1997 - 2004 Corvette: Technical Article: The Millenium Motor: Inside C5's LS1 Engine

The Millennium Motor: Inside C5's, LS1 Engine

Your first, in-depth look at what will power Corvettes into the next century.

by Hib Halverson

Adapted from material published on the Vettenet and ZR1 net mail lists in August 1996 and from a printed version in the August, 1996 issue of Corvette Fever magazine

Before the 1997 Corvette was even in dealers, it had been reported for a year or more that the all-new platform, known to insiders as "C5," would be the first General Motors Corporation product to use a new family of medium-displacement V8 engines. Though the car did not debut on the show circuit until January 6, 1997 and in dealers on March 6. 1997, way back on June 11, 1996 in Los Angeles, GM confirmed the engine rumor with a preliminary to the C5 launch: a press show spotlighting its engine.

My first reaction back then was that what's known as "RPO LS1, 5.7L SFI V8," is an outstanding design, engineering and manufacturing exercise destined to be yet another landmark in the history of America's Sports Car. My second reaction? A snicker at the show biz that clouded the engine's debut.

It is not unusual to introduce a new Corvette engine before its car. In 1988, media got a comprehensive technical seminar on the LT5 nine months before it was shown the ZR1. Of course, this is now; and that was then.

A major deficiency of this June 11 show and Chevrolet's other LS1 publicity efforts around the country in the summer of 1996 was that 1) they failed to adequately address the most striking feature of LS1: its pushrod valve gear and 2) they came wrapped in a spoof of medical TV shows. The Corvette community contains many potential C5 customers who were not served well by this program because its information value was degraded by its need to entertain.

The quality and timeliness of the in-depth, LS1, technical information reaching the Chevrolet enthusiast was further blunted by only average coverage to date from Corvette media and Chevrolet's decision to let Hot Rod magazine break the LS1 story ahead of all other publications. The stories that finally made it into print in the Corvette media were either too brief, poorly researched or lacked depth because their editors felt preempted by Chevrolet's leaking the story.

These shortcomings of these processes are why you have The Idaho Unofficial Corvette and Corvette Surfing WWW sites. Like a beacon of reality, we're going to cut through the smoke to the hard-core, gearhead story behind this stunning, new engine.

The LS1 press kit said, "Based on a timeless design by former Chevrolet Chief Engineer Ed Cole, the 'Gen III' 5.7-liter V8 marks a bright new chapter in the highly respected lineage that GM small blocks have established in more than 40 years."

I think Chevrolet understated its case.

LS1 is Brilliant

Rather than just a chapter in engine history; it's more like a whole new book!

What it is not is: "based on" Ed Cole's legendary Small-Block. LS1's greatness comes from being a clean-sheet-of-paper design. The only major feature it has in common with the Small-Block is a bore center-to-center measurement of 4.40 inches and we believe that exists for marketing reasons rather than an engineering case.

When and Why

By 1991, writing was already on the wall. While tens of millions of Small-Blocks had been produced in 36 years, the basic architecture would be a liability if customer demands for world-class performance, increasingly stringent exhaust emissions regulation and higher fuel economy standards were going to be met. While Chevrolet and the General Motors Powertrain Division (GMPD) knew the Gen II (LT1/4 and L99, introduced for 1992) and Gen I-E (light-truck, Vortec series engines, introduced for 1996) upgrades would stretch the Small-Block's life; it was clear that further improvement was needed, if those demands were going to be addressed in the late-'90s and early-'00s.

That winter, deep inside GMPD, study began of a third iteration of the Small-Block V8. Expectedly, someone coined the name "Gen III" and it stuck. The project had SAE net power and torque goals of 1 horsepower and 1 pound/foot of torque per cubic inch displacement. There was a weight reduction goal of about 60 lb. When asked about durability, reliability, drivability and pleasability objectives; GMPD said only that intent in those areas was "best in class." While that phrase was maybe a bit ambiguous, because Corvette has few direct competitors and none with big V8s, my road test of a C5 pilot car (VIN 00063) in March of 1997 showed the new engine exceeds expectations for drivability and meets them for pleasability. I suspect that time will show the engine's reliability/durability equaling and possibly exceeding that of the Gen II Small-Block.

The first major challenge may have been more philosophical than technical. John Juriga, LS1 Project Manager, talked about the initial design period, "Trying to decide what was the right engine technology for the application was probably the biggest hurdle we faced."

This was really not one decision, but a series of them that carried throughout the early phases of the program.

In February of 1993, a stunning decision, arising from this GMPD "soul searching," was to discontinue Gen III as a Small-Block and do it as a totally new, medium-displacement, V8. The change was made after it became obvious that a Small-Block could not meet the program’s goals; however, don’t think that Gen III work to-date had been for nothing. Significant technology developed for the still-born, Small-Block Gen III went into the 1996 LT4. Roller rocker arms, more aggressive camshaft, hollow-stemmed valves, intake and exhaust port enhancements, rolled-fillet crankshaft and "powdered-metal" rods, all early Gen III ideas, were pulled ahead for the last Small-Block in a Corvette.

Initially, it was thought that the first of the all-new Gen IIIs might show up in a low-volume, 1996 truck application, but as engineers better understood the time necessary to take it from paper to production and make it best-in-class; it was decided that the engine would debut for 1997 in Corvette trim. A similar, but slightly less powerful LS1 goes into the Camaro in 1998 and the all-new, ’99 or ’00 C/K trucks will get the iron block/aluminum head version. Perhaps other places a Gen III might appear are a "Monte Carlo SS" (front-drive, smaller displacement, aluminum), maybe a high-performance compact truck (iron block/alum. head) and in trucks over of 8600 lbs. GVW and higher (iron block/iron head).

