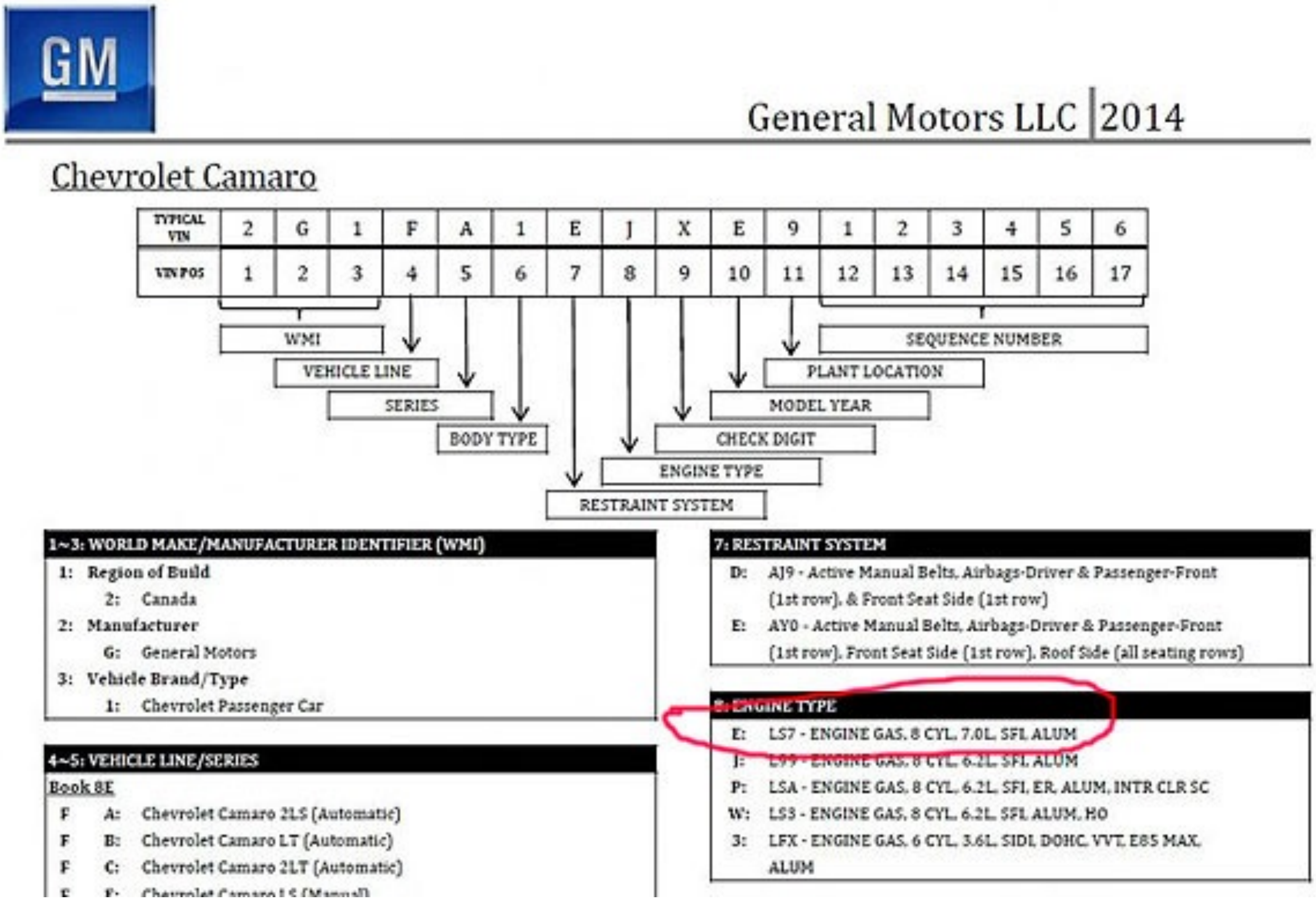
Ruthless Pursuit of Power: Lucky Seven Edition

The Mystique of the Z/28's 7-Liter, 7000-RPM, LS7

by Hib Halverson, Content Director



General Motors LLC | 2014

Chevrolet Camaro

TYPICAL VIN	2	G	1	F	A	1	E	J	X	E	9	1	2	3	4	5	6
VIN POS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

1~3: WORLD MAKE/MANUFACTURER IDENTIFIER (WMI)

1: Region of Build
 2: Canada
2: Manufacturer
 G: General Motors
3: Vehicle Brand/Type
 1: Chevrolet Passenger Car

4~5: VEHICLE LINE/SERIES

Book 8E

F A: Chevrolet Camaro 2LS (Automatic)
F B: Chevrolet Camaro LT (Automatic)
F C: Chevrolet Camaro 2LT (Automatic)

7: RESTRAINT SYSTEM

D: AJ9 - Active Manual Belts, Airbags-Driver & Passenger-Front (1st row), & Front Seat Side (1st row)
E: AY0 - Active Manual Belts, Airbags-Driver & Passenger-Front (1st row), Front Seat Side (1st row), Roof Side (all seating rows)

8: ENGINE TYPE

E: LS7 - ENGINE GAS, 8 CYL, 7.0L, SFI, ALUM
~~J: L99 - ENGINE GAS, 8 CYL, 6.2L, SFI, ALUM~~
P: LSA - ENGINE GAS, 8 CYL, 6.2L, SFI, ER, ALUM, INTR CLR SC
W: LS3 - ENGINE GAS, 8 CYL, 6.2L, SFI, ALUM, HO
3: LFX - ENGINE GAS, 6 CYL, 3.6L, SIDI, DOHC, VVT, E85 MAX, ALUM

Oops! Darn those pesky leaks! Image: Various Web Locations.

In 2012, Camaro Nation got a nice Christmas present when the "VIN Card" for 2014 leaked out of GM. It listed "LS7", the seven-liter engine formerly used in Corvette C6 Z06es, as a regular production option for the Camaro in '14.

Of course, official GM denied the leak was accurate. As Chevrolet's spokesperson for everything Camaro, Monte Doran, told us right at the end of 2012, *"It is our policy to not discuss future products, so I cannot comment on plans for the 2014 Camaro. I can tell you that a very early draft of our 2014 VIN card was leaked online. It was a preliminary version that included both inaccurate and incomplete information."*

Yeah, right.

Three months later, at the New York Auto Show, Chevrolet announced a limited run of Camaro Z/28s powered by LS7 427s.

2014 Camaro Z/28. Image: GM Communications

This car ain't nothin' but a trackrat's hot rod. You'll get the 427, the Camaro version of which is estimated to produce 500-horsepower, six-speed manual, the iron-case drive axle, coolers, a suspension more aggressive than a ZL1's along with the carbon brakes once used on C6 Vette ZR1s and Z06/Z07s. What you won't get is, also, interesting. These 427 Camaros are serious track cars with no acoustic insulation or trunk carpet, no power seats, no HIDs, no fog lamps, a single speaker sound system and optional air conditioning.

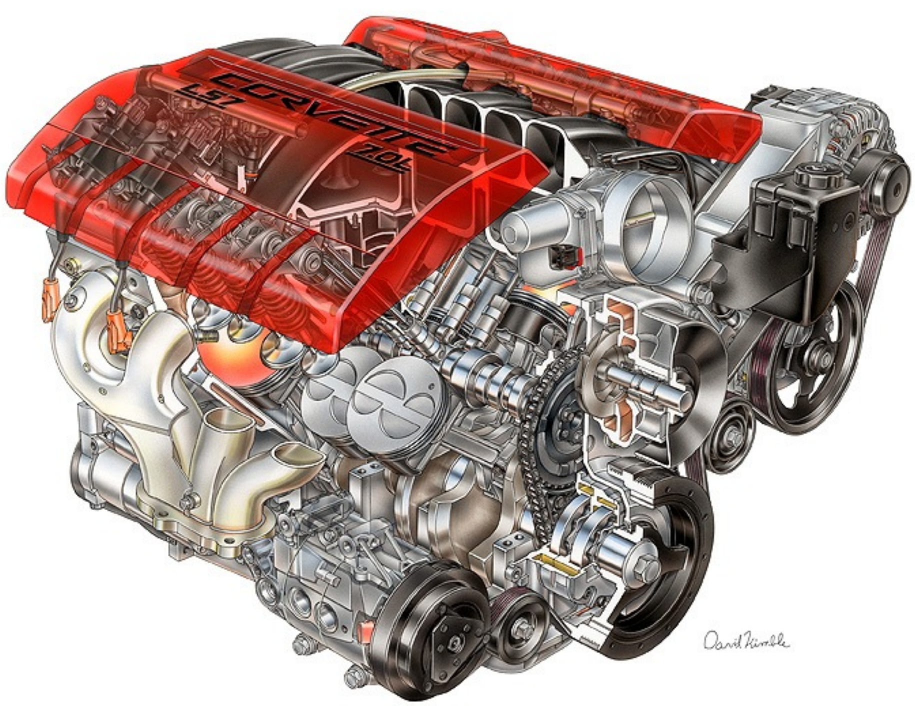
The Z/28's 500-hp surprise. Image: GM Communications

The Milestone LS7

I think that big, thumping 427 is the high water mark for Camaro engines. The ZL1 folks probably wanna slap me silly for saying that, but, the fact remains: LSA, for all its technology, still needs a supercharger to make its 580 horses. Without boost, it wouldn't get much beyond the LS3's 426.

About 150 of the LSA's 580-hp come from this–GM's interpretation of the Eaton, R1900, Twin-Vortices Series, Roots supercharger. Image: Author.

The 427 is an amazing piece of work: fat torque curve, 500-hp, normally-aspirated, at 6300-RPM and a 7100 rev limit. There's really cool stuff in that engine–titanium rods and intake valves, 11.0:1 compression, CNC-machined heads and a 7000-RPM valvetrain. The LS7's specific output (power÷displacement) is 1.18 and its power density (power÷weight) is 1.12. At this writing, seven years after the engine debuted in 2006, both are high marks for a normally-aspirated, production V8 made in the Western Hemisphere. Such performance makes for a mystique about that unboosted, stump-pulling, high-revving V8 which the supercharged 6.2 in the ZL1 lacks. So–while I appreciate the LSA, to me; LS7's case is more compelling.



The obligatory, but always stunning, Kimble cutaway shows the guts of a Corvette LS7. The Camaro version looks the same except for having black beauty covers and different exhaust manifolds. Image: David Kimble for GM Powertrain.

GM Powertrain Division likely objects to my "high water mark" statement citing the specs of the direct-injected, 450-hp, 6.2L V8 which will power the 2014 Corvette Stingray. No doubt, the "LT1", the first example of the Fifth-Generation Small-Block V8, is an outstanding technology showcase, but the fact remains: a 427 in a production Camaro is a very rare, it's only happened twice in the last 50 years. After the 2014 Z/28 build, you'll likely not see another unblown V8 making more than 450-horses.

Set the Wayback Machine for 1969.

Some say, "History repeats itself." The LS7 channeled a legendary engine of the past, the ZL1, all-aluminum, 427 developed for the '69 Camaro. Both are big-bore, pushrod V8s, influenced by Chevrolet's efforts in motorsports. The ZL1 was a race engine detuned and configured for street use. Some might say the LS7 is similar: Corvette C5-R race engine technology adapted to a production application with compromises for drivability, emissions compliance and fuel economy.

When it comes to Chevy aluminum block 427s, how far has technology marched? A ZL1 made about 560-horses at 6800-RPM. When tested with 1960s dynamometer procedures, the LS7 produces about 550-hp@6300 RPM, but has a fatter torque curve, weighs less, has far lower exhaust emissions and gets much better gas mileage. Further, it has better reliability/durability, requires less maintenance and is a lot nicer to drive. In today's money, a ZL1 cost about thirty large. You can buy an LS7 for a little over half that. The old ZL1 was installed in two Vettes, 69 Camaros and, later, sold over the counter, with somewhere between 90 and 300 produced. To date, around 9000 LS7s have been hand-built at GM's Wixom, Michigan, Performance Build Center (PBC). They've used in '06-'13 Vettes, sold as crate engines and, now, used in a Camaro. Seems we've come far in nearly half-a-century.

The 1969 Camaro all-aluminum 427.
Image: GM Powertrain.

The 2014 Camaro all-aluminum 427.
Image: GM Powertrain.

LS7 History Book

Ok–reset the Wayback to the early-'00s. In the American LeMans Series and at the 24 Hours of Le Mans, Corvette Racing had been eating everyone's lunch. Its all-conquering C5-Rs were powered by Katech-built, 427s. Based on production, LS1 architecture, they used a special cylinder block with larger-than-stock bore and stroke, racing valve gear, different cylinder heads, a motorsports-specific EFI and an intake restrictor.

Katech's C5-R 427s made about 600 horses at 6200-RPM.

Corvettes dominated LeMans, Sebring and Daytona during the C5 era. Under their hoods was a 600+ horsepower 427. Shown is a C5-R in the esses between the Dunlop Bridge and Tertre Rouge during the 2001 24 Hours of Le Mans.

Meanwhile, in the Summer of 2002, over at GM Powertrain in Pontiac, where development of production hardware took place, the Small Block team, researching an LS6 successor, was experimenting with a 6.4-liter (390-cubic inch) V8 of about 450-hp. The 2005 Corvette was in development and they were looking at this "six-four" as what might power the next Z06, due a year later. During the design of the 6.4's cylinder head, Katech's C5-R engines were an influence. The most noticeable feature of this head was vastly different intake port location and geometry, compared with the "cathedral" intake port used in LS1, 2 and 6 heads. This different intake port architecture would have far-reaching effects on Small-Block V8s over the next dozen years.

A Katech C5-R 427. Look at all those carbon fiber parts on that engine. Fast as hell and great eye candy. Image: GM Powertrain.

John Rydzewski, currently Assistant Chief Engineer for Passenger Car Small-Block V8 Engines, said in a 2008 interview about that head, *"A key enabler of this was moving the pushrod over. Now we had a bigger space, so we moved the port up, gave it a straight-on approach, made it larger, wider, with less turns and less bosses in the way of the flow path. The result is a huge improvement in performance."*

Six-four development progressed into the Fall of 2002, but there was growing skepticism about displacement. Some were thinking that closer to seven-liters might be necessary. Elsewhere in GMPT, people were doing computer analysis of what it might take to reach the 500-horsepower level and that pointed at 7.0L, too.

Dave Muscaro, who, six months later, would be appointed as Assistant Chief Engineer Passenger Car V8s, told us about that period. "*From a 6.4L vs 7.0L perspective, the goal of making 500 hp came sometime before I joined the program. I have a file showing analysis* *work to probe this power level was done at the end of October 2002. The analysis work was simply to see what airflow, friction, induction and exhaust restrictions, compression ratio, etc, etc, would be needed to create 500 hp. At that time, it was recognized that the engine displacement would likely need to go to 7.0L.*

The first time the CAC visited with John Rydzewski, the subject was the LS3 and the cylinder head it used which was derived from the still-born six-four. Image: Author.

Winter of 2002/03. Six-four development was well into the hardware stage. GM Vice Chairman for Global Product Development, Bob Lutz, along with senior Powertrain executives, then GM Powertrain Group Vice President, Tom Stephens, and then Small-Block Chief Engineer, Sam Winegarden, upset the apple cart by deciding the first number in the C6 Z06's power rating must be a "5". While this decision is a well-known part of LS7 history which added to its mystique, it would be ridiculous to assume that, one Friday after work, Bob, Tom and Sam, got together for beer and burgers then wrote "500-hp" on a bar napkin. More likely is that Mr. Lutz,, Mr. Stephens and Mr. Winegarden reviewed some of the analysis data Muscaro cites, considered where their V8 engine technology was then and where they wanted Corvette to be power-wise in the next five years, then set 500 horses has a goal for their engineers.

Why?

"Competitive Pressure was part of it. The Viper was one of the competitors out there–probably the biggest–and there were others," John Rydzewski, who took over as ACE from Muscaro in May of 2005, told us in a second, 2012 interview.

A decade ago, the most powerful Corvette engine, the LS6, made 405-hp but the Vette's underhood competition–most high-profile of which was the Dodge Viper's monster (but, also, inefficient) 488-cubic inch, 500-hp V10–was putting the Corvette's power rating to shame. There were others, too: Porsche Turbo-444-horses, Mercedes-Benz SL55 AMG-476-hp and Ferrari 575M Maranello-508-hp.

A 500-hp Corvette? Well… duh.

As Corvette Executive Chief Engineer, Tadge Juechter, who, during the C6 Z06 development, was Assistant Chief under David Hill, explained, *"The LS7 is the pure-blood, track engine. When we were developing it, we knew it was going to be normally aspirated. For a while, that* *engine was going to displace 6.4-liters and the first horsepower target was 450. The base engine was 400. We thought: Oh man, more than 10%–that'd be a nice bump. Remember, with the previous Z06, we were, first, at 385, then 405, so that* (50 more horsepower) *was our mindset as a good performance delta.*

Corvette Executive Chief Engineer, Tadge Juechter discusses the LS7 with the Camaro Homepage. Image: Author.

"The horsepower wars were on and, as we developed (the six-four), we saw these new entries coming out with higher horsepower. We had senior leadership–Lutz, Stephens and others–saying, 'The first number's gotta start with a '5'. At the working level, we wanted to get as much as we could. Powertrain didn't know if they could get to 500. There was a lot of pressure from the higher-ups saying, 'We think you can do it. Let's put that stretch target out there and let's see if you can get there.' They just said, 'Well, the original target was 450 and we're going to see what we can do.'"

About the same time, another decree came from then Chief Hill, himself, who mandated the 2006 Z06 accelerate from 0-60 in less than four-seconds. The only way to do that with the car's weight and 3.42 axle ratio was to stay in first gear, so–this 500-hp engine would, also, be a 7000 RPM engine. It's easy to understand Hill's quest–power to keep the Z06 a player in its market segment into the next decade. At this writing, nine years later, Hill's goal was achieved–by a comfortable margin.

By late Spring, 2003, the six-four was deemed incapable of 500-hp or 7000 RPM, so with newly appointed ACE Muscaro at the helm, the Powertrain folks working on the LS7 hit "reset" and began developing a new and even bigger engine. With the displacement now set at 7-liters, what Katech had been doing with its C5-R engines was even more influential on the Small-Block team at GM Powertrain.

"As to when we 'officially' switched to a 7.0L? That would be hard to pinpoint," Dave Muscaro continued. *"Before we 'switch' program direction, we do analysis and then test a 'mule engine' to prove our analysis. At the time I came in, we did not have any 7.0L engines, although a couple were ordered from Katech in November 2002. These engines did not yet exist, but the parts to build them were being contemplated and decided upon. So, when I came on the scene, one of the first things I did was sit down with Katech and devise a development plan to build some engines and start proving our ideas on how to make a 500-hp 7.0L. At this time, there may have been one or two 6.4L engines still running, but I was not much interested in trying to make the smaller engine work for a 500hp target. I do not recall any 'official' date when we decided upon a 7.0L displacement. Since we were short on power right out of the chute with a 7.0L, you can bet I didn't go back and try a smaller engine! So by default, a 7.0L was what it would become."*

Katech's Kevin Pranger, who was the "engine guy" for the C5-R and the 7-liter part of the C6.R program. Image: Author.

