BUILDING THE CHEVY LS ENGINE

Rebuilding and Performance Modifications

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INTRODUCTION

The LS family of GM engines represents substantial design changes and performance enhancements as compared to the early generations of what I'll generically refer to as the small-block Chevy engine. The LS2 is based on a 6.0L block and is a great choice for a performance build, able to take advantage of a wide range of performance aftermarket components. In this book, I primarily focus on the LS2 version and offer tips on building a performance-oriented engine to be used as either a replacement engine or as a swap engine in a custom, streetrod or muscle car vehicle. This book deals strictly with the build of the engine and does not deal with in-depth tuning or installation into a vehicle.

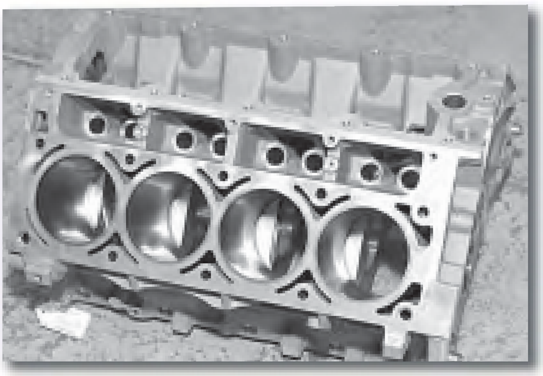
This book is intended to provide parts selection, fitting and assembly of the LS engine from a performance standpoint, primarily referring to the 6.0L LS2 as an example. So while I provide a bit of GM factory OE (original equipment) background and info on a number of OE parts that will be needed, the primary focus is building a performance engine, primarily using aftermarket components.

All LS factory specifications (torque specifications, bearing clearances, etc.) are provided. In order to help illustrate a performance build, I built a specific LS2 as an example, which I refer to as "Project LS2" throughout this book. While I focused on the LS2, all LS engines share essentially the same attributes in terms of clearances and assembly procedures.

The build I mention involves the use of a new LS2 aluminum block, slightly overbored and with a longer stroke as the basis of the build that produce 625.4 hp and 534 ft-lb (at the flywheel) on an engine dyno. We'll feature performance aftermarket components, including crankshaft, connecting rods, pistons, camshaft, lifters, rockers and cylinder heads. Whether you plan to turn your factory LS2 into a little thumper, or start from scratch with a brand-new block, the information provided here should be of assistance.

While all LS platform engines are relatively the same, in Chapter 1, I also discuss the differences and nuances of the LS7, LS3 and LS9 engine versions to serve as a reference for your particular project.

—Mike Mavrigian



LS6 5.7L aluminum block.

Chapter 1

The LS Family of Engines

The Gen III family of GM engines represents the previous generations of GM "small-block" engines. Since the debut of the LS1 in 1997, the LS family has gained substantial momentum in the performance aftermarket. It's time we started taking an in-depth look at the new small block, which is predicted to be as popular as the original Gen I Chevy small block that began production back in 1955. Gen II engines include the LT1/LT4 group, from 1992–1997.

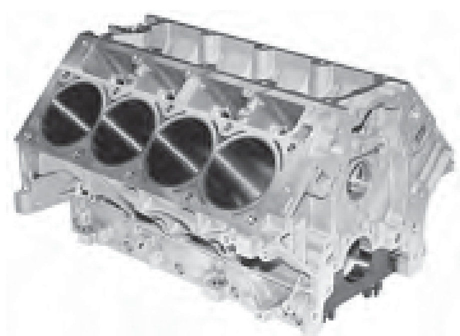
The Gen III engine (LS1, LS6) started from scratch…a clean sheet of paper in terms of design. Aside from cylinder bore spacing, rod journal diameter and lifter diameter, the Gen III and Gen IV has nothing in common with previous Chevy small blocks.

The entire Gen III and Gen IV family of engines includes more than only 5.7 and 6.0L versions. Included are the 4.8L LR4, the 5.3L LM4, 5.7L LSI and LS6, 6.0L LQ4 and 6.0L LQ9, 6.2L LS3 and LS9 and the 7.0L LS7.

Trucks and SUV Gen III engines featured iron blocks with iron heads, and in some applications, iron blocks with aluminum heads. The Escalade is the only SUV application that used an aluminum block and aluminum heads.

In Corvette, Camaro and Firebird applications, all LS1 and LS6 engines featured aluminum blocks with aluminum heads.

While I've provided overall background information on the entire LS series in this introduction, in this book, we'll focus on building the Gen IV LS2 in a performance approach as an example. All assembly techniques apply to all LS variants.



LS2 6.0L aluminum block.

LS Series Engines

LS Series	Displacement	Years	Block/Heads Materials	Bore/Stroke
LS1	5.7L	1997–2004	alum/alum	3.898"/3.622" (99mm/92mm)
LS6	5.7L	1999–2004	alum/alum	3.898"/3.622" (99mm/92mm)
LS2	6.0L	2005–2007	alum/alum	4.000"/3.622" (101.6mm/92mm)
LS3	6.2L	2008	alum/alum	4.065"/3.622" (103.2mm/92mm)
LS7	7.0L	2006–2008+	alum/alum	4.125"/4.000" (104.77mm/101.6mm)
LS9	6.2L	2009+	alum/alum	4.065"/3.622" (103.2mm/92mm)

Block Specs

	LS1	LS6	LS2	LS3	LS7	LS9
Deck Height*	9.240"	9.240"	9.240"	9.240"	9.240"	9.240"
Main Bore	2.751"	2.751"	2.751"	2.751"	2.751"	2.751"
Cam Bore	2.168"	2.168"	2.168"	2.168"	2.168"	2.168"
Location	*4.914"	4.914"	4.914"	4.914"	4.914"	4.914"
Cyl. Bore Spacing	4.400"	4.400"	4.400"	4.400"	4.400"	4.400"
Cyl. Bore Dia.	3.898"	3.898"	4.000"	4.065"	4.125"	4.065"

***Note:** Deck height refers to the distance from the main bore centerline to the top deck surface of the block (where the cylinder head mates the block). Cam bore location refers to the distance from the main bore centerline to the camshaft bore centerline). While most passenger car versions featured an aluminum block, most truck versions featured a cast-iron block, although some trucks used the aluminum block.

Gen III/IV Similarities to Gen I

The similarities of the Gen III to the Gen I engine are:

- 4.400" bore spacing
- 2.10" rod journal diameter
- valvetrain oiling through the pushrods
- 0.842" lifter diameter
- Single-piece rear main seal (similar to late Gen I and Gen II)

Gen III/IV Differences

Here are the primary design changes that represent the basics of the Gen III engine:

- OEM block deck height is 9.240" (up from 9.025")
- Firing order on all LS engines is 1-8-7-2-6-5-4-3 (Gen I/II is 1-8-4-3-6-5-7-2)
- Bank offset changed to 0.9488" (from previous 0.8800")
- Y-skirt block
- Cast aluminum sump
- No distributor provision
- Lighter weight (approx. 430 lb vs. Gen I 531 lb)
- Connecting rod length is 6.098" (vs previous 5.700")
- On-center beam connecting rods (no offset)
- Piston pin diameter is 0.940" (vs previous 0.927")
- Crank thrust has moved from the rear to the number 3 main bearing
- Cam-to-crank centerline distance is 4.914" vs previous 4.521")
- The crankshaft flange has moved 0.40" closer to the rear of the block
- Water temperature is controlled on the intake side of the water pump
- Replicated ports vs mirrored ports

Head Bolts

The LS1 and LS6 feature two different length hex-head cylinder head bolts (11mm x 100mm and 11mm x 155mm), later LS2, LS7, LS3 and L92 engines use only the 11mm x 100mm head bolt length. All LS heads also feature additional 8mm x 1.25 x 45mm "pinch" bolts, which are located at the inboard edge of each cylinder head. All LS heads require ten primary cylinder head bolts, plus five 8mm pinch bolts. All GM OE head bolts are torque-plus-angle and TTY (torque-to-yield) type, which should not be reused and feature OEM thread-locking compound. All head bolts enter blind holes, so none are open to water or oil.

LS1 and LS6 5.7L engines use two different length primary cylinder head bolts (10mm x 100mm and 10mm x 155mm), in addition to 8mm x 45mm inboard pinch bolts. The LS2 and LS7 engines use only the 10mm x 100mm head bolts, along with the 8mm x 45 pinch bolts.

Block and Crank Features

All LS blocks feature a 4.400" bore spacing and a bank angle of 45 degrees. The OE aluminum blocks are cast from 319 aluminum and feature vent holes (cast or drilled) in the main webs.

The LS series of blocks and cranks feature the thrust bearing located at the No. 3 main as compared to the rear-located early Chevy engines. Engine rotation is clockwise.

Note: While the Chevy service manuals may note that the damper bolt should not be reused, this is not because the damper bolt is TTY, because it's not. Rather, they recommend damper bolt replacement only because the underside of the bolt head features an OE friction-reducing contact surface that may be worn away on a damper bolt that has been installed and removed.

All LS series blocks feature individual main caps that are secured with a total of six bolts. This includes four primary (vertical) bolts plus two side bolts that enter through the outside of the block, above the pan rail. Because of this side-bolt design, which offers superior rigidity, main caps cannot be ground to reduce the bore size if align-boring is needed, as this would throw the side bolts out of register. If the main bores must be machined in order to correct a roundness or center issue, oversize-O.D. main bearings would then be required. The LS7 is the only version that came OE with forged billet main caps. All other LS main caps are powdered metal iron.

LS series engines utilize a front-mounted keyed, crank-driven oil pump.

All OEM LS cranks are cast, again with the exception of the LS7 cranks, which are forged.

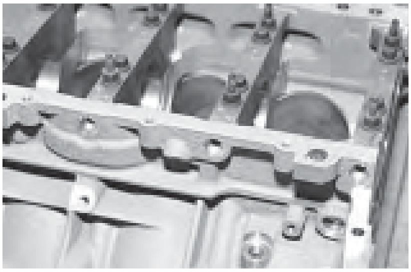
The LS1 and LS6 blocks, though sharing the same dimensions, differ somewhat, with the LS6 block featuring slight changes in main web design for crossover breathing (the LS6 block main webs are slightly skeletonized).

Crankshaft counterweights are cam-ground to clear piston skirts. This cam grinding also makes crank balancing a bit easier.

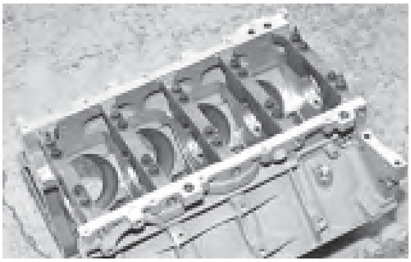
If sleeving is required for a conventional aluminum block, the cylinders are bored to size, then honed to size for each individual liner. Sleeving an LS block is fairly tricky, and LS-specific experience is a must. The new liners are installed at 270 degrees F, and liners are then torqued three times during the cooling process. Liner bottoms must also be notched for rod clearance. The block is then decked, the main caps are installed, and the main bore is bored or honed. The block is then double-vacuum impregnated. The liners are then

Crankshafts (OE Dimensions)

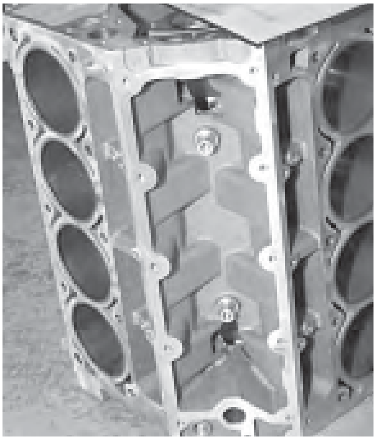
Series	Main Journal	Rod Journal	Stroke
LS1	2.559"	2.100"	3.622"
LS6	2.559"	2.100"	3.622"
LS2	2.559"	2.100"	3.622"
LS3	2.559"	2.100"	3.622"
LS7	2.559"	2.100"	4.000"
LS9	2.559"	2.100"	3.622"



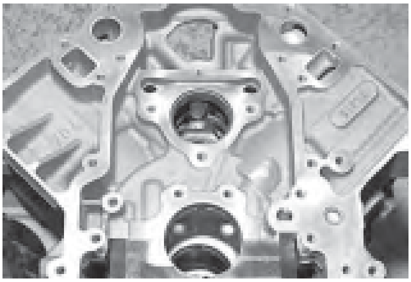
In addition to four vertical main cap bolts, each main cap also features one side-entry cap bolt per side for a total of 6 main cap bolts per cap.



The Gen III and Gen IV LS blocks all feature the crankshaft thrust bearing at the No. 3 main saddle/cap location, unlike early Chevy engines where the thrust bearing was at the rear main location.



The center valley of this LS6 block features two knock sensor bung locations. You don't need this. If you're running an LS2 with computer control, the knock sensor is on the side of the block. If you're running an LS2 with a carburetor, you don't need a knock sensor at all.



The OE displacement number is handily cast into the block at the right front wall (passenger side), adjacent to the timing cover mounting boss. Note the 7.0L mark on this LS7 block.

bored and honed for individual piston fit. My point is that the LS aluminum block sleeves are not installed in the "traditional" method. If re-sleeving is needed, it must be handled only by a shop that is skilled and experienced in LS sleeving.

Katech (an early and current pioneer in the Gen III and Gen IV engines) notes that a GM performance Parts Race Case is available that features 356 aluminum, siamesed bores, steel billet main caps and 7/16" main and head bolt locations. This block may accept 4.180" bores, although 4.125" bores are preferred.

Crankshaft Interchangeability—All LS cranks are created equally…sort of. All feature a 2.65" main journal and 2.100" rod journals, and all use the same rear main seal. All OE cranks are iron, except for the LS7 and LS9, which originally are fitted with forged steel cranks. Also, the LS7 features a 4.00" stroke. Others feature a 3.62" stroke.

Although not a permanent component of the crankshaft, the reluctor wheel tooth count can vary, with either a 24 or 58-tooth count. Early LS engines featured the 24-tooth wheel, while this was phased out as production rolled along in favor of the 58-tooth wheel. It really doesn't matter as long as you match the tooth count with the appropriate ignition controller and crank position sensor. Keep in mind that you can always swap out the reluctor wheel (although it's a precision job and requires special tooling).

Whether you're running injection or a carb, you'll need the reluctor wheel (also called a tone wheel). This multi-toothed steel signal wheel is press fit at the rear of the crankshaft and sends crank location signals to a crankshaft position sensor that mounts to the right rear side of the block. If you buy a new crankshaft, ask if it includes the tone wheel, and if it is included, ask if it's already installed. If the wheel is loose, it must be installed in a very precise manner using a special installation tool. Neither the crank nor the wheel is keyed, so installation requires a very specific procedure. Don't try this at home. Of course, if you're running with a carb and distributor (no electronic timing control), you don't need the tone wheel at all. By the way, the crank shown here is an aftermarket forged unit from Callies.