We suspect that the first, very early prototypes of the all-new, Gen III ran on the dynos at GM Powertrain sometime in the early spring of 1993. In-vehicle testing began at the GM Milford Proving Ground in the first week in May of 1993 with the "Chevrolet Engineering and Research Vehicle IV-A" (CERV4a) powered by a prototype, of 5.0 liters and having an iron block and aluminum heads. Eight months later a second car, the CERV4b fitted with a 5.7L iron block/aluminum head Gen III, was added to the test program.

The Gen III passed the "Concept Direction" "gate" in the development process in September of ’93. To do this, it had to have demonstrated the capability to meet the requirements set for the project. Then came Concept Approval. That happened in May of 1994 when the LS1 was within 10% of all development targets.

The C5 "alpha" build, which produced the first prototype cars that were reasonably close to how the 1997 Corvette would look, began in June of 1994. By late-summer, the alpha phase was in high-gear and most all used iron block/aluminum head Gen IIIs at first, with a few all-aluminum units showing up late that year.

The next C5 iteration, the "beta," began to appear at the end of June 1995. Betas were very representative of what production C5s would be and were the last cars built in Michigan at GM prototype assembly line. Betas used mostly, aluminum LS1s. By fall-’95, the beta build was complete, but the number of cars in testing, believed to have been about two dozen, sometimes exceeded the supply of reliable, all-aluminum engines. Betas not used in development where vehicle mass approximating production intent was necessary, sometimes got iron block/aluminum head engines.

By late 1995 or early 1996, the aluminum block shortage was less of a problem and the LS1 progressed to the point that final development in prototype C5s was underway. That continued into the April of 1996 when the engine was released for production.

An interesting aspect of the engine program was the "Cormaro". In the first six months of 1995, twenty C5 structure/chassis/powertrain combinations were fitted with modified '95 Camaro bodyshells. These cars were used well into 1996 for powertrain development and were a perfect way to put street miles on the LS1 without drawing attention...at least until ace spyshooter, Jim Dunne, published a picture of a Cormaro in AutoWeek magazine and identified the car as a Gen III V8 "test mule."

There was also an unknown number of C4s that were fitted with Gen III engines. These cars were used to develop cold-start ability and the traction control system software.

Alloy Block

Aluminum blocks, or "cylinder cases" as engineers say, are becoming common for production engines. Why? fuel economy and exhaust emissions regulation have forced vehicle weight reduction and aluminum blocks weigh less.

Aluminum has downsides. For a given chunk of metal, its strength-per-mass is less than that of cast iron. With liquid-cooled, aluminum block engines, corrosion and porosity are durability concerns.

GM's first attempt at a high-volume, aluminum V8, a 4.1L pushrod engine in Cadillacs in the early-'80s, had many problems. Stripped head bolt-hole threads are so common that, today, many dealers keep thread repair kits in stock. Engine failures due to coolant-contaminated oil are, also, common.

It's taken years of work and not just a few angry customers, but GM has developed aluminum block reliability and durability to where its comparable to iron engines. For its part, the General improved its aluminum engines such that by the late-'80s/early-'90s, later versions of the pushrod Caddy along with the DOHC engines, LT5 and premium V8 (the "Northstar" 4.9L and the Olds "Aurora" 4.0L), proved excellent designs. Problems of the type that plagued the old 4.1 are unheard of with LT5s and Northstars.

By the mid-'90s GM was ready to try another aluminum, pushrod engine. One of the first challenges was to design the case. John Juriga told us, "Overhead cam engines are simple from a block standpoint. (The LS1) made for a complicated block design. The deep skirt, six-bolt bearing caps, deep-threaded head bolt holes, camshaft and tappet locations and other features made it challenging to engineer."

If packaging wasn't problematic enough, due to aluminum's lower strength-per-mass and higher coefficient of expansion, dealing with block distortion, noise and vibration gave design engineers fits. Burning fuel generates the torque that makes a car go. It also makes heat and stress which cause an engine to distort. This distortion of a few thousandths of an inch might seem trivial; however, it causes increased friction, cylinder bore distortion and degraded piston ring seal, all of which negatively impact fuel economy, exhaust emissions, durability and, of course, performance.

If you could measure a running engine in real-time, you would note that the block "quivers" like a big tuning fork as a result of stress to the block by the engine's power impulses. This makes for noise and vibration, two more customer satisfaction issues.

Considerable design resources went into making the structure of the LS1 case both lighter and more rigid than that of the iron block engine it is replacing. Examples are: 1) many, external, stiffening ribs, 2) six-bolt, steel, main bearing caps and 3) the "skirt" that extends below the crankshaft centerline. These features make an extremely rigid case. Chevrolet refused to quantify this rigidity, but we suspect that it is significant. The pay-off is less noise and vibration, better fuel economy, reduced emissions, improved durability and higher performance.

"Once we had the design," Juriga continued, "there were casting and manufacturing issues that had to be resolved. First, what casting process to use. We went with a process that was relatively conventional in that it wasn't lost-foam or die-cast."

The LS1 block is made of 319 aluminum heat-treated to the T5 standard by the Montupet Corporation of Ontario, Canada. It is cast using the semi-permanent mold technique which Juriga described as "....a cross between die-casting and sand-casting." The case weighs 107 lb. Compared to the Gen II's 160 lb. block, that's a significant weight saving.

The engine uses centrifugally-cast, gray-iron liners. The liners to be quite thin, but very strong due to centrifugal force increasing the density of the iron during casting. The sleeves are, then, cast into the aluminum block at the foundry. When asked in June of '96 about these sleeves' tolerance of overbore during rebuilds, Juriga said that a thickness figure was unavailable and that, to date, GMPT had not addressed the service overbore issue. In a second interview, in March of 1997, John Juriga told me that the LS1 engines for MY97 and 98 will tolerate only about a .005-in. overbore which really amounts to just a clean-up hone. In 1999, the sleeves will be revised such that service overbore of .015-.020 is possible without compromising durability.

