sufficient torque capacity to survive behind the lively LT2 6.2-L V8 planned for the all-new 2020 mid-engine edition of GM's reimagined sports car.

To solve that dilemma, discussions began with Tremec, the Mexico City-based manufacturer which has supplied GM, Ford and FCA with manual transmissions for two decades. While Tremec had the expertise to make the mechanical components packed inside a dual-clutch box, the automated half of the equation – mechatronic actuators to engage the clutches and shift the gears – was beyond their ken. Tremec filled that need in 2012 by purchasing Hoerbiger Drivetrain Mechatronics, a Belgium-based supplier of electronic dual-clutch actuators with a customer list including AMG-Mercedes, Ferrari and McLaren.

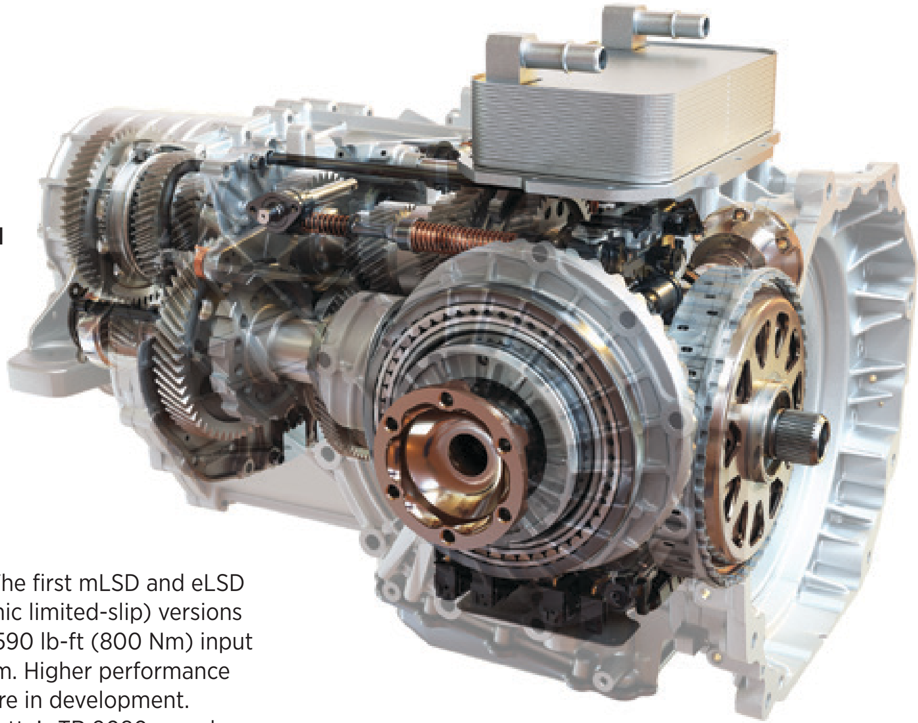
Invented by Citroen in the 1930s and patented by Imre Szodfridt in 1969, DCTs consist of a mix of manual and automatic transmission components and attributes. Celebrating the DCT's claim to fame, Corvette chief engineer Ed Piatek notes, "They change gears quicker than any human can shift a manual transmission." His team was convinced that a DCT was the optimum solution for the all-new Corvette and steered Tremec in that direction from the onset of C8 development.

Like conventional automatics, DCTs upshift without interrupting the flow of torque to the drive wheels. Like manual transmissions, they employ clutches and helical gears versus a torque converter whirling planetary gears. Porsche especially has enjoyed great success with what it calls PDK (Porsche *DoppelKupplungsgetriebe*), the most popular transmission type across its lineup. Understandably, GM and Tremec engineers used PDK as their key performance target.

Packaging triumph

Tremec owner Grupo Kuo announced its investment in DCT technology in 2016. The new TR-9080 family is aimed at high performance

TREMEC



Mechatronics know-how helped Tremec engineers design a super-compact unit. TR-9080 is available with both mechanical and electronic limited-slip diffs.

