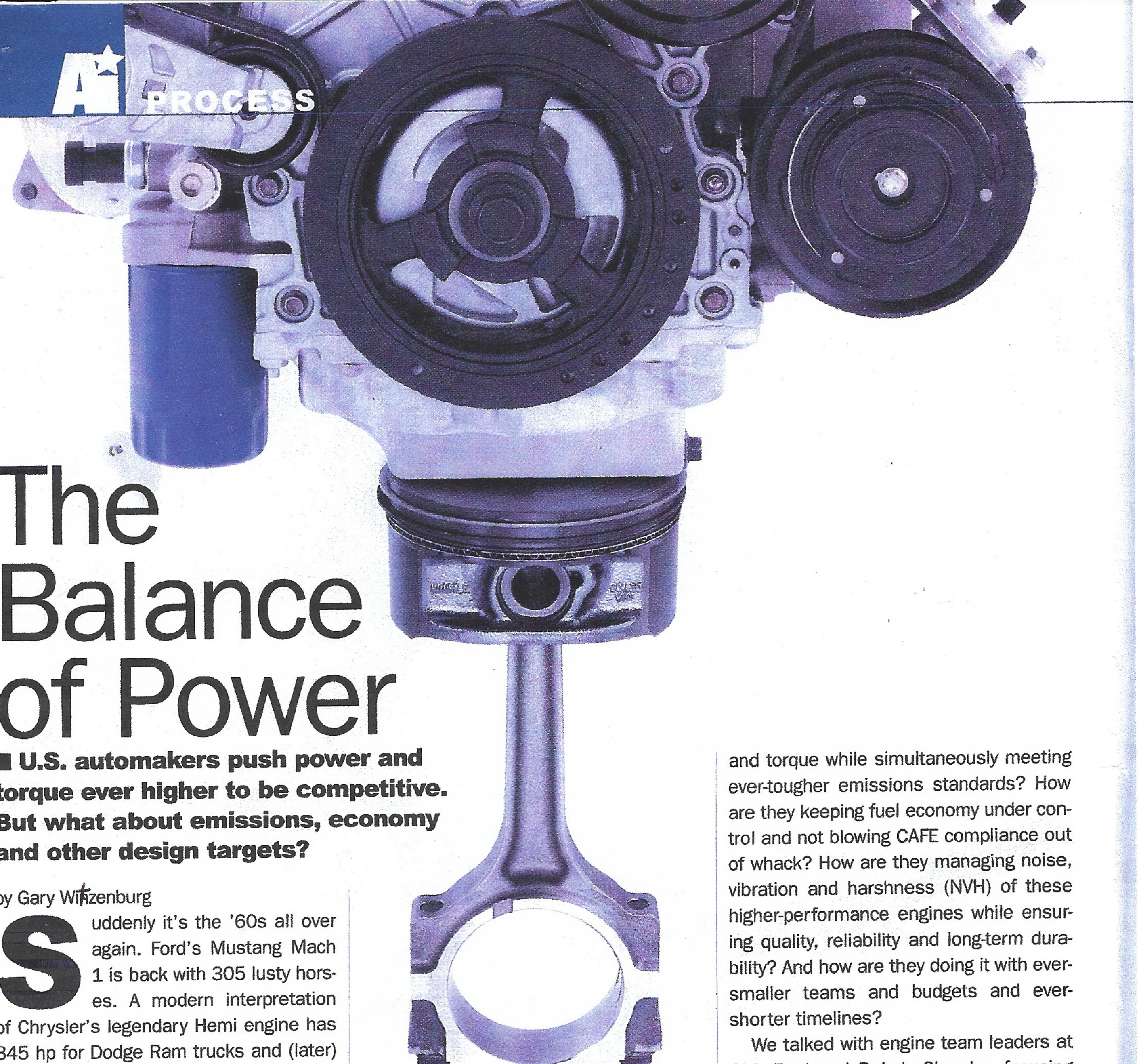


The Balance of Power

■ U.S. automakers push power and torque ever higher to be competitive. But what about emissions, economy and other design targets?

by Gary Witzenburg

Suddenly it's the '60s all over again. Ford's Mustang Mach 1 is back with 305 lusty horses. A modern interpretation of Chrysler's legendary Hemi engine has 345 hp for Dodge Ram trucks and (later) new rear-wheel-drive Chrysler cars. Pontiac's new GTO, derived from GM Holden's high-performance rear-wheel-drive Monaro, arrives late this year with 340 hp.