The liners are finished with a bore size of 99 millimeters (3.8976 -in.). That, with a stroke of 92 mm (3.6620-in), makes the LS1's displacement 5.665 liters or 345.69 cubic inches. Obviously, it won't fly with the Chevrolet marketing folks if, upon opening a C5's hood, people holler, "Hey, Vern! I got me one of these new, three hundert 'n' forty-six inch motors, here." so Chevy wants you to call it a "350" or a 5.7L engine.

John Juriga on working the bugs out of the manufacturing process: "Getting prototypes made without porosity, without cracks and on time was the next difficulty. To make a producible component–if I look back–was a steep learning curve for us. It was a challenge. It took us a while to get to where we could produce castings for our prototype builds in quantities that we needed."

At that time I also learned about the LS1 development via a good source on the C5 team. "We had problems with leaks due to sealing and porosity," I was told, "Both coolant in the oil and oil in the coolant. Another problem was getting engines. Any new engine program is going to have failures. Powertrain was working to solve them but there were times where vehicle development slowed because there were not enough engines. We even tried to fit LT4s in some C5s so we could push ahead with testing not related to powertrain, but the LS1 is shorter and the steering rack had been relocated rearward, so an LT4 just wouldn't fit."

Getting the manufacturing technology of the Gen III's aluminum block right proved a daunting task that took a couple of years. Clearly, people at GMPD working to make the LS1 reliable and durable put in a ton of overtime and had to make some tough choices. One of those had GM discontinuing its relationship with the initial block supplier, Alcoa. Some of Alcoa's manufacturing process were based on aerospace techniques. In this case, the attempted application of aerospace technology to automobiles was unsuccessful. Alcoa's failure to perform drove the GM decision to transfer the casting to Montupet. Other hard decisions came later upon discovery of a problem with the LS1's oiling system which is covered later in this article.

While these problems were traumatic, they are an expected part of the high-stakes business that is bringing a new engine to production. GM designs, develops, tests, then develops some more based on that testing. Eventually, this process results in a Corvette powerplant that is reliable, durable, drivable and capable of best-in-class performance. If my road test experience in a pilot cars along with the experiences of other magazine test drivers is any measure, GM has a home run in this engine.

Plastic Intake

How 'bout that plastic intake manifold, eh? Okay, we'll use the marketing buzz word "composite" once, but we common folk find the stuff of which that intake is made closer to plastic than anything else. Specifically, it's a Dupont material called "Nylon 66" that is a mixture of a Nylon and glass fiber reinforcement.

Plastic manifolds are easier to manufacture, weigh less, run cooler and better lend themselves to intricate designs. We wonder how long it will take C5 design chief, John Cafaro, to discover plastics can be dyed to get stuff like fluorescent-pink intakes? Ok. Just kidding. Ah....but don't get any ideas, Cafaro.

The first question about a plastic intake is, "Do they, like...melt when the engine overheats?" Well, if overheating means setting your C5 on fire; then the intake will probably melt; however, this manifold will withstand the heat of operating temperature, even that of an engine stuck in Death Valley in mid-August with a coolant overtemp situation.

This intake manifold uses some cleaver packaging. The plenum is beneath the runners allowing the runners to be long, but also to curl smoothly from their junction at the plenum, up and over to each intake port in the heads. The smooth curves, also, enhance airflow. The plenum occupies space in the valley, making the engine as short as possible. The intake is well-integrated with the intake ports, because, in the early stages, the same person had design responsibility for both.

Look closely at the throttle body on the front of the intake manifold and you'll see a major innovation. Instead of a throttle bell crank there is an electric throttle control (ETC). LS1 will be the first throttle-by-wire application in a GM car. The connection between your right foot and a C5 will be via a wiring harness. Throttle-by-wire has been used in aircraft for many years and on a GM light-truck, diesel application since 1995, but C5 will be its first performance car application outside of motorsports.

The LS1's sequential electronic port fuel injection (SFI), is similar to what has been used since 1994. Each cylinder has its own ACDelco Multech injector to meter fuel. A mass air flow (MAF) sensor, meters the air. The injectors are controlled by the PCM. It sets the fuel delivery schedule by applying data, such as crankshaft position, mass and temperature of intake air, engine speed, coolant temperature and a few other parameters, to fuel "look-up" tables in the PCM software or "calibration." Based on those look-up tables, each cylinder's injector is "pulsed" in the engine's firing sequence such that a precisely metered amount of fuel is shot down the intake port just before the valve opens.

Under many driving conditions, the PCM uses a "feedback loop" to trim fuel delivery to optimum levels. Free oxygen in the exhaust is an accurate measure of fuel mixture. The feedback comes from oxygen sensors (O2S) screwed into the exhaust manifolds. They measure the oxygen content and send that information to the PCM. When the engine runs in this "closed loop," combustion is optimized for best performance, exhaust emissions and drivability.

One interesting aspect where LS1 departs from the Small-Block is that the whole induction system, intake manifold, throttle body, injectors, fuel rails and wiring, is assembled by an outside supplier, shipped to the engine plant as one piece and simply bolted in place.

LS1 uses a tuned, intake port length as did the L98 of 1985-'91; however, LS1's 15-in. runner length is tuned for top-end power whereas L98s 21-in. runner was tuned for mid-range torque.

The Rest of the Basic Engine Story

The crankshaft material is cast, nodular iron, the same used for Gen II and many Gen I cranks. It is noticeably shorter than that of a Small-Block and the main bearing size is larger than that of all except the old 400. The rod bearing journals are the Small-Block "large journal" size. In fact, the only part in the whole darn engine that carried over from the Small-Block are the rod bearings. For improved strength, the crank uses the rolled-fillet journals introduced with LT4. The crank weighs a bit more because of the larger main bearing journals and an ignition trigger wheel that is part of the casting. In another departure from the Small-Block, to reduce the effect of crankshaft expansion on alignment of internal engine parts and external accessories; the crankshaft thrust is taken by the center main bearing rather than the rear unit.

The LS1 uses a sintered, forged, PF1159M steel connecting rod. Also called "powdered metal" or "PM," this technology was introduced in Corvettes for MY96. The basic, Small-Block rod currently in the GM Performance Parts catalog is also PM.