Kevin Pranger, Katech's manager for the C5-R engine program, was, also, interviewed for this article. He described Katech's first efforts at a 7-liter race engine and Powertrain's interest. *"We started putting liners in LS1 blocks. Then, GM cast us up a couple of special blocks with thicker aluminum so we could use thick wall liners with a larger bore,"* Pranger told the CAC. "*Those castings allowed us to do some testing. From that, we were able to come up a 4 1/8th bore and a four-inch stroke to make seven-liters. That's when GM decided to build an official, 4 1/8th bore 'C5-R Block'. They were able to amortize the tooling for the race program by selling the block in the* (GM Performance Parts) *catalog.*

"They (Small-Block engineers) *started coming over here, looking at what we were doing with the cylinder heads and the block,"* Pranger continued. *"They got a lot of ideas from that. The LS7 head looks a lot like the original C5-R, '005' castings. I think a lot of the LS7 was modeled after what we were doing with the C5-R."*

Tadge Juechter expanded upon Kevin Pranger's perspective, *"You talk about 'technology transfer' from the race program to the street program? LS7 is a perfect example*. *Some of the rank-and-file Powertrain engineers weren't accustomed to working on an engine like this, so we actually did get help from Katech and others who'd done race engines who helped with the porting design and other things. There were so many different ideas tried and so many blind alleys traveled down. It was an eye-opening experience. Developing that much power with normal aspiration and meeting emissions standards of today is something special. A lot of the lessons learned can be applied to future engines."*

Which they were, as we will see later.

"Significant change was needed to increase engine throughput." John Rydzewski stated about the engine's displacement. *"Increasing bore and stroke were enablers for the increased performance. Some of the executive leadership desired a displacement such as the iconic, 427 cubic inches. Our analytical and geometric studies supported the 104.775-mm* (4.125-in) *bore and 101.6-mm* (4.0-in) *stroke* (7.008-liters or 427.484 cubic inches). *They were selected for the LS7 program."*

Ya think some of John's "executive leadership" had been waxing nostalgic about 427 Vettes? Having dreams of four-inch-plus pistons and two-inch-plus intake valves? Hearing the seductive sound of a high RPM valvetrain motion? Feeling the thump of a big-inch motor pulling hard in the low-mid-range? Listening to the lopey idle of a big cam? Yeah–that's what those car-guy, true-believers were doing. Thank the car gods there were a few of them left.

In 2012, we met with John Rydzewski, again, with the subject this time being the LS7. Image: Author.

The folks who did the six-four head eventually saw the fruits of their labor on the LS3 under the hood of the '08 Corvette and the 2010 Camaro SS. The '09 ZR-1 and the 2012 ZL1 used nearly the same head, but it was made of a more robust aluminum alloy using a slightly different casting process. From an airflow perspective, the only difference was the supercharged head's intake port "swirl wing." Image: GM Powertrain.

And what of the six-four? Well–it was never considered for production–never made it into a car, in fact, but its development was not for naught. Six years later, the 6.4's head appeared on the Camaro SS's LS3 and L99 and, in 2012, after a slight revision in intake port design along with a change in material and foundry process, it, also, became the cylinder head used on the ZL1's, 6.2-liter supercharged LSA, but again–I digress.

Five hundred horsepower from a normally-aspirated V8 while meeting emissions and fuel economy standards was a tall order in late Spring 2003, when full-scale LS7 development began. Muscaro's Small Block Team was soon burning the midnight oil in a ruthless pursuit of power with a 500-horse, 7000-RPM, emissions-legal, no-guzzler, 427 as its objective.

Actually, perhaps as many kilowatt hours were burned as "midnight oil". General Motors has significant computer modeling and simulation resources. Computer software tools such as "Finite Element Analysis" (FEA), "Uni-Graphics" and "Computational Fluid Dynamics (CFD) were used during design and development. A different block casting and a new head were in the program even before the computers got warmed-up. Other key features of the engine were determined by computer modeling–a forged steel crankshaft, pressed in, rather than cast-in-place, liners and titanium connecting rods were, also, deemed necessary through modeling.

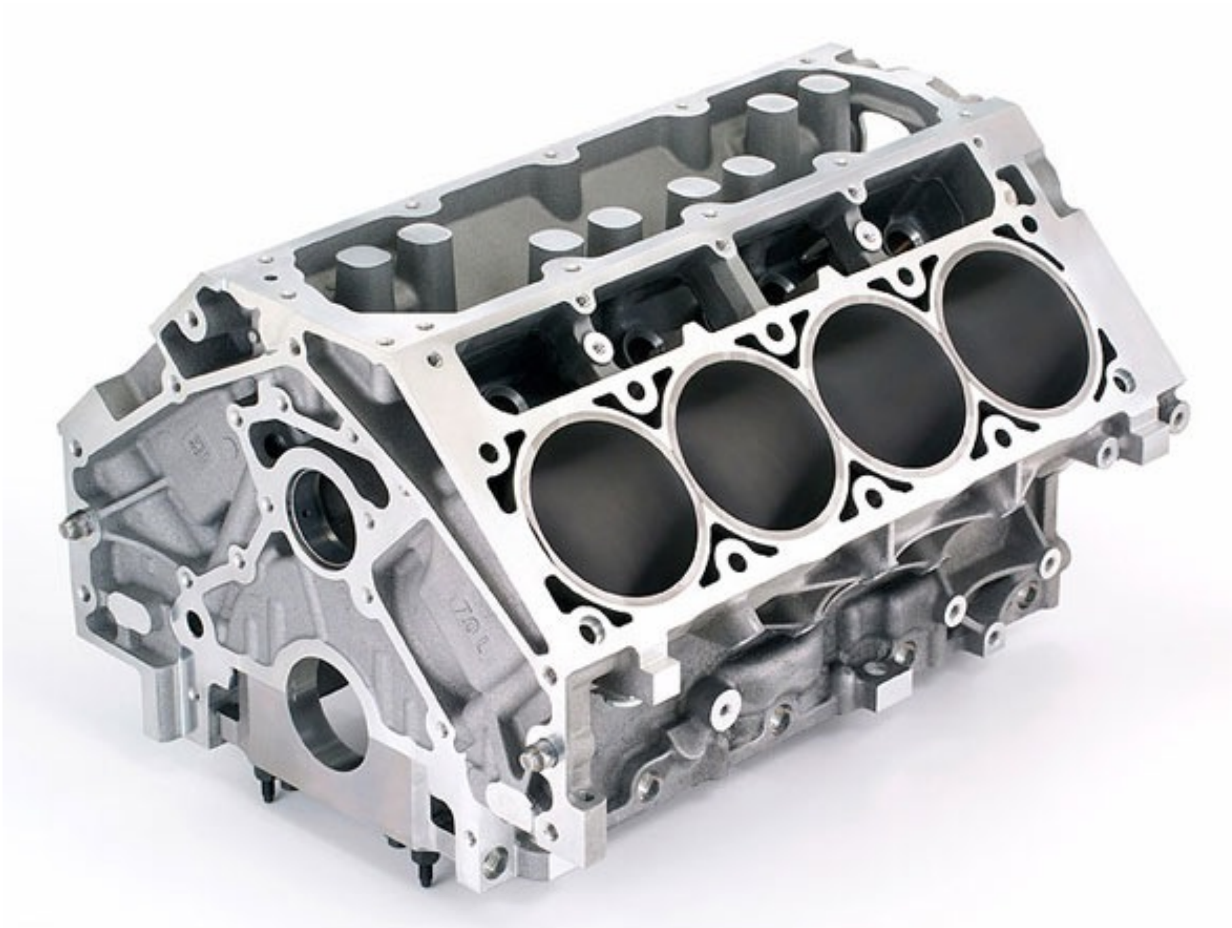
Back in '12, we also met with Sam Winegarden, the top engine guy at General Motors. He told us the LS7 has always been one of his favorite projects. He also gave us some inside views of what it was like when he was the Small Block Chief and LS7 was under development. Sam's story about computer modeling of combustion was a revealing insight to how quickly computers have compressed product development time. Image: Author.

The LS7 was developed on Sam Winegarden's watch as Small-Block Chief Engineer, He tells a great story about computer modeling. *"I was still Small-Block Chief, the first time these guys could model combustion. This would have been back in about '03 or '04. Dr. Gary Mendruziac* (formerly with GM Advanced Research) *started us down this journey and I always remember this. It took him one week to do the model for the induction stroke. Second week, he did the compression stroke. Third week he burned it. The fourth week was the exhaust stroke–a month of computer time to model one cycle. "Now, I can do that in a matter of a few hours. Just to give you an idea for how much faster the computers have gotten in that length of time. Eight years and we've gone two orders of magnitude faster."*

GM spent a couple of months on LS7 computer work before the first LS7s were assembled by Katech in the Summer of 2003. Shortly after that, more early development engines were done by Powertrain's experimental engine assemblers in Pontiac. Starting on 24 February 2004, development engines were built at the Performance Build Center.

Special Block and Crank

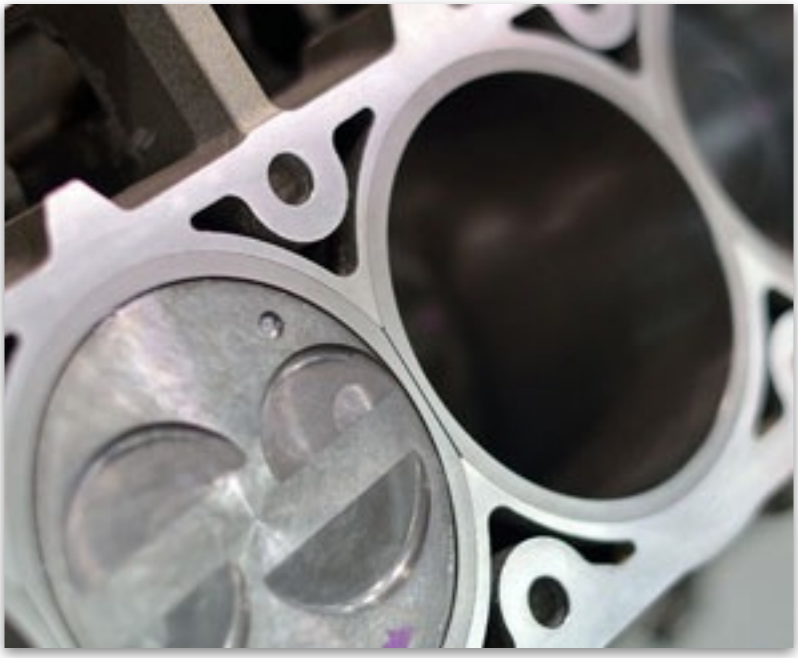
GM's production, aluminum V8 bare blocks, or "cylinder cases" are cast by Nemak, a world-class foundry in Monterrey, Mexico, which supplies engine manufacturers world-wide. The LS7 case shares qualities Gen 3/4 engines have had since their 1997 debut: deep-skirted, 319-T5 aluminum block, long head bolts threading deep into its main bearing webs, six-bolt main bearing caps, a center thrust bearing and gray iron liners which are centrifugally-cast for increased density to enhance strength and allow thinner cylinder walls. All this makes a lightweight, rigid, block structure offering good durability and reduced friction–all important basics for a specialized engine like the LS7.



The structure of the LS7 basic engine is a specific aluminum cylinder case. Image: GM Powertrain.

While the case is a Gen 4, it's a little different from its 6.2-liter siblings used in other Camaros. It has pressed-in, rather than cast-in-place liners; its water jackets had to be altered to accommodate them. The LS7's bore, 104.775-mm, 3.18-mm larger than that of the existing LS2, was greater than cast-in place liners would tolerate and still have adequate cylinder wall thickness, but it works if partially-siamesed, pressed-in liners are used. The liners, also, extend farther into the crankcase than do the cast in-place units. Because of the the LS7's, long stroke, the extra length is necessary as a guide and support for the thrust side of the piston skirt.

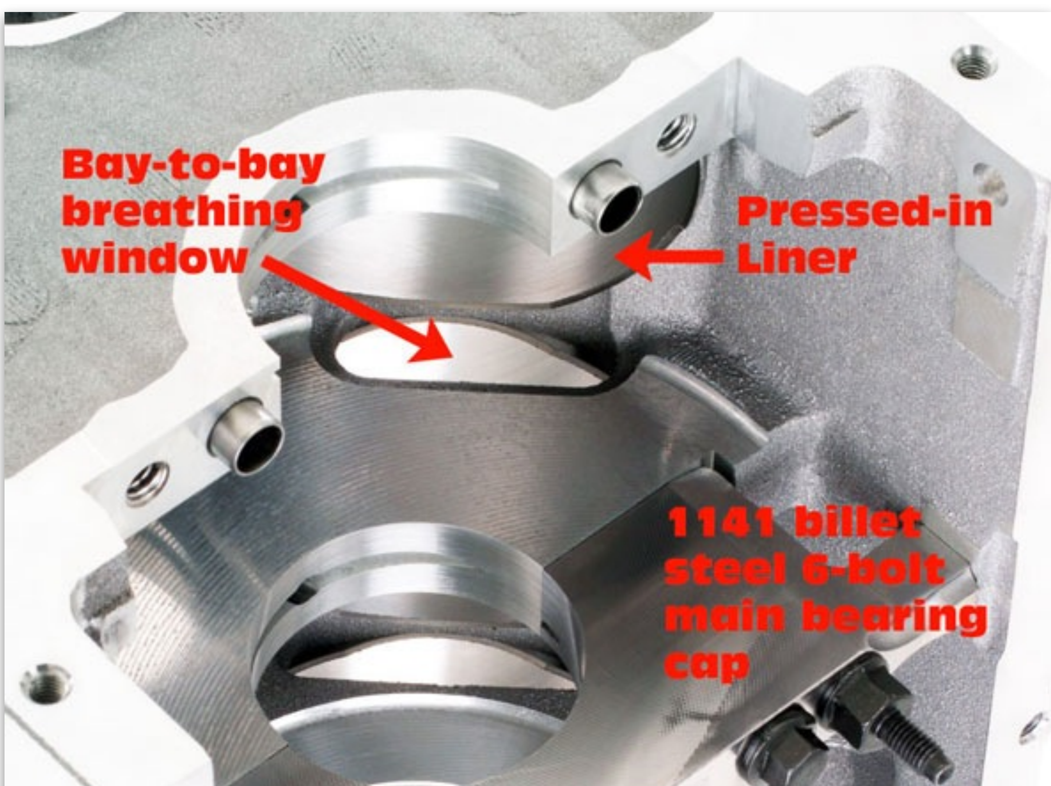
John Rydzewski told us that, after casting, LS7 blocks are shipped to a Linamar Corporation facility in Guelph, Ontario, Canada for rough machining, installation of the pressed-in liners, and finish machining operations. One of those operations, machining "hone over-travel clearance", became a major issue during the engine's late development stage. *"When the block is honed, the bottom of the honing tool needs clearance so it doesn't contact the block below the bore,"* John Rydzewski stated. *"Before the honing operation, the block is machined in that area to provide clearance. The resulting surface geometry has a big impact on the block structure. Hone over-travel clearance used to be machined* (LS1, -2, -6 and early LS7 development cases) *with a 3-mm radius. To get more strength in that area, we eventually changed to a more gentle, 8-mm radius. That was a big durability enabler at the LS7's power level."*



The pressed-in liners are siamesed for about a two inch section where two liners would interfere. There's no decrease in wall strength because the flat surfaces of the two liners support each other. Image: GM Powertrain.

As the pistons move up and down in their cylinders, they force air in and out of the spaces (or "bays") beneath them. At high RPM, these flow reversals are rapid, violent and really whip up the oil as well as creating power loss. One way to mitigate this problem is to vent each bay to its neighboring bays. Like other Gen 3 and 4 blocks, production LS7 blocks have openings or "windows" their main bearing webs between bays for this "bay-to-bay breathing". Rydzewski went on to say, *"Hone over travel machining, affects the size of the resulting windows in those bulkheads which are very significant to bay-to-bay breathing and horsepower.*"

In its ruthless pursuit of power, GM didn't just haphazardly put holes in the main webs. In fact, early development LS7 cases did not have windows at all because, initially, GM didn't know how to produce a block with both bay-to-bay breathing windows and reliability at 500-horsepower. Extensive finite element analysis along with thrashing engines to death–in some cases, literally–on the dyno and in prototype Vettes, eventually resulted in the LS7 block having both the necessary bay-to-bay breathing windows and more overall strength than any of its predecessors.

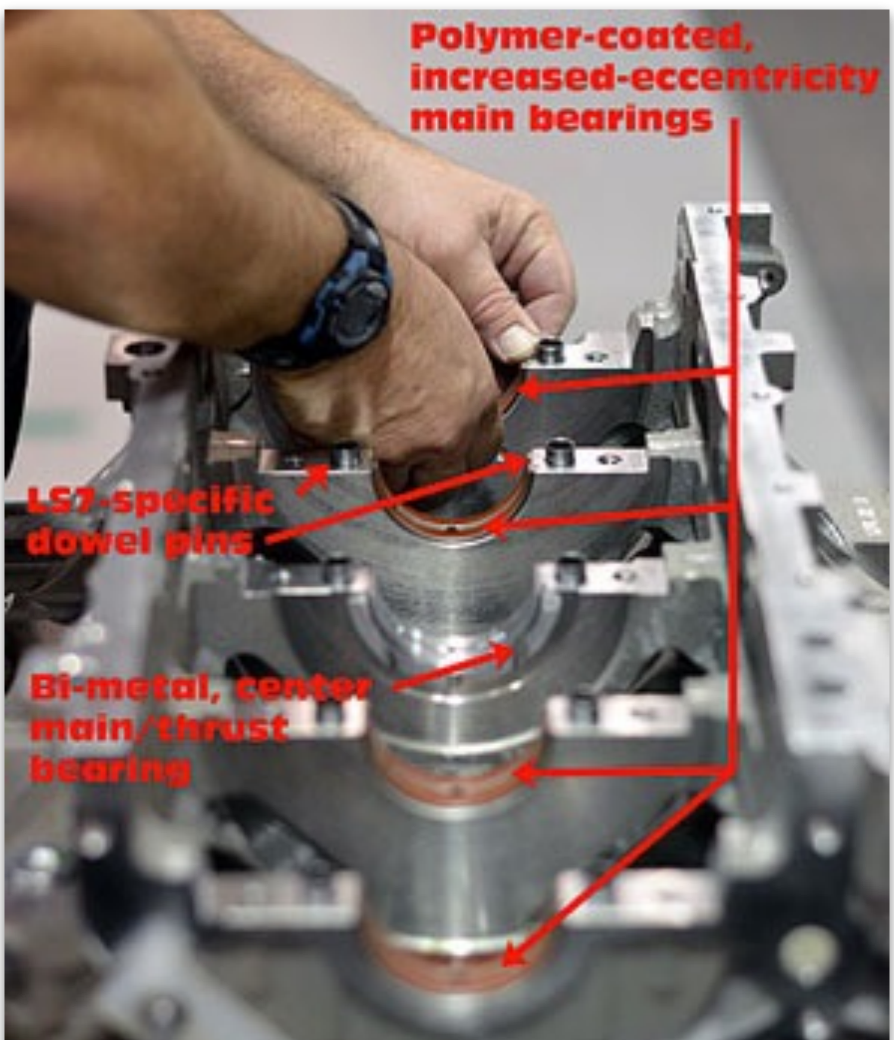


The backside of one of the bay-to-bay breathing windows in an LS7 case. Image: GM Powertrain.

Besides 8-mm hone over travel radii, other changes were made to increase the block's strength for use at the 500-hp level. First, the material used in the main bearing caps was upgraded from forged powdered metal to 1141 steel machined from forged billets. Secondly, each cap is located with by dowels making a more rigid structure once all six bolts are tightened.

Some of Linamar's block machining processes are unique to the LS7, but the final two are noteworthy in that they came directly from racing. While they are standard procedure at places like Katech, they are rare for a production engine. First, all LS7 cases are align-bored with deck plates installed and the head bolts tightened to specification. Second, all LS7 blocks have their liners honed with the same deck plates installed and head bolts tight.