Also be aware that the crankshaft snout is longer (by about one inch) on both the LS7 and LS9 applications, to accommodate the 2-stage dry sump pump drive. You can adapt an LS7 or LS9 crank to other LS engines, but it's not so easy when trying to use a short-snout crank for a dry sump drive (unless an aftermarket supplier offers a snout extension hub).

Block Valley and Cover Plate

Note: The LS2 block upper valley features a series of tower bosses with oil holes drilled through to the crankcase. In case you wondered what purpose these serve, these drilled towers were part of the original LS casting for engines that used GM's displacement on demand system. On a typical performance street or race application LS2 block, these serve no purpose at all. The special LS2 valley cover underside features O-rings that simply seal

Early LS engines (LS1/LS6) featured 24-tooth reluctor wheels on the crankshafts, while later cranks featured 58-tooth wheels. Either wheel can be used on any crank, providing the timing controller (OE ECU or aftermarket timing controller) is compatible with the wheel tooth count.

All Gen III and IV LS engines feature a front-mounted, crankshaft-driven gerotor style oil pump that is keyed to the crankshaft snout. This is but one example of the improvements that GM designed into the LS engines.

these towers off. Also, you may notice that the LS2 valley cover features a raised boss that's drilled and tapped. This hole accepts the oil pressure sensor. The underside of the cover plate also features a large and lumpy black plastic housing, feeding to a metal tube on the top side of the cover. This is for the PCV system.

Reluctor Wheel Differences

The LS crankshafts feature a toothed reluctor (also called a timing, or tone wheel), used for referencing crankshaft position. The crankshaft position sensor is located on the right rear side of the block; and the reluctor wheel is press-fit onto the rear of the crank.

There are two versions of this reluctor wheel. The factory production LS1 and LS6 features a 24-tooth wheel, while the LS2, LS3, LS9 and LS7 (2006 and newer) features a 58-tooth reluctor wheel. The primary reason that I wanted to mention this is for those folks who plan to use an aftermarket timing control (such as MSD's 6LS), since the control will be designed for either of these toothed timing wheels. Using MSD as the example, their part number 6010 6LS unit is designed to be used with a 24-tooth wheel, while their part number 6012 6LS is intended for use with a 58-tooth wheel. Refer to Chapter 5 in this book for details regarding reluctor wheel service.

Firing Order

All LS series (Gen III and IV) engines feature a firing order of 1-8-7-2-6-5-4-3. This represents four cylinder swaps as compared to the "standard" (Gen I and Gen II) small block/big block Chevy order of 1-8-4-3-6-5-7-2. Keep this in mind when connecting spark plug wires.

The firing order swap is accomplished via the camshaft (the layout of the lobes differs from older generation Chevy cams), so the change in firing order is not simply a matter of spark plug wire switching. The LS uses a unique firing order camshaft, different than earlier generation Chevy firing orders. Only an LS style camshaft may be used in an LS engine.

Fasteners

All OE threaded fasteners in the LS series of engines are metric. There are no inch-format fasteners anywhere in the original-equipment build.

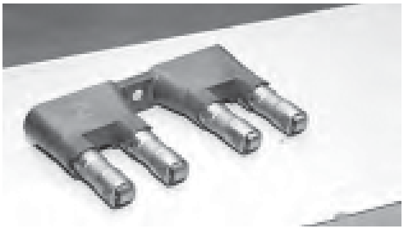
All OE cylinder head bolts, main cap bolts and rod bolts require torque/angle tightening. OE cylinder head bolts are also considered TTY (torque-to-yield) style bolts and should not be reused.

For any high performance build, it is highly recommended to use quality performance aftermarket bolts or studs (ARP is a good example), especially for the main caps and the cylinder heads. ARP bolts or studs, for example, don't require the OEM torque/angle tightening procedure, but allow torque-only tightening (ARP provides the torque specs with their fastener kits).

There are also no NPT threads found anywhere (water jackets, etc.). Instead, straight thread metric plugs are featured that use either O-ring seals or thread sealant.

Lifters

All LS series engines feature roller-tip lifters, and all feature a 0.842" lifter body diameter. Instead of using dogbones or metal finger-trays to locate the roller lifters (to prevent lifter rotation in their bores), special LS-only composite plastic "lifter trays" are used. These trays each hold four lifters. The cylinder block features a large recessed area above each set of four lifters to accept these trays.



All LS roller-tipped lifters must be registered to remain in plane with the cam lobes and must not be allowed to rotate. While other engine designs utilize separate dogbone keys (flats on the side of the lifters are guided inside the dogbone openings to prevent lifter rotation) or pairs of lifters bridged together by pivoting plates, these plastic lifter trays (also called buckets) serve the same purpose while also making it easy to remove or install lifters. In addition, when changing a camshaft, it's not necessary to remove the lifters. With rocker arms relaxed or removed, simply rotate the crank and cam. This will push the lifters up into the trays as they "snap" in place within the trays, holding the lifters up and out of the camshaft's path. Once the new cam is in place, finger pressure on each lifter will pop them loose and onto the lobes.

With the exception of the LS9 forged aluminum pistons, OEM pistons are hypereutectic (cast with high silica content) construction and feature a moly/graphite skirt coating that's screen printed onto the skirts. Hyper pistons are just fine and dandy for OE power levels, but if you plan to boost cylinder pressure, dump 'em and buy a set of aftermarket forged slugs. Regardless of what piston you choose, moly/graphite skirt coating is always a good idea to reduce cylinder wall and skirt scuff during cold starts or in high heat conditions.

Because of the need to clear the crankshaft's reluctor wheel, pistons require additional clearance at the pin boss area at the No. 8 piston. Since all eight pistons need to weigh the same from a balance standpoint, all eight pistons will require this undercut clearance design, especially when adding longer stroke.

During assembly or disassembly, the lifters are held by the trays, allowing a complete set of four lifters and their tray to be installed or removed as a set (lifters and tray together).

Remember: Any roller lifter must not be allowed to rotate within the lifter bore, since the roller tip must remain in plane with the cam lobe. All roller lifter setups feature some method of keeping the lifters in register to prevent lifter body rotation. The LS engines simple use a different (plastic tray) retention approach. Flat surfaces on the lifters align within flat faced pockets in the lifter trays. This flat-to-flat engagement serves to keep lifters in plane with the cam lobes.

Pistons

All OE LS pistons are hypereutectic cast type (alloy with high silica content), except for the LS9 piston, which is a forged aluminum piston (required to handle the higher cylinder pressures associated with supercharging/forced induction). Again, this refers only to original equipment—strong forged aluminum pistons are readily available from aftermarket performance piston makers for any LS application (JE, Diamond, Ross, Probe, CP, etc.).

Be aware that when a reluctor wheel is in place, LS type piston No. 8 requires a narrower profile at the pin bosses in order to clear the crankshaft reluctor wheel (used for picking up crankshaft timing). This is especially important if a stroker crank is being used. This is referred to as a side-relief or side-notch piston. Since No. 8 piston requires this relief, then all eight pistons must be of the same style in order to accommodate piston weight balance matching. Common piston deck height is generally 0.006"–0.008" above deck.

Connecting Rods

All OEM LS connecting rods are constructed of forged powder metal (PM) and feature cracked caps, with the exception of LS7 and LS9 rods, which are made of forged titanium for both strength and reduced weight. Center to center length of most rods is 6.098", while the LS7 rod is 6.067". Also, only LS7 rods will work with LS7 style pistons, due to the design of the piston's inner bracing. Finally, the LS7 rod requires a unique rod bearing (p/n 89017573). If you're building a real go-getter engine from scratch, and especially if you're building a stroker, nix the OE rods and buy some forged steel rods from one of the performance aftermarket sources such as Scat, Oliver, Callies, Lunati, etc. In addition to high strength and durability, quality aftermarket rods are also available in a variety of lengths to accommodate a range of popular stroke combinations.

While the "standard" small-block/big-block Chevy engine featured an offset connecting rod, the LS series features on-center connecting rods (pin bore in relation to big end bore). *Do not* use offset connecting rods in any Gen III engine!

According to Katech, the OE powder metal rods are surprisingly strong, while the primary weak point is the OE 9mm rod bolt. Changing to high performance aftermarket rod bolts (such as those

OEM connecting rods in all LS engines (except LS7 and LS9) are powdered metal, (PM) construction. While surprisingly strong for powdered metal, if you plan to build additional ponies, and especially if your plans include nitrous and/or turbo or supercharger boost, trash the OE rods and buy some high quality forged steel rods.

The OEM connecting rods (except for LS7 and LS9) feature PM construction and are pressure cast in one piece, so in order to create a removable cap, the big end of the rod is actually snapped off, creating an irregular mating surface on both the rod and cap. This is called a "cracked cap" design. While it may sound crude at first, there's a reason: The irregular surfaces created allow the cap to perfectly register onto its rod, which induces no chance of off-center assembly. The downside is that if the big end ever needs to be resized, it theoretically can't be done by traditional methods (where both mating surfaces are ground flat, the cap is installed back onto the rod and then the big end bore is honed back to proper size), although I know some shops that have successfully done this. As a rule, if a cracked-cap PM rod big end is deformed or damaged, the rod should be tossed and replaced. In this photo, I've loosened the rod bolts and pulled the cap slightly away, to make the fractured parting line visible. When fully tightened, the parting line absolutely disappears.

While all other LS engines use powdered metal, cracked cap connecting rods from the factory, the LS7 and LS9 feature forged titanium connecting rods, right from GM.

Whenever servicing cracked cap rods, the caps must be kept with their respective rods. In any high performance application where cracked cap rods will be used, it's highly advisable to use superior aftermarket rod bolts in place of the OE TTY (torque-to-yield) rod bolts.

available from ARP or A1) is recommended. At this point in time, there are plenty of aftermarket forged rods from which to choose, to provide much greater durability than the OE PM rods. The OE rod bolt is 9mm, but Katech and other rod makers offer a 10mm rod bolt to work with their connecting rods. If you plan to build a high performance LS engine, an array of rods are available from aftermarket firms such as Lunati, Scat, Eagle, Crower, etc. These are forged rods that feature machined cap mating surfaces. Only the OE rods feature powdered-metal/cracked cap construction.

Cracked cap rods are so named due to the method in which the big end caps mate to the rod. A powder metal rod is formed as one piece. The rod big end is placed in a vise-clamp fixture at the GM factory and the cap is literally snapped off to create the separate cap. The resulting parting surface is uneven, which may sound terrible, but there's a point to this approach. By snapping the cap off of the rod, the cap now registers perfectly to the rod by virtue of the uneven mating surface. This provides a great cap register. However, this also means that you cannot recondition such a rod by machining the cap, resecuring the cap to the rod and honing a fresh bore. The only safe way to recondition the big end of a cracked cap rod is to overbore the big end by 0.002" and then use 0.002"–oversize OD rod bearings, but only if the rod big end has stretched out of round by less than 0.002". If a cracked cap rod big end is distorted (out of round), the best fix is to replace the rod. However, if you build the engine using forged aftermarket rods, the rods may easily be reconditioned in the conventional manner at a later date of needed.

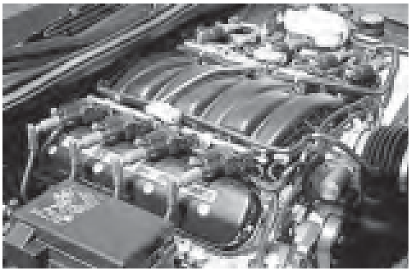
LS2 Interchangeability/Similarities

Note: When using an OE LS2 block, be aware…

- LS2 blocks feature the knock sensor on the side of the block, while LS1 and LS6 blocks feature the knock sensor in the lifter valley.
- The LS2 cam sensor has been moved to the

Cylinder Overboring (LS1/LS6/LS2)

Version	Displacement	Bore Dia.	Max Overbore
LS1	5.7L (345 cid)	3.898"	3.930"
LS6	5.7L (345 cid)	3.898"	3.930"
LS2	6.0L (364 cid)	4.000"	4.032"
LS3	6.2L () cid)	4.065"	4.097"
LS9	6.2L () cid)	4.065"	4.097"
LS7	7.0L () cid)	4.125"	4.157"



All LS engines require the use of eight individual-cylinder coil packs. While these coils are traditionally mounted atop the valve covers, you can relocate them (with extended wires) to clean up the engine. The only version that doesn't need the eight coil packs is an LS engine that has been modified to run a carburetor and a gear-driven distributor.

timing cover location, which requires the use of the LS2 cam gear
• LS2 knock sensors are dedicated for LS2 and are not interchangeable with LS1/LS6 knock sensors.
• An LS1 engine management computer will control an LS2 engine.
• LS2 blocks feature an original 4.00" bore, while LS1/LS6 blocks feature a 3.898" bore.
• Crankshafts, connecting rods, pistons and cylinder heads are interchangeable between LS2 and LS1/LS6 engines.
• LS2 cylinder heads are made from the same raw castings as LS6 heads.

LS Block Cylinder Boring

The LS6 will safely overbore to the same diameter as the LS1, but the LS6 features a sturdier engine case and is a better choice for overboring than the LS1. The larger-displacement LS2 is a less-expensive block and features a superior block as compared to either the LS1 or LS6, and offers much more interchangeability with LS6 parts. Confusing, isn't it? Welcome to the world of LS.

How large a displacement can you easily obtain by increasing bore diameter and stroke? The LS1 or LS6 (originally 345 cid) can be sized to a max of 427 cid using a 4.000" stroke. The LS2 (originally 364 cid) can be oversized to 427 cid max as well. See chart above for max overboring sizes.

Why can't you (or shouldn't you) go further with an overbore? The problem lies with the very common sloppy placement of the LS aluminum block cylinder sleeves.

Camshafts are unique to the LS series of engines. They feature a unique firing order and offer no distributor drive gear. Just remember that when you shop for a camshaft upgrade, you can't use "small-block Chevy" cams…you must use a dedicated LS cam.

It's very common for the sleeves to be placed slightly eccentric, likely due to core shift during the block casting. If the sleeves were perfectly symmetric and located exactly where they're supposed to be, you could go further. However, to be safe, you should consider a max overbore by about 0.030" to 0.032". Otherwise, you run the risk of thinning out the sleeves in certain spots, which can get pretty ugly. Generally speaking, stick to overboring by about 0.030" as your maximum.