To make a sintered rod, a mold is filled with steel powder which is "briquetted" or compressed under extremely high pressure. Then, the rod is "sintered" which heats the metal just to its softening point causing the steel molecules bond and making a dense, very strong part. Next, the rod is put through a conventional forging process. Lastly, it is shotpeened. The combination of these manufacturing techniques results in a rod with "net shape," which requires no machining for profile or balance and is more consistent in mass than rods of traditional manufacture.

The LS1 rod is also known as a "cracked rod" because the big-end is fracture split. During the finishing process, to split the big-end; a stress riser is cut into its inside diameter. The rod is stressed such that it fractures at that riser. The jagged surface left on both pieces precisely locates and locks the rod cap in place once the rod is assembled. For simple assembly and mass reduction, the LS1 rods use a 9 mm. capscrew rather than a rod bolt and nut to hold the big-end together.

Rod length is 6.1 in., .400-in more than the LT1/4 rod. The extra rod length reduces rod angularity and piston speed which decreases friction and noise and increases durability. LS1 rods have no balance pads making for less overall mass and allowing the engine to rev quicker. Undoubtedly you’re asking, "Hey, wadaya mean ’no balance pads.’? How do they balance the rods, then?"

Well, they don’t

Small-Block rods were held to a weight tolerance of ±5 grams, per end, after balancing. The LS1’s PM rods are manufactured to a tolerance of ±3 grams for the small end and ±4g for the big end without machining for balance. Such are the advantages of a net shape.

How good is this connecting rod? Many stock rod Small-Blocks, after lengthy time in severe duty, will display fretting corrosion of the inside diameter of the big end. This is due to the big end flexing a tiny bit under the bearing shell. The LS1 rod, under similar operating conditions, shows virtually no fretting. Bottom line: The LS1 rod is the strongest connecting rod ever used in a GM, production, mid-displacement V8.

The new engine has of cast aluminum pistons. Their compression height is 34mm and they weigh 434 grams each. Unlike production Small-Block pistons, they have no steel reinforcement strut.

The old engine needed that feature to control piston expansion because the manufacturing process controls used previously and bore distortion due to the old engine's having head bolts threaded into the block decks, made for wide variation in bore sizes. To keep piston-to-bore clearance such that acceptable durability would come even with the smallest, expected bore size; piston expansion had to be restricted and that was done with the steel reinforcement.

With the Gen III engine family, process controls at the block machining stage are tighter and there is no bore distortion due to head bolts because their threads are very deep in the block. With bore variation significantly reduced, piston expansion control is not an issue, so the steel strut was eliminated making for a lighter piston that is less costly to manufacture.

The biggest visual differences between pistons for the new engine and those for LT1/4s are 1) LS1 units have no valve reliefs, 2) they have 6mm. less compression height which allowed the longer connecting rod and 3) the top ring was moved up 1.5mm.

There is a ton of technology in piston and rings aimed at reducing friction. The rings use the same basic materials as before but the design is different. The LS1 top and second rings have 1.5mm faces vs. the 2.0mm rings used in LT1/4. The tension of all rings have been reduced by about 30%. Reduction in ring face widths and tension would never have proven reliable from a cylinder sealing and oil consumption standpoint, if process control improvements did not result in reduced bore variation and improved consistency in individual bore diameters.

The LS1's pistons are lighter than a LT1/4 piston. A bore size 2.5mm smaller, 6mm less compression height and the lack of a steel strut make this possible. Improvements in LS1 rods and pistons have reduced the weight of each rod/piston assembly by 120 grams compared to the same LT4 pieces. That is a significant decrease that guarantees the engine will rev quicker (and it does!!) and be more durable at high engine speeds.

Oiling System Snag

After the aluminum block and plastic intake, the most noticeable part on an LS1 is the oil pan. Sources involved in C5 testing call the intricate aluminum casting a "bat wing" pan. It's part of the lower engine structure and contributes to overall cylinder case rigidity. Gen III continues the recent tradition of little oil filters but the filter mounts on the rear of the oil pan rather than the block. As with LT1/4s, no oil cooler is available and the factory fill will be synthetic oil. Testing shows the oil temperature range to be similar to what we see in Gen II Small-Blocks.

The new engine uses a gerotor oil pump that is driven off the front of the crankshaft. Gerotor pumps are used in many recent engine designs. They are less complex, less costly to make and require less power to pump a given volume at a given pressure.

Oil distribution has changed significantly from that of the Small-Block because of: 1) the front pump, rear filter arrangement (the old engine had both at the back) and 2) the LS1's main oil galley feeding the main bearings and the camshaft simultaneously (the Small-Block main galley fed the cam bearings first, then the mains). John Juriga tells us that the Gen I/II oiling system was very reliable and that the change in oil routing in the new engine came mainly out of manufacturing concerns.

One of the unexpected challenges of the C5 vehicle development program centered around the LS1's control of oil drainback and oil supply during high rpm operation with the vehicle sustaining maximum lateral acceleration (max. lat.), In February of '95, during maximum lateral acceleration testing on the skid pad at the GM Desert Proving Ground, problems with engine oiling began to crop up that were unrelated to earlier difficulty with cylinder case porosity. There may have been half-a-dozen or more engine failures due to this new problem. There was much head-scratching about why C5s were popping motors as if it were happy hour at a Winston Cup qualifying day.

By the end of the first quarter of 1995, it was established that the trouble was caused by two problems: 1) crankcase windage. The LS1's deep-skirted block, six-bolt main bearing caps and a higher oil level that goes with a shallower oil pan effectively divided the crankcase into four distinct "bays." Early blocks did not allow efficient transfer of air between bays as the pistons moved in their bores. At high rpm, the violent turbulence caused by this absence of pressure relief aerated the oil. This problem also restricted oil drain-back from the upper end of the engine. The combination of oil foaming and poor drainback degraded the oil supply. 2) lateral acceleration. At "max. lat.", oil level in the pan could reach a 45 degree angle from horizontal. Combine these two problems, sustain them for several seconds and, often, the oil pickup would suck air and oil pressure would be lost. No pressure meant certain engine bearing failure and that brought premature end to the testing excitement.