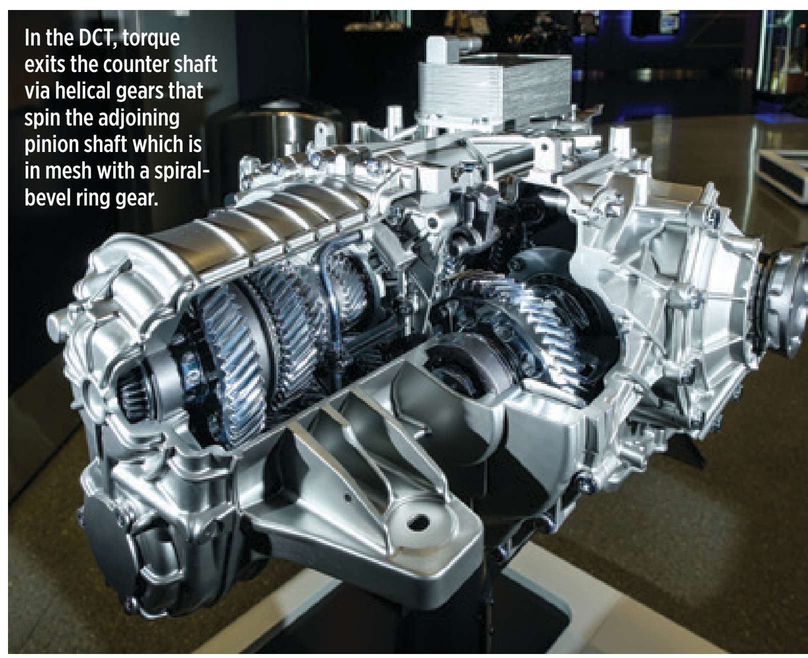
rear-drive applications. The first mLSD and eLSD (mechanical and electronic limited-slip) versions are capable of handling 590 lb-ft (800 Nm) input torque at up to 7,500 rpm. Higher performance and efficiency versions are in development.

A look inside the Corvette's TR 9080 reveals the densest package of shafts, gears, actuators and electro-hydraulic servos to be found in any modern automobile. Five aluminum castings support the two clutches, six shafts, five synchronizers, two dozen gears, five shift rods and multitude of bearings needed to provide eight forward speeds, reverse, and lockup for parking.

Add to that three electrohydraulic control bodies, an assortment of speed and position sensors, and a master electronic controller managing every aspect of the TR 9080's operation. The 8.8:1 overall ratio spread yields nose-bleed launch acceleration, quiet and efficient cruising, and a gear for every in-between occasion. The mLSD variant is standard in the base Corvette and the eLSD optional (with the Z51 Performance Driving package).

Connecting the LT2 engine's crankshaft to the TR 9080's clutch basket is the responsibility of a flywheel carrying the starter ring gear and a centrifugal pendulum damper that's needed to quell torsional vibrations erupting during the engine's migration between V4 and V8 firing modes (a fuel efficiency improver). Tremec purchases this assembly from a Tier-2 supplier.

Next in line are the two normally open wet clutches positioned concentrically to save space. Hydraulic pistons rotating with the clutches force them into engagement when commanded to do so by the transaxle's electronic control module. The outer clutch's five driven plates spin the main shaft carrying odd-numbered gears located at the rear of the transaxle. The inner clutch's six driven plates (more because they're smaller in diameter) spin



In the DCT, torque exits the counter shaft via helical gears that spin the adjoining pinion shaft which is in mesh with a spiral-bevel ring gear.

the other main shaft which carries even-numbered ratios located forward in the transaxle. These two main shafts are concentric, with the inner clutch connected to the outer shaft and vice versa.

As in manual transmissions, all main shaft gears are permanently meshed with mating gears spinning on the counter shaft. No torque is delivered until two of the five triple-cone synchronizers are moved by a computer-controlled actuator to connect the selected gears to the main (input) and counter (output) shafts. Torque exits the counter shaft via helical gears that spin the adjoining pinion shaft which is in mesh with a spiral-bevel ring gear.

BOTH IMAGES: GM

Inside Tremec's SUPERCAR DCT

Gear Position	Ratio (:1)
1st	2.91
2nd	1.76
3rd	1.22
4th	0.88
5th	0.65
6th	0.51
7th	0.40
8th	0.33

C8 Corvette gear ratio chart and DCT installation (at right). The TR 9080 will skip ratios, as long as both even and odd gears participate in the downshift, i.e., 7th to 4th, 6th to 3rd, or 5th to 2nd.