Once Linamar finishes LS7 blocks, they are cleaned and shipped to the Performance Build Center for assembly. We visited the "PBC". in the Winter of 2012 to assemble an LS7 (see:http://www.corvetteactioncenter.com/specs/c6/corvette-engine-build-experience/index.html#.UO29RI51-dU) and while there, we learned there is no pre-assembly parts cleaning at the PBC. When Linamar cleans a block, they are spotless. Other suppliers are, also, required to furnish parts which are clean and ready for assembly. We asked Rob Nichols, the facility's Engineering Supervisor, how they ensure that. *"We visually check all parts and if they are not to our liking, we send them back,"* Nichols told the CAC. *"Periodically, we test-wash blocks and crankshafts. Any contaminants fall into a filter we place at the bottom of a wash basin,"* Nichols told the CAC. *"The weight of these filters is pre-measured. We take the filters and sediment and bake them in an oven to dry out the filter and debris. Then, we reweigh the combination. The difference between the base weight and the weight of the filter with debris gives us the amount of sediment washed off of the parts. We have tolerances for the amount allowed. If it falls out of spec, we alert the supplier and* (do further testing to) *make sure all incoming product is conforming."*



LS7 main bearings being installed at the PBC. Mark Kelly/GM Powertrain.

The LS7 was the first production engine to use "increased-eccentricity" main and connecting rod bearings. The term refers to the thickness of the bearing. Eccentric bearings get slightly more thin from the center to the edge where the split line relief starts. The difference in thickness is the "eccentricity". Mark Damico, Design System Engineer–Small-Block Base Engine, who has worked on the Gen 3/4/5 engine program since 1993, told us that, prior to the LS7, bearings were either the same thickness from the center to edge or they had a very slight eccentricity. LS7 bearings have much more eccentricity, .0006-in for the number 1, 2, 4 and 5 mains and a whopping .0011-in for the rods. This higher level of eccentricity improved durability because bearings of this design flow more oil and are more tolerant of bearing bore distortion which increases with cylinder pressure. Use of high-eccentricity bearings eventually expanded to other Corvette engines, the LS9 in 2009 and LS3 dry-sump in 2010 along with the Camaro's LSA in 2012.

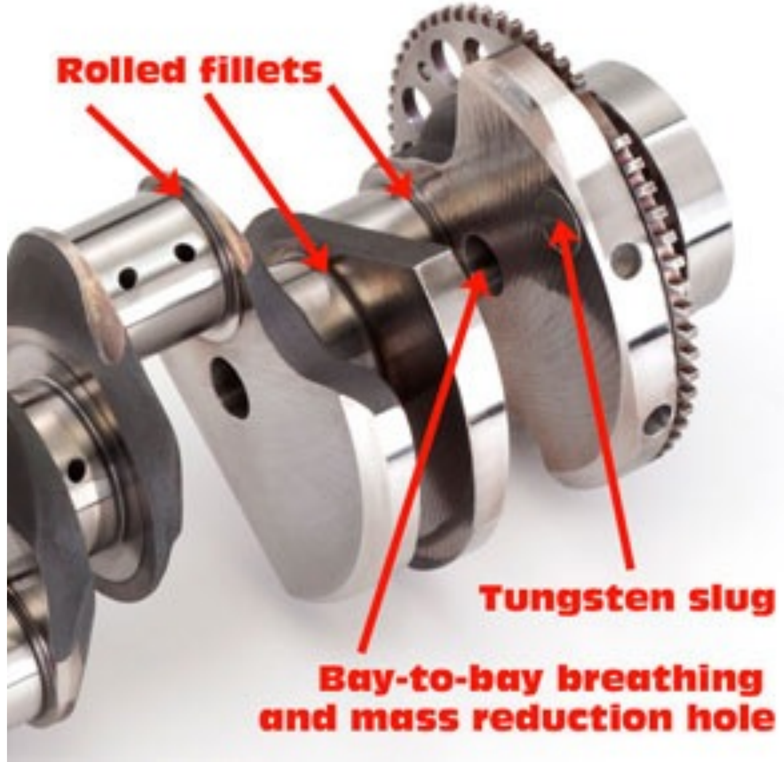
If there's a downside of high-eccentricity bearings it's that clearance checking in the field is a little more complicated in that care must be taken to *always* check the clearance at about 90° to the bearing part line. Also, parts choices when bearings are replaced can be critical. If aftermarket bearings are chosen they *must* have a level of eccentricity that is similar to that of OE bearings because–if the bearings have less eccentricity–the engine will have either insufficient oil flow in bearings or–if the bearings have more eccentricity–insufficient oil pressure.

An LS7 rod bearing with its obvious red, polymer coating. In a short period after the first engine start, some of the red wears away leaving the anti-friction polymer coating to fill the microscopic voids in the surface of the aluminum. Image: GM Powertrain.

Until the 2012 model year, bearings of traditional, "tri-metal" (steel backing, bronze second layer and a top layer of lead) construction were used in the LS7's #1, 2, 4 and 5 main bearing positions and in the connecting rods. European Union legislation enacted in 2011 prohibits the import of products containing lead, so the main and con rod bearing designs were changed. Lead was replaced with a synthetic polymer making a "bi-metal-with-polymer" design. The center (#3) main bearing remains aluminum on a steel backing. According to Mark Damico, because of the firing order used on all Gen 3, 4 and 5 V8s, the second and fourth main bearings are subjected to the highest loads. After a long period in service, if an LS7's bearings are going to wear, it'll be the #2 and #4 mains which show it, first. The two end bearings may see a lesser level of wear due to (#1) the accessory drive or (#5) the flywheel. The center main experiences the least vertical load and while it is an increased-eccentricity design, it's never required a lead overlay nor polymer coating.

An early style, 4140 forged steel, LS7 crankshaft. Image: GM Powertrain.

Rolled fillets at the edges of each each bearing journal improve the strength of the crankshaft. All but the front main journals are hollow to both reduce mass and facilitate bay-to-bay breathing. Tungsten, a heavy metal, is used to balance the end two counterweights. Image: GM Powertrain.

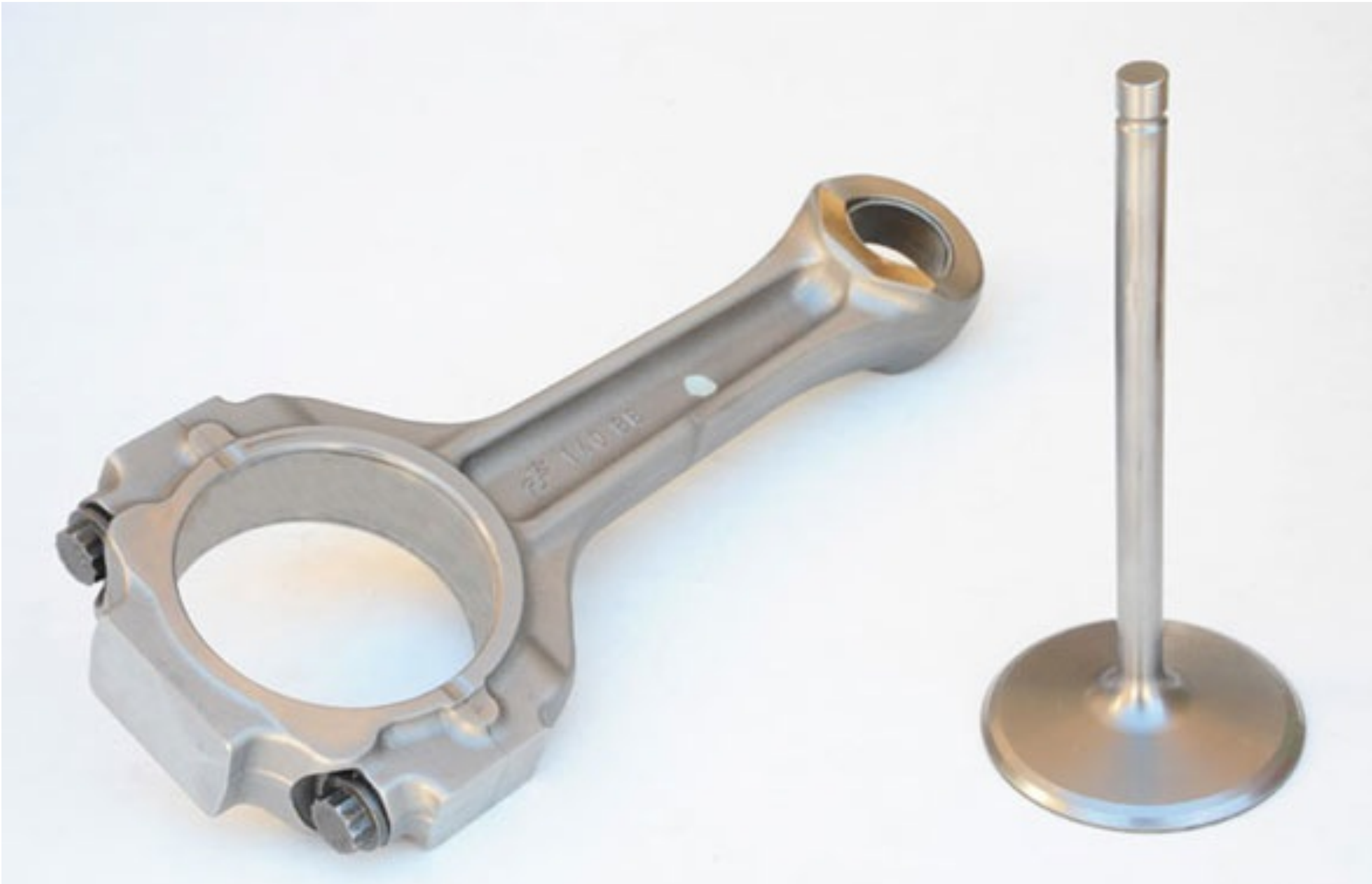


An LS7 engine part which I think is so pretty is the crankshaft. With its appealing brownish-coppery color and intricate finish machining–darn it–it's just too cool-looking to be in an engine. The eye candy that they are, LS7 cranks are pretty trick parts for a production application being micro-alloy steel forgings manufactured by specialty supplier, SMI Crankshaft in Fostoria, Ohio. The cranks have some journals which are hollow for less mass and, in the case of main bearing journals, improved bay-to-bay breathing. All the journals have rolled fillets for increased durability and, like race engines, the front and rear counterweights are balanced with "heavy metal" slugs made of tungsten. Early LS7 cranks were 4140 steel. Later LS7 cranks, including all the Camaro units are 44MNSIVS steel. *"The reason we switched,"* John Rydzewski told us, *"was it eliminated one of the processes in fabricating it. With 4140, you have to quench and temper the crankshaft before final machining. With this new material, you don't have to quench and temper because* (the steel) *has a different grain structure. The end result is the same properties but* (using the new material) *eliminates a step reducing the cost of manufacturing."*

Under the watchful eye of PBC Assembler, Mike Priest (left), the author installs a late-style LS7, 44MNSIVS forged steel crankshaft. Image: Mark Kelly/GM Powertrain.

Featherweight Engine Artwork

Part of the LS7's mystique is its use of titanium. Its connecting rods and intake valves are a rare application of that lightweight material in a production engine.



To get the LS7 to reliably turn 7100 RPM, lightweight titanium rods and intake valves were required.

Titanium is a silver-gray metal. The ninth most abundant metal, it's often found in mineral deposits and small amounts are in most living things. Number 22, on the periodic table, engineers often refer to it by its chemical abbreviation "Ti" (pronounced "tie"). Titanium's density is somewhere between that of aluminum and stainless steel. As strong as some steels, but 45% lighter, It has the highest strength-to-mass ratio of any metal. Its other noted property is excellent resistance to corrosion. It is slow to react with water and air because it forms its own, oxide coating which protects it from further reaction. Ti is fairly hard, non-magnetic and does not conduct heat or electricity very well. Interestingly, besides aerospace, military and industrial applications–and LS7 engine parts–titanium is a popular metal for jewelry. Before I got married, my then-fiancée asked me what kind of wedding ring I wanted. "Titanium, because of its strength-to-mass ratio my dear."

Making Ti engine parts isn't easy. While the metal is abundant, it rarely occurs in pure form. Typically, it's produced using the "Kroll Process", a complicated and quite costly pyrometallurgical procedure. In a series of high-temperature chemical reactions, raw titanium "sponge" is extracted from rutile, a common mineral.. Next, Ti sponge is melted into ingots. Since titanium ignites before its melting point is reached, this is done in a vacuum or an inert atmosphere–other than nitrogen, of course, because Ti is one of the few elements which burns in pure nitrogen. The Vacuum Arc Remelt (VAR) process produces titanium ingots which are then rolled into flat or bar stock then forged into LS7 rods and intake valves. Machining titanium can be difficult, because it galls or softens if improper tooling or inadequate cooling is used, i.e.: if you screw-up the machining process, a lot of expensive raw material ends up scrap. How expensive? At this writing, titanium ingots run about $10.30 a pound. For comparison, aluminum was about 93 cents a pound and benchmark, cold-rolled steel was about 37 cents a pound.

The LS7's forged titanium con rod is a work-of-art in many ways. Visually, it's so pretty that, if they weren't so expensive, people would buy them as intriguing Christmas tree ornaments, attention-getting paper weights, unusual props for jugglers or for "industrial-chic" themed interior decorating. Ok, seriously–the Ti connecting rod is pretty because of the silvery-gold-colored, chrome-nitride (CrN) coating typical of titanium engine parts. It's, also, a work of "engine-development-art" as it took a lot of computer analysis and engine testing to get it to where it could be reliable and durable to the standards GM has for all production engines.

The LS3 rod on the scale weighs in at 22.74-oz. The LS7 Ti rod in the foreground weighs 16.38-oz., 28% less. Image: Author.

Why a Ti rod? Not for the reasons most might think. Indeed, substituting forged titanium for forged steel significantly reduces mass allowing the rotating assembly to accelerate quicker improving the engine's response and reducing parasitic losses as the engine speed accelerates, however, titanium LS7 rods are more a durability measure than a performance enhancement.

On the power stroke, when the piston and rod assembly reach the bottom of their travel, inertia combined with what's left of combustion pressure apply a great deal of load on the oil film between the upper bearing shell and the crankshaft journal. During LS7 computer modeling, the Small-Block team discovered that with the, Group III, 5W30 synthetic engine oil used in Corvette engines, connecting rod bearing oil film strength would be unacceptable when the engine was under the heaviest load and at high RPM. Further, they decided a titanium rod would provide the mass reduction necessary to decrease those inertia loads such they would not exceed the film strength of the oil.

"During development of the 6.4-liter, we didn't use a ti con rod," John Rydzewski

said. *"It was an investment-cast (steel) con rod. It had a lot of mass lightener pockets–less material (than a forged LS6 rod) to keep the mass down. However, with the seven-liter, the longer stroke and higher engine RPM was a concern for proper oil film thickness.*

During one of the CHpg's LS7 interview sessions, Asst. Chief Engineer, Rydzewski discussed the LS7's titanium rod. GM Powertrain's Communications Manager, Tom Read looks on. Image: Author.

"Our analysis capability is really good for oil film thickness. This analysis comprehends engine speeds, loads, temperature, mass/inertia and geometry. At high speed, you have a lot of inertia, a lot of reciprocating mass which will reduce oil film thickness. We had to make a big move to increase the film thickness robustness. That (a titanium rod) was the most straight forward way to do it."

That begs the question: rather than an expensive set of Ti rods, why not just a better engine oil? You can buy a lot of premium, ester-based, 10W30 synthetic oil, which has better film-strength properties, for the cost of those rods.

Well...it's just not that simple. To use forged steel rods and a higher film-strength oil, General Motors would, first, have to admit that fabled Mobil 1 5W30 and its "Dexos 1" successor, were inadequate for use in the LS7. That was so not-gonna-happen. Plus–while it is true that there are engine oil products with better film strength properties than the factory-fill 5W30 used in LS7s; when we asked John Rydzewski about that, he commented, *"A higher weight oil can improve film thickness, but that, alone, would not have met the design requirements."* So, the LS7 has those bitchen ti rods, with their durability advantages and the better throttle response they provide, to add to its mystique.

Rydzewski continued, *"Titanium rods are good for reducing reciprocating mass but their downsides are: they are expensive,* (Note: we couldn't get cost numbers from GM but, according to Stan Lorence, Parts Manager at Tom Henry Chevrolet in Bakerstown PA, a replacement LS7 titanium rod is nearly four times the price of a steel, LS3 rod). *They take a lot of machining steps. They come from Mahle in Germany, so there is a long lead-time. The process–forging, a lot of machining and application of the* (chromium nitride) *coating–is* *complicated. There are few suppliers out there which can do titanium rods for production applications.*

"We've had pretty good luck with them. We've never broken a rod because of the strength. An unusual property of a titanium rod (compared to a steel rod) *is its different modulus of elasticity. They bend a little bit differently and that concerned us at first. Because of the different modulus of Ti, the stiffness requirements had to be comprehended in the design. Many sections of the Ti rod were larger than required for a con rod made of conventional* (forged steel)*.*

"Also, we had issues with 'Ti dust wear' during our first round of builds. And then we started seeing some signs later on, once we got into parts that came off manufacturing equipment. The two rods (on the same crankshaft journal) *rub against each other. Titanium on titanium does not wear well. If you have sharp corners, particles can break off. They get between the rods and start wearing away the coating and get you into trouble."*

The arrow points to the groove or divot which was added to LS7 rods to combat Ti dust. Image: Author.

Ti dust forced implementation of special manufacturing procedures at Mahle. At the part line between the rod and cap, there can be slight misalignment resulting in a sharp edge which can abrade the adjacent rod. The ti dust problem was traced to that area. For engines built for the second phase of development, a small groove was added on the sides of the rod's big end right at the parting line which eliminated the possibility of any sharp edges. Besides Ti dust control, during the LS7 development, other procedures were introduced to avoid impact damage to the rod which causes stress risers and damages the coating.

Cutting-Edge Piston

In a departure from what most people, including some veteran mechanical engineers, would expect, the LS7 engine does not use a forged aluminum piston. It uses a cast, eutectic aluminum piston, but that's greatly simplifying the issue as there's quite a story to the LS7 piston. *"They started out with forged on the six-four."* John Rydzewski told the CHpg. *"When they picked a* (piston) *supplier for the seven-liter, it was Mahle which came back and said, 'We can do this in a cast piston. We've got the knowledge and it will work.' The decision was to proceed with a cast piston. It met all the requirements–met the specifications and it was less expensive."*

In February of 2012, we visited Katech to learn more about its role in helping GM bring the LS7 to market and cast piston was an issue we covered. *"One of the big challenges with a* *cast piston was durability at 7000 RPM,"* Katech's CEO, Fritz Kayl, told us. "*We did stuff later in the program on that. We met the power targets pretty easy but the durability side was more of a problem. The big challenges were piston speed and how to reduce parasitic losses.*

"With a four-inch stroke, you have tremendous piston speed. I'll give credit to GM–they set that (cast piston) *as a challenge and they were not going to give-up on it. Certainly we didn't have that technology here. Everything we do in racing is forged pistons, but with the LS7, forged pistons were off the table.*

Katech's Fritz Kahl explained piston speed to us in an interview at his Clinton Township, MI facility. While the LS7s piston speed is only 200 feet/min. higher than that of the C5-R race engine, inertia loading on the pin and pin bosses increases with the square of the speed and the LS7 uses cast pistons while the C5-R engine used forged. Image: Author.