Throughout the summer and fall of 1995, the lights burned late in Powertrain Headquarters at GM's "Tech Center" in Warren Michigan. In the end, three solutions were found. First, to address the oil foaming and poor drain-back, the structure of the Gen III case was modified to allow pressure transfer between bays. Second, to improve oil supply at max. lat., a complex oil pan design incorporating sump extensions (the bat wings), extensive baffling and trap doors was devised. Third, to help with with the first two problems, the oil capacity was increased from four to six quarts.

Interestingly, the LS1 oil pan is reminiscent of the wet sump, road race oil pans used by amateur racers before SCCA allowed dry sump oiling systems in the mid-1970s. In fact, a dry sump oil system for LS1 was studied, but never went past the paper stage due to cost and concerns about low oil temperature during warm-up.

Last June, Project Manger Juriga assured us that the critical problem had been solved; however,we learned afterwards that the anomaly will still occur in extreme situations of high-rpm, sustained, max. lat. operation. An example might be abusive skid pad testing done by some of the less-experienced automotive media.

We also learned that, in an unusual solution, that in mid-’96 GM Powertrain wrote the LS1 PCM calibration such that, if high rpm and high lateral acceleration are sustained for a substantial length of time; the electronic throttle control (ECT) will reduce throttle opening to slow the car. In a follow-up interview in March of 1997 for the WWW versions of this story, John Juriga confirmed that the ’97 Vette’s PCM calibration is written that way.

We know C5 was tested extensively at the Road Atlanta, Road America and Grattan, Michigan road race tracks, so we believe that, in most real-world driving situations you’d see in a Corvette, including road racing; the LS1 oiling system is dead-nuts-reliable. However, if a LS1 is run on a skid pad at high-rpm and max. lat. for 45 or more seconds, we suspect that ECT will reduce the throttle opening.

Cylinder Head Wizardry

From a performance standpoint, cylinder heads are the most significant feature of LS1. An airflow genius at GM Powertrain, named Ron Sperry, oversaw the design. To hardcores seriously into Chevrolet heads, Sperry is a folk hero. Fifteen years ago, working for the legendary Vince Piggins in the Chevrolet Special products group, he contributed to the original Chevy "Bow-Tie" heads. Evidence that success in motorsports transfers to production is that the L98 aluminum head, introduced on Corvettes a decade ago, was derived from philosophies used in those late-’70s/early-’80s race heads.

Later, Ron Sperry perfected his craft working for Herb Fishel at the Chevrolet Raceshop. He was responsible for two of Raceshop’s landmark designs of the mid-’80s: the raised-runner, NASCAR Small-Block head and the symmetrical-port, big-block, Pro Stock head.

Ron Sperry joined the V8 Group at GM Powertrain as the Cylinder Head Release Engineer in the fall of 1987. Need more proof that racing improves the breed? His first task was developing the production, Gen II head that debuted on the 1992 LT1. A source close to the Raceshop told us simply, "He (Sperry) showed them (GM Powertrain) how to make power with it." Sperry’s early work on Gen III resulted in the LT4 head. He was able to tweak just a bit more out of a mature design such that LT4 is the high-water mark for production, Small-Block V8 cylinder heads.

Ron saw the LS1 project as a great challenge and a wonderful opportunity in that he was able to develop a cylinder head for an all-new, production high-performance V8 engine with few of the performance constraints he had worked under in the past.

All previous, production Chevrolet V8 heads have two distinct intake and exhaust port designs. A unique feature of the LS1 head is what GM calls "replicated" ports. Each intake port is exactly same and each exhaust port is exactly the same. This eliminates combustion inconsistencies between cylinders due to variance in port flow quality and quantity.

The heads are sand cast of 356 aluminum, heat-treated to the T6 specification. Engineers use the term "valve angle" to describe the angle between cylinder bore centerline and the valve stem centerlines. It is probably the key geometrical relationship in a V8 head because it influences combustion chamber shape and size, spark plug placement, valve diameters and port design. With V-type engines, the less valve angle; the better. The LS1 angle is 15,° three less than the best of the Raceshop's Winston Cup heads and significantly below the production Small-Block's 23°.

The LS1 intake port volume is 200 cc. which is a bit of a misnomer because of some of that volume is used for injector spray space; nevertheless, intake volume is generous. The exhaust port volume is 70 cc. The valve seat angles are 30°, 45° and 60°. The chamber roof around the valves blends smoothly with the seat's top angle. The valves are stainless steel. The intake valve size is 2.00 in. and the exhausts are 1.55-in. with both having smaller, 8mm. valve stems. The valve face angles are 30°, 46° and 60°. The valve guides are pressed-in, sintered-iron units impregnated with material that enhances lubrication. Chamber displacement is 67.3 cc which makes for a compression ratio of 10.2:1.

The most important aspect of this head from a performance standpoint is an intake port that offers the charge air a straight shot down to the intake valve. In that respect, the difference between the intake port in the best of the old (LT4) and the first of the new (LS1) is nothing short of dramatic. We were very lucky to get to talk with the cylinder head ace himself, Ron Sperry and he said, about the design philosophy he and his team of engineers used for the intake ports, "We worked hard to make sure we had all eight cylinders as close to being identical, from a geometry standpoint, as we could. Each port is a continuous, runner-to-valve configuration. We don't have the air turning right or left to any significant degree. There is a relatively large runner opening and it tapers down so that as (the charge air) gains speed, it's also gaining directional stability such that the air is moving towards the valve in a very directed manner. We get the air and fuel into the cylinder with the same level of energy from bank-to-bank and port-to-port. "

Sperry added that a big enabler for the port design was packaging. By using four head bolts around each cylinder rather than the Small-Block's five, there was more room for the ports. Additionally pushrod holes, head bolt bosses and rocker arm mounting bosses were placed such that they impacted the intake ports as little as possible.