To facilitate mounting the Corvette's engine one inch (25 mm) lower than the C7 edition, the TR 9080's architecture has the input shafts located at the bottom of the transaxle, below the final drive and counter shafts. Base Corvettes are equipped with a multi-plate limited-slip differential with a 4.89:1 final-drive ratio. Customers opting for the Z51 option receive an electronically modulated limited-slip diff with a 5.17:1 ratio. Transmission gear ratios (see table) are common.

During an upshift, the next ratio begins engaging before the gear in use is fully released. That process lasts 100 milliseconds, during which there is no interruption in torque delivery. To assure expeditious response, hydraulic circuits are as short as possible and the solenoids are engineered for fast action. Because the torque has to go somewhere (unless neutral is selected), no gear is skipped when the car accelerates from rest or slows for a turn or stop. The exception is when the driver floors the throttle to command maximum forward thrust. In this instance, the TR 9080 will skip ratios, as long as both even and odd gears participate in the downshift—as in 7th to 4th, 6th to 3rd, or 5th to 2nd.

'Burn-out' mode

Tremec assembles the TR 9080 at a $50-million, 125,000 ft2 Wixom, Michigan, facility opened in 2017, using global-sourced components. One of the major challenges engineers faced was developing a single fluid to serve all of the TR 9080's lubrication, cooling, clutch conditioning, and hydraulic servo actuator needs. The magic elixir is a Pentosin FFL-4 synthetic fluid supplied by Fuchs Lubricants. An 11-liter supply is carried in a bottom pan, pressurized by a gear-driven pump, and cooled by a stacked-plate heat exchanger (circulating engine coolant) mounted atop the transaxle. The fluid change interval is 22,500 miles (36,210 km) with a recommended filter replacement every 7,500 miles (12,070 km).

Aside from the remarkable acceleration available with eight gear ratios and the lack of thrust interruption during shifts, the new TR 9080 is programmed to interpret the driver's intentions and respond with impressive performance. Shift paddles attached to the Corvette's steering wheel provide the driver instant authority. A Driver Mode knob on the center console selects Tour, Sport, Track and Weather calibrations tailored to prevailing road conditions. Two additional modes allow drivers to customize engine, transmission, suspension and instrument display functions to their liking.

This smart transmission will downshift early during aggressive braking before a corner, delay an upshift during hard lateral acceleration exiting a bend, and hold a gear during a throttle lift to avoid unnecessary shifts. To achieve the car's 2.9-3.0-second 0-to-60-mph performance claimed by Chevrolet, the TR 9080 provides a 'burn-out' mode to warm the rear tires, and launch control to optimize engine rpm during the race through the lower gears. The engine is held at 3,500 rpm before the first-gear clutch engages. Pulling both shift paddles simultaneously releases both clutches. In Drive, pulling one paddle will switch the transmission to Manual shift mode.

To compensate for eliminating a traditional stick-shift transmission from the options sheet, Corvette engineers had to venture far beyond the placid behavior provided by past automatics. Early press reviews have already declared that the TR 9080 DCT is Mission Accomplished. The tougher critics to satisfy – the ones who matter most – are Corvette buyers in line for delivery beginning March 2020. ■

LINDSAY BROOKE

Sweating the details OF C8 DEVELOPMENT


Corvette's new aluminum-intensive spaceframe laid bare.

How GM's Corvette engineers tackled challenges in the move to a mid-engine architecture.

by Don Sherman

Shifting 500 lb (227 kg) of engine mass rearward by 7.5 feet (2.3 m) and moving 300 lb (136 kg) of transmission components aft by almost three feet transformed the 2020 Chevrolet Corvette Stingray into a budding supercar. General Motors' motive behind adopting a mid-engine layout for the eighth-generation (C8) Corvette was to improve acceleration, braking and handling via substantially increased rear-tire loading. While numerous test-drive reviews and 'Of the Year' trophies mark that mission accomplished, there are lessons behind the hoopla: how GM engineers solved problems they encountered reinventing America's sports car.

"Porsche was our primary benchmark, especially in reference to their PDK dual-clutch automatic transmission's overall dynamics," revealed executive chief engineer Tadge Juechter, in an interview with SAE's *Automotive Engineering*. He said GM also purchased a Ferrari 458 for testing and tear-down analysis.

The first running Stingray prototypes exhibited a high-frequency whirring noise emanating from accessory drives for the alternator, AC compressor and water pump located at the front of the engine. This caused concern, as the noise was being generated only a foot from the occupants' ears. Insulation placed on the firewall wasn't as effective in muffling the noise as the engineers had hoped, Juechter noted. So, they analyzed Ferrari's solution: an unusually thick rear window.