Each U.S. maker has a specialized high-performance group. Ford's Special Vehicle Team offers a 390-hp SVT Mustang Cobra, a 380-hp SVT F-150 Lightning pickup and a 170-hp SVT Focus. DaimlerChrysler's Performance Vehicle Operations (PVO) offers the new 500 hp Viper SRT-10 roadster and a Viper V-10-powered Ram SRT-10 pickup and a 215 hp turbocharged Neon SRT-4 are on the way. GM's new Performance Division (GMPD) is developing high-performance models for every GM brand, beginning with a 345 hp Chevy Silverado SS pickup, a hot V-8-powered Cadillac CTSv and a sizzling supercharged Saturn Tuner Coupe.

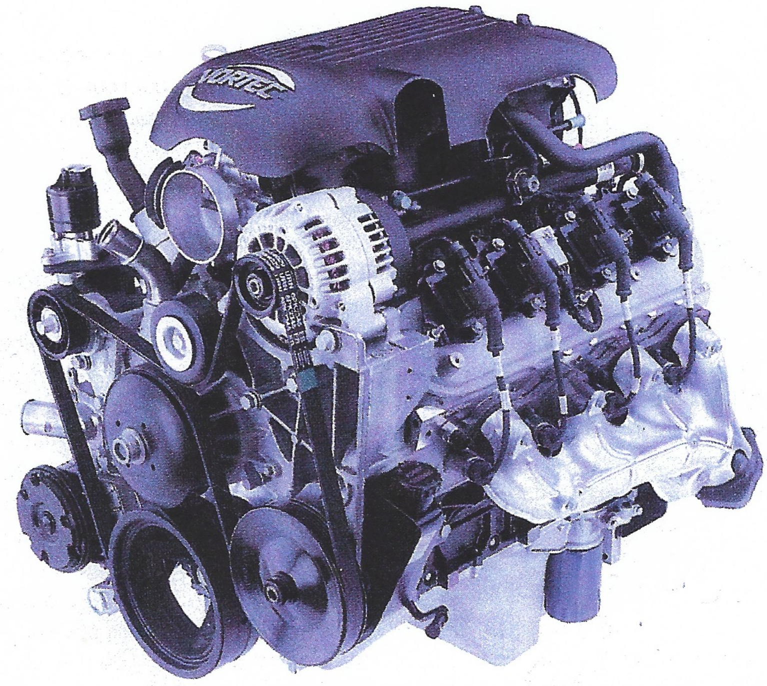
Compared to the one four decades ago, today's performance war is very different and far more challenging. About all you needed then were bigger engines with bigger carburetors and bigger exhausts. Then you could wedge those big cubic inches into mid-size, even compact cars. There was money in engineering budgets and plenty of eager engineers to get it done. There were just four U.S. players (counting AMC), with virtually no import competition. And no emissions or economy regulations.

How are today's engineers meeting market demand for ever-increasing power and torque while simultaneously meeting ever-tougher emissions standards? How are they keeping fuel economy under control and not blowing CAFE compliance out of whack? How are they managing noise, vibration and harshness (NVH) of these higher-performance engines while ensuring quality, reliability and long-term durability? And how are they doing it with ever-smaller teams and budgets and ever-shorter timelines?

We talked with engine team leaders at GM, Ford and DaimlerChrysler, focusing primarily on the oft-conflicting objectives of higher performance, higher fuel efficiency and lower exhaust emissions. As volume examples of 300-plus-hp engines, we chose GM's 6.0 L Vortec V-8, Ford's new 5.4 L 3-valve Triton V-8 and Dodge's new 5.7 L Hemi V-8.