Another important feature of the LS1 intake port is it has better "injector targeting" than any Small-Block head. Injector targeting is important to idle quality and exhaust emissions. Ideally, port-injected engines should have injectors squirting a stream of fuel straight down the port, directly on the back of the hot intake valve. The temperature helps vaporize the fuel and the turbulence of the charge blowing down the port and around the valve does the rest. With the Small-Block, a straight shot at the valve was not as effective because the line running from the injector to the valve was nowhere near parallel to the port centerline. Ron Sperry: "Each port's fuel injector is targeted on the valve. We established a (port) centerline in space. The port runs back from the valve to the injector in a manner that is more linear with the injector target line."

A good cylinder head design gets the exhaust out as freely as it lets the charge in. Ron explained

LS1 exhaust port philosophy, "The 15-degree angle goes a long way to fixing most of the problems we had (with the Small-Block exhaust port). The chamber is a very open design. Chamber volume is bigger than its predecessor, 54cc in the LT4 and 67cc with this engine. The 15-degree angle removes many of the short turn radius (where the port floor transitions to the valve seat) problems.

"All the surfaces are friendly in approaching the valve seat area. The valve is shrouded a bit on the bore side, but that’s about the only area there’s any restriction to getting exhaust out of the engine. We did employ the venturi-type seat that we put in the LT4 but it doesn’t have to be as drastic. The exhaust ports have some really good (flow) numbers right out of the box. They are as good as some of of the exhausts we’ve seen with modified, Bow-Tie stuff."

If you retain only one part of this discussion of the LS1 head, remember that most of this cylinder head technology goes towards one goal: increasing volumetric efficiency. If you pack more air into the cylinders, the engine makes more power. The LS1’s much better intake and exhaust port designs allow better volumetric efficiency at all engine speeds. The payoff is higher performance.

LS1’s head gasket sealing is better than that of the Small-Block. The long head bolts go 88mm down into the block and have very long threads of a unique size and pitch designed for high load. They screw into threads in the case’s main web areas. The idea is to pull the sleeves and the immediate surrounding area of the decks tight against the head by exerting force at the bottom of the sleeves. An additional feature is the bolts’ length. A fastener exerts the most force when its stretched slightly and the long bolts allow a lot of material for stretching.

One final, interesting aspect of the LS1 head and deck design is that it has a negative deck-height figure. One of GMPD’s goals in combustion control was to decrease "crevice volume" which is, loosely speaking, the "squish" volume between the flat, non-chambered, part of the head exposed to the bore, plus the volume between the piston and bore above the top ring. At top dead-center, an LS1 piston top is actually 0.2mm (.008-in.) higher than the block deck and protrudes into the space surrounded by the head gasket. A typical rebuild procedure is to machine or "deck" the block to correct misalignment or lack of flatness. Once the first LS1’s need overhauls, engine rebuilder will have a learning curve with figuring out how to deck an LS1 case and preserve piston-to-head clearance.

Pushrods and Why

By now, you’ve probably exclaimed several times, "Heck, guys, your ah....’new’ engine has got friggin’ pushrods. How in blazes can ya call that ’revolutionary technology’?"

For ultimate performance, it’s tough to beat DOHC and 32-valves; nevertheless, GM Powertrain decided to use pushrod-operated valve gear for the LS1. Why? To quote John Juriga, "The LS1 is the only engine in the Corvette for 1997. We think a base engine at 345 net horsepower is plenty of power. If that can be done with one cam, 16 pushrods and two valves in each hole; we can live with that."

There has to more to this issue than that, and we intended to ask Ed Koerner, Gen III Chief Engineer, to comment further. Unfortunately, Chevrolet denied our request for an interview with him. We later sent Chevrolet a question about the valve issue to forward to Mr. Koerner, but that went unanswered as well, so heck; we had to guess.

First, the obvious: money. It costs less to build a pushrod engine. There is one cam, not four; one cam drive chain, not three, 16 valves and associated parts, not 32 and a less complex head design. To have a reasonably flat torque curve, the DOHC LT5 needed a complicated, expensive, computer-controlled, secondary throttle system. The LS1's advanced, two-valve head eliminates the need for that. Lastly, the C5 version of the Gen III is derived from a cast iron passenger car/light-truck powerplant to be built in the tens of millions, so the cost of developing the LS1 can be distributed over a much larger sale of similar engines.

Second and less obvious: attitude. It is unlikely General Motors will ever again see the brash thinking that spawned the LT5. Development costs were excessive, purchase price was high and sales numbers were too low. In 1992, GM was almost broke and at one point, literally, only days away from closing its doors. These were sobering thoughts to the high-level execs who wrote the checks and answered to stockholders. The aftermath, the downsized, "Dilbert Era" of the mid-90s, was traumatic for the General's bad-boy, car-guys. LS1's technology is cutting-edge, but it had to come from a different side of the blade than did LT5. This new engine's existence was contingent on cost-effectiveness, as well as performance and that meant 16, pushrod-operated valves.

Want more? Well, how 'bout marketing? Gen III's main, target market is going to be trucks. About 25,000 a year will go in Corvettes but hundreds of thousands a year will go in trucks. Many people don't see overhead camshafts as a positive selling point for truck engines. Truckers want cheap, simple, reliable and durable powerplants and that means a single cam and pushrods. A final consideration may be packaging. The C5 engine compartment was not designed for the width a four-cam engine.

Our reaction to the LS1's valve gear? Well, frankly, we don't think any Corvette needs technology for its own sake. We have too much of that already. The LS1's superior cylinder head allows near-LT5-level performance right now with only two valves per cylinder. Like John Juriga, we can live with that. If you think the LS1 can't touch the LT5; development engines are running on GM Powertrain dynos at the 400hp level with little modification. Will there be a "super-LS1" in the C5? Our fearless forecast is: yes, perhaps by 2000; however, you'll see a 400hp LS1 even sooner from Corvette tuners like Doug Rippie and John Lingenfelter.