"At that time, piston speed for racing (C5-R forged piston) *was about 4500 feet-per-minute but 7100-RPM for a Corvette LS7 is 4700 feet-per-minute.* (LS2 and LS3 cast piston speeds max'ed at 4000-fpm.) *And of course, bearing loads and everything else goes up with* (the square of) *piston speed. That's why the concern. They had some problems with pistons in the early going but they got it solved. As it turned-out, they* (GM and Mahle) *were right. Those pistons are durable.*

So, how did Mahle pull off an advancement some thought impossible? By combining a special aluminum alloy with a new casting method, more robust heat treating and new developments in piston structure.

The LS7 piston is cast from a eutectic aluminum/silicon alloy having small amounts of copper and nickel. This alloy, "Mahle 142," was first used for pistons in the LS6 engine of 2001. "M142" offers increased strength and less expansion at high temperature providing better control of piston-to-bore clearance, both at the skirt and the ring lands. That improved dimensional stability reduces piston noise, improves oil control and enhances durability.

In an interview, Aaron Dick, the Application Manager assigned to the LS7 piston development at Mahle, told the CAC, *"We did* (a cast piston) *primarily for weight-reduction.* A *requirement was very lightweight reciprocating masses. Taking that challenge, we looked at a new, patented casting process we had. We were able to cast the piston lighter than we could make a forging."*

Mahle developed the "Ecoform" casting process in the early-'00s as a mass reduction strategy and LS7 was one of its first applications. This casting technology creates recesses, or cavities, in the ring belt which could not exist in a forging. The resulting high-strength, reduced-mass, cast piston was cutting edge technology for high-volume, production engines in the mid-'00s.

This cutaway Mahle Ecoform piston, while not an LS7 unit, is typical of pistons made with that process. It is very light because of cavities the process forms in the underside of the piston which could not exist in a forging. Image: Mahle.

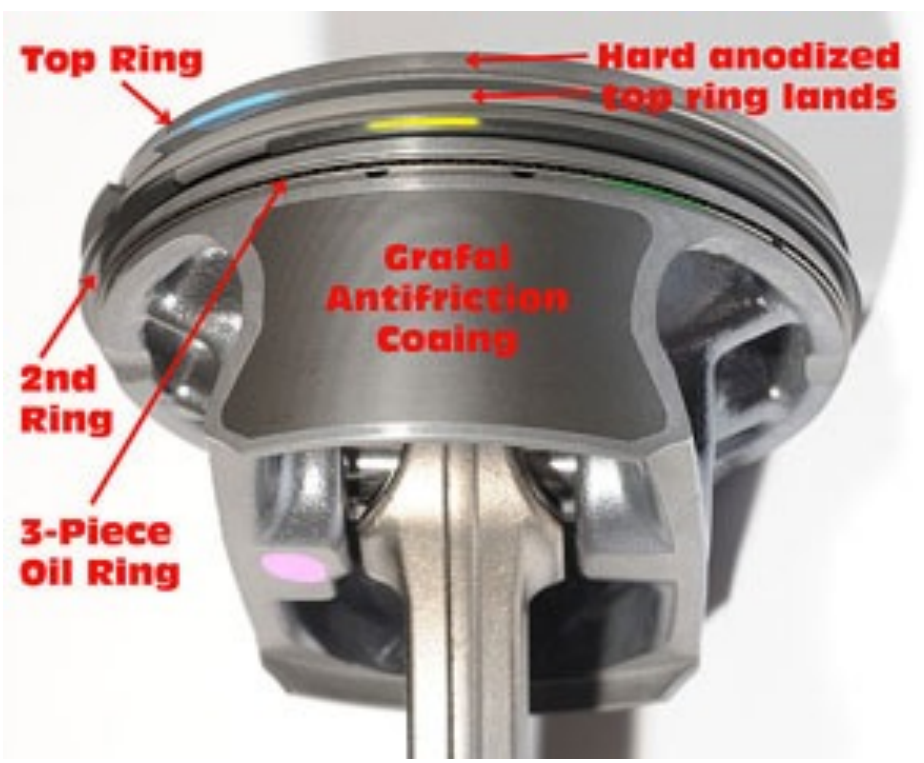
The heat treat specification for the LS7 piston is, also, a departure from the norm and intended to improve strength. *"The vast majority of gasoline pistons have a T5 heat treat where the LS7 has a T7 heat treatment,"* Dick continued. "*That increases the strength and the hardness of the piston and that adds strength at the pin bosses–the lower temperature parts of the piston. At high temperatures, the heat treatment is not as critical. In the piston crown, for example, it's not helping as much, but in the lower end of the piston, the T7 heat treat improves the properties of the material. This helps when you have 'inertia loads'–high speed but no loa*d. *For example: if you downshifted going into a corner, when the engine revs up,* (inertia loads) *are trying to rip the piston pin out of the piston."*

The LS7 piston has "asymmetric" skirts with the major thrust face being wider than the minor face, a configuration responsible for another slight mass decrease. The skirts are coated with "Grafal", Mahle's proprietary, polymer coating which reduces friction, increases scuffing resistance and allows less piston-to-bore clearance leading to less engine noise.

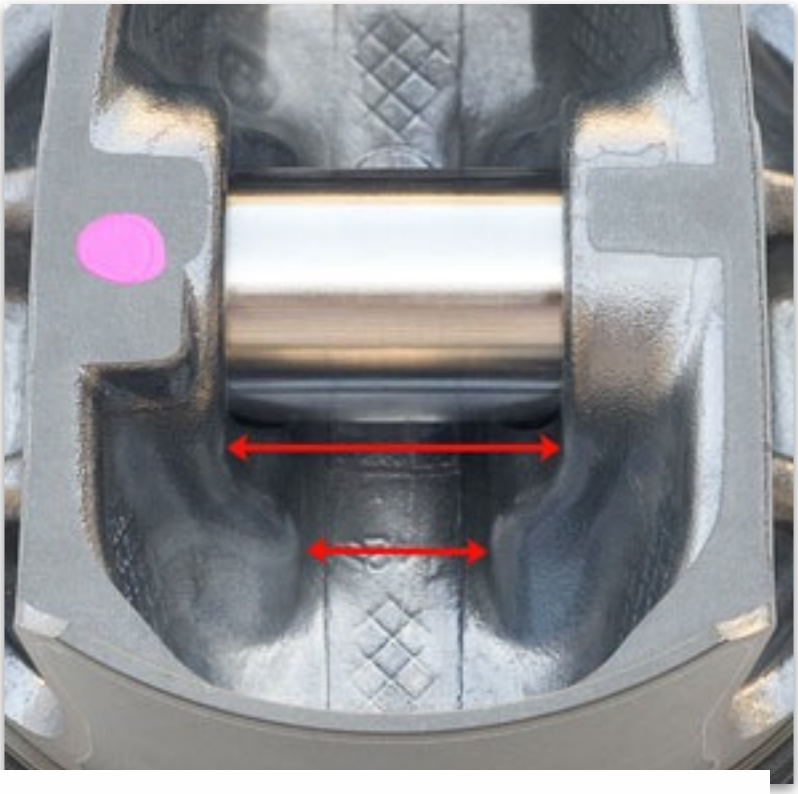
The underside of an LS7 piston and its wrist pin are both engineered for reduced mass. Image: Author

An LS7 piston pin, or "wrist pin"–arguably one of the most highly stressed parts in a high-performance engine–is made of a gas-nitrided, chromium-molybdenum-vanadium steel meeting the 31CrMoV9 specification. This is a more robust material than normally used in GM V8 pistons. it allowed the wall thickness of the pin to be less and the inside diameter to be tapered to reduce mass but still enabled the pin to meet GM's abusive fatigue life tests. The piston is phosphate-coated, the main purpose of which is to improve the reliability of the pin bores during the break-in period. The pin locks are circlips, but they're made with 1.8-mm rather than 1.6-mm wire to increase the circlip's tension. During development, according to then Small-Block Chief, Sam Winegarden, the LS7 engineers learned that, at high RPM, the loads on the 1.6-mm circlip at top-dead-center and bottom-dead-center can deform it and pop it right out of the pin lock groove. Going to the more robust circlip solved that problem.

More "light-weighting" comes with the LS7 piston's skirt asymmetry. Image: Author.



Areas immediately adjacent to the top ring groove are hard anodized and the surfaces of the piston skirts are coated with Grafal, a polymer-based antifriction material pioneered by Mahle with the 2002 LS6 piston.

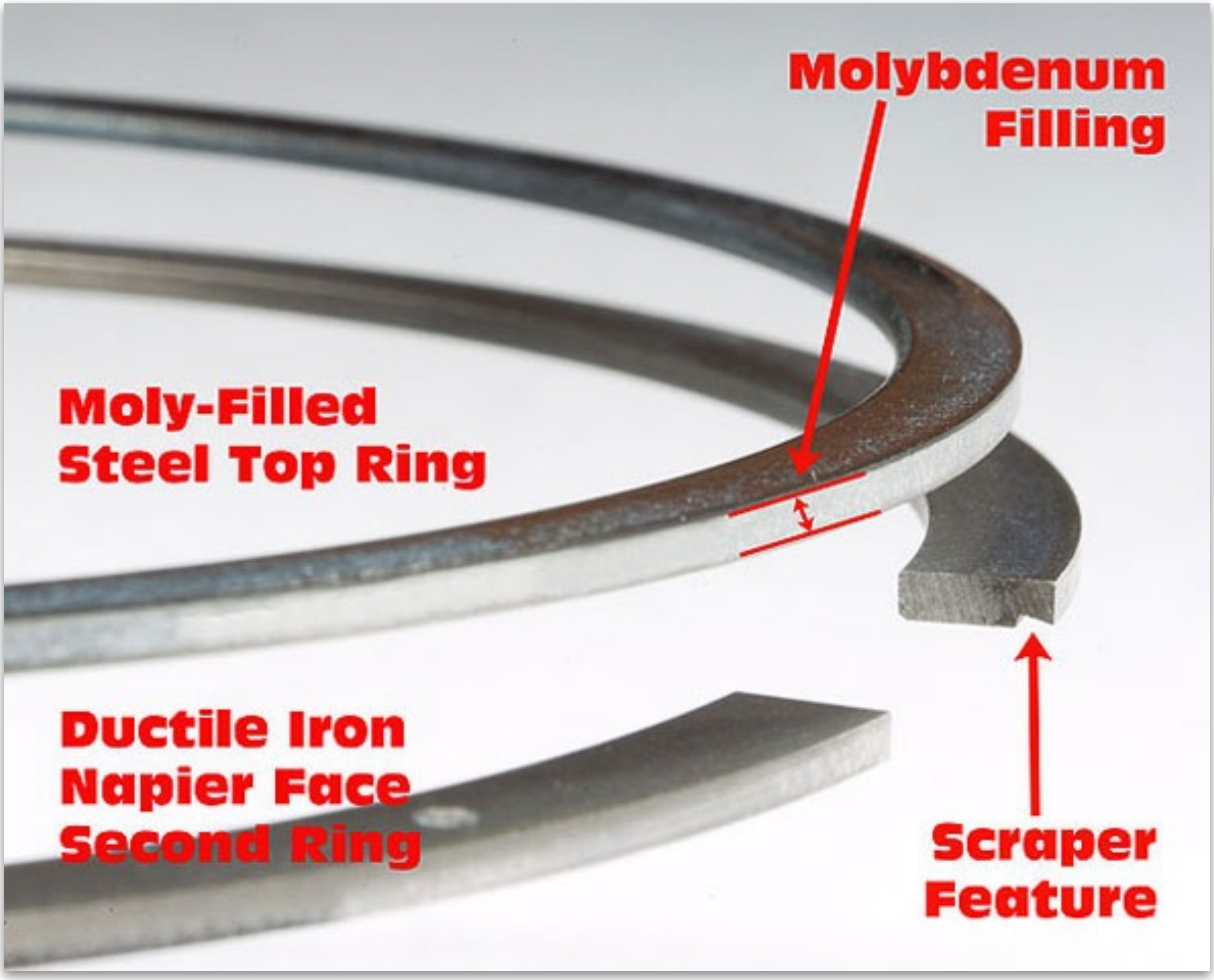


Again, looking at the underside of the piston, to increase strength, the top portion of the wrist pin bore bosses, indicated by the shorter arrows, are wider than the bottom portion. Image: Author.

Additional mass reduction comes in shortening the piston pin, but to do that and preserve the ability of the pin bosses to carry the load, the pin bores were moved closer together and the tops of the pin bores curve inward to further strengthen that area. To clear those parts of the pin bores, the small end of the connecting rod is formed with a pronounced step with the top being more narrow. Another reason for a shorter pin? It provides clearance between the crankshaft reluctor wheel and number eight piston.

An '06-'11 Corvette LS7 piston/rod assembly. The Camaro unit is identical except for a polymer-coated, bi-metal rod bearing. The four valve reliefs are a welcome feature of the piston top for those wanting to go to an aftermarket cam profile. Image: GM Powertrain.

The piston top has four valve reliefs which, according to Aaron Dick, are not necessary with the stock LS7's valve lift. They exist because, after the design was finalized, GM wanted slightly less compression, so four valve reliefs were added. An unintended, but sometimes welcome consequence, is that these reliefs provide adequate valve-to-piston clearance for some aftermarket camshafts, such as Katech's "Torquer" series of LS7 cams, having more aggressive profiles without having to change pistons. The ring grooves are machined with a slight upward tilt which counteracts the rings' tendency to flex downward under operating pressures and temperatures. The top ring land is hard anodized to prevent microwelding on the flanks of the ring groove.



The top ring is filled with moly as an antifriction measure. The LS7's Napier second ring was developed for the 2002 LS6 and later used on all Small-Blocks. A "Napier ring" has a distinct shape that enhances oil control by scraping oil off the cylinder walls as the piston moves down in the bore. Image: Author.

The LS7 ring package starts with a 1.2-mm, moly-filled, steel top ring. It is "coined" to give it an upward twist which flattens under combustion pressure improving ring seal. The second ring is, also, 1.2-mm, but is made of ductile-iron and has a Napier-face for enhanced oil control. The oil ring is a 2-mm, 3-piece unit consisting of two gas-nitrided rails and an expander.

Most of this cutting-edge piston technology is aimed at reducing mass but, also, increasing durability. Aaron Dick's closing statement says it all about the level of technical sophistication in the piston assembly: *"it's a very, highly-engineered piece for a specialized application."*

During engine assembly, techniques similar to those used in the engine shops at Katech or Hendrick Motorsports are used to install the pistons, including an awesome ring compressor which the author insists would look excellent in his tool box. Image: Mark Kelly/GM Powertrain.

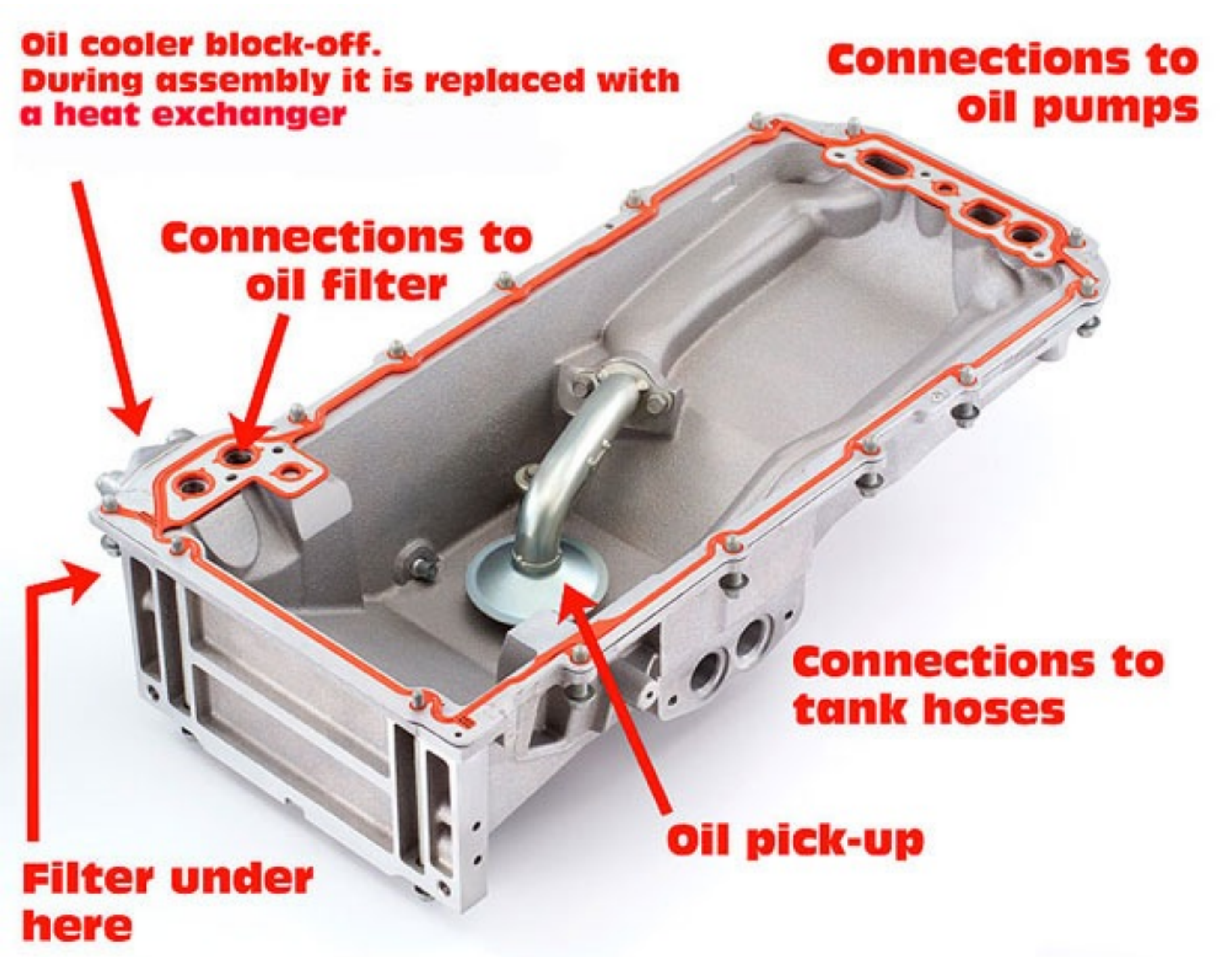
Dry-Sump Oiling

The performance requirements Dave Hill's Corvette Team gave the folks at Powertrain were demanding: 500-hp, 7000 RPM and engine reliability under levels of acceleration, braking and cornering forces unattained by previous stock Corvettes. Computer modeling quickly demonstrated that, to meet those requirements, the Z06's wet sump oiling days were over. Even the best of GM's wet sumps, the fabled "bat-wing" oil pan of the C5 days, could not be relied upon for consistent oil flow at the LS7's lofty RPM range and at the Z06's gut-wrenching handling limits, so LS7 became the first production GM engine to use a dry sump oiling system.

Mocked up in the photo studio, the 2010-2014-spec., LS7, dry sump components. Image: GM Powertrain.