"For C8, we increased the thickness of that piece of acoustic glass to 8.6 mm (0.34 in), which is nearly three times as thick as the 3.2-mm (0.13-in) tempered glass shrouding the engine bay," he explained.

Jordan Lee, global chief engineer for GM's small-block V8, added: "It's a balancing act — hearing the satisfying sounds, such as the engine's throaty intake and exhaust rumble, over distractions such as belt whir, injector tick and valvetrain clicks." He noted that while most competitors hard-mount their fuel injectors between the engine's cylinder heads and fuel rails, GM has been using an isolated arrangement in the small block since 2014.

"For C8, GM's NVH engineers invested extra effort in developing effective insulation materials and assuring that the seal around the laminated acoustic glass at the rear of the cockpit is sufficiently robust to hush the belt whir," Lee said. Further dialing-in of build processes is aimed at eliminating audible fuel-injector noise in the production cars.

A related issue is that the driver's view rearward is through both the near-vertical glass panel in the rear cabin bulkhead and the long, nearly horizontal hatch over the engine compartment. In addition to providing rear visibility, the bottom edge of the glass hatch and surrounding surfaces must vent heat and moisture from the engine bay. What Juechter calls C8's "chimney" passes large volumes of hot, wet vapor during rainy driving and when the car is parked following a drive. A fan helps vent

GM

Built for speed *and* for comfort: The C8 chassis is designed to deliver near-neutral characteristics on the track with a slight amount of understeer during normal street driving.

GM

that heat from the engine bay. In addition, all the electrical connectors subjected to road splash have weathertight seals.

When the hatch glass is soiled, the driver's view to the rear is diminished. To address this concern, Corvettes with up-level 2LT and 3LT interior trim are equipped with a two-way center mirror. Mode one offers a conventional view through the two glass panels. The second choice is an electronic display provided by a high-definition camera mounted to the trailing edge of the roof. Assuming the lens is clean, the camera provides a broad rear view, unobstructed by the wide roof pillars and often-soiled hatch glass.

As is not uncommon in other rearview camera-mirror applications, reviewers have reported that it takes a second or so for their eyes to focus when the camera view is in use. All Corvettes have a conventional backup camera as standard equipment.

Stymied by the FEAD

Given the C8's aggressive cornering capability, powertrain engineers knew it was essential to improve the 6.2-L LT2 V8's lubrication system. Lee explained that with the previous-generation Corvette, "dialing in the lube system was like threading a needle. We lost several C7 engines when the oil pickup in the tank was starved during high-g maneuvers." Another issue was oil blown out the optional dry sump's vent system.

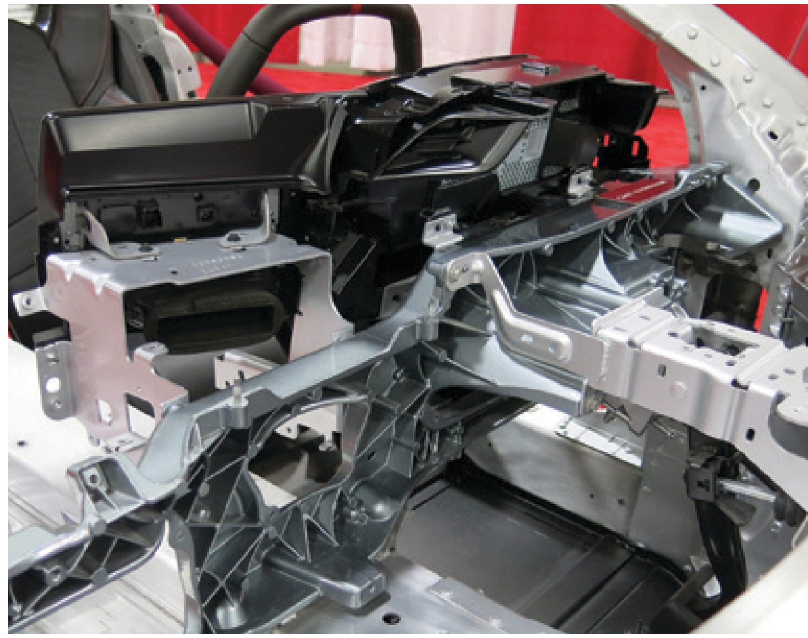
To solve these problems, the C8 program opted for two additional scavenge pumps to assure that track performance would be uncompromised. "Thanks to the new engine-mounted dry-sump oil reservoir that's now standard equipment, we encountered virtually no [oil-starvation] drama during development," Lee reported. "We were astounded how well it works and throughout C8's comprehensive test program we experienced only one engine failure."