Gearhead's View of the Valvetrain

The LS1 camshaft is machined out of a steel billet and is rifle-drilled to reduce mass. A camshaft sensor, necessary on engines with SFI for the PCM to "know" where the engine is in the firing order, is just ahead of the rear bearing journal. Compared to LT4, the LS1 cam has larger bearing journals, all the lobes have bigger base circles and lift is less, especially the intakes. Going to the larger base circle and less lobe lift reduces valve train loadings because the acceleration rate is lower.

The new engine's rpm limit is about the same as that of a LT4. That, along with the lower valve acceleration rate, allowed many valve train parts to have less mass which permitted use of lower tension valve springs and that lessens the impact as the valve hits the seat on closing. Valve train noise is reduced which, according to John Juriga, was a big goal of the Gen III program. Specific to Corvettes, maybe that is not all that great an idea. The Corvette Mystique partially grew out of mechanical lifter camshafts. Give us that' 92 LT1 valve noise, thank you very much.

The valve lifters are the roller hydraulic variety and are the second of the two pieces that carry over from the Small-Block. The centerlines of the lifters, pushrods and the valve stems are parallel. The Small-Block had them at angles to each other. These angles caused side loading which accelerated valve guide and lifter bore wear and increased friction. The LS1's "in-line" valve train reduces friction and allows some parts to be made smaller and lighter.

Bet ya saw those fancy roller rocker arms, too. Some Corvette owners are gun-shy of roller rockers because of the fiasco with not one, but two recalls during MY96 of a large number LT4s due to rocker arm failures caused by roller tip pins falling out. Ironically, the second recall affected all the cars of the first. Is that, like....a "re-recall"? Sorry, but we couldn't resist that. We know customers told not to drive their LT4s because of an initial shortage of recall repair parts saw little humor in that situation.

For those with such roller rocker "phobia"; LS1 is good therapy. Its rockers are investment cast steel rather than aluminum and the roller tip pins are held securely in place. The rocker arm ratio is 1.7:1 vs. the LT4's 1.65:1 and other Small-Blocks' 1.5:1. The higher mechanical advantage of the LS1 rocker amplifies the smaller lobe lift such that valve lifts for an LS1 are: .472-in. for intake and .479-in. for exhaust compared to the LT4's .476/.479 lifts. Chevrolet refused to share additional valve timing data with us.

John Juriga's last words on the LS1 camshaft were, "We didn't go more aggressive on the cam, so at this point, the engine has a lot of potential. First time out, we could meet our target with a camshaft that is conservative."

This might indicate that there will be a lot that performance tuners will be able to do with this engine's camshaft.

Cooling the Traditional Way

Remember 1992, when Chevy raved about the Gen II's reverse-flow cooling? Well, reverse is, apparently, out. The new engine uses conventional pushrod V8 cooling. Coolant is pumped into the block, around the cylinders, up into the heads, then out to the radiator. The reason Gen II went reverse was that, to make the power Corvette Development wanted; it had to have a higher compression ratio (LT1, 10.2:1; LT4, 10.8:1). Higher compression made for detonation. The cooling system was revised to run the cylinder heads cooler as an antidetonant strategy, and to run the cylinder bores hotter for higher oil temperature and less friction. Clearly, reverse-flow cooling, the publicity darling of the Gen II engine, was really nothing more than a fix that allowed the limited cooling of the old Small-Block head to work with the higher compression necessary to reach the 300 horsepower level.

Air in the cooling system becomes problematic if it gets into the water passages surrounding the combustion chambers. This often causes localized boiling and that, in turn, allows hot spots to develop on chamber walls and they cause detonation. The problem with reverse flow is that with coolant flowing downward and air bubbles flowing upward; keeping air out of the Gen II cooling system was difficult.

Though the LS1 has a lower static compression ratio; its cylinder heads have improved combustion chamber design and intake ports that breathe better. Those features allow them to make more power. The clean-sheet-of-paper approach also allowed design of the cooling passages around the chambers to be more efficient such that the engine can put out more power than the Gen II but yet have coolant flow in the conventional direction to eliminate problems with aeration. With a better combustion chamber and water jacket design and improved antifriction technology in the block, pistons and rings; it made sense to go back to the normal-flow cooling system.

Like most engines of the last 20 years or so, the LS1 uses a 195 degree thermostat. Nominal coolant temperatures are similar to what we see in LT1/4 engines. The new engine will use "Dex-Cool" coolant introduced last year in many GM vehicles. Dex-Cool has entirely new anticorrosive chemistry that is longer lasting and more friendly to cooling system parts, especially seals.

Ignition

Gen III’s ignition system is evolutionary. In 1990, with the LT5 engine, Chevrolet introduced a distributorless ignition system (DIS) to the Corvette. The next step is the LS1’s coil-per-cylinder idea.

The ignition hardware is mounted atop the valve covers. Each cylinder has its own coil and coil driver assembly and a short plug wire connects each a spark plug. The reasons for moving the coils to the covers are simple: 1) less spark energy is dissipated by short spark plug wires so more energy available at the plug, in fact, it increases nearly 100% and 2) shorter plug wires reduce radio frequency interference with on-board computers and the sound system.

The other big ignition story with Gen III is a different firing order. Gone is the time-honored 1-8-4-3-6-5-7-2 sequence. This new engine fires 1-8-7-2-6-5-4-3. The cylinders are numbered the same: left bank: 1-3-5-7 and right bank: 2-4-6-8. The reason for the new firing order is better idle stability and less vibration.

The rest of the ignition system is conventional. The ignition advance is controlled by the PCM based on manifold pressure, air temperature, engine speed, coolant temperature and a few other data. The PCM computes the optimum trigger point then sends a trigger impulse to the coil driver at the appropriate cylinder.