All agreed that the fundamentals are basic: for higher power and torque, you need higher flow — more air and fuel in, more exhaust out. For cleaner emissions and higher economy, you need a more complete burn — which also, by the way, improves performance. The big challenge is in how, and how well, each accomplishes these objectives. As more than one put it, "The devil is in the details."

GM continues to refine its five-year-old Gen III small-block V-8s while preparing to phase in cylinder deactivation ("Displacement on Demand") to boost economy. Ford chose a three-valve (two intake, one exhaust) design for the latest member of its modular V-8 family, then added Variable Cam Timing (VCT) and Charge Motion Control Valves (CMCV) to increase turbulence at low engine speeds. DC reached back into heritage and revived the hemispherical combustion chamber, this time with dual plugs to enhance the burn in its new 5.7 L Hemi V-8.



GM's Vortec V-8 is a marvel of engineering because it does more with less. Pushrod construction, two valves-per-cylinder, single spark plug and world class performance.

General Motors 6.0 L Gen III Vortec V-8

GM's third-generation small-block V-8 family covers a wide array of applications — 4.8 to 6.0 L and 270 to 405 hp — and is found in nearly half of the vehicles it sells. Several 6.0 L versions range from 300 to 345 hp in both light-and heavy-duty pickups and SUVs. John Juriga, GM Powertrain assistant chief engineer for Gen III V-8s, says it's mostly a matter of working on the fundamentals, the "blocking and tackling" of engine design: "There is no magic," he says "We're looking at ports, chambers, every aspect of improving volumetric and thermal efficiencies and reducing friction.

"One of our strategies is to keep the low end intact. If we can make more power and torque at high rpm without sacrificing low-end flow or adding friction, these higher-performance engines can run on the FTP (Federal Test Procedure) effectively the same as the lower-power versions." One tricky part of the FTP is getting converters to light off as quickly as possible. "The catalytic converter is a combustion chamber," Juriga explains. "It needs to heat up before those noble elements — the platinum, rhodium and vanadium — can start reacting with exhaust gases. When it's cool, when you first start your car or truck in the morning, exhaust gases go out the tailpipe unburned."

Juriga identifies several key enablers: "Number one, our analysis is very, very good and getting better all the time. That helps us design our chambers to increase top end flow without gutting the low end or adversely affecting idle or combustion characteristics. Second, our control systems are constantly improving. We have much better spark and fuel controls, and better knock sensors. If you have a very good combustion system — chamber, ignition system and fuel control — you can start improving other fundamentals, such as going to higher compression ratios, without having to compromise other areas.

"Compression ratio (CR) helps performance and economy but hurts hydrocarbon emissions, so you may have to put more catalyst 'loading' in your converters — that's a cost trade-off — or move them closer to the engine. A lot depends on the type of chamber you have and how efficient it can be, so it goes back to designing the combustion chamber to handle higher compression ratios without adversely affecting emissions. A lot of effort is spent on that area, and on cam timing and cam profiles."

Despite CRs as high as 10.0:1 in the Cadillac Escalade's 345-hp H.O. 6.0 L (and 10.5:1 in the 405 hp 5.3 L Corvette LS6 V-8), none of these engines requires premium fuel. "With higher compression ratios," Juriga says, "we're getting fuel economy benefits at lighter-load, part-throttle conditions where we're not NO_X-limited. We've gone to 'premium fuel recommended' because higher octane allows us to run with greater spark advance, but our control systems are good enough to live with regular unleaded if a customer puts that in. Our knock sensors, when they hear detonation, can retard the spark quickly enough to prevent damage or pinging, and that goes back to intelligent control systems."

Another key factor has been maintaining a very common family architecture — many components in the 4.8 are the same as in the 6 L, and the assembly process is exactly the same. Still another is advanced materials. "All our engines use composite intake manifolds that improve airflow and are lighter in mass and lower in cost. They also don't transmit heat, so we get a cooler intake charge. We search the world for the latest materials to make lighter valvetrains to handle higher, more aggressive cam profiles for more power and torque. New catalytic converters are less restrictive to reduce back pressure and can handle higher temperatures so you can place them closer to the engine for quicker light-off, yet not burn them out once the engine heats up."