One challenge that has thus far stymied engineers is a straightforward procedure for replacing the front-of-engine accessory drive (FEAD) belts. Doing so requires dropping the entire engine-transaxle assembly from the car. Corvette owners can only hope that will be a rare occurrence necessary only every 100,000 miles or so.

While shuffling powertrain component locations, C8 engineers also switched from semi-elliptic composite suspension springs (pioneered on Corvette' rear axle in 1981) to steel coils. "We would have preferred to keep the composite springs because they are quite efficient from a mass standpoint," Juechter explained. "Unfortunately, with our low-mounted engine and transaxle, there's no room for the tall crosscar path that a rear composite spring requires. In a rear view of the chassis, the arc of the spring would occupy the exact same space as spinning transmission gears."

Once C8's rear suspension design changed to coil springs, the engineers had to follow suit in front. Juechter said this was because of the significant difference between composite- and coil-spring force-versus-deflection characteristics. "To match the ride

Executive chief engineer Tadge Juechter said his team would have preferred to retain the semi-elliptic composite springs used on previous Corvettes.



Details of C8's magnesium crosscar beam and instrument module. Note deep-section center-tunnel structure.

and roll rates at both ends of the car — something we deem absolutely essential — we switched to a steel coil spring at each corner," he explained.

Rear-tire mass loading

The other fundamental C8 design change is a new aluminum spaceframe consisting of six elaborately ribbed die castings — which the engineering team dubbed "the Bedford Six" because they're manufactured at GM's Bedford, Indiana, facility — plus 14 conventional castings, extrusions, stampings and hydroformed parts joined with a variety of fasteners and structural adhesive. Flow-drill screws used at dozens of locations pierce an attaching hole and form threads to secure frame components. As in C7, suspension control arms and knuckles are stiff aluminum forgings and castings.

Thanks to the more robust spaceframe, C8's torsional stiffness is 7% greater than C7 with its roof panel in place and 12% stiffer in the open configuration, according to GM engineers.

In its C8 review, *Car and Driver* reported an increase in the Corvette's center-of-gravity height. Confirming that, Juechter shed light on the situation: "While C8's engine and transaxle are both mounted as low as possible in the chassis, there are several parts that are higher than before," he said. "The rear coil springs are not only heavier than the previous composites, they reside above the tops of the tires and are anchored at their upper ends by substantial pockets cast into our new spaceframe."

In addition, C7's low-mounted torque tube is gone and C8's exhaust system sweeps upward as it flows rearward, raising the height of the catalytic converters, Juechter noted. The net result: the C8's center-of-gravity height is 470 mm (18.5 in) — 15 mm (0.59 in) higher than C7's.

An oft-sighted reason for choosing mid-engine over alternative powertrain layouts is to minimize the car's polar moment of inertia for optimum agility. Asked to compare C8 and its predecessor, vehicle performance manager Alex MacDonald calls the polar-moment-of-inertia figures of both C7 and C8 "pretty comparable." That said, two substantial components now reside some distance from the center of gravity.

"C8 has two large radiators full of coolant situated in the nose of the car," MacDonald noted. "And our fairly heavy transaxle lives at the opposite end of the car, well behind the center of mass. So, positioning the engine near the middle doesn't automatically yield a low polar moment of inertia. In the end, the added traction achieved with 60 percent of the Corvette's mass loading its rear tires is a greater influence on overall performance."

Another non-trivial challenge facing the C8 team was tightening EPA and global regulations for brake-dust emissions. Studies have shown that the dust created by vehicle brake-pad abrasion is the source of approximately 20% of total PM2.5 (fine particulate) vehicular pollution.