Detonation protection is similar to what's been used in the past. There are two knock sensors (KS) working in a feedback system with the PCM. When a KS "hears" detonation, the PCM retards timing a set amount and for a set time, then waits for additional sensor input. If the detonation stops; timing is gradually reset to the value called for in the PCM calibration. If detonation continues, timing is retarded an additional amount.

Spark plugs are an AC, platinum-tipped plug of a type similar to that introduced in 1992 on the LT1.

Exhaust, emissions control and accessories

LS1 exhaust manifolds are double-walled and welded-up from hydro-formed, tubular stainless steel. The double-walls prevent heat loss between the head and catalytic convertors which is a big factor in how quickly the cats. start catalyzing the exhaust. Late cat. "light-off" is a significant contributor to exhaust emissions during cold starts and early warm-up. Unlike the LT1/4/5 engines, the LS1 cats. are not attached right at the exhaust manifold outlet. They are a bit farther downstream and because of that, it was necessary to add measures to reduce heat loss and preserve quick cat. light-off.

The rest of the LS1 emissions controls are similar to what has been used on Corvette since about 1990. There is an electric air injection reactor (AIR) pump that runs after start-up for a short length of time set by the PCM. Interestingly, the LS1 is the first Corvette engine since the early-;70s that can pass exhaust emissions standards with out an exhaust gas recirculation (EGR) system. LS1 has the second generation, on-board diagnostics (OBD-II) used, in part, since 1994, and, in entirety, starting in 1996. The LS1 PCM has more computing power than the '94-'96 units which allows the new engine to be OBD-II-compliant in a more "seamless" manner. Additionally, it allows the C5 platform to meet more stringent emissions regulation due in the late-'90s and early-'00s.

OBD-II is one of those wonderful Federal mandates that's raised the cost of cars but will have little practical impact on air quality. Nevertheless, it has satisfied the vote-getting needs of politicians who pander to the environmental lobby and it has driven some pretty amazing technology from car companies.

The biggest difference between so-called, "OBD-I", used on Corvette from the late-'80s to 1993, and OBD-II is that the current system requires the PCM to predict potential failures of emissions controls as well as notifying of failures that have already occurred. Two significant features enabling this prediction are catalyst monitoring and misfire detection.

The catalytic converter makes a large contribution to reducing emissions. OBD-II monitors cat. performance by taking oxygen readings from a second pair of oxygen sensors downstream of the cats. When the downstream readings begin to mimic the upstream readings, the PCM assumes cat. performance is starting to degrade and turns on the malfunction indicator light (MIL).

Misfire detection is the most complex engine management problem faced by the car companies in a decade. It demands a very fast, powerful and sophisticated processor in the PCM, very accurate crankshaft position data and some technically innovative software. The PCM reads very small and extremely rapid variation in crankshaft speed as the engine accelerates and decelerates in reaction to power impulses. Inconsistent variations in those accel. and decel. rates are indicative of engine misfire. Specific types and durations of misfire can be a sign of other emissions system problems and will turn on the MIL. The trick comes in accurately determining what's misfire and what's not. That has stumped some of the automobile industry's biggest players, especially with manual transmission powertrains.

GM Powertrain Division leads the industry in diagnostics. Since full-OBD-II compliance became law (generally, with the 1996 model year) there have been cases of car companies discontinuing manual transmissions on some models due to failure to meet the misfire detection challenge. The most notable example occurred in 1996 when there was no manual version of Toyota's flagship Supra Twin Turbo. It has also been rumored that the Mazda RX7 TT's departure at the end of 1996 was also, in part, because of Mazda's inability to address OBD-II. The 1997 Corvette has a manual transaxle available because GMPD has successfully answered the misfire detection challenge with the LS1.

Most of the accessories used on the LS1 we have seen before. LS1 uses a dependable, ACDelco, CS-series alternator. A geroter pump supplies steering power assist. The water pump, of course, is new as is the air conditioning compressor. As with several recent GM engine programs, most notably the Gen 1E for trucks; noise and vibration inherent in accessory mountings was carefully researched, then reduced by designing very rigid accessory mounts, quiet running accessories and an accessory drive that uses two serpentine belts. One drives the air conditioning compressor and the other drives the rest of the accessories.

In Closing

The various PR apparatus at Chevrolet, GM Powertrain and GM Midsize/Luxury Car Division would like everyone to think that Corvette development is as simple, quick and trouble-free as is bringing to market a new type of vegetable slicer, hair dryer or whiffle ball racquet.

Not Even

Development of an all-new engine is a monumental task requiring hundreds of individuals to work tens of thousands of man-hours. It is complex, costly and filled with surprises. It is a credit to the team at Powertrain that it addressed each challenge with effective solutions.

Well, this new medium-displacement V8 is quite an engine, don't you think?

LS1 generates 345hp at 5600 rpm and 350 lbs/ft. torque at 4400 rpm. Maximum engine speed is 6200 rpm. Compared to the LT4, it generates 15 more horses with peak power 200 rpm lower. It produces 10 more lb/ft. torque with peak torque 100 rpm lower. Chevrolet refused our request for a chart of LS1's torque curve, but we believe it's a bit flatter than that of the LT4. All this performance comes from a package weighing 66 pounds less and measuring half-an-inch shorter than a Gen II Small-Block. Some of us still compare today's power ratings to the gross power figures of the 1960s. If that was still being used, LS1 would put out about 390-400hp. Most notable is that this engine is the first two-valve V8 to reach the one-net-horsepower-per-cubic-inch plateau. That is a monumental engineering achievement.

I recently received a very interesting insight to the power of the LS1. A high-level Corvette Development executive told me that he personally back-to-back tested both a stock, 1995 ZR-1 and a 1997 prototype. The ZR-1, with 60 more horsepower, was a mere second-a-lap faster than the C5. That says much about the '97's new engine, lighter weight and better handling.

Bottom line...the new LS1 is all Corvette and one hell of an engine.

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