While some view these engines' cam-in-block, pushrod architecture as antiquated compared to more mechanically efficient overhead-cam designs, GM prefers to think of them as elegantly simple. Pushrod valvetrains are also less complex, less expensive, easier to service and smaller in package size for a given displacement — and also provide a tremendous advantage for utilization of fuel-saving DOD, which GM will begin phasing in as standard in certain truck applications in 2004. This simple, inexpensive system should improve both rated and real-world economy by eight percent or more by shutting off half the cylinders at light loads. DOD could be engineered onto OHC engines but would be a lot more complex and costly.

Here's how it works: When conditions are right, the control system commands hydraulically activated pins to release, allowing the lower halves of those lifters to telescope into the top halves when pushed by the cam lobes, so the valves are not activated. With both valves closed following combustion, the pistons in those cylinders come up and compress the exhaust gases instead of pumping them out. On the downstroke, the gases expand, then compress and expand again, like a spring.

"We want compression to energize the rings to prevent drawing oil into the chamber," Juriga explains, "and we want to keep those cylinders warm because you don't want cold cylinders when you start them up again. It becomes a four-cylinder engine running at a more open throttle condition, improving volumetric efficiency and reducing pumping losses, with very little loss in the system." He adds that the control system must be highly intelligent for DOD. "For example, we have to provide a different fuel schedule to get those cylinders to fire off again without a problem."

Also, DOD provides a greater percentage improvement on larger engines because a larger engine spends more time in the four-cylinder mode.

Ford 5.4 L three-valve Triton V-8

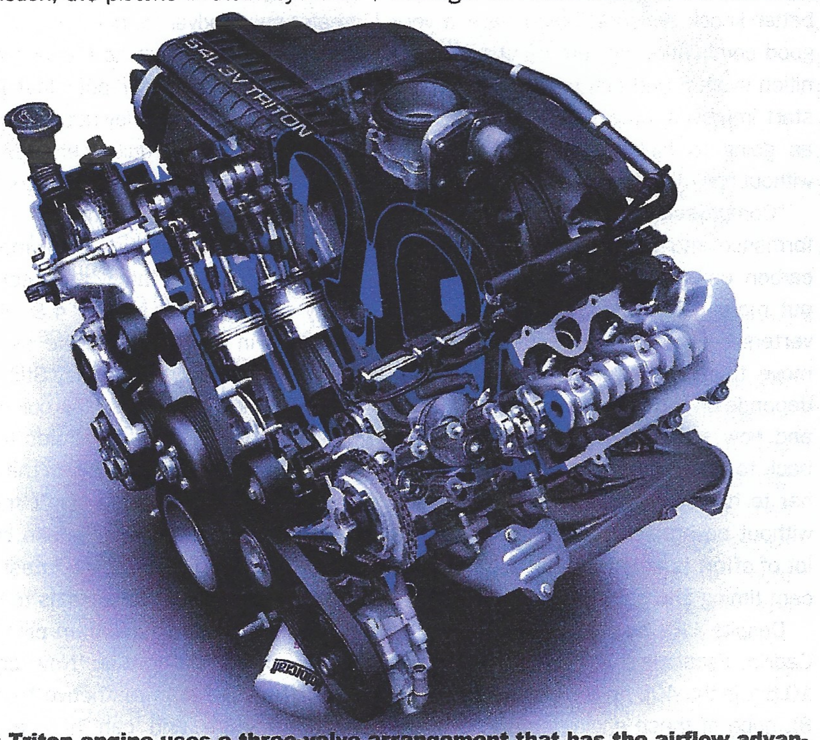
"Emissions standards are becoming increasingly difficult," says Peter Dowding, manager of Ford's Modular V-8 and V-10 engines, "so we have to come up with innovative ways to meet them. As an engine designer, I want to make the most use out of every pound of fuel that comes into my engine. You have to be very efficient with each combustion event, make it as clean as you possibly can, so you have less unburned HC to take care of afterwards. I want the cleanest burn in the right time to minimize emissions and maximize fuel economy. Part of that is what you choose as a combustion system."