"Our biggest surprise was Powertrain's choice of a dry sump." Katech's Fritz Kayl told us. *"In the early parts of the program, we were able to show them what performance advantages you can get out of dry sump system, but we never thought they would consider it.*

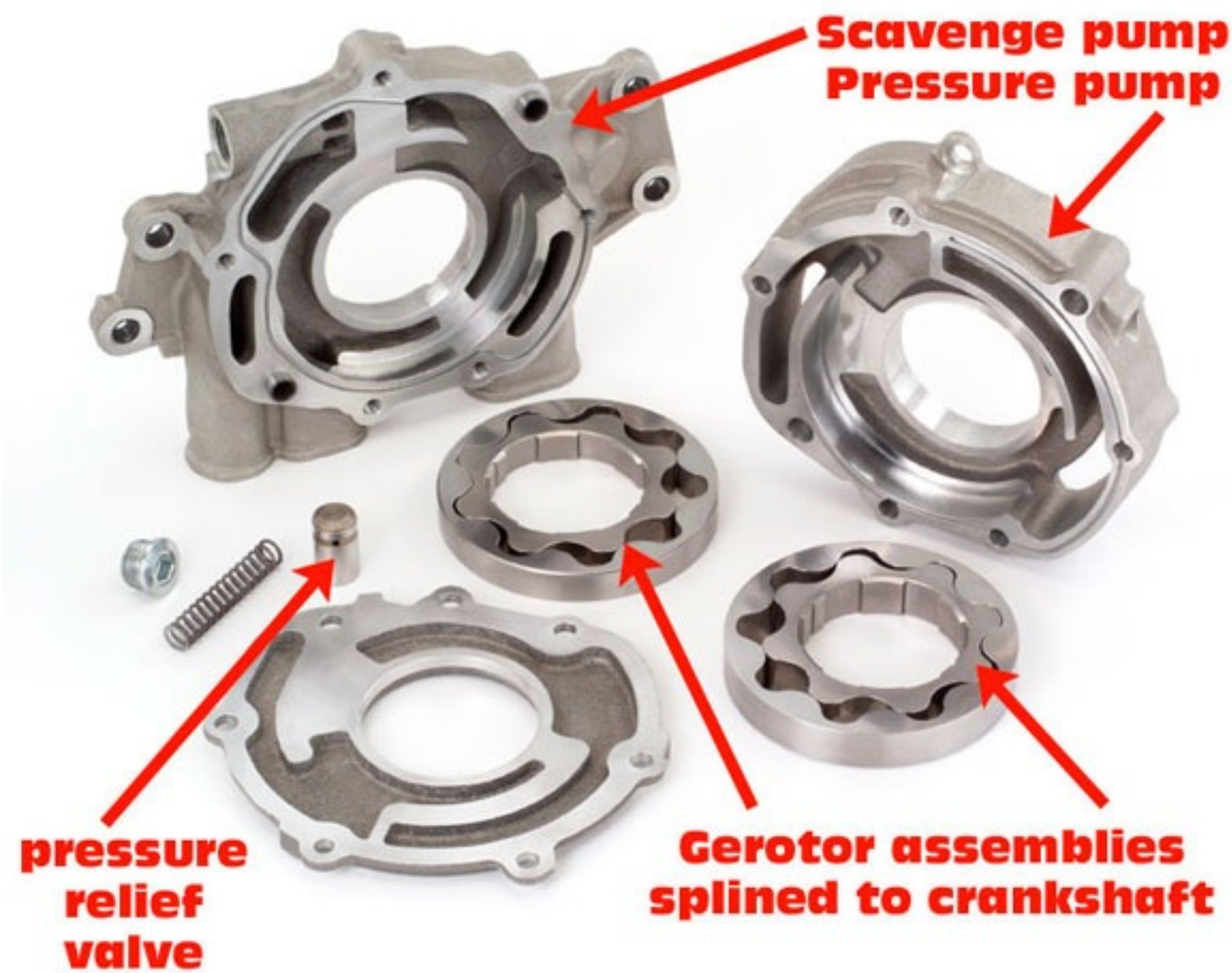
"We bid on doing the dry sump for that engine but we did not get it, so we weren't really involved in the production side too much. The actual production dry sump system running the scavenge pump off the crank, behind the pressure pump, I thought, was pretty unique and it works pretty well. Certainly not an all-out race set-up, but darn good for a production car."



Late LS7 oil pan. Image: GM Powertrain.

Actually, "dry" sump is a misnomer because it's not truly dry, at least in the sense of some of the complicated dry-sump systems on C5-Rs or a NASCAR Sprint Cup car. The LS7 system is more of a "semi-dry" sump in that there's oil inside the crankcase and the oil pan. What's different is the "sump" part–that is, the engine's entire oil supply–is not stored in the lower part of the oil pan beneath the crankcase, but rather in a remote-mounted tank. The oil pan contains a limited amount of oil, because, when the engine is running, it's constantly drained or "scavenged" by a "scavenge pump".

"GM had never developed one before," John Rydzewski began his discussion of the dry sump. *"We benchmarked systems on racing engines and from other manufacturers which have* (production) *dry sumps like Porsche and Ferrari. We saw how complicated they are. You can do a very complex, multi-scavenge with each* (crankcase) *bay scavenged individually by a pump having five stages, like on a race engine. That's the extreme and not what we wanted for this car. We wanted something to give us the performance we needed. We wanted it more affordable. We wanted to make it as compact as possible."*



LS7, two-stage oil pump components. Image: GM Powertrain.

The LS7 development team settled on a two-stage design. Gen 3/4 engines already had crankshaft-driven, gerotor oil pumps, so it made sense to add a second gerotor scavenge pump. Both are inside a two-cavity housing located at the normal oil pump position on the front of the block.

Oil is sucked out of the bottom of the pan, into the scavenge pump, through a passage in the bottom of the pan, then through hoses and into the dry sump tank located in the right rear corner of the engine compartment. Oil enters the bottom of the tank and flows through a tube to the top of the tank. Flow then reverses through a system of baffles and perforations, down the inside perimeter of the tank. That spiraling, downward flow separates the air and crankcase gases out of the oil.

The Camaro LS7 oil tank. Image: GM Powertrain.

The lower part of the tank is the engine's oil reservoir. The air and gases rise to the top, are ingested by the Positive Crankcase Ventilation (PCV) system and consumed by the engine. At the bottom of this tank is conditioned oil–"conditioned" meaning the vast majority of air and gases are gone and it's a little bit cooler because it's been in the tank for a while. On top of that, as the engine is subjected to accelerating, braking and cornering forces, the pick-up tube is always submerged. It doesn't suck air and that's the key to the reliable, consistent oil supply an LS7 needs.

An LS7 oil heat exchanger. Image: Author.

Like most road racing engines, the Z/28's dry-sump system includes an engine oil cooler. It is an oil-to-coolant heat exchanger originally developed for the C6 Corvette ZR1 and is bolted to the oil pan on the driver side of the engine.

Cylinder Heads

One of GM Powertrain's strong points is its ability to engineer really great cylinder heads and, the LS7 is clearly demonstrative of that ability. A forged crank, Ti rods, lightweight pistons and dry sump oiling are neat stuff in any production car, much less one of the Vette's price range, but, from a performance standpoint; the most significant pieces of hardware on an LS7 are its cylinder heads.

Although C6 debuted in 2005 with the LS2, Gen 4 Small-Block V8 under the hood, the LS2 head was a actually a Gen 3 hand-me-down, having been used on the 2001-04 LS6. The LS7's head was the first Gen 4 head to go to production and if there had been a mission statement for its development, it might have been: "maximum performance with minimum complexity".

In late-Summer, 2003, the Society of Automotive Engineers magazine *Automotive Engineering International* published an article about a head with three valves-per-cylinder being part of a 500-hp, Corvette engine. Math art in the AE article and photos which appeared on the Internet later showed complex pushrod valve gear. This article sparked speculative chatter on Internet forum sites along with articles in other magazines suggesting that a 24-valve engine would be in the "next" Z06.

The most important part on the engine is this cylinder head. Ti intake, raised ports, rolled-over 3° and fully CNC'ed. It's the key to the LS7's amazing performance. Image: Mark Kelly/GM Powertrain.

While the the "3-valve" had been under development by GM's Advanced Powertrain Group and might even have been a last-ditch attempt at getting 500-hp out of a 6.4, it was never a part of the LS7 program. The team at Powertrain working on the seven-liter stuck with the two-valve configuration which had worked so well with the LS1, -2 and -6 engines. In a discussion of the three-valve head, Jordan Lee, who's now Chief Engineer for Small-Block V8 Engines, told the CAC, *"Our philosophy is not to add technology for technology's sake. If technology is really not a performance benefit, we won't implement it."* As such, the three-valve head became part of the LS7 mystique and another curious footnote in Corvette engine history.

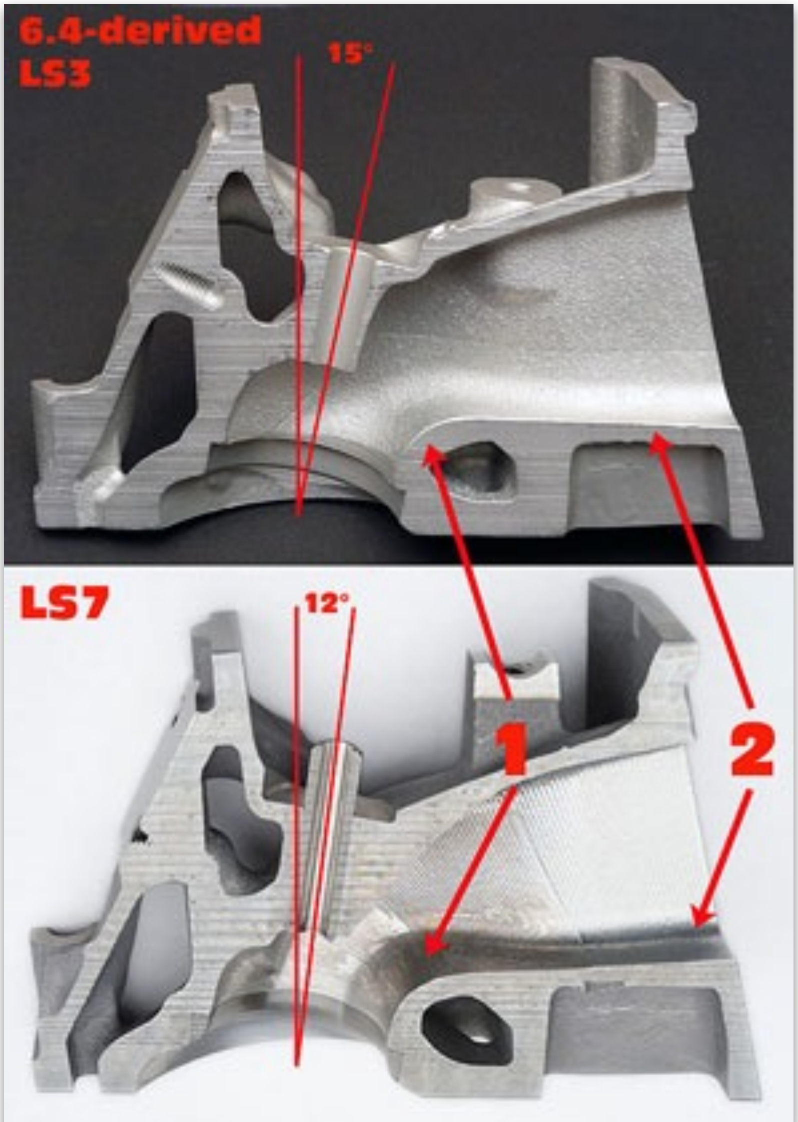
A prototype Gen 4 V8 with the three-valve head circa Summer 2003. Image: Dave Emanuel.

Using computer analysis tools, port models in "flow boxes" and single cylinder test engines, the cylinder head team, under Design Responsible Engineer, Dennis Gerdeman, developed and tested a multitude of intake port, exhaust port and combustion chamber shapes before ordering any prototype LS7 parts. This process added two more big architectural changes to the square ports and revised pushrod locations developed for the six-four head. First, valve angle was decreased from 15° to 12°. Secondly, intake port was raised. Its floor was lifted 9-mm. (.354-in.) and its roof was raised 5-mm (.197-in.), for an overall cylinder head height increase of 7-mm (.284-in.). These changes improved air flow. Also, at this point in the development, combustion chamber displacement was set at 70-cc's. For this article, the CAC recorded a long interview with Dennis Gerdeman. It began with a discussion of the early LS7 head work.

"We were working on this (6.4L LS6 successor) *and they gave us a target* (450-hp) *and we achieved it early in development,"* Gerdeman told us. *"It wasn't long after that when* (GM upper management) *came back and said, 'We need to raise the bar and increase our target to 500 horsepower.' It was really late in the development stage and that sent us all scrambling. That's when we started pulling out all the stops–the bigger bores, the titanium rods and inlet valves–and really stretched the limits of the Small-Block.*

"It was (early) *2004 when we were going through this accelerated development crunch. A lot of it was hardware. When we were looking strictly at air flow, we were doing a lot of work on the air flow bench, nearly all of it with single cylinder flow models. From an air flow analysis standpoint, we were very limited back then. We weren't nearly as developed in CFD* (Computational Fluid Dynamics) *analysis tools as we are, today."*

The head is cast of 356-T6 aluminum by Nemak using the semi-permanent mold process and cold-box cores. For machining, the head is shipped to the same Linamar facility which does the block. An LS7 head is machined entirely by five-axis, Computer Numerical Controlled (CNC) machining centers having automated tool changing. The use of 5-axis CNC allows all machining operations of critical head features–ports, chambers, valve seats and the deck–or "joint surface" as cylinder head engineers say–to be accomplished with no set-up change between them and that enhances the accuracy of the machine work. We asked Dennis about the decision to use all CNC machining for the LS7 head.



Top is the LS3 descendant of the 6.4 head and bottom is the LS7 head. They were shot from slightly different angles so, due to an illusion, the LS7 port size doesn't seem as large as the 6.4's but it is. The key features of these two images are the difference in valve angles along with: 1) the contour of the short turn radius of each head and how the LS7's more developed short turn improves air flow and 2) the height of the LS7's port floor and how the port entry is raised up above that of the six-four. Image: Author.

"The Engine Power Analysis Group told us, 'You're gonna need such-and-such air flow to have a chance at 500 hp.' We had a good feel for the geometry we needed for the perfect transition from the ports, across the valve seat and into the chamber. We also needed to reduce cylinder-to-cylinder (air flow) *variation and you just cannot get there with a conventional casting and machining process.*

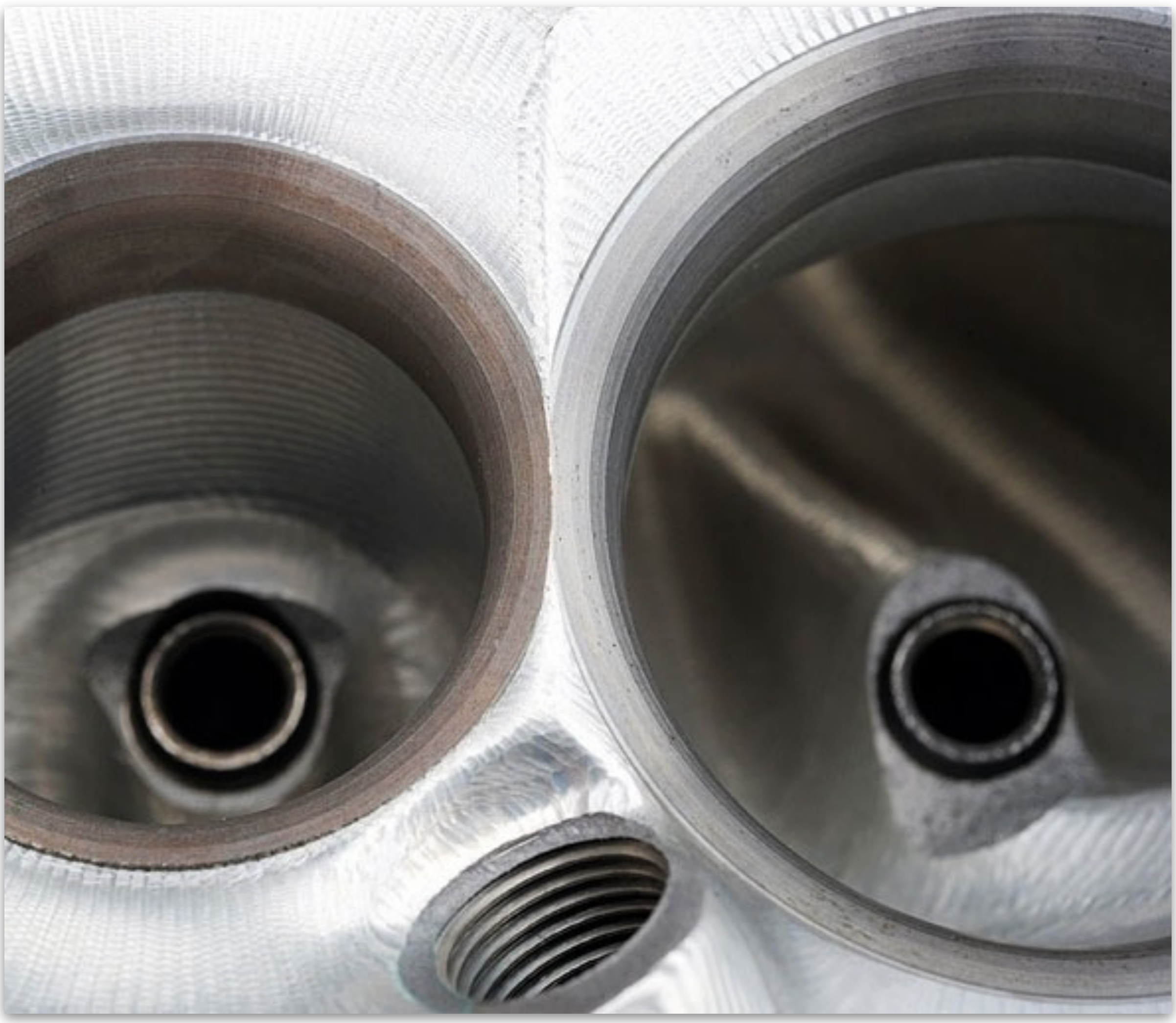
"With conventional castings–and we have some excellent casting suppliers–their variation is too high to ensure those perfect transitions. With conventional plunge machining of the valve seat and casting draft (note: "draft" is the slight taper, perpendicular to parting lines, required with sand-cored features of semi-permanent mold castings, such as ports. This "core draft" is required in order to extract the sand port cores from the steel tooling in which they are created.)*, you can't get those perfect transitions. That's when we decided to CNC. At first it was the chambers and the valve seats but then, looking at the ports, we said, 'There's no way to get the airflow we need without CNC machining there, too.' The only way to get that is to do an unconstrained, three-dimensional, CNC'ed port shape.*

"We have the seats and guides installed. They CNC the ports, chambers and seats in the same machine set-up. There's no stack-up from fixture-to-fixture–little or no variation from the CNC porting, to the seat machining and to the joint surface, so our chamber volumes and our seat machining transitions are as good as you can get. It all comes down to the repeatability of CNC machining. Any variation from that is very, very small."

Other subjects Dennis and I covered were how Katech's C5-R engine program influenced the LS7 cylinder head development and valve unshrouding. Finally, we got into Mike Chapman's work.

When a valve opens, there are parts of the valve opening which are closer to the combustion chamber or cylinder bore walls than the rest. The closeness of these walls is called "shrouding" and it restricts air flow though the valve opening. Obviously, the more you move the valve opening away from the chamber or bore walls–i.e.: "unshrouding" the valve–the less restriction there is and the better your air flow will be.