Modifications intended to achieve greater strength and durability include changing to aftermarket forged crankshafts, forged connecting rods and forged/billet CNC pistons, billet main caps, high-strength aftermarket connecting rod bolts, the use of head and main studs (in place of the original head and main bolts) and oil pump modification, among other tricks. Oil pump mods include disassembly, deburring the pump inside and out, porting the oil entrance, polishing the pressure relief section and reassembly.

Camshafts

All LS series camshafts are of the roller style and they feature a unique firing order. The LS series of engines utilize a camshaft timing sensor. To provide a signal to the sensor, 1997–2005 LS engines feature a cast-in reluctor on the camshaft, located immediately in front of the #5 main cam journal. 2006 and later (LS2) camshafts eliminate this reluctor, with cam timing picked up at the cam sprocket.

An incorrect rumor has it that when using the stock valvetrain geometry, the safe maximum camshaft lift must be kept to 0.570", since the rockers begin to dig into the valve tips beyond that lift. However, Katech's Jason Harding told me that this isn't true, since World Challenge race engines that they've built typically feature as much as 0.595" lift with no problems. Camshafts that provide valve lift beyond 0.595" will require either

LS1 Engine Specifications

This engine was featured in 1997–2004 Corvettes, Camaros, Firebirds and GTOs.
Block part number: 12561166
Block type: Cast aluminum with 6-bolt, cross-bolted main caps
Balance: Internal
Bore x stroke (in): 3.90 x 3.62 (99 x 92mm)
Camshaft duration (@0.050"): 200 deg intake/203 deg exhaust
Valve lift (in): 0.500" intake/0.500" exhaust
Camshaft p/n: 12561721
Camshaft type: Hydraulic roller
Compression ratio: 10.25:1
Connecting rod p/n: 12568734
Connecting rod type: Powdered metal steel
Crankshaft part number: 89017522
Crankshaft type: Nodular iron
Cylinder head part number: 12559855
Cylinder head type: Aluminum, symmetrical port
Displacement: 5.7L (346 cid)
Maximum rpm: 6000
Piston p/n: 88984245
Piston type: Hypereutectic aluminum
Recommended fuel: 92 octane
Reluctor wheel: 24X
Rocker arm ratio: 1.7:1
Rocker arm p/n: 10214664
Rocker arm type: Investment cast, roller trunnion
Valve size: 2.00" intake / 1.55" exhaust

piston dome notching for valve clearance or switching to aftermarket forged pistons that already feature valve pockets.

By the way, standard LS series OE rocker arm ratio is 1.70:1. The LS7 features 1.80:1 rockers.

See Chapter 10 for OE and aftermarket camshaft specifications, as well as additional information on special firing order (SFO) camshafts.

Comparing Cylinder Heads

Cylinder heads are covered in detail in Chapter 3. Some of the major differences are:

LS3 cylinder heads feature rectangular ports (a feature borrowed from the LS7), 63cc combustion chambers, 2.16" intake valves and 1.59" exhaust valves. The camshaft features an aggressive 0.551" of intake valve lift, with less overlap than the LS2

LS6 Engine Specifications

Featured in 1999–2005 and introduced in the Z06 Corvette in 2001 and also used in the first generation Cadillac CTS-V. The LS6 features a unique block casting with enhanced strength and improved bay-to-bay crankcase breathing.
Block part number: 12561166
Block type: Cast alum with 6-bolt, cross-bolted main caps
Balance: Internal
Bore x stroke: 3.90" x 3.62" (99 x 92mm)
Camshaft duration (@ 0.050"): 204 deg intake/211 deg exhaust
Valve lift: 0.525" intake/0.525" exhaust
Camshaft p/n: 12565308
Camshaft type: Hydraulic roller
Compression ratio: 10.5:1
Connecting rod part number: 12577583
Connecting rod type: Powdered metal steel
Crankshaft part number: 12583565
Crankshaft type: Nodular iron
Cylinder head p/n: 12564825
Cylinder head type: Aluminum, symmetrical port
Displacement: 5.7L (346 cid)
Maximum rpm: 6500
Piston p/n: 88984245
Piston type: Hypereutectic aluminum
Recommended fuel: 92 octane
Reluctor wheel: 24X
Rocker arm ratio: 1.7:1
Rocker arm type: Investment cast, roller trunnion
Valve size: 2.00" intake / 1.55" exhaust

for even greater airflow and power.

The basic differences between the LS2 and LS3 include a stronger LS3 block casting, LS7-type cylinder heads (in terms of intake ports) and a more aggressive camshaft profile. Also, rocker arms are similar to the LS7 arrangement, where the intake rockers are offset.

Intake and exhaust rocker arms are identical for all LS1, LS6 and LS2 heads. However, L92, LS3, L92, LS9 and LS7 intake rocker arms feature an offset.

In summary, the intake and exhaust rockers are interchangeable through all LS1, LS6 and LS2 heads. The same exhaust rocker arm is used on all LS1, LS6, LS2, L92, LS3, L99 and LS9 heads. The same offset intake rocker arm is used on L92, LS3, L92 and LS9 heads. All LS7 rocker arms are unique to the LS7, due to their higher ratio (1.8:1) length. All other LS rockers (except the LS7) feature a 1.7:1 ratio.

LS2 Engine Specifications

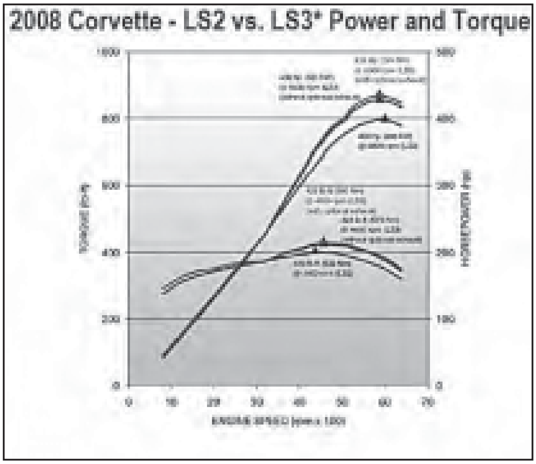
Featured in 2005–2007. This marked the beginning of the Gen IV design. Offered in the Corvette, GTO and SSR roadster. The LS2 was the standard engine in the Pontiac G8 GT. The LS2 is one of the most adaptable engines, since LS1, LS6, LS3 and L92 cylinder heads may be used.

Block

Displacement: 6.0L (364 cid)
Block type: Cast alloy with 6-bolt cross-bolted main caps
Bore x Stroke: 4.000" x 3.622"
Length: 20.43"
Width: 18.11"
Deck height: 9.235-9.245" (9.240" average)
Cylinder bore diameter: 4.0007–4.0017"
Thrust wall: center main (No. 3)
Camshaft tunnel dia: 2.168-2.169"
Block deck flatness: 0.004" within 6" area/0.008" length of deck (max)
Main bore dia: 2.750¬2.751"
Camshaft bearing bore dia (1&5): 2.345–2.347"
Camshaft bearing bore dia (2&4): 2.325–2.327"
Camshaft bearing bore dia (3): 2.306¬2.308"
Lifter bore dia: 0.843–0.844"
Cylinder bore dia: 4.0007–4.0017"
Cylinder bore taper: 0.0007" (max at thrust side)
Cylinder bank angle: 45 degrees
Cylinder bank offset: 0.949"
Bore center spacing: 4.400"
Firing Order: 1-8-7-2-6-5-4-3 (unique to LS)
Spark plugs: AC 41-931
gap: 0.040"

Crankshaft

Rotation: clockwise (viewed from front)
Runout: 0.000118" (max/production)
Main bearing clearance: 0.0007–0.00212"
Rod pin dia: 2.0991–2.0999"
Rod pin taper: 0.0002" (max)
Rod pin width: 1.902"
End play: 0.0015–0.0078"
Main journal dia: 2.558–2.559"
Main journal taper: 0.0004" (max)
Main journal out-of-round: 0.000118" max
Crankshaft runout: less than 0.001" (measured at no. 3 main bearing)
Reluctor wheel runout: 0.01–0.028" (max)
Flywheel bolt base circle: 3.110"
Stroke: 3.622"
Main seal I.D.: 4.527"
Thrust wall width: 1.029-1.032"



Horsepower and torque comparisons of the LS2 6.0L and LS3 6.2L engines as offered in the Corvette. Courtesy GM.

Connecting Rods

Type: I-beam, powdered metal (PM) construction w/ cracked cap design
Bearing bore dia.: 2.224-2.225"
Rod bearing clearance: 0.0009–0.0025"
Bearing width: 0.9449"
Side clearance: 0.0433–0.0200"
Center to center: 6.098"
Piston pin bore dia: 0.9436
Piston pin boss width: 0.9449"
Piston pin press: 0.0008–0.0017"
Rod bolts: 9mm x 1.0 x 43mm

Camshaft

Type: Hydraulic roller
Camshaft endplay: 0.001–0.012"
Journal diameter: 2.164-2.166"
Intake lift (at valve): 0.525"
Exhaust lift (at valve): 0.525"
Duration @ 0.050": 204 deg int; 211 deg exh
LSA (lobe separation angle): 116 deg
Intake centerline: 118 deg
Exhaust centerline: 114 deg
Lobe lift (int): 0.306"
Lobe lift (exh): 0.305"
Camshaft runout: 0.002" (max)

Cylinder Head

Compression Ratio: 10.9:1 (with OE flat-top pistons)
Combustion chamber volume: 64.5cc
Intake port volume: 210 cc
Exhaust port volume: 70cc
Max. valve lift: 0.570"
Block deck flatness: 0.003" (within 60.0" area; 0.004" overall length max)
Intake manifold deck flatness: 0.0031"
Exhaust deck flatness: 0.005"
Intake port type: Cathedral
Height: 4.732" (deck to rocker cover seal surface)
Valve angle: 15 degrees
Intake valve: 2.000"
Exhaust valve: 1.55"
Valve guide material: powdered iron
Valve guide separation: 1.913"
Valve seat angles: 30/45/60 degrees
Valve stem dia: 0.315"
Comb. Deck surface flatness: 0.003" within 60.0" area
Comb. Deck surface flatness: 0.004" (overall deck length)
Exh. Deck surface flatness: 0.005"
Int. deck surface flatness: 0.0031"

Note: If a camshaft is selected that provides greater than 0.570" valve lift, dished or pocket-relieved pistons will be required).

Oil Pump

Type: Gerotor, crankshaft snout driven
Diameter: 3.543"
Gear thickness: 0.421"
Pressure relief: 60 psig (factory)

Pistons

Type: Cast hypereutectic (late-production 2002 and beyond should have coated skirts)
Weight: 434 g
Piston to bore clearance: 0.0007–0.00212"
Piston deck height: + 0.008" (above deck)
Top land thickness: 0.177"
Pin to pin bore clearance: 0.0004-0.00078"
Pin dia: 0.943-0.943"
Pin to conn. rod (press fit): 0.00027-0.00086"

Note: While factory piston-to-bore clearance is on the tight side with stock hypereutectic pistons, aftermarket forged pistons will require greater piston-to-bore clearance. Generally speaking, this can range from 0.003" to as much as 0.006", depending on the specific piston application. Always follow the piston-to-bore clearance recommendation provided by the piston manufacturer.

Top compression ring thickness: 0.59" (1.5mm)
Second ring thickness: 0.59" (1.5mm)
Top ring end gap: 0.008–0.0160"
Second ring end gap: 0.015–0.027"
Top ring groove clearance: 0.0012-0.0040"
Second ring groove clearance: 0.0014–0.0031"
Oil rail thickness: 0.188" (ea)
Oil rail gap: 0.009–0.031"
Oil top rail gap clocking: 25 degrees from top ring gap
Oil 2nd rail gap clocking: 25 degrees from oil expander ring
Oil groove clearance: 0.0005–0.0079"

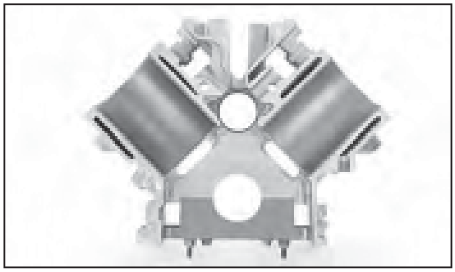
Valvetrain

Rocker arm ratio: 1.70:1
Rocker type: investment cast, roller trunion
Valve lash net lash: no adjustment
Valve diameter: 2.00" int; 1.55" exh
Valve face angle: 45 degrees
Valve seat angle: 46 degrees
Valve seat runout: 0.002" (max)
Valve seat width (int): 0.0400"
Valve seat width (exh): 0.0700"
Valve stem clearance (int): 0.001–0.0026"
Valve stem clearance (exh): 0.001–0.0026"
Oil seal installed height: 0.712–0.752"
Valve stem dia: 0.313–0.314"
Valve spring free length: 2.080"
Valve spring pressure closed: 76 lb@1.800"
Valve spring pressure open: 220 lb@1.320"
Spring installed height (int): 1.800"
Spring installed height (exh): 1.800"
Valve guide installed height: 0.682" (from spring seat surface to top of valve guide)
Roller lifter dia: 0.700"
Valve material: stainless steel/hollow stems, Na filled exhaust
Oil capacity (OE): 5.5 qts w/filter; 5.0 qts w/o filter

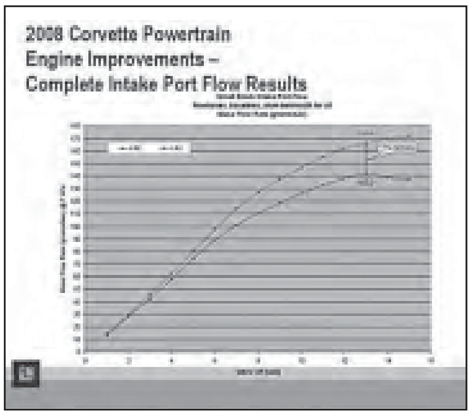
LS3 Engine Specifications

Introduced on the 2008 Corvette, the LS3 offers 430 hp in a 6.2L package (378 cid). The LS3 block features larger bore diameters at 4.065" and a strengthened casting for added support (this is a different casting as compared to the 6.0L LS2 block). The LS3 is offered in the Pontiac G8 GXP and is also standard on the 2010 Camaro SS. The L99 version is equipped with GM's fuel-saving Active Fuel Management cylinder deactivation system and is standard on 2010 Camaro SS models equipped with an automatic transmission.