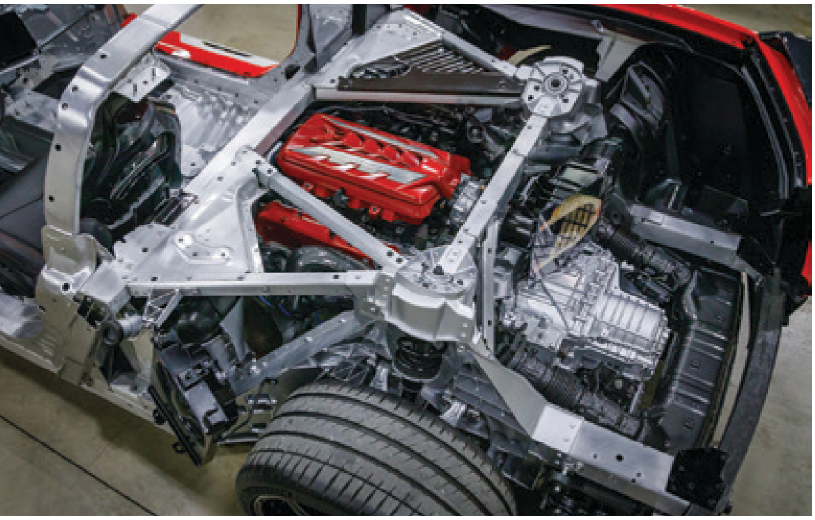
"We had to reinvent our brakes," Juechter explained, "because our previous pads' 25-percent copper content is no longer permissible. To avoid abrasion of the new pad material, we can no longer use the drilled and slotted rotor venting that flushes water from the friction surfaces during wet driving. While I personally prefer the look of slotted rotors, they're gone in C8."

Balancing handling and ride quality

An unsung C8 achievement is a base curb weight increased by only 70 lb (32 kg) over its predecessor despite added

BOTH IMAGES: LINDSAY BROOKE

Sweating the details **OF C8 DEVELOPMENT**



C8 rear structure is a feast of clever engineering solutions. Note near-vertical rear window aperture, side-mounted engine bay fan, exquisitely webbed castings, and carbon-composite rear bumper beam.

features: roomier passenger accommodations, the new Tremec TR-9080 8-speed dual-clutch automated-manual transmission with one more gear than C7's manual transmission, dry-sump lubrication, increased cooling capacity and larger rear wheels and tires. Even with the more stringent 2020 EPA test procedures, highway fuel efficiency increases by 2 mpg (to 27 mpg).

To hold the line on weight, Juechter's team supplemented its sharp-pencil engineering with a few carbon-fiber composite components. One is an industry-first curved and hollow rear bumper beam. The supplier, Shape Corp., uses pultrusion technology developed by Germany's Thomas Technik and Innovation to draw carbon fiber material, wet with urethane-acrylate resin, through a die. The resulting beam, which is 4.9-lb (2.2-kg) lighter than an aluminum extrusion, bolts to the Corvette's spaceframe extensions.

Another ultralight part is the center tunnel close-out panel, supplied by the Molded Fiber Glass company. It is made using MFG's PRiME liquid composite molding process. Two carbon fiber and three fiberglass sheets wet with vinyl ester resin are molded under pressure, yielding a stiff 10.4- x 49.5- x 0.16-in (26.5 x 125.7 x 4.0-mm) panel weighing only 4.9 lb. It attaches to the bottom of the aluminum spaceframe with 30 fasteners.

The new Corvette's passenger compartment floor panels are SMC (sheet molding compound) moldings topped with stamped aluminum panels at the rear to support the car's bucket seats. Front and rear luggage-compartment bins made by MFG use ultralight SMC with a specific gravity below 1.0 — indicating that each part would float in water. A die-cast magnesium crosscar beam bolts between the A-pillars to rigidly support the dash panel. For the first time, the Corvette's bottom surface is flat and smooth to minimize aerodynamic drag.

One enduring C7 owner gripe is front-tire chatter during cold-weather, full-steering-lock maneuvering. According to Juechter, considerable effort was invested in remedying that shortcoming.

The C8 team had to rethink Corvette's foundation brakesets to meet stricter global regulations for brake dust emissions.

"In the past, we pushed our front-engine performance limits with near-racing tire compounds and steering geometry favoring handling," he said. "Unfortunately, below 40-degrees F, this results in stick-slip tire chatter that owners notice. To improve this in C8, we revised the steering geometry to improve the Ackermann correction and walked back a bit from our previous aggressive tire compounds because they're less essential with mid-engine to achieve our performance goals."