"We went to the C5-R guys at Katech and looked at their valve geometry, sizes, positions relative to the bore walls and we decided that was a great place to start," Gerdeman continued*. "We took the six-four head and kinda melded it into stuff that we gleaned from the C5-R. We still had to start with the six-four head because there were certain manufacturing limitations far as geometry and production durability. The C5-R. started us down the path of siamese valve seat inserts, which was a real unique feature for us–something we'd never done before. The siamesed seats were driven by the valve size and getting maximum unshrouding from the bore wall. We were making a lot of prototype flow boxes that we could measure on a flow bench and playing with different configurations but, until we went siamesed* (and unshrouded the valves)*; we just weren't getting the air flow we needed.*



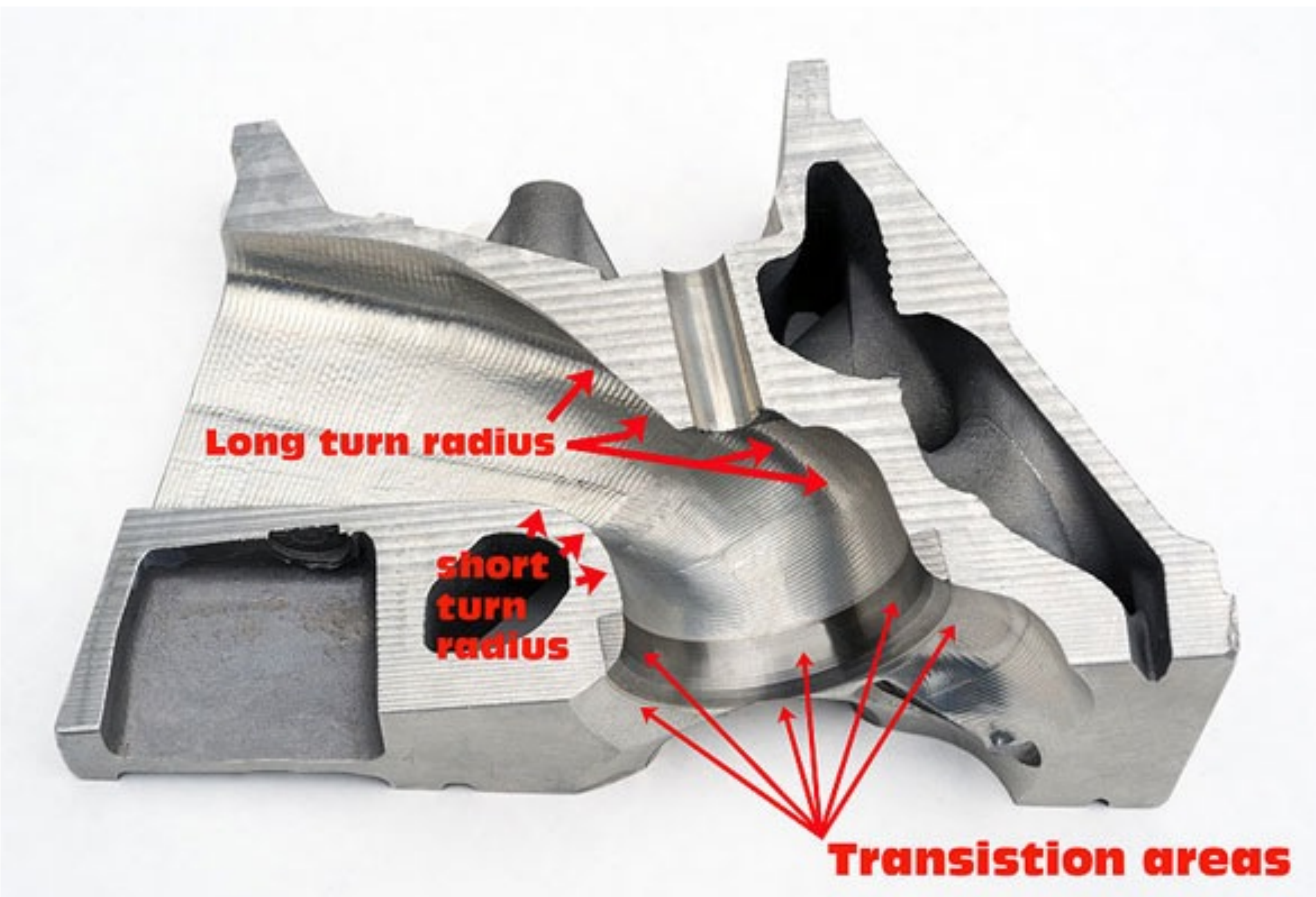
A key development in the early stages of the LS7 head program was going to siamesed valve seats. That unshrouded the intake valve thereby improving airflow. Image: Author.

"We had transfer machining lines at the time. On a transfer line, trying to change things like valve angles and locations is impossible without huge investment. We decided, with this

volume, to go with an outside machining company. After sourcing, it turned out to be McLaren which ended up (Sept. 2003) *getting bought by Linamar.*

"McLaren had worked with Chapman Racing. They said, 'Hey, talk to Mike (Chapman) *and let him take a stab at this thing.' We had already developed a siamesed layout and what we thought we wanted for unshrouding and valve sizes. Chapman started working through the intricacies around the valve seat, the angles, the blends to the port and the port's geometry around the valve guide. He did a lot of tweaking of port shapes. At the time, we were pretty happy with our intake flow–Chapman did a couple little tweaks there–but he spent a lot of time on the exhaust valve seat and port."*

Next we got into a long discussion about various design features of the LS7 which contribute to its performance. The first subject Dennis covered was the all-important short turn radius which, for those who are learning cylinder head nomenclature, is where the port floor curves down, then transitions to the valve seat.



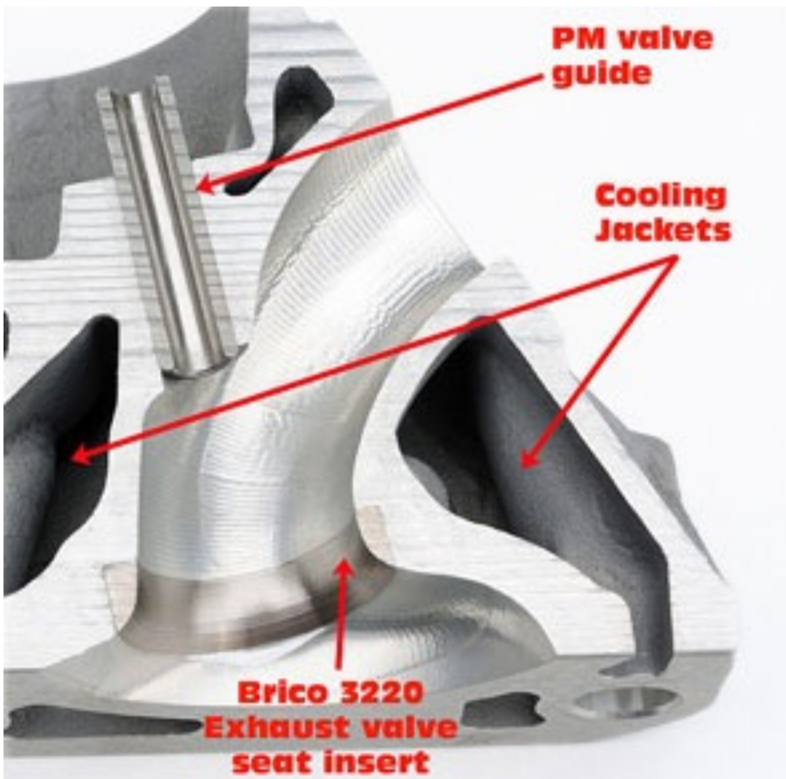
The short and long turn radii along with those transitional areas of which Dennis Gerdeman spoke during our interview are easier to understand when you have a saw-cut head to look at. Image: Author.

"From an inlet standpoint, it's the height (of the port)*, the shape of the short turn and the area schedule–how the* (cross-sectional) *area changes as you go down the length of the port–that's important. We spent a lot of time developing the short turn and from a CAD standpoint,*

it was a lot of complex geometry because, whatever we ended up with; we had to have a CAD model.

"Another focus was the shape of the seat insert after CNC machining and its transition across the 45° valve seat and into the chamber. Making those transitions as smooth as possible and as much like a radius as it comes out of the port and into the chamber is another key feature. You want those geometries as close to a radius as possible, but you still need a very defined flat for the valve seat, itself. There are four angles plus a radius. It is very subtle as the fourth angle blends into the radius. This radius is different on the short turn side than it is on the long turn side. The short turn, the long turn and even the sides: they're all a little different–another advantage of CNC machining. If it's a cast port or an as-cast seat insert, you are driven to the same geometry all the way around.

"The exhaust side is very similar," Gerdeman continued. *"Again, there's a unique area schedule. We spent a lot of time on the exhaust fine tuning that. Also, the exhaust has even more of a pronounced difference between the short turn and the long turn sides.*



The exhaust port–the parts of the chamber just below it have the same type of turn radii and transition areas. You can see why LS7s exhaust ports flow really well. Image: Author.

"Area past the guide is critical, but we still had to keep as-cast material around the valve guide for temperature control to avoid durability issues. In some (racing) *cylinder heads, almost all the as-cast aluminum is gone–racers will feather the aluminum material out almost to a knife-edge adjacent to the guide. We've got to still meet our durability targets, so we can't machine it all away. The valve guides are installed in the head prior to the CNC machining. We have an as-cast port shape which provides roughly 1.5-millimeters of finish stock* (left for the CNC work) *everywhere. When they do the CNC machining, they have to come up and clear that valve guide insert. The CNC program can only get so close, so you're going to see as-cast material* (at the end of the guides) *just because of that.*

"It's really designing the entire chamber as a complete system. It's the maximum unshrouding on the sides where the valves come closest to the bore wall. The key is developing blends and transitions so the airflow across the valve seat stays attached to the shape of the chamber and ports as much as possible. In the case of the inlet, air flow comes across a very open area towards the exhaust side and you want it to stay attached to that wall. Any time you start getting detachment of the air flow, whether it's the ports or the chamber, you get

turbulence which drives your effective area down and you start losing air flow. It's like you're making the port or the chamber smaller.

"The four angles on the intake seat really help, even with high lift flow. The more angles you can cut, the more of a perfect radius you end up with. At low lift, a lot of flow on the inlet side is going to come from the unshrouding of the valve and how far it is from the bore. Then, at the higher lifts, it's how well you can keep that air flow attached to the walls and reduce turbulence.

"We worked the backside of the intake valve and the geometry transitions across the seat angles to valve stem. We, also, tried various valve margin heights and settled on what we have there as best for air flow."

Near the end of the LS7 cylinder head development, Gerdeman and his team looked beyond just air flow. They studied how the air and fuel mixed in the chamber as it flowed across the valve seat and as it continued to mix once the intake valve closed and the compression stroke began. They, also, looked at the homogeneity of the mix near the spark plug and, once the ignition kernel developed, how the flame front propagated across the combustion chamber.

This is a view from the port entry, down the intake port towards the valve guide. Note how the guide is streamlined but not knife-edged or removed all together like is done with some racing heads. Image: Author.

Same type of view down the exhaust port. Image: Author.

Some of this research was done at Chapman Racing with a "wet flow bench" which mixes colored liquid with air flow inside a transparent bore to simulate a mix of fuel and air flowing into the cylinder. The see-through bore and the color allowed the cylinder head engineers to observe the homogeneity of the air-fuel mix as it came past the intake valve seat and flowed across the chamber then into the bore as the piston moved down in the cylinder. The LS7's cylinder volume was huge and getting a homogenous a mix as possible was a challenge but an absolute necessity if the engine was going to meet fuel economy and exhaust emissions targets.

The engineers' observations at Chapman racing encouraged them to experiment with a aerodynamic device in the roof of the intake port between the valve guide and the long turn radius. Described by Dennis Gerdeman as a "wing," it looks more like a ridge or a deflector. It is intended to impart a specific directional swirl to the flow as it enters the cylinder bore while the piston moves down on the intake stroke.

The motion imparted by this deflector is complex. It's somewhat like swirl, towards the spark plug, but it, also, generates downward spiraling motion towards the centerline of the bore. In the end, this one feature of the LS7 intake port did much to enhance the homogeneity of the air-fuel mix in the engine's large cylinder volume and contributed to the engine's high combustion efficiency.

The deflector which was added to the intake port just above the valve after research on Chapman Racing's web flow bench. What's to bet half the head porters who've tried doing LS7 heads, grind that away? Image Author.

Interestingly, while Chapman's wet flow bench was cutting edge stuff in 2004, it's an anachronism, today. By the late '00s, GM's analysis capabilities had grown tenfold such that CFD, with an enhancement called "rain drop analysis," could simulate wet flow down ports, though valves and seats and into cylinders and do it in a few hours of computer time rather than weeks of work with flow boxes on a wet flow bench.

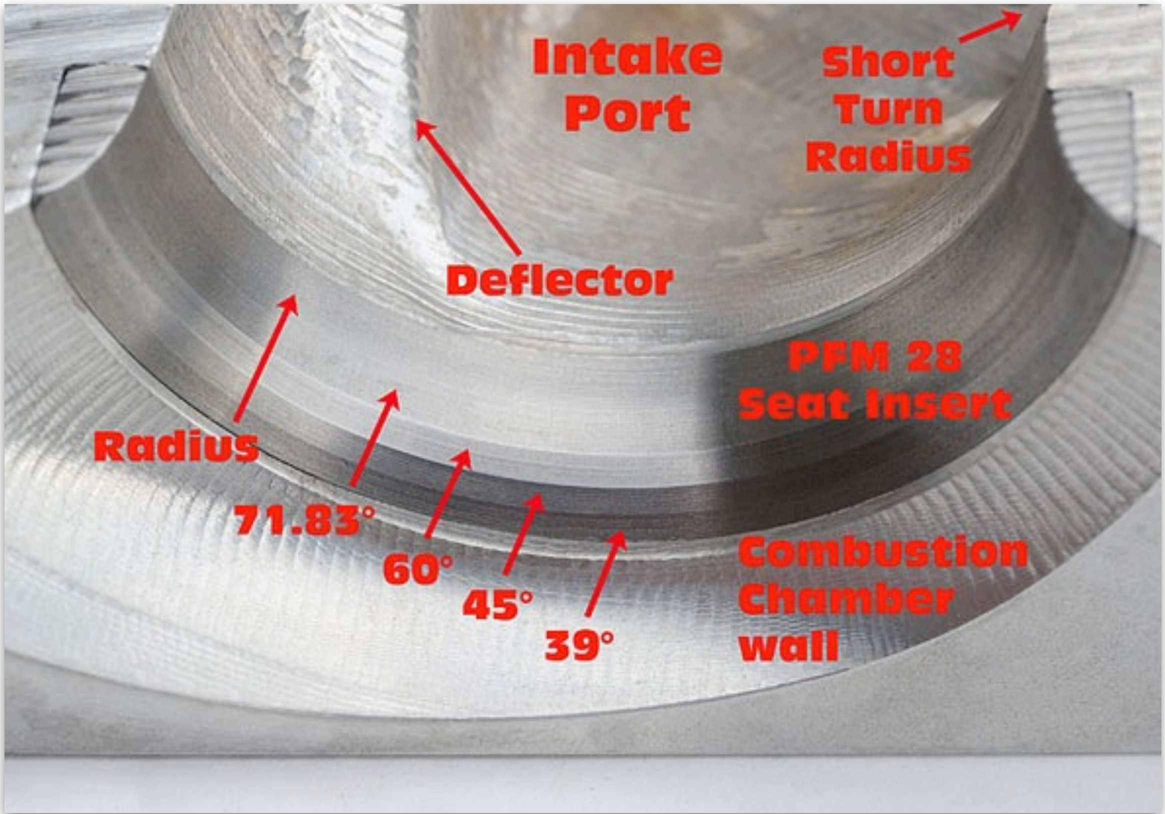
Judy Jin, Design Release Engineer for the LS7 cylinder head, tells us that two different valve seats are used. The intake seat is made of a specific material, PMF 28, which is compatible with the titanium intake valve. The seat couldn't be too hard because, once you wear through the titanium valve's hard-faced coating and into the softer, but very abrasive titanium below, both parts fail in short order. You have to protect that coating, but still have a seat that's hard enough to avoid valve seat recession. Since they had never done titanium intakes before, the cylinder head team consulted with Federal-Mogul, seat insert supplier for other aluminum Gen 3/4 heads, and leveraged F-M's experience with titanium valves for racing. Actually, the first material F-M recommended and GM tested, PMF 28, turned out to be the one which worked.

A copper-infiltrated LS7 exhaust valve seat prior to installation in the head. Image: Author.

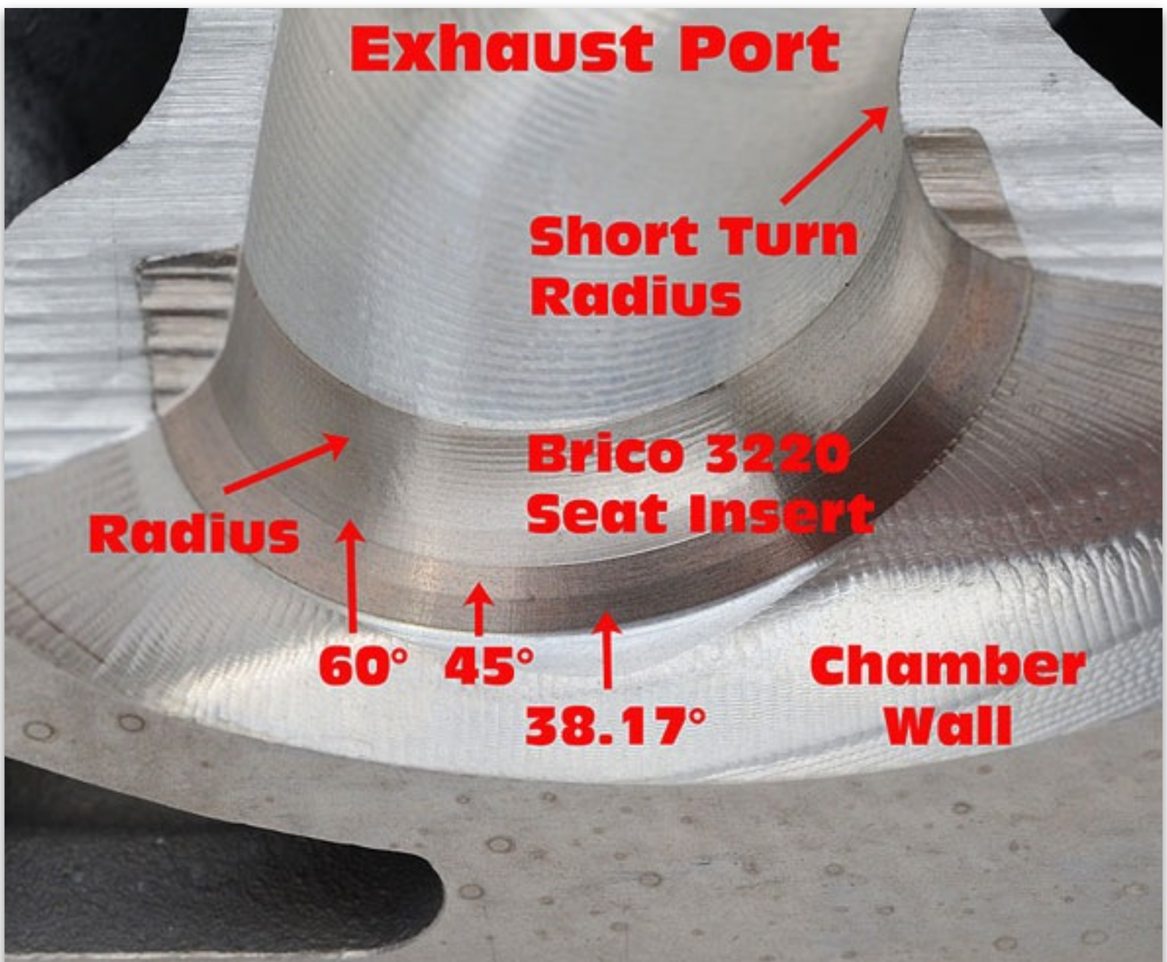
The exhaust valve seat, also supplied by F-M, is Brico 3220 material, used in a variety of GM aluminum heads. The Small-Block does not have coolant flowing completely around the valve seat inserts. Because of the siamesed valve seats, there's no cooling at all in the "valve bridge" between the ports. When things get extra hot, you want rapid transfer of heat away from the valves and seats and into the water jacket. For that reason, the exhausts use "copper-infiltrated" seat inserts. Federal-Mogul, takes a powdered metal blank and puts a copper cap over it. They run it though an oven, the copper melts and wicks into the microscopic voids in the powdered metal. The copper-infiltrated seats improve heat transfer out of the valves, through the seats and into the water jacket by 4-6%.