Engine p/n: 19201992
Balance: Internal
Block part number: 12584727
Block type: Cast aluminum with 6-bolt main caps
Bore x stroke: 4.06 x 3.62 (103.25 x 92mm)
Valve lift intake/exhaust: 0.551/0.522
Valve size intake/exhaust: 2.16 / 1.59
Camshaft duration (@0.050"): 204 deg intake/211 deg exh
Camshaft p/n: 12603844
Camshaft type: Hydraulic roller
Compression ratio: 10.7:1
Connecting rods p/n: 12617570 (powdered metal)
Crankshaft p/n: 12597569 (nodular iron)
Displacement: 376 cid (6.2L)
Maximum rpm: 6600
Piston p/n: 19165089
Piston type: Hypereutectic aluminum
Recommended fuel: 92 octane
Reluctor wheel: 58-tooth
Rocker arm ratio: 1.7:1
Rocker arm intake p/n: 12569167
Rocker arm exhaust p/n: 10214664
Rocker arm type: Investment cast, roller trunnion
Reluctor wheel: 58X
Firing order: 1–8–7–2–6–5–4- 3 (standard LS firing order)



Cutaway view of the LS3 block. GM added a bit more strength and rigidity to the LS3 and LS9 blocks. Courtesy GM.



Intake port flow comparison of the LS2 and LS3 cylinder heads. Courtesy GM.

LS7 Engine Specifications

The LS7 block (externally essentially the same as the LS1), is made with a unique casting, with bigger 4.125" bore pressed-in dry cylinder liners (LS1/LS6/LS2 blocks feature cast-in-place sleeves) and a siamesed cylinder bore design. Main caps are steel instead of powder metal, and the block is machined with deck plates installed. Final displacement (in stock form) is a whopping 7.0L (427 cid), making it the biggest (in terms of displacement) LS-series engine and rated at 505 hp. Bore size is 4.125" and stroke is 4.000" (as compared to the LS1/LS6 5.7L (3.90" bore/3.62" stroke). The LS7's forged crank is made from 4140 chromoly steel for added strength. Pistons are cast hypereutectics that are upgraded with full-float pins, anti-friction skirt coating and anodized ring lands. Compression ratio is 11:1. Connecting rods are forged titanium, and the heads boats lightweight titanium intake valves.

Type: Gen IV V8 "big" small block that features 427 cid
Block part number: 17802854
Block type: 7.0L cast aluminum w/6-bolt steel main caps & dry press-in bore liners
Balance: Internal
Displacement: 7.0L (427 cid)
Horsepower: 505 hp @ 6300 rpm
Torque: 470 lb-ft @ 4800 rpm
Bore x stroke: 4.125" x 4.000"
Compression: 11:1
Main caps: Forged steel
Cylinder head p/n: 12578450
Valve diameter: 2.20" int (titanium); 1.61" exh (sodium filled)
Chamber volume: 70cc (CNC ported/specific LS7 pattern
Crankshaft p/n: 12568819
Crankshaft type: Forged steel, internally balanced
Connecting rods: Forged titanium
Connecting rod p/n: 12586258
Pistons: Hypereutectic aluminum
Piston p/n: 89017774

LS7 complete engine. Courtesy Pace Performance.

Connecting rod length: 6.067
Camshaft: Hydraulic roller
Camshaft p/n: 12571251
Valve lift: 0.591" int & exh
Camshaft duration @0.050": 211 deg int/230 deg exh
Rocker arm ratio: 1.8:1 (intake rockers feature offset)
Rocker arm type: Investment cast/roller trunnion
Reluctor wheel: 58X
Maximum rpm: 7000 rpm
Fuel: 91 octane
Max rpm: 7000 rpm
Firing order: 1–8–7–2–6–5–4- 3 (standard LS firing order)

Note: The LS7 engine (OE) uses a dry-sump oiling system similar to that found on the original LS9.

LS9 Overview

The LS9 engine was intended for the ZR1 Corvette. Touted as the "most powerful production engine GM has ever created," the LS9 features the Eaton R2300 supercharger, running at 10 lb boost through a liquid-to-air intercooler. The move to the supercharger was reportedly made because the LS7 made "only" 505 hp in stock trim, so adding the supercharger was the "easy way out." This avoided using more exotic cylinder heads and a drastically more aggressive cam profile (and a higher compression ratio).

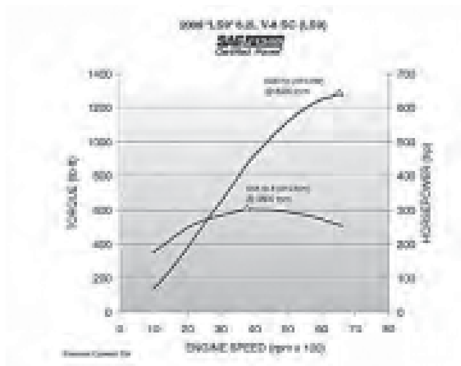
Unlike the lesser-power brethren of the bulk of the LS family, the LS9 features titanium intake valves and forged pistons instead of hypereutectic pistons. Main caps are also forged steel instead of powder metal.

Note: The LS9 GM crate engine (p/n 19201990) is designed with a dry-sump oiling system (external oil pump and remote oil reservoir), plumbed with –12 AN hoses. Oil delivery is controlled by a gerotor style oil pump (the pump consists of two pump housings, two separate gear sets and a pressure relief valve. The rear gear set serves as the primary pump and the front gear set serves as the secondary pump. The oil pump assembly is driven by the crankshaft sprocket. The primary pump draws oil from the oil tank, filtered through a tank screen. The oil is pressurized as it passes through the primary pump and sent through the engine block lower oil gallery. A pressure relief valve in the primary pump that maintains specified pressure. Pressurized oil is sent through the black's lower oil gallery to a full-flow oil filter. Oil then is directed to an external oil cooler. Oil returns from the cooler and is then sent to the upper main oil galleries. Oil from the left upper gallery is sent to the crankshaft main bearings, valve lifters 1, 3, 5 and 7, camshaft bearings and piston oil nozzles 1, 3, 5 and 7. Oil from the right upper oil gallery is directed to the valve lifters 2, 4, 6 and 8 and piston oil nozzles 2, 4, 6 and 8.

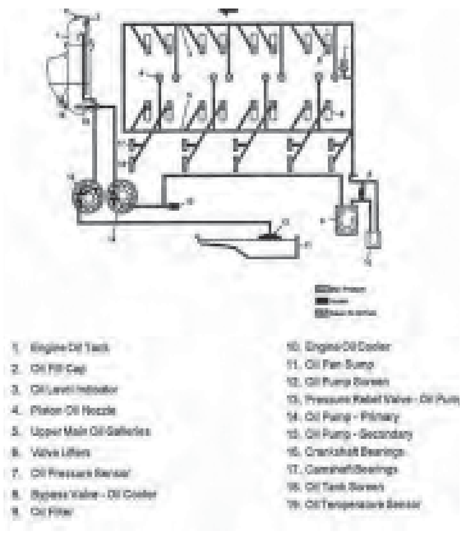
The piston oil nozzles provide oil to the underside of the pistons to cool these areas (these were added to help control the higher pressure/heat generated with the supercharger). The piston oil nozzles feature an internal check ball that is held in the normally closed position until system oil pressure exceeds 43.5 psi. Oil exits the valve lifters and is then pumped through the hollow pushrods to lubricate the rocker arms and valve stems. Oil returns to the shallow pan, where the dry sump's secondary pump draws oil (through a screen) and returns the oil to the remote oil reservoir tank.

The remote oil tank features an oil level indicator, oil fill cap, oil temperature sensor, positive crankcase ventilation valve (PCV) and a serviceable oil pump screen. The oil pressure sensor is located at the top rear of the engine, on the upper valley cover.

Dry-sump oil systems (commonly used in many race engine applications) offer several benefits as compared to a conventional wet-sump system (where the oil pan serves as



LS9 horsepower and torque chart. Courtesy GM.



This illustration shows the dry-sump oil system layout for the LS9 crate engine. Courtesy GM.

Cutaway view of the LS3/LS9 exhaust port. Although subtle, the roof of the port on the LS3/LS9 exhaust path rises a bit for a smoother exit path. Courtesy GM.

Cutaway view of the LS2 exhaust port for comparison. Courtesy GM.

Cutaway view of the LS3/LS9 intake port. Courtesy GM.

the oil reservoir, with a submerged oil pickup). A dry-sump system provides positive oil delivery under all vehicle operating situations (hard acceleration, braking, hard turns), without concern for the oil in the pan migrating away from the pickup. Oil is also kept cooler (and temperature more precisely regulated, since the oil supply is located in a remote tank). An additional benefit, especially for vehicles with extremely low ride height, is improved ground clearance due to the elimination of an extended-depth sump oil pan (again, since the oil supply is in a remote tank).

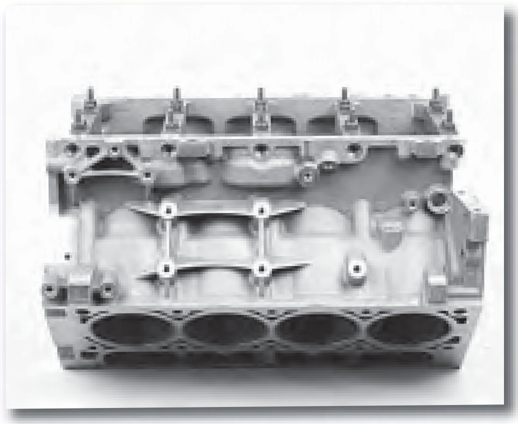
LS9 Engine Specifications

Type: Gen IV small block V8
Displacement: 6.2L (376 cid)
Horsepower: 638 hp @ 6500 rpm
Torque: 604 lb-ft @ 3800 rpm
Bore x stroke: 4.065" x 3.62"
Balance: Internal
Compression: 9.1:1
Supercharger boost ratio: 10.5:1
Supercharger: Eaton R2300 four-lobe Roots-style displacing 2.3L
Block type: Cast aluminum, six-bolt cross-bolted main caps
Main caps: Forged steel
Cylinder head: Cast aluminum, rectangle port
Valve diameter: 2.16" int; 1.59" exh (titanium int & hollow stem, sodium-filled exh)
Chamber volume: 68cc
Crankshaft: Forged chromoly steel, internally balanced
Connecting rods: Titanium
Pistons: Forged aluminum
Camshaft: Hydraulic roller tappet
Valve lift: 0.562" int; 0.558" exhaust
Camshaft duration @0.050": 211 deg int/230 deg exh
Rocker arm ratio: 1.7:1
Connecting rod length: 6.067
Oil pressure (min w/hot oil): 6 psig @ 1000 rpm
18 psig @ 2000 rpm
24 psig @ 4000 rpm
Recommended oil: 5w30 Mobil 1 or equivalent (GM4718M spec)
Oil filter: AC Delco p/n UPF48R
Recommended fuel: 92 octane
Max engine speed: 6600 rpm
Spark plugs: GM 12571165 (AC Delco 41-104)
Spark plug gap: 0.040"
Firing order: 1–8–7–2–6–5–4- 3 (standard LS firing order)

Piston oil squirters were added to the LS9 block to reduce under-piston temperature. The use of oil squirters is a common approach in several engine designs, including the Honda B18C1 engine block to name but one example. Courtesy GM.

Chapter 2

OEM & Aftermarket LS Blocks



A new LS2 GM block is shipped with OEM powdered metal main caps, with cam bearings already installed.

A myriad of LS-series engine blocks are available, both from GM and a variety of aftermarket manufacturers. If you intend to build a mild-to-hot LS engine, a production block will certainly fit the bill.

If, however, you intend to build an extreme performance all-out race engine, check out aftermarket suppliers such Dart, RHS, World Products and Katech. Katech offers custom-machined production blocks suitable for racing, and Dart, World Products and RHS offer blocks that are specifically designed for all-out competition use, with thicker decks, strengthened main webs and caps, improved priority-main oiling systems, and are designed to accommodate larger bore diameters and longer strokes, as compared to the OE blocks.

If you're building from scratch (no core), you can base your OE block selection on desired cubic inches. Remember that overboring the cylinders must be handled carefully, due to the limitations of the OE cylinder liners. Most LS blocks (originally 3.622" stroke) can accommodate up to a 4.000" stroke (minor block clearancing may be needed). The LS7 block can handle a bit more stroke (OE stroke is 4.000"). See Chapter 4 for details on bore and stroke combinations.

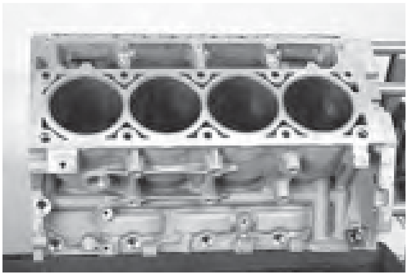
Block Overview

OE production blocks feature powdered metal main caps, with the exception of the 7.0L block used in the C5-R (racing) Corvette, which features billet steel main caps. All aftermarket performance LS blocks feature billet steel main caps. The powdered metal main caps are fine for street and many high performance applications, and should be fine up to about the 650 hp range. Beyond that, steel main caps are the way to go.

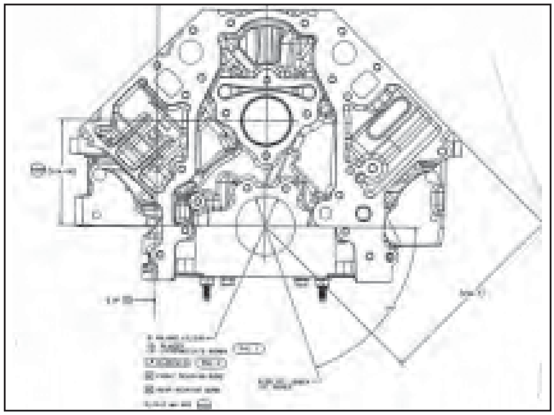
As far as overboring the cylinders is concerned, be aware that all aluminum blocks feature iron sleeves, since the parent aluminum isn't hard enough to withstand piston ring pressures. With that said, overboring a GM OE production aluminum block can be a challenge, since the sleeves are relatively thin-walled, and because of bore shifts that can occur during block casting. When the sleeves are finish-machined, a slight offset (in terms of sleeve wall thickness) can occur. While the bore centerline may be fine, due to casting shift, when the sleeves are finish-machined, this can result in variations of sleeve wall thickness (thicker on one side and thinner on the opposite side). Because of this, depending on the individual block at hand, a safe overbore might be limited to as little as 0.005" in some cases (again, this will vary with each block). There are no standards here…treat each block individually. If you intend to go crazy with oversizing the cylinders, you're better off with an aftermarket block.

Unlike previous-generation Chevy engines, the Gen 3 and Gen 4 LS blocks all feature the thrust bearing location at the center (No. 3) main web location. This holds true for both OE and aftermarket blocks.

The five main caps on an OEM LS2 block are made from



All LS blocks feature a cylinder bore center-to-center spacing of 4.400". Note that each cylinder features four head bolt holes.