Dowding's team chose a SOHC three-valve system for their new Triton V-8, which makes its U.S. bow in Ford's all-new 2004 F-150 pickups later this year. This design enjoys much of the flow advantage of a four-valve head without the cost and complexity of two more cams and eight more exhaust valves. Debuting with 300 hp and 365 lb.ft. of torque (15 percent more power and five percent greater peak torque than the two-valve 5.4 L Triton), it has excellent potential for future enhancement and will surely find its way into SUVs and rear-wheel-drive cars down the road.

"You talk about horsepower wars, but this is really about torque," Dowding says. "The amount of torque, or twisting motion, that we can get to the tires. We looked at what features were available and psyched out our technology points carefully: three-valves-per-cylinder, higher compression ratio, central spark plug, variable cam timing, charge motion control valves, header-style manifolds, integrated air/fueling system and attention to detail for vibration and noise."

Locating the spark plug dead-center at the top of the chamber required a long, slim new-design plug. "We wanted a continuous flame kernel from the center of the combustion chamber across the whole of the cylinder," Dowding says. "And the combustion system is so stable that we can provide a lot of ignition retard to make burn take place later, which puts a lot of heat into the exhaust system and lights the catalyst off quicker.

"Another important detail is that the last discharge of any exhaust stroke is carbon-rich, and VCT allows us to attract that charge back into the chamber and re-burn



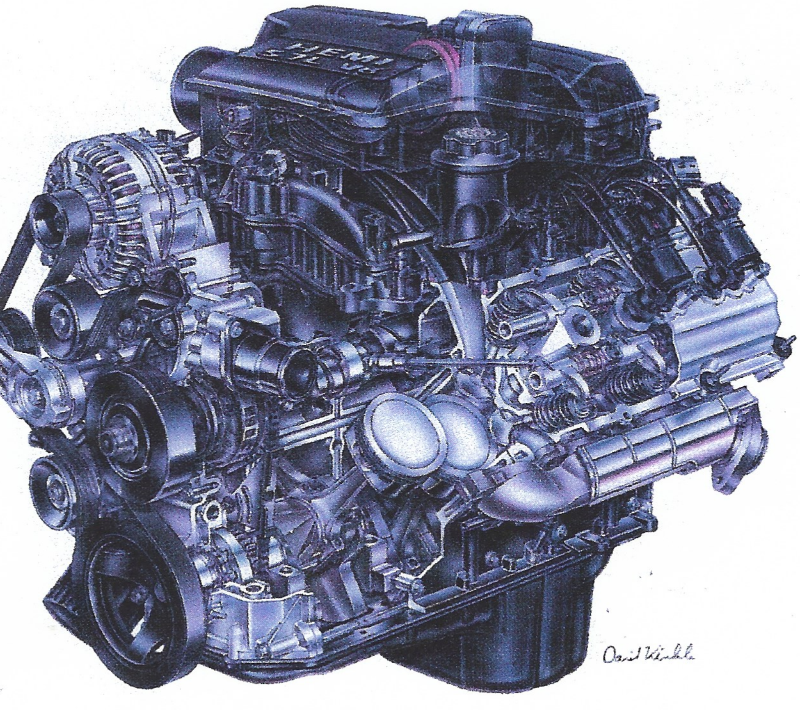
Ford's Triton engine uses a three-valve arrangement that has the airflow advantages of a four-valve system, but with a single overhead cam and much fewer machined components.

it, which is very, very good for HC emissions. Our Charge Motion Control Valves can generate turbulence in the incoming fresh charge, mixing and swirling the air and fuel together with that previously-burned gas before igniting it. That is very significant because it allows us not only to reduce NO_x but also to re-burn that HC-rich discharge." As a result, the previous engine's external EGR (exhaust gas recirculation) system is no longer needed.

Dowding adds that his team's toughest challenge may have been NVH refinement, "because you can't really attack that until you've got the whole design together. Our NVH group did extensive testing in anechoic chambers and came up with some innovative ways of identifying areas where noise and vibration were occurring. Then we'd task the engineers responsible for those parts with bringing their levels down, put those into the next prototype iteration and test it again. You build on the prior level of design until you can get into the range you want.