Ms. Jin added that, because the valve centerlines are so close, the valve seat installation at Linamar is a multi-step process, most of which is done in the five-axis CNC set-up which also machines all other critical features of the head. First, a separate CNC cuts a small "scallop" into each intake seat insert. Next, during the head's main CNC session, the seat pockets are cut such that they overlap slightly, creating the siamesed appearance. The round exhaust seats are installed into the head's exhaust seat pockets and, finally, each intake seat insert is installed with its scallop fitting over the side of the adjacent, exhaust seat insert. This process eliminates any “bi-metal” machining of the pockets which would occur if the exhaust insert was installed into the head, first. This is the preferred process because the seat pocket tooling produces the highest quality results if it cuts only aluminum.

Judy Jin, a Small-Block cylinder head engineer, led the discussion about LS7 valve seats and valve seat and face angles. The finishing of the valve faces and seats–four angles on the seats and two or three on the faces–is more sophisticated than most production engines and more typical of a racing head. Image: Author.



This image details the space near the intake valve seat. The LS7 intake seat and transition areas are a very sophisticated system intended for one goal: maximum air flow. Image: Author.



The surfaces in the vicinity of the exhaust valve seat are designed with optimal exhaust gas flow in mind.

After the seats are installed, they are machined to the proper angles. On the all-important intake, starting at the combustion chamber roof, the seat angles are: 39°, 45°, 60° and 71.83° followed by a radius. The exhaust seats are cut with 38.17°, 45° and 76° angles, then a radius. In both cases, the valve face seats on the 45° portion. Each seat and radius are machined by one milling tool in a single plunge movement of the 5-axis CNC's table.

The internal structure and the cooling jackets of the LS7 head are much the same as that of other Gen 3/4 heads going back to the LS1. *"Nothing special in the cooling jackets compared to other Gen 3/4s. You try to get the coolant as close as you can everywhere else on the back side of the chamber, "*Dennis Gerdeman told us, *"but you still have to have very large fillets to handle the high combustion pressures. It's structural integrity vs. cooling, so you have to strike a balance between the two. Nothing different though than the other Gen heads. They all have that same balance."*

Even seemingly minor features can be of utmost importance, such as the small horizontal pad in each combustion chamber next to the spark plug. *"Those are 'locators,'"* Dennis told us. *"When the casting is first set-up for the initial machining operation, they need locators. Each chamber has one because you want them all to be common* (have the same displacement), *but we use the pads in two end chambers and a horizontal pad on the intake side of the deck face as the initial locating points for the machining operations. We don't machine them away because, if we ever have an issue identified later on and believe it's a casting issue, we want to be able to go back to the cast locators and take CMM (coordinate measuring machine) measurements."*

Linamar also assembled the heads then shipped them to the PBC in Wixom. When you see one of these heads before it goes on an engine, you'll marvel at its appearance and feel. Its huge, glittering, CNC'ed ports, gleaming titanium intake and stainless steel exhaust valves and the shimmering, silvery combustion chamber walls are sweet eye candy for we engine guys.

"*The appearance of the CNC work is a balance between cycle time and surface finish,"* Dennis Gerdeman commented. *"Ideally, you'd want to make it smoother but when it really came down to it, the gains were marginal at best. The cycle time already is so long. When you consider you have to do eight ports and four chambers and all the seat machining, it's a lot of time in the machine. Each head takes about two hours."*

Left to right: the Author, Performance Build Center Engine Assembler, Mike Priest and GM Powertrain Communications Manager, Tom Read. We all agree. Each of us should have one of these heads on display in our living rooms because they are so pretty.
Image: Mark Kelly/GM Powertrain.

Even the exterior surfaces of the heads have a "premium" look and feel because of the semi-permanent mold process used to cast them. Like the crankshaft, the LS7 head is one of those parts that's just too damn pretty to be run on an engine. All and all, it's a high-tech piece both in performance and appearance. An interesting bottom line on the LS7 head comes when one compares it's airflow numbers with those of the head on the Camaro SS's LS3. In a straight-across comparison, the LS7 head flows about 20% more air, a huge improvement.

We asked Dennis Gerdeman, if he could revisit the LS7 head design, today, what he'd do differently. *"From an analysis standpoint, our tools have improved significantly over what we had back when we developed this cylinder head," Gerdeman replied. "I would probably play with valve sizes, again, and locations within the chamber just to see if there's a little more we could squeak out of this from an airflow perspective. I don't think it would change significantly, but we may have ended up with a little larger exhaust–maybe a slightly smaller intake. It may even have led to a slightly different intake port shape with a different area schedule.*

"Those are probably the two things I'd like to revisit: the intake port and small tweaks to the valve sizes or centers, because with the tools we have today, you can accomplish that in hours instead of weeks. Before you had to make a CAD model, send it to a job shop and have them cut you a flow box then, flow it on the bench and try again. Now we can do it with analysis in a fraction of the time."

The LS7 head gasket is standard faire for today's high-performance engines, a 3-layer, multilevel-steel (MLS) design.

Dennis and I ended our LS7 cylinder head discussion talking about how the engine's mystique comes from the power it makes without boost and its drivability. *"When you think what you can pull out of a Small-Block naturally-aspirated–making that 500-hp–it's pretty amazing,"* was his final observation.

Cam and Valve Gear

LS7's valve train was yet another field on which GM Powertrain moved the technology ball forward for another first down. Not only does the LS7 have a hydraulic lifter valve train which runs to 7100 RPM, 500-RPM higher than that of the C5 Z06 engine and beyond the capability of even the solid lifter engines of the bygone Musclecar Era, but it has a huge, 2.20-in intake valve–the largest ever in a production GM V8, besting the 2.19 intake used in Camaro high-performance 396 and 427 Big-Blocks of late-'60s. Valve lifts are an astonishing .593-in. and .589-in. for intake and exhaust, a significant leap past the '02-'04 LS6 camshaft, previously GM's most aggressive. Duration at .050-in. lift jumped 6° to 210° on the intakes and a whopping 20° to 230° on the exhausts. While lift and duration are often cited in comparisons of cams, a more telling measurement is lift area which, when you graph the valve lift, is the area below the curve. With the LS7 cam,

compared to LS6, lift area rose 12% on the intakes and 15% on the exhaust, both significant increases.

Like all roller cams, the LS7 unit is machined from a steel billet. The lifters come in fours in plastic lifter guides. Image: Author.

"The design philosophy on that cam is similar to the LS6, the ramp designs are very aggressive," Jim Hicks, who lead the LS7's valvetrain development. *"We were limited in what we could do with camshaft because you've got a cam bearing*

Camshaft Profile, Exhaust Comparison
(All lift figures are valve lift)

year RPO	int. lift	int. dur. at .004	int. dur. at .050	int. open at .004	in. close at .004	in. open at .050	in. close at .050	int. CL	int. area	int. area increase
MY01 LS6	13.34 mm .525 in	270°	204°	9° BTDC	81° ABDC	18 ATDC	42 ABDC	118° ATDC	1862.9 mm/deg.	-4%
MY02 LS6	14.01 mm .551 in	267°	204°	7° BTDC	80° ABDC	19° ATDC	43 ABDC	120° ATDC	1936.9 mm/deg.	0
MY05 LS2	13.34 mm .525 in	270°	204°	9° BTDC	81° ABDC	18° ATDC	42 ABDC	118° ATDC	1862.9 mm/deg.	-4%
MY06 LS7	15.06 mm .593 in	276°	210°	8° BTDC	88° ABDC	18° ATDC	48° ABDC	122° ATDC	2166.4 mm/deg.	12%

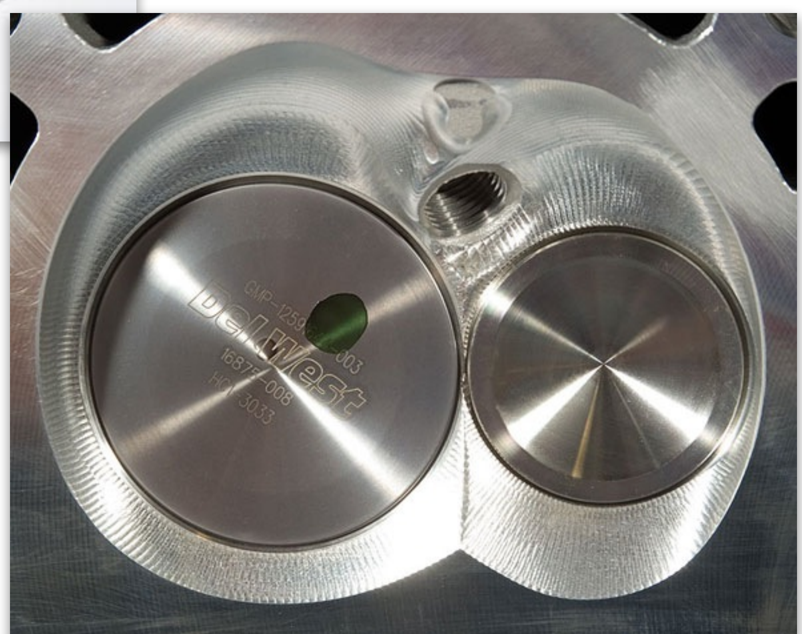
Camshaft Profile, Exhaust Comparison
(All lift figures are valve lift)

year RPO	exh. lift	exh. dur. at. .004	exh. dur. .050	ex. open .004	ex. close .004	ex. open .050	ex. close .050	exh. CL	exh. area	ex. area change
MY01 LS6	13.33 mm .525 in	275°	211°	65° BBDC	30° ATDC	37 BBDC	6 BTDC	114° BTDC	1914.6 mm/deg.	-8%
MY02 LS6	13.91 mm .547 in	282°	218°	69° BBDC	33° ATDC	42 BBDC	4 BTDC	115° BTDC	2046.6 mm/deg.	0
MY05 LS2	13.33 mm .525 in	275°	211°	65° BBDC	30° ATDC	37 BBDC	6 BTDC	114° BTDC	1914.6 mm/deg.	-8%
MY06 LS7	14.95 mm .589 in	296°	230°	81° BBDC	35° ATDC	53 BBDC	3 BTDC	119° BTDC	2359.4 mm/deg.	15%

diameter and the nose can only go so high. We had to drop the base circle down to a smaller radius so the nose radius could be larger. In addition to that, we went to the higher rocker ratio and that gets us to the (valve) *lift we needed. Then, we tried to make everything as light and as stiff as possible.*

The higher rev limit, a gargantuan intake valve, more aggressive valve train velocities and a big increase in lift area required some trick valvetrain features previously reserved for racing applications. The first task was to reduce valvetrain mass. Inspired by Katech's C5-R 427s using a titanium intake valve, Hicks and the LS7 valvetrain engineers decided on a Ti intake and a hollow-stem exhaust valve as two ways to get the mass down. Despite a valve head which is 22% larger, the ti intake weighs 19-grams less–a 21% reduction–than the smaller diameter and shorter stemmed, LS2 intake valve. The ti intake valve, supplied by long-time titanium valve manufacturer, Del West Engineering, was the World's first application of the super-light metal in a production automotive valvetrain.

Back in the day, people thought any high-RPM application needed a dual-row, timing chain, but in recent years, GM has developed some pretty stout single row, true rolling chains. Evidence of that is the LS7's timing set. Still not convinced? The Katech chain set, as used in the C5-R 427s, is, also, single row. Image: Author.



This is what a PBC assembler sees during LS7 assembly–a view only an engine wonk can love, if you ask us. You can't miss the humongous Del West titanium intake valve. A small chamber, siamesed seats and minimum valve shrouding means the valves almost touch each other. The curves of the chamber walls and roof along with the CNC machining is sweet eye candy, too.

*"We started with a hollow-stem, steel valve, kinda like the LS6, with a very thin head, "*Hicks said*. "We reached a point where the power the engine was making was flexing the valve head enough that we had problems with the valve heads cracking. Combustion pressure causes the valve head to flex. Imagine pushing on the top of a tin can, moving it in-and-out. If the section* (thickness of the valve head) *gets too thin relative to the amount of pressure in the chamber, you'll get this flexing and, eventually, a pie-shaped section breaks off. We found this with test engines. At the time, we were, also, doing some work with Katech. They were using a lot of our parts in the World Challenge, the first year of the Cadillac CTS-V program and they failed some of our valves, as well.*

"We had to make a change and going to a thicker-head steel valve wasn't an option," Hicks continued, *"because we wanted a 7000 RPM red line. We looked at a couple of alternatives–some really kind of radical. ultra-light steel valves. I tested a few of those and they failed miserably. Then we said, 'Alright. We gotta do what ever it takes.' We went to the titanium for mass and strength because, with the titanium head you could go to a flat, almost no cup on the combustion face–make a nice, thick section through there–and not take a big mass penalty, so you end up with a lighter valve which is also strong.* (The LS7 intake) *was the first production application for Del West and the largest diameter titanium valve in any production engine."*

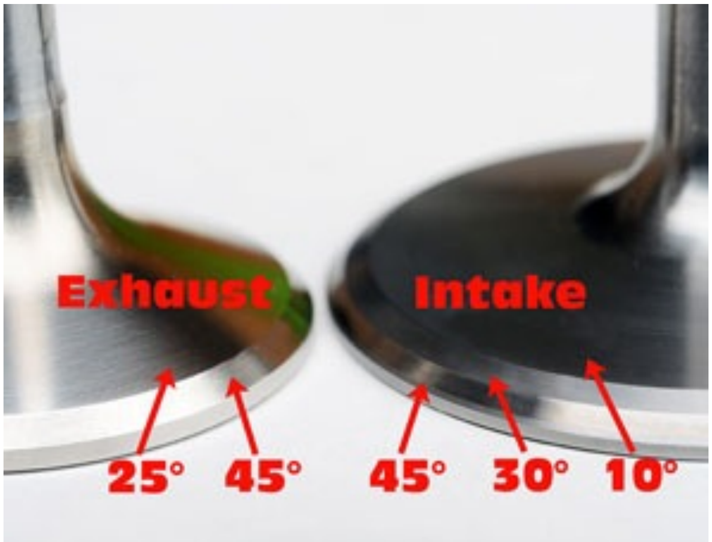
Jim Hicks, who was the lead engineer for the LS7 valvetrain explained that the cam's base circle was made smaller so the effective lobe lift would increase. That along with 1.8:1 rockers resulted in the amazing (for a production cam) valve lift. Image: Author.

The same protective, CrN coating used on the connecting rods is on the intake valves but getting that coating just right was a tough task for Jim Hicks and the engineers working on the LS7 valvetrain. One of the issues they had to address was a "Ti dust wear" problem, similar in nature to what afflicted the connecting rod development. When the CrN coating wasn't right, it would fail and highly-abrasive Ti dust would develop between the valve stem and guide causing rapid guide wear.

"Developing the stem coating which was going to work well with our production-style, PM guides was another challenge. Most racers use bronze guides or some other type of aftermarket guide which is cost-prohibitive. A moly-sprayed stem, which is typically used a lot on titanium valves (for racing)*, is very expensive. We wanted to come up with an alternative, so we worked on a chrome-nitride, vapor deposition coating. It took a little development, but it worked out really well for us. It was more cost-effective and just as good or better than the moly spray. There's some tricks to that process and we worked with Del West in developing them. The parts need to be very, very clean. The right processing steps need to be used. The coating thickness is very important and needs to be maintained to a tight tolerance. I think Del West is using it now for some of their aftermarket parts, too."*

Racy stuff–titanium intake and hollow stem exhaust valve. The stems are gun drilled, filled with sodium, the SilChrome head is welded in place, then the valve is machined.

The intake valve faces are machined at 45°, 30° and 10° and this is done before the CrN coating is applied because the coating also enhances face durability of titanium valves. Typical of Ti valves, tool steel "lash caps" are used on the ends of the valve stem. *"We actually tried to get away without a lash cap,"* Jim Hicks said, *"and do a welded on, steel 'wafer' which was another development program. We were trying to friction weld it.*



You can do it, but it's not consistent enough and you can have some which come apart. That program was unsuccessful, so we ended up just using a conventional lash cap like they use on racing engines."

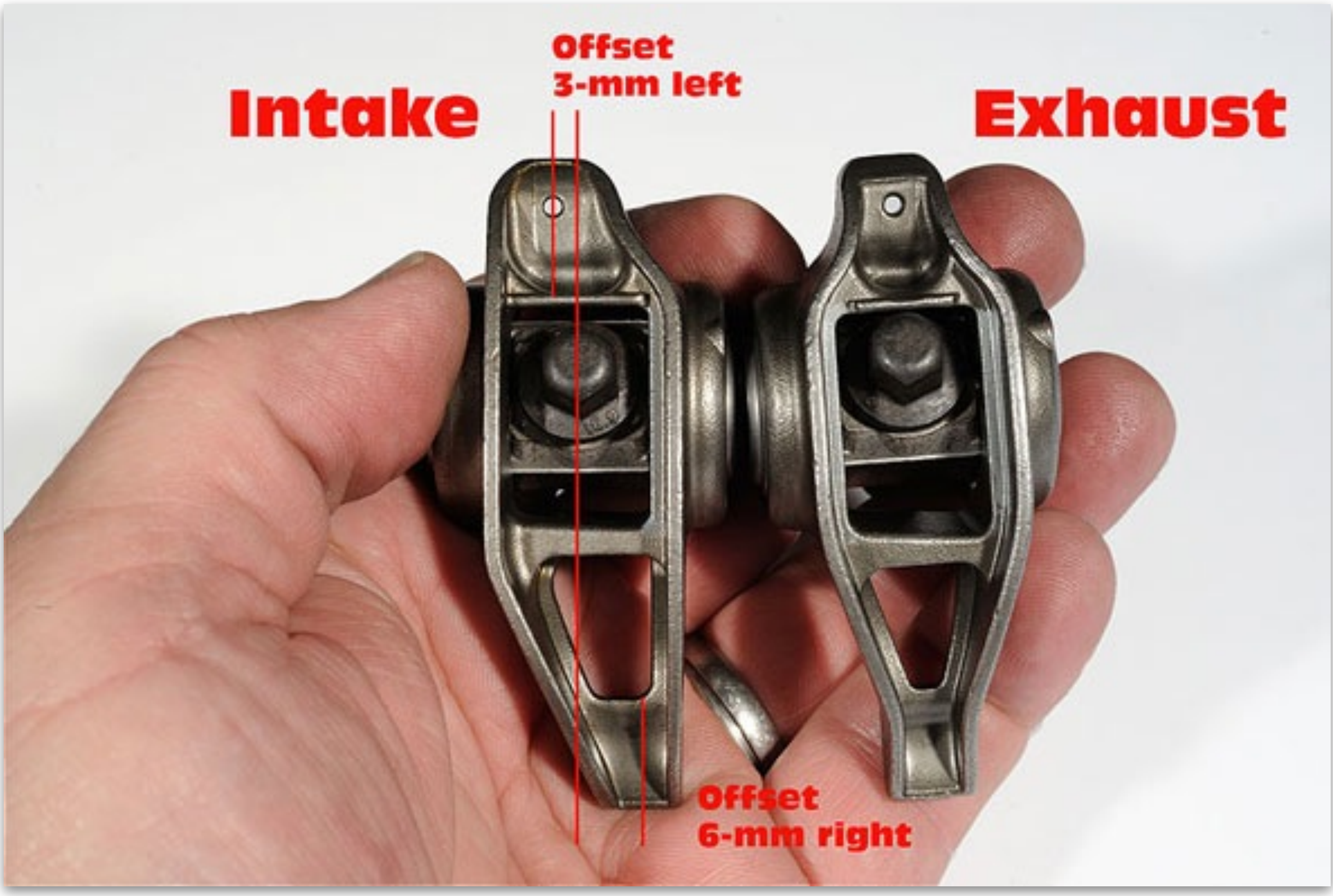
The LS7 uses unique valve springs. They are the typical GM "beehive" design, but they are 0.160-in. taller than all the Gen 3/4 springs GM used previously. The extra height is to accommodate the LS7's greater valve lift. These springs have 16-lbs. more open pressure, too.