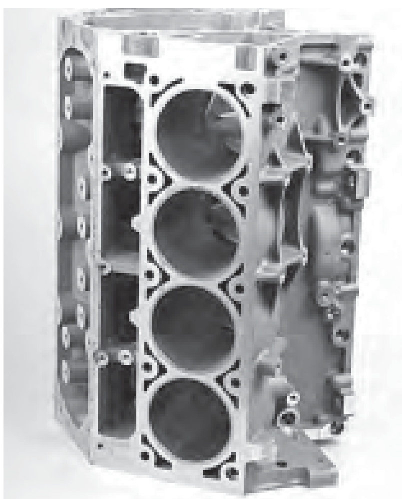
The blueprint drawing shows cam-to-crank centerline as 124.08mm (4.885") and deck height (crank centerline to each deck) as 234.7mm (9.240"). Illustration courtesy GM.

powdered iron and are secured with six bolts each (four vertical 10mm x 2.0 bolts and two 8mm x 1.25 side bolts). Remember: All LS engines feature all-metric threads at all threaded locations. Don't complain…there's nothing wrong with metric fasteners. Metric-shy folks need to get over their hang-ups. Just remember that all threaded locations are metric. ARP and other high performance fastener manufacturers now offer a full line of metric fasteners for LS engines, so there's no problem in upgrading if you opt to trash the OE bolts and studs for higher quality high-performance fasteners.

When dealing with the main caps, be aware that main cap fit may be on the tight side. On some OE blocks, it is common for the side main cap registers to be tight enough that the block actually needs to be "spread" a bit in order to remove/install the caps. If you run into caps that are tight and are not easily removed or installed by hand, DO NOT machine material from either the caps or the block to make cap service easier. A special threaded turnbuckle-style tool, called a "block spreader" is available through the aftermarket to gently spread the block walls apart by a few thousandths of an inch. The tight fit of the main caps is a feature of the precision fit of the caps, and is a factor in the main bore geometry. Again, NEVER modify either the block or the caps if you experience a tight main cap fit. Do not force, file, or hammer a main cap into place.

The rear of an OE production block, in addition to accepting current GM transmission mounting, can easily be modified to accept an older style (Gen 1) bellhousing by simply drilling and tapping an extra hole in the block's rear face at a blank boss on the right (passenger) side.

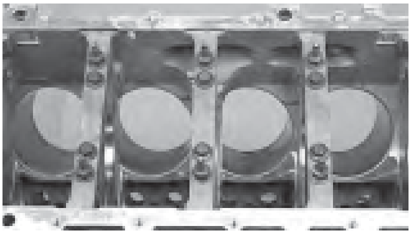
If you start with a bare block (as opposed to



The GM factory-original LS2 block features a 4.00" cylinder bore and can safely be overbored by +0.030" if desired (as long as the block doesn't feature excessive cylinder bore core shift).

buying a short block or long block core), you'll need a handful of bits and pieces, including lifter buckets, a top valley cover, rear bellhousing dowels, a front oil expansion plug, a rear oil valve & plug, cylinder head dowels, threaded water jacket plugs and oil plugs, a front (timing) cover, a rear cover

OE LS blocks feature a cast-in displacement size. The LS2 block features a "6.0L" on the right front of the block, inside the recess area (to the left of the cam tunnel as you're looking at the front of the block. The right rear of the block features the same mark. Most OEM LS blocks are identified in this way (the LS7 block features a "7.0L" casting mark in the same location, etc.). Don't count on aftermarket blocks to be labeled in the same manner.

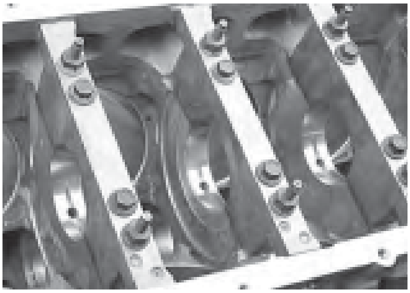


The five main caps on an OEM LS2 block are made from powdered iron and are secured with six bolts each (four vertical 10mm x 2.0 bolts and two 8mm x 1.25 side bolts). Remember that all LS engines feature metric threads at all threaded locations. ARP and other high-performance fastener manufacturers now offer a full line of metric fasteners for LS engines, so there's no problem in upgrading if you opt to trash the OE bolts and studs for higher quality high-performance fasteners.

that incorporates the rear main seal, a set of 8mm main cap side bolts, and a camshaft retainer plate and bolts. These items are available individually or as a block completion kit (see page 21) from any GM parts dealer. In addition, whether you plan to run the engine injected or carbureted, you'll also need the appropriate crankshaft position sensor and camshaft position sensor. If you start with a used engine core, be sure to retain all of these items. Throw nothing away.

Note: The left (driver) side of the block front features an open oil galley passage that is sealed with a 16mm metal expansion plug. Remove this plug (if you're dealing with an used engine core) for block cleaning purposes. Whether you're dealing with a new or used block, install a new plug during final assembly (after the block has been washed for the last time).

The crankshaft position sensor (this aligns with the crankshaft's reluctor or timing wheel) installs into a smooth-bore hole in the right side of the block, towards the rear. The sensor seals with an O-ring, and is held in place with a built-in clamp that is secured to the block with a single bolt.



Unlike earlier generation Chevys that featured the thrust bearing at the rear cap, all of the LS engines feature the crankshaft thrust bearing at the center (No. 3) main bearing location. Note the slight recess around the No. 3 main to accommodate the bearing thrust faces.

If you plan to use new aftermarket roller lifters, be sure to purchase the lifters before machining the block. Depending on the brand of aftermarket lifters, oil clearance may be on the tight side, which would require minor lifter bore honing. That doesn't mean that anything is wrong—it's common practice to check and obtain proper lifter bore clearance with any fresh build or rebuild. Measure lifter diameters and lifter bore diameters and hone to obtain proper oil clearance if necessary. Never assume that any lifter will automatically provide the required oil clearance.

As we mentioned earlier in the LS overview in Chapter 1, the lifters are located in plastic lifter buckets. These buckets, or trays, guide the lifters, and are installed into large recesses located above the block decks. Each lifter bucket holds a group of four lifters. Each lifter bucket is secured to the block with a single 6mm x 1.0 shouldered bolt. (Special bolts are used for lifter bucket mounting. Don't substitute these with generic 6mm bolts.)

The entire LS series of engines (Gen III and Gen IV) represent a radical departure from the early Chevy small-block and big-block engines. There is no interchange of parts. The LS series represents a completely redesigned platform. Once you're familiar with the LS family of engines, you'll soon discover that it's a definite improvement over the earlier generations in terms of power potential, ease of service and reliability.

OEM Blocks

We'll list info on all LS variants, but to start off with an example, the GM P/N 12568950 aluminum LS2 block is available from Scoggin-Dickey, Pace Performance and other GM Performance Parts dealers for approximately $100.

This LS2 6.0L block is considered a Gen IV block, which is basically the same block with minor changes as compared to the LS1 and LS6 5.7L Gen III blocks. The cam position sensor has been moved to the front timing cover, and there is no knock sensor provision in the engine valley. The LS2 features a knock sensor location on the left side of the block.

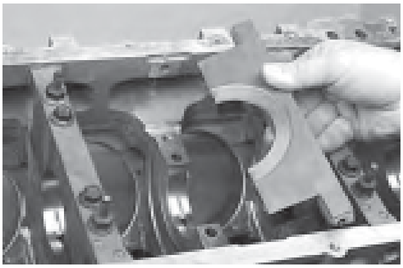
This block is a direct replacement for 2005–2007 LS2 Corvette, SSR, GTO 6.0L and Trailblazer SS.

The OE block is cast from 319-T5 aluminum and features iron sleeves, 6-bolt iron main bearing caps, a specified 9.240" deck height and 4.00" cylinder bores. This block will accept LS1, LS6, LS2, L92 or LS3 cylinder head designs.

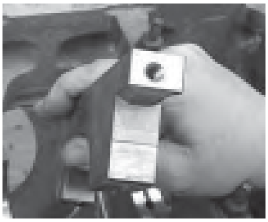
When it comes to obtaining factory OEM (original equipment manufacturer) blocks, choices abound. You can pony up for a brand new block from GM Performance Parts dealers such as Scoggin-Dickey Performance Center or Pace Performance. That isn't a bad price at all for a brand-new virgin aluminum block. By comparison, a new GM aluminum LS1/LS6 (5.7L) block goes for about $990. The GM 6.0L LQ9 cast iron block sells for about $733. The 6.2L L92/LS3 aluminum block goes for around $1,435.85, and the LS7 7.0L aluminum block will set you back about $2,725. If you want a 6.0L aluminum LS2 block, the $1,100 or so is definitely doable as your starting point for the build.

***Used Blocks*—**Finding a used bare block (6.0L LS2 or other LS version) can be tough, since most boneyards are not about to tear down a complete engine just to part it out. You'd need to contact a production engine rebuilder or smaller engine builder who specializes in LS engines who may stock engine cores and components. If you can find a used LS2 block, expect to pay around $500 to $800 for a usable bare block. I've been down that road, and to make a long story short, if you want to start with a bare block (as opposed to buying a short block, long block or complete engine), you're better off simply buying a new block from a GM parts dealer such as Scoggin-Dickey or Pace Performance. The block will be fresh with no damage, and considering all of the time you'd waste trying to locate a decent used bare block, the $1000 or so for a new aluminum block or a mere $750 for a new cast iron LQ9 6.0L block is worth the price.

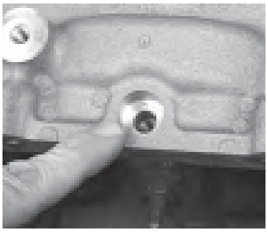
Granted, your choice of block will depend on



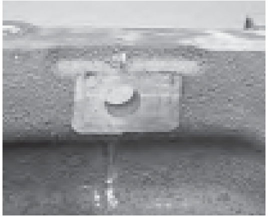
The OE main caps on this new LS2 block were surprisingly easy to remove by hand. However, a previously assembled and run block (where the main cap side bolts have been torqued to specification and have been exposed to dynamic and thermal stresses) may be a bit more snug, sometimes requiring the use of a spreader bar to allow cap removal without damaging the cap-to-block mating surfaces. The spreader bar is nothing more than a short turnbuckle adjuster bar that can be used to slightly spread the two opposing sides of the block apart, just enough to remove the cap. NEVER pound or pry against the aluminum surfaces of the block. If you booger the inboard mating pads of the block (where the side bolt section of the main cap mates against the block), you may distort the block during main cap tightening, requiring the block to be align-honed.



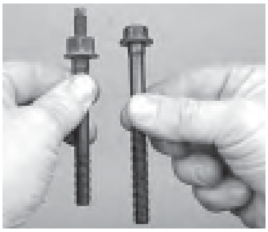
Since the main caps use 8mm side bolts in addition to the primary vertical 10mm bolts, pay extra attention to the care and cleanliness of the side bolt mating surfaces on both the caps and block.



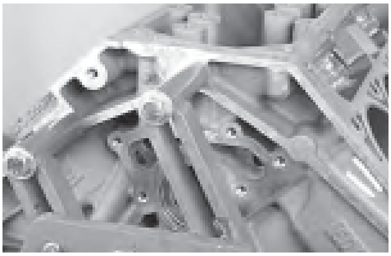
This close-up shows one of the main cap side bolt holes (exterior block view). Flanged 8mm x 1.25 bolts are required here.



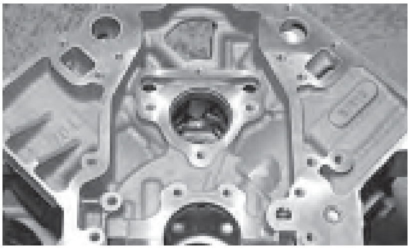
A machined flat is featured on each of the block's inner wall locations for the main caps. Again, be careful to avoid damaging these relatively soft aluminum surfaces.



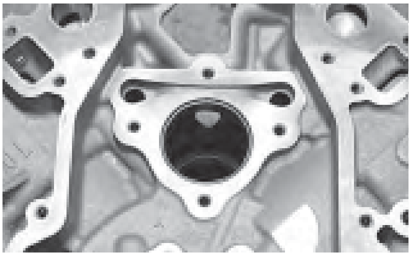
The main cap center bolts are 10mm with a 2.0 thread pitch. The inboard bolts feature a hex head, while the outboard vertical bolts feature a stud tip to for mounting the oil pan baffle. The outboard bolts (left) feature a primary shank length of 85mm, while the inboard bolts (right), have a shank length of 100mm.



The rear of the OEM LS2 block features pre-drilled and tapped 10mm x 1.5 bellhousing bolt holes to accommodate the new style transmissions, but even the OE block will accept an old-style Gen I Chevy bell-housing by drilling and tapping one extra hole in the blank boss, as seen in the upper right in this photo (round blank boss on right passenger side), about an inch and a half below the upper rear head bolt hole on the right deck. Drilling and tapping a 3/8"x16 hole in this boss isn't a bad idea, if for no other reason than to make it easier to mount the rear of the block onto a conventional engine stand.



When you buy a new GM block, the camshaft bearings are already installed. Nevertheless, don't assume that all is well. Check each camshaft bearing for placement, scratched/dings and for size.



This front view shows the camshaft bore. Note the crossover oil path that connects the two oiling galleys above the cam bore.

your build plans. If the direction of your build is to use a longer stroke and to take advantage of high-quality aftermarket parts (pistons, connecting rods, camshaft, etc.), then why buy a partial or complete used engine, since the only item you'll keep is the block, front and rear covers and valley cover? I recently built an LS engine starting with a new LS2 block and block kit (front/rear/valley covers, etc.). I over-honed to a mere 4.005" bore and used a 4.000" stroke Lunati crank (for a final displacement of 403.13 cid and a compression ratio of 10.6:1 (pump gas build). Along with Trick Flow aluminum heads, off-the-shelf JE pistons, a radical custom Crane roller cam, Lunati connecting rods, Harland-Sharp roller rockers and an Edelbrock Super Victor intake manifold and 800cfm Edelbrock carb, the engine easily spit out 625.4 hp and 534 ft-lb of torque on the engine dyno.

The most common route for folks today is to grab a used LS engine from a junkyard, taken from a wrecked Camaro, Vette, GTO, etc. If all you want is an LS engine that runs, and you don't plan to rebuild it or modify it, then this is the way to go. Find one with relatively low miles (preferably an engine taken from a vehicle that wasn't smashed badly in the front or from a vehicle that was dunked in a flood), hose off the exterior dirt and grime, and install it.

But if you plan to modify the engine to improve performance (and plan to rebuild it along the way, to verify that the internals are correct, such as main and rod bearing condition and clearance, crank straightness and condition, connecting rod condition, rings, cylinder walls, etc.), you can spend a little less dough and simply buy an engine core with little regard to mileage.