"The computer-aided tools and checking processes available these days really help. You have to use all of the available tools of the time to achieve all of the things you've set out to accomplish: more power, more torque, lower emissions, more efficiency and more refinement. If you focus on any one of them, you can start to lose some of the others. You need all the pieces of this puzzle to balance these competing objectives and move every single one of them forward.

"We're meeting much more difficult emissions standards, we're improving fuel economy, and we've increased the amount of torque and power without having to change the displacement. It was a very interesting technical challenge, and one that's being executed very well."



DaimlerChrysler's Hemi uses dual plugs to control the burn rate for fewer emissions and better idle quality. The name Hemi also carries huge brand equity.

DaimlerChrysler 5.7 L Hemi Magnum V-8

DC's new Hemi V-8 is related to past ones primarily in combustion chamber philosophy. The first 180-hp Chrysler Hemi V-8 arrived in 1951, but the one most remembered is the 426-cid street version of the company's Daytona-dominating race engine. Offered in limited numbers from 1966 to 1971, it offered an advertised 425 hp and 490 lb.ft. of torque under that era's more liberal rating system.

This latest one, standard in Dodge Ram HD pickups and optional in light-duty versions, debuted in 2002 with an impressive 345 hp and 375 lb.ft., an impressive 41 percent increase in power and 12 percent more peak torque vs. the 5.9 L Magnum V-8 it replaces.

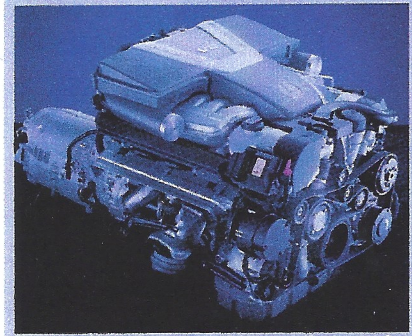
"One enabler for increasing output is getting the engine to breathe very, very well," says Bob Lee, Chrysler group director of rear-wheel-drive engine engineering, "So we set that up and said, 'we want airflow, and we know how to get it — hemi head, big valves — and we know how to use analytical techniques to control it. Then we'll use dual spark plugs to get the burn rate we need.' That's how we attacked it, kind of a 1-2 punch. We went for the airflow first, and then cleaned it up using analytical tools to get the chamber shaped right and dual plugs in the right places. Without the hemi head, we would have never gotten the airflow out of two valves and would have had a very different compromise.

"One of the biggest benefits was a combustion simulation that allowed us to get to the chamber we've got, allowed us to select the hemi engine and address many of the deficiencies of the old one — the emissions characteristics, the idle quality. So you see things like dual spark plugs, shallow chamber, flat-top pistons, and all of those things came from using those simulation tools.

"Another benefit," Lee continues, "is that we can leverage expertise from different sources — partly from the merger, if you think about what we can learn from Stuttgart — plus Mitsubishi and Hyundai. We need to be aware of the best out there, and we now have a much bigger pool of expertise with which to share. For specific expertise, we brought outside people into the program as part of the team effort. That's another kind of difference in approach that allowed us to make much better trade-offs than we might have a few years ago."

Since a hemisphere is by definition one half of a sphere, we ask what qualifies this engine as a hemi. "Two things," Lee responds. "One is the shape of the combustion chamber. The old 426 Hemi's chamber

The Three-Pointed Star Approach



Mercedes-Benz's three-valve twin plug Vee engines have extremely high output and very low emissions, but everything comes at a price.

Another way in which today's pitched performance battle differs from the past is intense competition from off-shore makers. While most live at much higher price levels, the U.S. market offers a bountiful selection of high-horse BMWs, Mercedes, Audis, Jaguars, Lexus and Infiniti, to name a few. The majority employ DOHC four-valve engines, often with turbo- or supercharging instead of large displacements, to make prodigious power and torque.