Face angles on both valves. On the both there is no specific top cut, rather the part of the finish machining adjacent to the 45° face is done at 10° on the intake and 25° on the exhaust. Image: Author.

The exhaust valves have 2143 stainless steel heads for heat resistance and hollow, sodium-filled, SilChrome stems which are induction-hardened to have a good wear surface for the rocker arms. The benefit of a sodium-filled, hollow stem is mass reduction–about 18%–and, because sodium is an excellent heat transfer fluid, getting heat out of the valve head and into the guide. Exhaust face angles are 45° and 25°. Both valves move in powdered metal guides.

Lash caps go over the tip of the stem of a titanium valve and prevent direct contact between the rocker arm and the stem. Without a lash cap, the stem of the Ti valve and the rocker arm tip would quickly wear. "Beehive" springs have been used on Gen 3/4/5 engines since the Camaro LS1 was introduced in 1998, however, the LS7 uses a specific beehive spring with more height and higher open pressure. Image: GM Powertrain.

To get to the 7100-RPM red line such that the Z06 could go 0 to 60 in first gear required more than just "light-weighting" the valvetrain on the valve side of the rocker. It had to be as stiff as possible on the pushrod side. The pushrods are steel but, compared to other Small-Block pushrods, are larger in diameter, have more wall thickness, and to accommodate the taller head, greater length. Obviously, all that makes for a heavier pushrod, but, from a performance perspective, there is a greater benefit in keeping the pushrod side as stiff as possible, asopposed to as light as possible.



A pair of LS7 rockers showing the offsets of the intake part.

LS7 pushrods are longer and have a ticker wall than do other Small-Block units. From a performance standpoint, the weight of the pushrod is not as important as it's stiffness. Image: Mark Kelly/GM Powertrain.

The LS7 rocker arms are made of investment-cast steel, the same material as other Gen 3/4 rockers. The investment casting process is ideal for production roller rockers because it's strong, allows complex shapes with mass only where its needed and is cost-effective. The intake rockers are a unique design with the pushrod seat offset 3-mm to the left and the valve stem pallet offset 6-mm to the right, allowing the pushrod to be moved over to make room for the revised intake port location and shape. Typically, Gen 3/4 Small-Block rocker arm ratios are 1.7:1, however, the LS7 was the first to use a 1.8:1 rocker ratio. The reason for that extra "tenth-of-a-ratio is the same reason hot-rodders put 1.6 rockers on traditional Small-Blocks: more valve lift!

Lastly, the LS7s valve lifters not only play an important part in the valvetrain's 7100 RPM capability but they are a stalwart design, as well. Other than some occasional small changes in oil metering rates and plunger travel, the part used in a 2013 LS7 is virtually the same part used in 1987, when GM introduced roller hydraulic lifter cams to its engines with the LB9 305 in the old 3rd Gen cars. The same basic part, in service for 26 years speaks volumes about the soundness of the design.

The LS7 hydraulic lifter is durable at 7000 RPM. Amazingly, it's a 26-year old design. It was introduced on the LB9 of 1987 and other than some changes in hydraulics and plunger travel, it's still used today. The trick, Chevy Performance lifter is the same except it uses a lightweight ceramic check ball rather than a steel ball as do OE lifters. Put those in an LS7 with an aftermarket cam and, given the right valve spring pressure, the engine can rev even higher. Image: Mark Kelly/GM Powertrain.

Induction and Computers

The LS7's intake manifold shares some qualities of previous Gen 3/4 intakes. It's made of black Nylon 6, no coolant flows in it and the throttle body and injectors bolt to it. Other than that, it was a new design. *"We had to match to a different port in the cylinder head,"* John Rydzewski told us. *"We tried to get as much flow as possible. The intake runners are sized and tuned for the engine's performance envelope. They're a little bit shorter* (than those of LS1, 2 and 6). *It's a three-piece, molded and vibration-welded assembly with a seal to prevent crosstalk between runners. It uses a 90-mm throttle body, the biggest we make at GM."*

The LS7 intake is a bit different than that used previously. Obvious is its rectangular rather than round ports. Maybe not so obvious is a bit less runner length to better suit the LS7's torque curve. Image: Author.

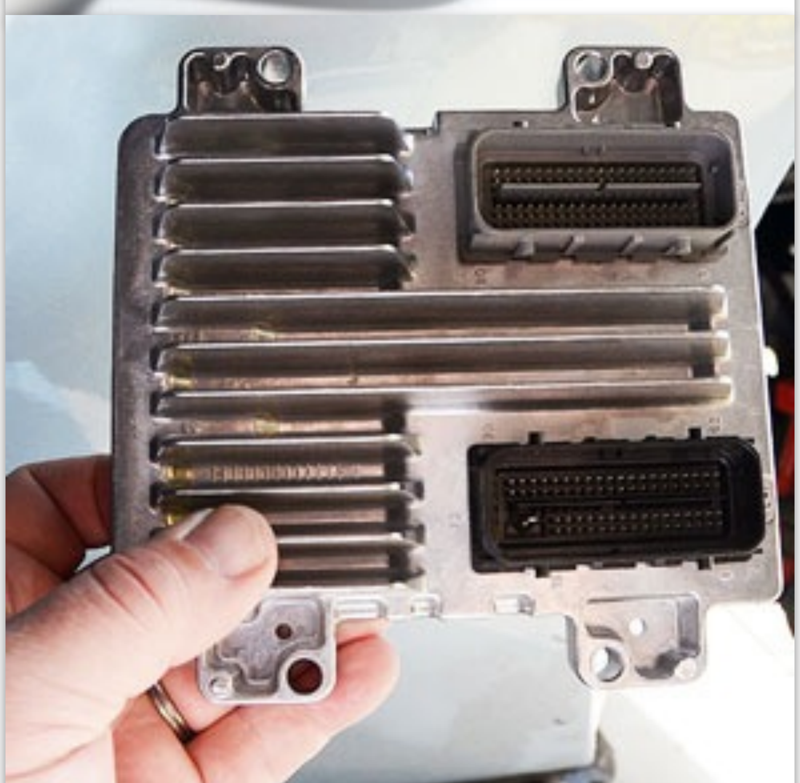
The intake manifold, throttle body, fuel injectors and fuel rail are assembled by a supplier and shipped to the Performance Build Center in Wixom as one piece. The LS7 uses a "4-bar" fuel system which runs at 400-Kpa or 58-psi. The injectors flow 5-gram/second (39.6 lbs/hr.) at 58-psi. They're made by

Bosch have all stainless internals–the norm because of ethanol-blended gasolines–and are a ball-and-socket-with-dispersion-plate design.

The LS7 debuted in 2006 with the GM E38 engine controller which uses a Freescale Power PC chip as its main microprocessor. Interestingly, the Power PC "Reduced Instruction Set Computer " (RISC) chip was originally developed in 1991 by an alliance of Apple, IBM and Motorola (now Freescale) for Macintosh personal computers. Today, Freescale PPC chips are common in all kinds of automotive engine control, chassis control, body control and telematics applications.

The LS7 throttle bore is 90-mm, biggest in GM. Even the LSA's throttle body has only an 87-mm. bore. Image: Author.

There are four slightly different versions of the LS7's E38. The first was used in '06 and '07, the second in '08, the third in '09 and '10 and the final variation for '11-'14. All these different versions increased processor speed, enhanced memory maps and eventually added a second micro processor.



A Z/28s E38 engine controller. Image: Author.

The Final Push

As the LS7 development closed on deadlines forced by GM's intent to debut the engine in the 2006 Z06, the engine's power output had plateaued somewhat below the 500-hp goal set by that pesky senior management.

For a while it looked like 480 was going to be the number," Corvette Chief, Tadge Juechter recalled in a Spring 2012 interview with the CAC*, "but then, they pulled the rabbit out of the hat at the end. This was on the eve of production! I'm talking about the end of '04. We're already ordering material to build our nonsaleable validation vehicles at the plant so, we're holding up* *the presses at that point, trying to decide–'Ok, guys, what is the horsepower?' and remember, it was, also, the first engine in the auto industry certified to* (the then-new) *SAE standard. That was another level of rigor that we had to go though. The very last part released for production was the Z06 badge which said '505-hp'. In fact, we were thinking we'd have to go to production without any number on there because we didn't know what it was going to be."*

In this final six-months the key advance which put the LS7 "over the top" was a late modification to the LS7's cylinder case. As we said in the first part of this article, early in the development program, unlike its predecessor LS6, the LS7 block had no main web windows for bay-to-bay breathing. The CAC's discussions with former LS7 boss (and current Chief Engineer for V6 engines), Dave Muscaro, revealed how his team found about another 10-hp by developing block windows which did not compromise strength. *"We were pushing 490-495hp for about the last 6 months of development,"* Muscaro told us. *"The one area we knew still had promise was in our bottom-end breathing. If we could improve bay-to-bay breathing, we could reduce the work required by the bottom side of the pistons to move air around. The Corvette is extremely challenging in this area due to the engine's low position in the car. The ground clearance requirements disallow ample room in the oil pan to aid in lower end breathing which puts additional challenges on finding ways to reduce the* (power loss in) *lower end pumping work.*

"So (while other areas of the LS7 development moved ahead) *we continued to look for ways to improve breathing by way of the engine block itself. The LS6 utilized openings in the main bearing webs to help its bottom end breathing but, up to this point, we had not been able to identify similar LS7 engine block changes that could withstand the additional loads put on it by the power levels being achieved. After numerous design iterations run through structural analysis computer modeling, we came up with engine block design revisions* (one was the change in hone over-travel radii discussed earlier) *that incorporated bay-to-bay breathing portals–known as hone over-travel windows–that met all structural durability requirements.*

A computer rendering of the window and hone over-travel machining which was a big player in GM's final effort in the ruthless pursuit of power which resulted in 505 horses: Drawing: John Rydzewski/GM Powertrain.

"That final look in this area", Muscaro continued, *"gave us a design which met the structural requirements and one which we knew would also improve our lower end breathing and therefore increase the engine's power output. Blocks were ordered to this design revision and we began testing them. In those tests, as predicted, we saw an immediate improvement in our bottom end breathing as demonstrated by the engine's power level increase of 10-15 hp. We proved the revision's durability and made the new block part of our production package."*

That last block change and a few other little tweaks saw final development LS7s meet the 500-hp goal senior management set almost two years before. The engine was revealed to media in January 2005 at the Detroit Auto Show. GM had decided the LS7 would be certified using the Society of Automotive Engineers (SAE) then-new Standard J2723 "witness test". The SAE Standard to which the dyno test data is corrected had not changed–it was still J1349. What's different is: for a manufacturer to say an engine is "SAE-certified" requires that manufacturer test the engine in an ISO9000/9002-approved dynamometer testing facility and that the testing be witnessed by persons approved by the SAE. On 14 March, 2005, the J2723 testing was done and the engine produced 505 SAE net horsepower at 6300-RPM and 470 SAE net pound/feet torque at 4800-RPM. A little over three weeks later on, 10 April, the LS7 was the first engine to ever have its power output certified to the SAE J2723 standard.

We let Dave Muscaro have the final word on the LS7 development. "*Working in GM like we do, we work as a team. We don't 'win individually' nor do we 'lose' individually. Rather, when we create a successful production engine program, like the LS7, the whole team has reason to celebrate. Was I glad to be a part of it? You bet! I worked with many great engineers and I sweat the details on each part of the engine with each of them. I learned from them how to make each of their parts great, and when we put them all together, we had the LS7. From airflow and CNC'd ports to all the lube challenges high g-forces bring, to offset rocker arms and titanium valves/rods, to a very large throttle body and a forged crank–we all sweat many little details. So in the end, I consider myself very fortunate to have worked with all these great engineers who helped create the LS7 engine."*

Power For Another Z

Fast forward to summer 2011. As to where the GM marketing and engineering folks got the idea to stick the LS7 in a Camaro and make a killer track car? Chevrolet hasn't offered much about the Z/28's origins and development, perhaps because, when the car was introduced in New York, the final stages of that, along with SAE and government certification testing, were not complete.

We'll guess that, about the time Camaro engineers were in the middle of developing the 1LE package for 2013 SSes, they, also, watched as Ford upped the ante with the 444-hp, light-weight, Mustang BOSS 302 Laguna Seca. There might have even been a few internal emails which could have said something like: "Oh s&%t. We didn't go far enough with 1LE!"

Ford used Monterey Historic Automobile Races in 2011 as the backdrop for its media preview for the BOSS 302LS. Image: Ford NA Communications

Part of the solution, of course, was the Corvette Z06's LS7, which made Ford's supercharged five-liter seem kind of puny. It had 505-hp, weighed less than the supercharged LSA, was the same size as the existing LS3 and, best of all, since the C6 Corvette would cease production in February of 2013, leaving the PBC with some unused capacity, a modest quantity of the engines could be available. All that would be necessary to get the LS7 into a Camaro was a few unique induction and exhaust parts along with calibration, validation and certification. The Camaro structure had already proven capable of supporting 556-lbs/ft. torque, but the LS7 only made 470. Through the ZL1 and 1LE projects, a lot of pretty stout driveline and suspension parts already existed.

The BOSS's engine is this 444-hp, 302 cuin., DOHS, supercharged V8. News Flash: this engine's specific output is 1.47, but the big dog of supercharged pony car engines is Chevy's LSA, with a specific output of 1.53.

It didn't take a rocket scientist to see a potential match made in heaven. We'll guess that sometime in late-2011 or early-2012, at the Camaro Development Team and at John Rydzewski's Passenger Car Small-Block group over at Powertrain, a project got underway to adapt the LS7 for use in a Camaro lighter than a 1LE. The two big development changes for a Z/28 427 came with the air filter assembly and the exhaust manifolds. Other changes were relocating the dry sump tank from the right rear to the front of the engine and changes to the LS7's accessory drive necessary to make a non-A/C version of the engine available.

Because of the limited space under a Camaro's hood, the LS7 air filter assembly and air duct had to be a unique design. Obviously, the 90° bend adds restriction compared to the C6 Vette design, so the Z/28 uses a conical, oil-cotton air filter element to gain back some of that lost airflow. Image: GM Powertrain.

Because of the limited space under the hood of a Camaro, the original air filter assembly developed for the Z06 wouldn't work so, the Z/28 LS7 got a unique air box. Like that on all Camaros, it's on the driver side, behind the radiator core support and connects to the throttle body by an air duct with a 90° elbow. The mass air flow sensor is between the elbow and the filter mount. To restore some of the airflow lost with the duct, there is an open element, oiled-cotton-gauze air filter typical of aftermarket Camaro air boxes.

The Camaro LS7 exhaust manifolds. Again, limited underhood space forced a somewhat more restrictive design than used on a Corvette so, GM went with a stainless steel, Tri-Y configuration which tucks in close to the engine and exits near the rear of the block, rather than the C6 Z06/ZR1 unit, which is a shorty header with a center exit. Image: GM Powertrain.

The exhaust manifolds are different, too, because of the same underhood packaging constraints. Rather than the Z06's shorty header, the Camaro engine uses a fabricated, stainless steel "Tri-Y" manifold. The four primary pipes are grouped, according to the engine's firing order, into two pipes and then into a collector just above the outlet flange which is located at the rear of the engine. While the Z/28's exhaust manifolds and its exhaust system are somewhat more restrictive than what was used on the Corvette Z06, the performance hit is only about 1%–a minor issue. Heck, you might gain that back simply by going to ester-based, synthetic lubricants in the engine, transmission and rear axle.

About a year later, word of this new variation of the LS7 began to leak out, first, with the 2014 Camaro VIN Card surfacing and, then, after New Year's, sparse chatter around Camaro Nation hinting of a secret development project, known as "The HP". That veil of secrecy was lifted at the New York Show with the introduction of the Z/28

Durability

Every engine manufacturer does reliability and durability testing. "Reliability" is the quality of being consistent in performance, i.e.:, not failing. "Durability" is the quality of being able to withstand wear, i.e.: being reliable for a long period of time in service.

John Rydzewski and Jim Hicks touched on the reliability of individual parts such as titanium rods and intake valves during the discussions we had with them. Once the entire engine reaches a near-production form, its durability testing begins. Back in the old days–say the late-'80s–some of the testing was on the dynamometer, but a lot of it was in cars on test tracks. In recent years, with advances in dynamometer technology and with the application of computer controls, more of the testing is done in dyno cells fitted with equipment which can alter the engine's attitude to simulate various acceleration, corning and braking loads. Even with all this advanced dyno testing ability, GM still track tests engines in cars as a final validation of the engine's performance, reliability and durability.

During the cylinder head discussion, Dennis Gerdeman, talked about durability testing.

Would premium ester-based lubricants gain back the 5-hp loss? Image: Red Line Synthetic Oil Corporation.

"We had a durability schedule that we were running," Gerdeman said. *"They call it the 24-hour track schedule. It was kind of our benchmark as we were going through the final validation of the hardware, from the whole-engine perspective. They ran a lot of these 24-hour track schedules, so we got quick overnight results. It was a very strenuous test. They did run the cars on the track, but most of* (the durability testing) *was on engine dynos. We could validate any corrections we were making to any of the hardware components–not necessarily to the cylinder head, but to valve train related pieces and all the other mechanicals–pistons, cams and so forth."*

Another standard GM Powertrain torture test to which the LS7 was subjected is a 300-hour dyno test at wide-open throttle with the load varied such that the engine goes back and forth between peak torque (4800-RPM) and peak power (6300-RPM) in 125 RPM increments. The LS7 also was brutalized with a "thermal shock test" which runs engine coolant ranging between -40°F (burr) to about 250°F (ouch!) through the engine while it's running.

LS7 at a Glance

- Displacement: 7008-cc/427.484-cuin.
- Bore center distance: 111.76-mm/4.4-in.
- Bore x Stroke: 104.775 x 101.6-mm/4.125 x 4-in.
- Compression ratio: 11.0:1
- Firing order: 1-8-7-2-6-5-4-3
- Power: 505-hp@6300 rpm SAE net
- Torque: 470-lbs/ft@4800 rpm SAE net
- Engine weight: 206-Kg/454-lbs.
- Fuel delivery: sequential port fuel injection
- Fuel required: premium
- Emissions controls: 3-way catalytic converters, positive crankcase ventilation

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