Block Completion Kit—Of course, any time you buy a bare block (OE or aftermarket), you'll also need to buy a bunch of LS block accessories such as front and rear covers, top valley cover, screw-in water jacket and oil plugs, etc. If you plan to run the engine in fuel-injected trim, you'll also need the complete host of sensors (knock sensor, water temp sensor, oil pressure sensor, crank position sensor, cam position sensor, etc.). GM offers convenient block completion kits (see charts on next page) that have everything you need. If you plan to run the engine with a carburetor, you won't need the whole setup, but you'll still need a crank position sensor (to pick up timing at the crank reluctor wheel), cam position sensor, water temp sensor and oil pressure sensor.

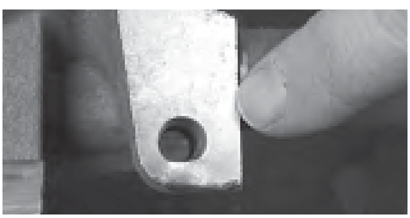
Naturally, if you already have a used engine core, you'll already have all of this stuff, which, depending on condition, can be cleaned up and reused with the exception of the front oil expansion plug, front timing cover seal, and maybe the rear-mounted plastic block oil valve. When I built my first LS2 performance engine, I didn't have an engine core to steal parts from, so I had to purchase all of the above items (I started from scratch).

LS1/LS6 Block Completion Kit
P/N 19153789

Qty	GM Part No.
1	12577927 valley cover
1	12561211 cam sensor
1	12561243 front cover
2	1453658 bellhousing dowel
1	12589016 camshaft retainer plate
4	11561455 cam retainer bolts
1	12588670 timing chain damper
1	12560228 crankshaft sensor
4	12570326 cyl. head dowels
4	12551162 lifter guides
1	12615666 rear cover

LS7 Block Completion Kit
P/N 19213580

Qty	GM Part No.
1	12570471 valley cover
1	12598292 front cover assembly
4	21007339 plugs
1	12556437 camshaft retainer
1	11609289 plug
1	11610259 cyl. head plug
5	12551177 M8 X 1.25 flanged head bolts
4	12570326 cyl. head dowels
1	12572013 rear cover assembly
1	12573460 oil plug
1	12596334 windage tray
2	11588426 plugs
4	09427693 plugs
2	01453658 bellhousing dowels
1	12561663 plug
1	12573107 oil pressure sensor
1	12585546 crankshaft position sensor



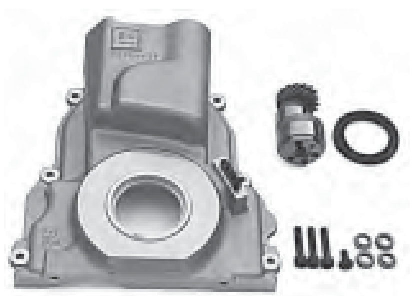
When buying a factory GM (new or used) LS aluminum block, check it for shipping damage. This rear bellhousing leg (starter mount location) was damaged, requiring the bolt hole to be redrilled round. No big deal, but by finding and correcting problems such as this early on can save time and hassle down the road during the build.

LS2 Block Completion Parts

If you start with a bare block, you'll need a host of GM odds and ends to complete the block, in addition to the primary components. Even if you start with an aftermarket bare block, you'll need most of the following items as well, although some aftermarket block makers include a few miscellaneous items, so check first.

Qty	GM Part No.
1	12570471 valley cover w/bolts
4	12595365 plastic lifter trays w/bolts
1	9427693 front oil expansion plug
1	1453658 pair of bellhousing dowels
4	12570326 cyl. head dowel sleeves
1	12561513 crankshaft snout key
1	12573460 plastic block oil valve/plug
1	12561663 threaded water drain plug
3	11588949 threaded oil plugs
1	12600325 front timing cover w/cam sensor & bolts
10	12556127 8mm main cap side bolts (2 packs of 5 ea)
1	12588670 plastic timing chain damper w/bolts
1	12615666 rear block cover w/seals and bolts
1	12589016 camshaft retainer plate
4	11515756 cam retainer plate bolts

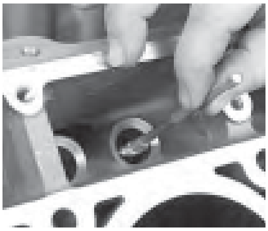
Note: If you plan to use performance aftermarket main cap bolts or studs, you won't need the 8mm main cap side bolts from GM, as these will be included in your aftermarket main cap fastener kit.



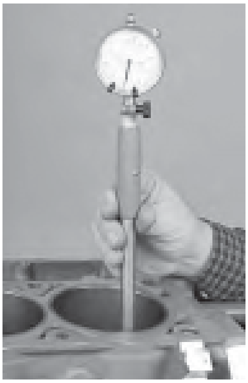
All LS engines are designed as distributorless (with ignition being handled by individual coil packs and a timing control module or central ECU). However, for old-school setups where you prefer to use a distributor and carburetor (or where these mods are mandated by a race sanctioning body), GMPP offers a distributor adapter kit. The aluminum housing mounts to the block (allowing mounting of a Ford small-block HEI-type distributor). The distributor's gear is driven by a stub gear that is bolted to the nose of the LS camshaft. These kits can be hard to find, since not all dealers stock them. Be aware that while it's easy and cheap to convert an LS engine to carburetion instead of fuel injection, it's not cheap to convert to a distributor setup, since this requires not only the distributor mounting kit shown here, but a unique/special water pump and complete new pulley system as well. It can get expensive, up $2500 or so. A better old-school setup is to keep the individual coil packs, get an aftermarket (MSD) timing control module and an intake manifold with a four-barrel carb.

It is not unusual for OE cast blocks to feature slight core shifts during the casting process. On this new GM LS2 aluminum block, note how the cylinder liner was apparently bored slightly off center. When the casting was made, the cylinder bore was a bit off center. When the liner was then final machined on a robotic machining center, proper center (or at least as close to proper as found in a factory high-production run block) was then achieved. The result is a liner that's ticker on one side and thinner on the opposite side. This isn't a problem if the tolerance is minimal. Corrections (to achieve exact on-center bores) is easily done at an engine builder's shop that has access to a CNC machine.

While the GM factory uses powder metal main caps, the aftermarket block makers use steel billet main caps for superior strength. The powder metal main caps are actually stronger than you might think (can usually handle upwards of 650 hp or so). However, if you plan to make some serious power and want to beef up the bottom end, it's a very good idea to upgrade to steel caps when rebuilding a factory block. It's good insurance.



While measuring lifter bore diameters, take your time and record each bore's diameter. Some OE and aftermarket blocks may feature slightly tight lifter bores, requiring honing to size for proper oil clearance. Never hone lifter bores until you have your desired roller lifters in hand and have measured lifter diameter.



While any block, new or used, should be at least final-honed to size (and finish) for the pistons and rings to be used, always check each cylinder for roundness and consistency. This will tell you if the bore is tapered or inconsistent with loose/tight spots.

On this particular example, we measured and found that the bore centerline location was fine relative to the block and main centerline. An eccentric-machined cylinder liner such as we see here simply means that you may not be able to over-bore as much as you might want to.

Tower Bosses—Some LS blocks feature a series of tower bosses in the top valley. These bosses are open to oil (small hole in the top of each boss), and some blocks don't feature these towers. The towers are for displacement on demand systems (where engines feature solenoid actuated pushrods for selective cylinder firing) and variable camshaft timing (actuated by hydraulic actuator cam phaser, where cam timing automatically adjusts depending on load requirements). The displacement on demand system deactivates valves on alternating cylinders (effectively turning a V8 into a V4). The system uses special lifters fitted with unique plungers. When the master ECU senses light load conditions, alternating cylinders are deactivated to save fuel. Big deal. If you're building a performance engine, don't worry about this stuff. The top engine valley cover plate is offered in two versions…one that accommodates the pushrod solenoids and one that features O-ring seals on the bottom of the tray to seal off the towers. Just use the top valley cover plate that has no holes on the top and that features O-ring seals on the bottom. If the block has the oil towers, these seals will block off the oil passages on the top of the towers. To my knowledge, the only production vehicles that featured the 6.0L LS2 with displacement on demand and variable cam timing were GM SUVs.

In addition to the 6.0L aluminum blocks (used in 2005 Corvette and 2005–2006 GTO), 6.0L LS2 cast iron blocks are also available. These were used in truck applications. The cast iron block has two distinct advantages: it's cheaper to buy, and it allows a bit more latitude in terms of cylinder overboring, since you don't have to worry about boring cylinder liners too thin. The disadvantage: heavier and not as cool.

OEM Production Vehicle Applications

LS1/LS6 5.7L (aluminum p/n 12561166)
2001 Z06 Corvette

7.0L p/n 12480030
Used in the C5-R Corvette. Features 4.125" bore. Will accept up to 4.000" stroke without machining block. Billet main caps and main & head studs. All standard LS components may be used.

LS2 6.0L P/N 12568950 (aluminum)
(when looking for junkyard engines)
2005–2006 Pontiac GTO
2005–2006 Corvette SSR
2005–2007 Corvette
2006–2007 Cadillac CTS-V
2006–2009 Chevy Trailblazer SS

LS7 7.0L P/N 19212580
Direct replacement for 2006–2009 7.0L LS7. For use with any LS or LSX series cylinder heads.

L92/LS3 6.2L P/N 12584727
Direct replacement for 2007–2008 L92 and LS3 6.2L
Use only LS1, LS6, LS2, L92 or LS3 cylinder heads

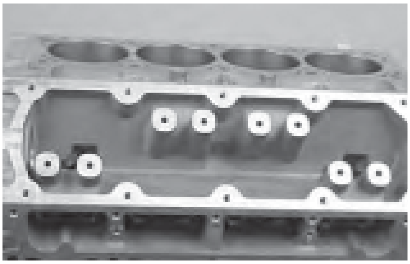
LS9 6.2L P/N 12621983
Direct replacement for 2009–2010 ZR1 Corvette

LSA 6.2L P/N 12623968
Direct replacement for 2009-2010 Cadillac CTS-V 6.2L

Block Specs

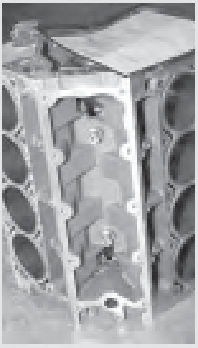
	LS1	LS6	LS2	LS3/LS9	LS7
Deck Height*	9.240"	9.240"	9.240"	9.240"	9.240"
Cam Bore Dia	2.168"	2.168"	2.168"	2.168"	2.168"
Main Bore Dia	2.751"	2.751"	2.751"	2.751"	2.751"
Cam Bore Location*	4.914"	4.914"	4.914"	4.914"	4.914"
Cyl Bore Spacing	4.400"	4.400"	4.400"	4.400"	4.400"
Cyl Bore Dia	3.898"	3.898"	4.000"	4.065"	4.125"

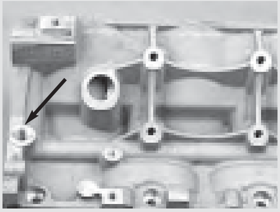
*__Note:__ Deck height refers to the distance from the main bore centerline to the top deck surface of the block (where the cylinder head mates the block). Cam bore location refers to the distance from the main bore centerline to the camshaft bore centerline.



If the block features these oiling tower bosses in the top valley (for displacement on demand system), simply buy the top valley cover that features O-rings that seal these off (GM p/n 12570471).

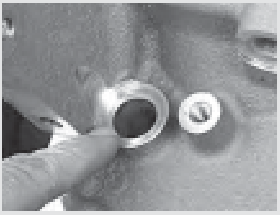
If the block does not feature the oiling towers, any top LS cover will do. If the cover has O-rings, first remove the O-rings so that you don't have to worry about them falling into the valley down the road.



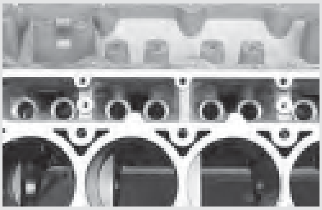


The large threaded boss on the left side of the LS block accepts a 30mm straight-thread water jacket plug. This is easily ordered from a Chevy parts dealer. The straight-thread plug will feature an O-ring for sealing.

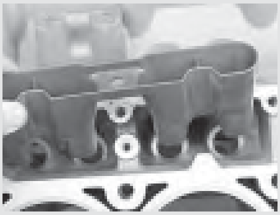
The front left of the LS block features an open oil galley passage. This must be plugged with a 16mm press-in expansion plug. You need this plug with a new bare block. This plug should be removed on used blocks before washing, then replaced with a new one at assembly.



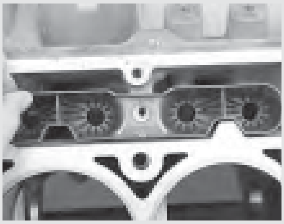
The smooth bore hole on the lower right side rear area of the LS2 block provides a mounting for the crankshaft position sensor. The small tapped hole in the adjacent boss allows the sensor bracket to be secured.



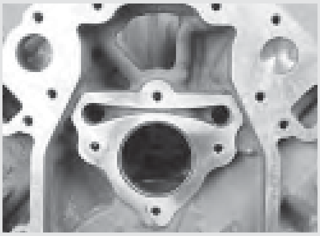
LS blocks feature lifter bore locations that are recessed in deep pocket areas above the decks.



The OE plastic lifter trays (also called lifter buckets) drop into these cavities.



Each lifter tray accepts four lifters, and is secured to the block with a single 6mm x 1.0 shouldered bolt.



If you buy a used block, closely check the oil galley ports above the camshaft tunnel and make sure that they are clean and free of burrs.

The LS engine blocks were originally designed by GM using complex CAD programs and computerized imaging. The Gen III and IV LS platform offers a host of improvements as compared to the early generations of Chevy engines.

Aftermarket Blocks: The Ultimate Cool Stuff

If you have the budget and prefer to build a custom LS engine starting with the strongest and most precise blocks available that also offer different deck heights, bore sizes, deck thickness and will readily accommodate longer strokes, and offer improved oiling and cooling systems, then an aftermarket performance LS block is for you. At the time of this writing, I am aware of three sources for kick-butt pro-level LS blocks that you can play with and will allow you to expand your power horizons beyond what's available with the stock blocks. These include Dart Machinery, World Products and RHS (Racing Head Service).