The net result, Juechter noted, "is nowhere near as much stick-slip chatter as we had in C7, even with the tighter turn circle provided in C8's equipped with our MR (magnetorheological) dampers." Now in their fourth design generation, the highly effective MR dampers supplied by BWI cost $1,895 over the $5,000 Z51 Performance Package.

The Corvette development team collaborated five years with Michelin to develop new run-flat tires for C8. The base rubber is a Pilot Sport ALS (all season) while Pilot Sport 4S (summer only) radials are included with the Z51 option. This is the first application of all-season tires on the Corvette, which should encourage owners to use this supercar more months of the year in northern climes.

Juechter is on record not wanting C8 to be a handful at the cornering limit — a preference dating to his youth under the wing of a fighter-pilot father who enjoyed owning and driving Porsche 911s. "We definitely didn't want our first mid-engine

FROM LEFT: GM; LINDSAY BROOKE

Developed in parallel with the 2020 Corvette Stingray, the C8.R racecar driven by Antonio Garcia, Jordan Taylor and Nicky Catsburg earned a fourth-place finish in its maiden race at the Rolex 24 At Daytona to start the IMSA WeatherTech SportsCar Championship. The trio completed 785 laps for 2,794.6 miles — the greatest distance for any Corvette entry in Rolex 24 history.

RICHARD PRINCE/CHEVY RACING

effort to earn a reputation as a car that's tricky at the limit," he asserted. "There are numerous variables that must be addressed to achieve benign, totally controllable handling. By that, I mean near-neutral characteristics on the track with a bit of understeer during normal street driving."

A key variable is lateral compliance, which begins at the tire sidewall and continues through the wheel's construction, wheel bearings, suspension knuckles, rubber bushings and control arms all the way to the suspension anchor points on the spaceframe. "We want the tire's stick-slip characteristics to be very progressive with gradual changes in the coefficient of friction," Juechter explained. Suspension geometry was tailored to provide a small amount of steering into the turn as the car rolls. The lateral compliance built into the suspension bushings also provides a few minutes of steer angle under high lateral loading, he said.

Engine-mounting strategies were also deliberated, with the team deciding to "softly" mount the LT-2 V8 for vibration isolation. "But you definitely don't want a two-stage step function when the engine reaches the limit of its roll," Juechter explained. "So, the compliance and damping built into the engine mounts are also important." Finally, spring, anti-roll bar and damper calibrations were selected to work with all the other variables to give the driver the perception of a totally integrated driving experience.

Dimensional factors

In the plan view, the 2020 Corvette Stingray has a fighter-jet look with an aggressively curved nose tip and front corners drawn back tight — seemingly a triumph of styling over engineering. The car also is 2.2 in (5.6 cm) wider and 5.3 in (13.5 cm) longer than its C7 predecessor. The increase in length is attributable to ergonomic and storage improvements. Fore-aft seat travel was increased by an inch (25.4 mm) and the seat-backrest recline angle doubled, to 18 degrees, to better accommodate tall occupants. The C8's extra length also provides storage space in the rear trunk for the removable roof, a feature considered essential in Corvettes.

The increase in overall width is due to wider rear tires and wheels. "It's not practical to tuck them in closer to the centerline if you want outstanding ride and handling balance," Juechter said. "We prefer long suspension travel with lower spring rates than are common in competitors. Shortening the halfshafts isn't practical because that increases universal-joint angularity, greatly reducing the life of the rubber boots surrounding the U-joints."

Also contributing to the C8's added width is the substantial duct integrated into each rear quarter panel. These openings are responsible for ingesting an enormous volume of air for engine induction and engine-bay cooling (cars equipped with the Z51 performance package have a third radiator on the passenger side to assure that they're fully track capable at ambient temperatures of 100 degrees F).

Juechter acknowledges that the wider fenders and rear tires are responsible for a frontal area that's slightly greater in C8 (2.075 m^2/22.3 ft^2) than in C7 (2.023 m^2/21.78 ft^2). Because aerodynamic downforce is notably greater with the Z51 performance package, a C8 so configured has an 0.322 drag coefficient versus C7's 0.313 Cd.

The bottom line is a 2020 Corvette Stingray chassis and body engineered to fully exploit the performance strides delivered by the SAE-certified 495-hp LT2 V8 and the Tremec DCT. Considering the new Corvette's $59,995 base price and the sold-out 2020 production run, Juechter's team has seemingly wrought the supercar value of the century. ■