One notable exception is Mercedes-Benz. Most '03 M-B models are motivated by V-6, V-8 and V-12 engines with (like Ford's new Triton V-8) three valves and (like Chrysler's new Hemi) two spark plugs per cylinder.

Chrysler might say, "Who needs three valves?" Ford might boast, "Who needs two plugs?" And GM might chuckle, "Who needs any of that?" M-B says, "This cutting-edge technology boasts up to 40 percent lower emissions, 13 percent better fuel efficiency and 25 percent lower weight, not to mention a broader torque range" compared to its own previous designs.

The single exhaust valve results in about 30 percent less surface area at the exhaust port, relative to a comparable four-valve engine, which M-B says "dramatically reduces exhaust heat losses between the engine and the catalytic converter. This translates to higher exhaust temperature and converter light-off about 12-seconds earlier" for greatly reduced emissions during the critical warm-up stage.

"Using one less exhaust valve," M-B adds, "also makes room for two spark plugs per cylinder, and an innovative offset-phase twin-plug ignition system matched to the new three-valve technology actually improves performance." The dual ignition system activates the two plugs one after the other in quick succession (rather than simultaneously), with varied "stagger" depending on engine load and speed.

This new dual ignition system also allows an extremely lean fuel/air mixture and late ignition timing (retarded by 5 to 10 crank degrees) during warm-up, which further increases exhaust gas volume and temperature to help heat up the converter more quickly.

M-B's 5.0 L three-valve V-8 generates 288 hp in the ML500 SUV and 302 in the E500 and S500 sedans, CL500 and CLK500 coupes and SL500 roadster. The awesome 6.0 L twin-turbo V-12 is good for 493 hp and an incredible 590 lb.ft. of torque in the S600 and CL600 luxury sedan and coupe — **GW**

wasn't technically a hemi because it was a section, not half, of a sphere. This new one is similar but a smaller section. The other is the relationship of the valves to the crankshaft. The valves are located opposite each other with their centerlines perpendicular to the crankshaft.

"With the old engine, the shape of the piston was what made it not very good. The piston had a very large 'pop-up' — it was shaped like a house — so the flame initiated in the center but had a hard time getting all the way around both sides of the chamber and cleaning out the HC. That's one of the things the modeling showed us we had to fix if we were going to use a hemi configuration again. The trade-off was to shallow up the chamber and go to basically a flat piston with just a 1 mm radius on top, so the flame travel is much faster and cleaner. In combination with the dual spark plugs, that allowed us to get rid of that bad characteristic of the old engine. Also, for very good reasons based on the modeling, a couple millimeters of material are added to the sides of the chamber to enhance charge motion and burn. This "fill" technique was done by Don Garlits and others for racing in the '60s, but not in production."

The new design's dual spark plugs (unlike the old one's single plug) are not centrally located. "It's virtually impossible to do that with the valves being what they are," Lee explains, "and even if you could, that arrangement is not as good as getting the combustion out near the periphery and initiating it from two different sources. The two plugs are beneficial for idle stability, burn rate and completeness of combustion, and they have even greater benefit with leaner mixtures and with lots of EGR."

Lee points out that it isn't just the technical challenge but the combination of business and technical challenges — achieving the right solutions at the right cost — that make today's engine designs so difficult. "To address that," he says, "a couple of things are interwoven here. First and foremost are the tremendous advances in analytical tools, which in many cases allowed us to figure out the cost/benefit trade-offs without going to prototype tools, without doing experiments in an expensive lab environment and without the errors that come in experimentation.

"We've made some changes in our business model and the team environment, and I think the engineers kind of thrive on the hard part," Lee replied. "If the environment is created correctly, the challenge is clear, and the toolbox is available to them, then they really, really come together. We saw it on the 4.7 and learned how to manage it better on the 3.7. I think this new 5.7 is the best thing we've done. I think they're very proud of it and were happy to work on it as hard as they did."

Three companies, three very different approaches, all apparently successful. Despite increasing toughness of the challenges facing it, as long as the tools and materials available to engineers continue to improve, there should be a lot of life left in the old internal combustion engine before something better and at least as practical and affordable comes along to replace it. ★