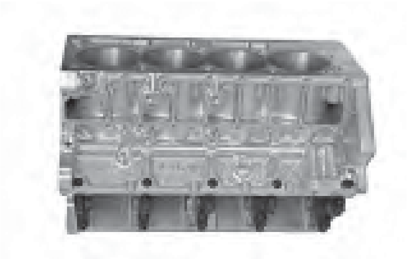
Dart's Billet LS Block—Dart is revered as one of the world's premier engine block and cylinder head makers. Their first offering for the LS market is a billet aluminum LS block. A "billet" component is not cast. They start with a high-density forged cube of high-grade aluminum (a massive chunk of alloy), and produce the finished product by means of CNC machining. That's right…using a multi-axis and multi-tooled computer-operated high precision machining center, the entire block is machined to extremely tight tolerances. This is as good as it gets. We're talking about an engine block that is near-perfect out of the crate. The high-density forged material provides vastly superior strength as compared to a cast product, and the computer-aided machining provides perfectly square and flat decks, perfectly centered cylinder bores, lifter bores, cam bore and main bore. When a manufacturer CNC machines a block (even if it's a casting), they are able to follow the exact design specifications without the variable of mass-production machining where tolerances cannot be as closely held. The core material (the billet cube) provides the added strength, rigidity and resistance to core shifting that routinely occurs with just about any OEM cast block. In basic terms, this LS block from Dart (as are all of Dart's blocks) is a truly "blueprinted" example of the precision machinists' craft.

Two additional advantages of a billet-stock machined engine block involve both weight and appearance. Since the entire block is carved out by a machining process, the exterior of the block features a smooth machined surface. The machining process eliminates unnecessary weight in the process. Weight reduction isn't a concern with a street application, but it's always a factor in racing applications.

A nice benefit of the CNC-machining from billet stock is that Dart can provide whatever deck height you want (within LS design limitations).

The ultimate in cool is a billet block, where the entire block is machined from a dense aluminum cube. Here an LS1 block begins its birth at one of Dart's CNC centers. Courtesy Dart Machinery.

Dart's billet LS1 block is a thing of incredible strength, precision and beauty. It's pricey, but if you have the bucks, you'll be the coolest guy on your block. Courtesy Dart Machinery.



The Dart billet block involves an incredible amount of machining time. Even the water jackets have been machined. It boggles the mind. The clever guys at Dart deserve a medal for designing, perfecting and producing these jewels. Steel billet main caps are included. Courtesy Dart Machinery.

Note: Although I'd like to provide additional specifications for the Dart billet block, each Dart LS billet block is treated as a custom order, so there are no standard specs. Each block is machined per the customer's wishes, in terms of bore sizes, deck height, etc.

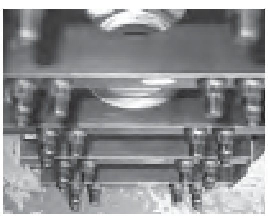
World Products Warhawk Block—World Products (makers of a wide range of blocks and cylinder heads) offers their Warhawk LS block. This is a high-quality A357 T-6 aluminum casting that is CNC finish-machined. The lineup includes their Warhawk LS1, LS2, LS6, LS7 and the C5R engine blocks.

The Warhawk LS block is available in 9.240" and 9.800" deck heights. Bore sizes range from 4.000" to 4.155". The standard deck 9.240" block

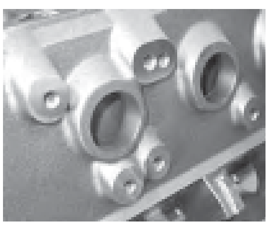
Warhawk Specs

Deck heights: 9.240" (0.600" minimum deck thickness) or 9.800"
Motor mounts: Accepts LS or early Gen small-block Chevy
Head stud/bolts: Provisions to use 2 extra fasteners per cylinder (opt.)
Bore sizes: 4.000", 4.125", up to 4.155"
Cam bores: Can be machined up to 60mm for large roller bearing camshafts
Stud holes: Counterbored to eliminate distortion
Components: Accommodates all standard GM LS-series
Oil system: Can accommodate dry sump (scavenge pickup at rear)
Crank clearance: 4.00" stroke to 4.500" stroke
Main caps: Billet steel C5R-style with 200,000 psi ARP fasteners
Lubrication: Priority main (feeds crankshaft first and top-end last)
Weight: Approximately 130 lb with sleeves

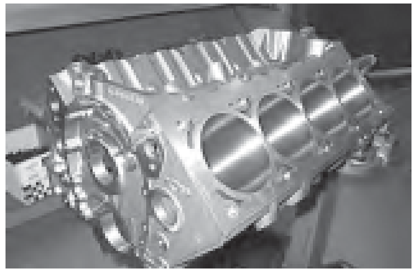
World products' Warhawk LS block is a premium aluminum casting that's CNC-machined to precise tolerances. Various deck heights, bore diameters and cam tunnel options are available. And like the Dart and RHS blocks, priority oiling (where the mains get oiled first) is part of the design. Bores are also siamesed and feature all-around water jacketing. Steel billet main caps are included. Courtesy World Products.



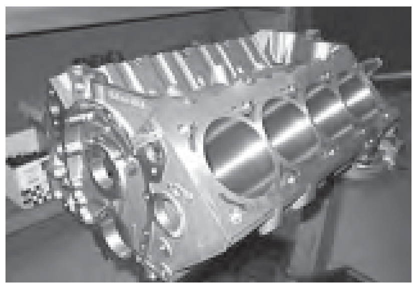
The Warhawk steel main caps are precision-ground and feature ARP main studs. Courtesy World Products.



Like most aftermarket blocks that are LS-oriented, the Motown block will accommodate early generation motor mounts. Courtesy World Products.



In an effort to blend early Gen I and current LS technology together in a hybrid platform, World Products also offers their Motown block. This essentially an early generation block that will accept LS cylinder heads. Courtesy World Products.

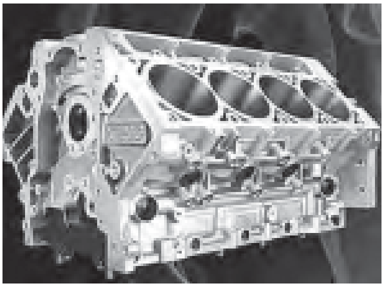


World Products also offers an aluminum Gen II style Chevy block, designated their Motown block, that is designed to accept the superior-performing LS cylinder heads (this allows for a more traditional Chevy buildup in terms of the rotating and reciprocating assembly, but takes advantage of current-technology LS heads. Courtesy World Products.

accommodates up to a 4.000" stroke crank, while the tall deck 9.800" block allows up to a 4.500" stroke. This translates into a maximum displacement of 402.1 to 488.1 cid. The block accepts either LS or early Chevy motor mounts.

Racing Head Service LS Race Block—Racing Head Service (RHS) offers a radical street-performance/all-out racing block based on the LS platform. This is a hardcore racing piece of work. The block is cast from A357-T6 aluminum and is available in either unfinished, bored/ready to hone or finished versions. All machining by RHS is performed on a CNC machine. This block is offered in a variety of deck heights, ranging from 9.240" (stock), 9.250", and tall-deck versions at

The RHS LS Race Block is a high-quality aluminum casting that is also precision machined/finished on CNC machining centers. The block will accept either LS or early generation motor mounts (bellhousing mounts will also accept early or late bellhousings). Various deck heights and bore diameters are available. The RHS LS block isn't intended for just any LS application. The beefiness and extra-thick meat is intended for radical street machines or all-out race applications. Courtesy RHS.



The RHS LS aluminum race block is designed for extreme street and race applications. Decks heights include 9.240", 9.250", 9.750" and 9.760". The block accepts either stock or 60mm roller bearing camshafts. Longer strokes are accommodated via raised cam tunnel, outboard relocation of the side oil galley and reliefs in the block for added crank clearance. Other features include increased windage passages under bores and around main caps. Courtesy RHS.

9.750" and 9.760". The camshaft tunnel is raised 0.388"/9.86mm (to increase rod clearance for long strokes), and will accommodate either stock diameter camshafts or oversized 60mm camshafts with roller bearings.

For the raised-cam versions, Comp Cams offers a two-link longer timing chain kit.

Features include siamese-cast bore walls (4.100–4.165") with press-in spun cast iron liners. Decks are beefy (0.500" thick on standard deck blocks and 0.750" thick on tall deck block). Standard (5.87" and tall (6.38" deck cylinder sleeves are available, as well as extra-long liners for standard 5.87" and tall 6.38" decks.

Considering the bore and stroke combinations available, this means that the RHS LS Race block can provide the foundation of a maximum displacement of 485 to 501 cid.

RHS made a bunch of design modifications to accommodate long crankshaft strokes, including cam tunnel raise, substantial reliefs in the block under the bores and moving the side oil galley further outboard. If you plan to build a stroker, this block has design features to accommodate up to a 4.600" stroke. Other block features include chilled main saddle bulkheads for added strength, a larger main cap surface area (again, to promote increased rigidity and less main bore distortion) and increased windage passages under the bores and around the main caps (minimizing windage in the rotating assembly leads to improved engine lubrication at higher rpm).

Blocks feature a six-bolt per cylinder deck design, with full water jacketing around all cylinders (based on the LS7 design). Extra large windows in the valley allow access to the 6th head bolts.

The cam tunnel will accommodate either stock or the larger 60mm roller bearing camshaft (includes cast-in lock screw pads). Lifter bores are standard 0.842", but material is available for oversize lifter access (accepts 1.060" bushing for keyed lifters). In standard deck height versions, maximum pushrod angularity is less than two degrees. Blocks include Ampco 45 camshaft thrust plate and aluminum rear cover. Lifter bores are designed to clear tie-bar lifters.

Provisions exist for Gen III and IV camshafts and knock sensors and valley cover.

The race block is also dry sump–friendly, with provisions for serious dry-sump systems. Large front and rear AN-12 side feeds are provided.

Blocks also have provisions for piston oil squirters (cast-in and machined). All blocks feature priority main oiling (where main bearings are fed first). The side oil galley is moved outboard for additional long-stroke clearance. Blocks are compliant for race mounts for Gen I, II, III and IV. All threaded holes feature rolled threads for added strength. ARP main studs are included. Enough material is present to accept up to 1/2" diameter fasteners.

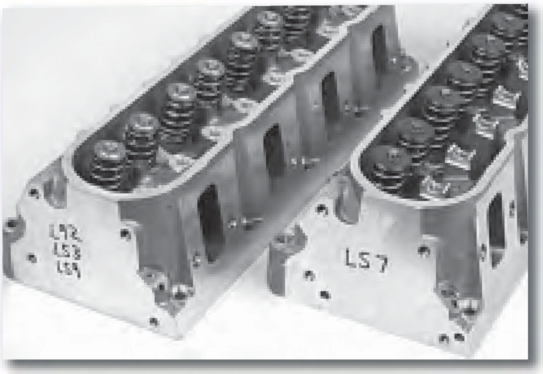
As part of RHS quality control, each block is CT scanned (similar to a medical CAT scan) to ensure maximum precision and consistency.

The block isn't cheap, but if you're planning to build a serious ground-pounder within the LS platform, this block deserves a serious look.

Katech Custom LS2 Block—Katech, located in Michigan is one of the leaders in LS engine development (master builders of some killer street and pro drag and championship road racing LS engine packages). One of the blocks they offer starts off as a 6.0L LS2 GM block. They remove the existing cast-in cylinder bore liners and install their own heavier-wall cylinder sleeves, using a proprietary sleeve installation process (it's a tricky and complex job and not comparable to traditional cylinder sleeving), allowing them to provide cylinder bores up to a whopping 4.130" diameter. These blocks are also clearanced to accommodate a 4.000" stroke. The OE aluminum casting is also vacuum impregnated, a process that effectively seals any porosity that might be present in the casting. This is a greatly enhanced LS2 block, basically expanding this excellent block's performance potential.

The KAT-A4677 production LS2 aluminum block has been resleeved. It has a machined case with premium liners to accept up to a 4.000" stroke and 4.130" bore. It is double vacuum impregnated, decked and clearanced for 4.000" stroke.

These blocks are custom-ordered to provide the specific bore diameters and deck height desired. Katech will clearance the block for the specific stroke the customer wants.



The later Gen IV LS cylinder heads basically include two different heads, one for the LS3, LS9 and L92 (left) and one for the LS7.

Chapter 3

OEM & Aftermarket Cylinder Heads

GM's production LS cylinder heads are great pieces, the mostly notable of which is probably the L92 head. These heads produce decent power, but if you really want to play with the big boys, you'll have to look toward the performance aftermarket. Aftermarket firms such as Trick Flow, Dart, RHS, World Products, AFR, Edelbrock and Pro-Filer have studied the OE heads in terms of port volumes, port angles, valve angles, airflow and combustion chamber design and tweaked and improved them to a whole 'nother level.

Bear in mind that when you purchase new cylinder heads, you often have a choice of either complete heads (already fitted with valves, springs, keepers and retainers) or bare heads. Purchasing bare heads allows you to custom machine to incorporate individual tuning modifications, and to select the specific valves and springs that you prefer for your application (for instance, a builder may prefer a specific brand and material for his valves, or may need to install valve springs that match the operational needs of a specific camshaft).

Heads that are listed as CNC machined have been machined (intake and exhaust ports and chambers) to exacting and matching specifications (essentially "blueprinting" the heads). Some manufacturers offer cylinder heads that are listed "as cast." This refers to a very exacting casting process that mimics a CNC-ported head without the need to actually perform extensive CNC machining.

OE Head Features

All GM OE LS heads feature PM (powdered metal) valve seats and powdered metal guides (this PM formulation provides the lubricity of bronze and the longevity of cast iron guides).

All LS1, LS6 and LS2 heads feature tall cathedral-style intake ports. The LS7, L92 and LS3 heads feature rectangular intake ports.

Cathedral-style intake ports (GM OE) measure in the range of 3.125" high x 1" wide. These are easy to identify due to their tall, narrow shape and somewhat radiused top profile.

All LS heads, with the exception of the LS7, feature as-cast chambers and ports. The LS7 heads feature CNC-machined chambers, intake ports and exhaust ports.

According to Katech, all cylinder heads within the LS family are interchangeable among blocks, with the exception of the LS7 heads. The LS7 cylinder heads cannot be mounted to other LS blocks, as the wider valve layout would result in valves contacting the bores.

A variety of OE Gen III heads are available, including an iron small port (initially used on the 4.8L truck engine), the

OEM Cylinder Heads	Casting No.
LS1	853
*LS6	243
LS2	243
LS7	8452
L92/LS3/LS9	5364

*Features an intake and exhaust port design change as compared to LS1.

Note: A Mexican LS2 cylinder head, casting number 799, is also available, but features a rougher finish than the U.S. casting.

GM LS & LSX CYLINDER HEADS

(All heads are aluminum. All exhaust ports are standard LS. All rockers are bolt-down except for shaft-mount C5R and LSX CNC-machined bare heads)

Description	P/N	Port vol.	Valve angle	Chamber vol.	Intake/Exhaust valve dia	Intake port type	Notes
LS1 '97–'98	10215339	200	15	70	2.000/1.550	cathedral	
LS1 '99–'01	12559853	200	15	70	2.000/1.550	cathedral	
LS1 '01–'04	12564241	200	15	70	2.000/1.550	cathedra	
LS2/LS6	12564825	210	15	64.5	2.000/1.550	cathedral	
LS6	12564824	210	15	64.5	2.000/1.550	cathedral	hollow/sodium-filled valves
LS2	12576063	210	15	64.5	2.000/1.550	cathedral	solid stem valves
CNC LS6	88958622	250	15	61.9	2.000/1.550	cathedral	11.2 compression
CNC LS6	88958665	250	15	65	2.000/1.550	cathedral	10.5 comp.
CNC LS2	88958765	250	15	64.5	2.000/1.550	cathedral	solid stem valves
Bare L92	12615361	260	15	70	2.165/1.590	L92	solid stem valves
Stock L92	12615355	260	15	70	2.165/1.590	L92	solid stem valves
CNC L92	88958698	279	15	68	2.165/1.590	L92	solid stem valves
Stock LS3	12615879	260	15	70	2.165/1.590	L92	hollow/sodium-filled valves
Bare LS3	2615361	260	15	70	2.165/1.590	L92	
Bare LS7	12578450	270	12	70	2.200/1.610	LS7	
Stock LS7	12578449	270	12	70	2.200/1.610	LS7	titanium/sodium-filled valves
C5R	25534393	210	11	38	2.180/1.630	C5R	as-cast, no seats/guides
LSX-L92	19201807	260	15	70	2.000/1.550	L92	hollow/sodium-filled valves
LSX-LS3	19201805	260	15	70	2.160/1.590	L92	hollow/sodium-filled valves
LSX-LS7	19201806	270	12	70	2.200/1.610	LS7	titanium/sodium-filled valves
LSX-CT	19166981	302	11	45	2.200/1.610	LSX-CT	shaft rockers, CNC machined
LSX-DR	19166979	313	11	50	2.250–2.280 in 1.600–1.650 ex	LSX-DR	shaft, CNC bare

LS1 aluminum head, the LS6 aluminum head with 63cc chambers, the LQ4 aluminum head with 67cc chambers and LS6 heads with larger ports and larger chambers.

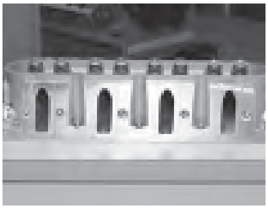
Note: Use caution when interchanging heads and blocks because valve to bore interference may occur.

All LS cylinder heads feature a cylinder bolt layout that provides four bolts at each cylinder location, which provides an improved clamping load, more evenly distributing the clamping forces where it counts…around each bore location.

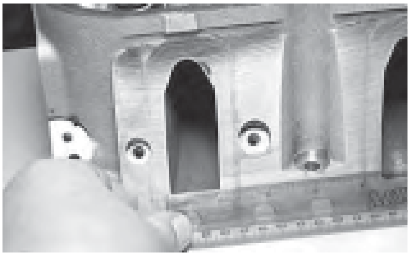
Some aftermarket head makers offer a six-bolt head to accommodate mounting to LSX and other aftermarket race blocks, for high-cylinder pressure applications.

Another feature of LS cylinder heads involves the valve cover mounting. Early Gen III LS1 heads featured valve cover bolt locations along the perimeter of the valve cover. Later LS cylinder heads feature a center-bolt layout, where special grommeted valve cover bolts enter through the roof of the valve cover. This brings up another point: because the OE coil pack layout positions the coils on top of the valve covers, the valve cover bolts are not readily accessible without removing the coils. Two options are available to get around this

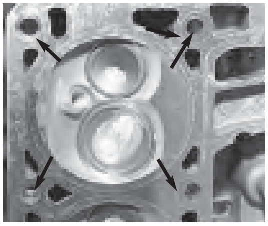
LS cylinder heads feature a handy three-digit casting identification number. Shown here is an LS1 head with casting number 853. LS2 cylinder heads are marked with number 243.



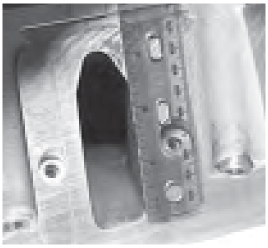
These vertical intake ports are commonly referred to as cathedral-shaped ports. Both cathedral port and rectangular port heads are also available from various aftermarket cylinder head manufacturers.



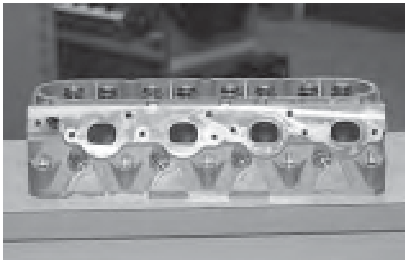
Cathedral ports measure approximately 1" in width.



LS cylinder heads feature four bolts per cylinder, providing even clamping load distribution.



Cathedral ports measure approximately 3.125" in overall height.



Exhaust ports are "D" shaped, and are evenly spaced, unlike early generation small-block Chevy heads where center ports for cylinders three and five and four and six are located close together.

problem. Moroso makes a super-nifty coil pack mounting system that is hinged, allowing you to easily swing the row of coils out of the way (or to easily remove the entire bank of coils as a unit). Another solution is to use a coil relocation system (Katech has a cool setup for this) that relocates the coils to the rear of the engine. This also cleans up the engine appearance. As an option, Katech also offers way-cool powder-coated valve covers that do away with the coil pack mounting bosses.

OEM LS3, LS9 and LS7 Cylinder Heads

Basically, we're dealing with two separate cylinder head castings when addressing this later generation of LS engines. The LS3, LS9 and L92 all use essentially the same cylinder head foundation, featuring a four-digit identification number (top of head just outside the valve cover rail) 5364. The LS7 cylinder head is unique, with identification number 8452.

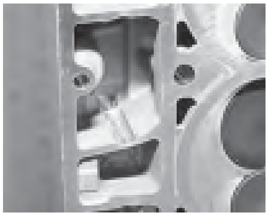
The LS3, LS9 and L92 head is an "as-cast" head, with intake and exhaust ports and combustion chambers shaped during the casting process. The LS7 cylinder head features intake and exhaust ports and combustion chambers that are finished by CNC machining.

Identifying an LS7 head from the LS3, LS9 and L92 head is fairly easy…the LS3, LS9, L92 head features flat rocker pedestals (to accept separate rocker arm rails), and the ports and chambers feature a cast finish. The LS7 head features individual rocker arm radiused stands and all ports and chambers display a machined surface.

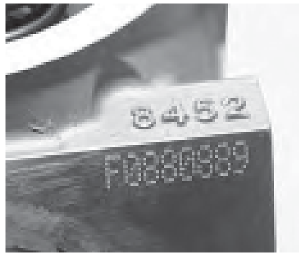
In addition, the LS3, LS9 and L92 heads feature the tapered beehive valve springs, while the LS7 head features straight valve springs without the beehive taper.

Unlike the LS1, LS6 and LS2 heads that feature the tall, skinny cathedral intake ports, the LS3, LS9, L92 and LS7 heads feature a conventional

Both LS6 and LS2 cylinder heads feature a casting number of 243.

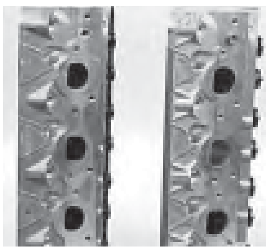


Cylinder heads feature pushrod clearance reliefs.

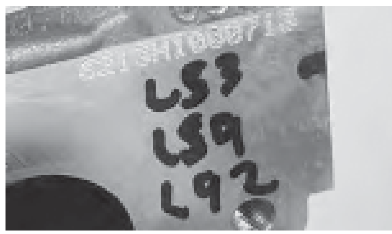


LS7 cylinder heads are identified by the casting number 8452

Both the LS3, LS9 and L92 head (left) and the LS7 head (right) feature rectangular intake ports, unlike the cathedral ports used on Gen III LS1, LS6 and LS2 heads.



LS3, LS9 and L92 (left) and LS7 heads (right) feature similar exhaust ports.



The LS3, LS9 and L92 head features an exterior identification number of 5364.

rectangular shaped intake port style.

Intake port dimensions also vary between the two head versions. The intake ports on the head used for the LS3, LS9 and L92 are 1.250" wide x 2.550" tall, while the intake ports on the LS7 head are 1.350" wide x 2.40" tall.

Interchangeability

Which LS heads will physically swap out to the various LS blocks?

Basically, you need to pay attention to the block's bore diameter. Running a cylinder head intended for a larger bore size can result in valves crashing into the block. For instance, you cannot install an LS3, LS9 or LS7 head on an LS1, LS6 or LS2 block (at least not without some creative deck/bore notching to clear the valves).

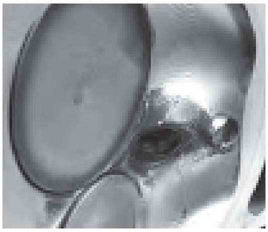
One of the primary reasons that you can't simply swap cylinder heads is due to the head's valve layout and valve head diameter. Heads that were designed for larger bore blocks (such as the LS7, for example) can easily create valve to top-of-cylinder bore clearance issues. If in doubt, you'll need to temporarily install the heads (outfitted with light-duty checking valve springs) and check for valve interference, where the valve head may contact the top of the bore. In this case, you'll need to notch the top of the bores to provide valve clearance. So, pay attention when purchasing replacement heads. If you have an LS1, LS6 or LS2 block, make sure that you buy heads that are designed to work with that block, to avoid the need to modify the block.

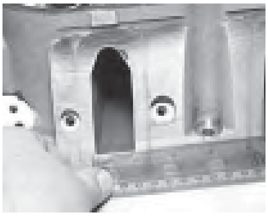
***Swapping Summary*—**Here's a rundown on LS head swaps:

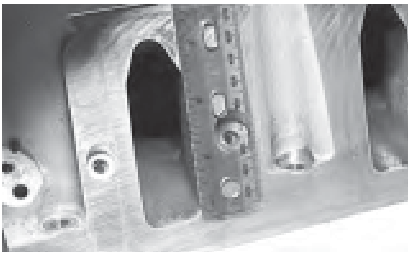
- LS1 and LS6 blocks will accept only LS1, LS6 and LS2 heads.
- LS2 blocks can use LS1, LS6 or LS2 heads, as well as L92-style heads, which includes LS3 and LS9 heads.
- LS3 and LS9 blocks can use LS1, LS6, LS2, LS3 or LS9 heads.
- The LS7 blocks can accept any LS head.

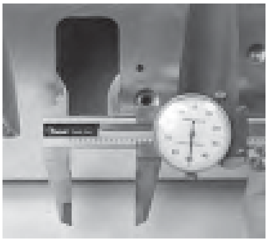
Be aware that while production LS1, LS6, LS2, LS3 and LS7 engine cylinder head bolts are 11mm in diameter, the LS9 block uses 12mm diameter bolts.

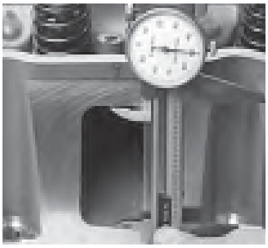
***OE Intake Port Styles*—**We've discussed intake port styles and sizes already, but to summarize:

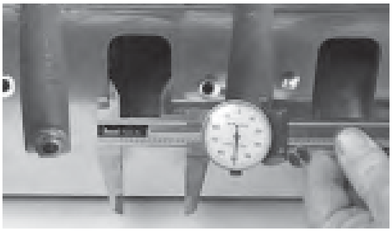

The LS7 head ports and chambers were CNC machined to achieve more precise volumes.


The LS1, LS6, LS2 type of head features cathedral shaped intake ports (tall with tapered tops) and are about 1" wide.

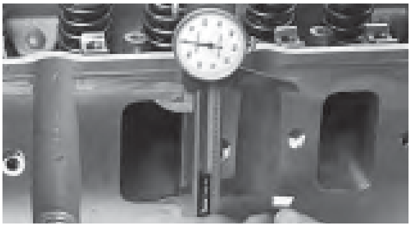

The LS1 cathedral ports measure approximately 3.25" high.


The LS3, LS9 and L92 intake ports measure about 1.250" wide.


The LS3, LS9 and L92 intake ports measure about 2.550" high.


The LS7 intake ports measure 1.350" wide.

In some OEM applications such as the LS7, exhaust valves feature hollow/sodium-filled exhaust valve stems for enhanced heat dissipation.


The LS7 intake ports measure 2.40" high.

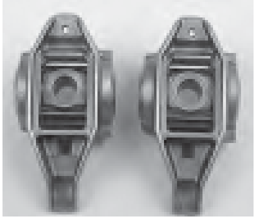
The cathedral port was used originally on the LS1, LS6 and LS2. There are two OE rectangular port styles, including the LS7 style and the L92 style. The LS7 rectangular ports feature 270cc volume. Since any cylinder head intake port must be matched to the intake manifold port, only an LS7-style (in terms of port shape and dimensions) intake manifold will work with an LS7 style head. The L92 style ports are a bit narrower and a bit taller as compared to the LS7 ports. Again, intake manifold selection must match port style and dimensions.

Valves

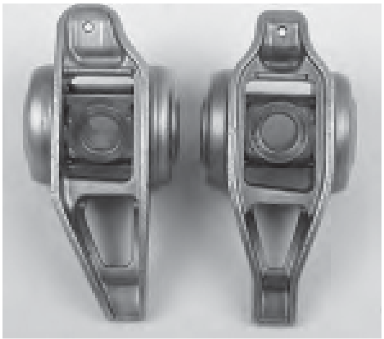
A few early LS engines feature solid stems, while most feature hollow, sodium-filled exhaust stems. The LS7 uses titanium intake valves and hollow sodium exhaust valves.

When replacing valves (if you buy new fully

All OE LS rockers feature a trunion-bearing pivot. These bearings are notoriously weak and are prone to failure in high performance use. The OE rockers can be sent out to aftermarket rocker makers for a bearing upgrade, or you can replace the rockers with stronger aftermarket units.



Shown here are intake and exhaust rocker arms for the LS1, LS6 and LS2 cylinder heads. These intake and exhaust rockers are identical, and feature a ratio of 1.7:1.



The LS7 features its own unique rocker arms, at a 1.8:1 ratio. The intake rocker arm also features an offset. Also note the longer, more pronounced lightening openings on the valve end of the rockers, as compared to other LS rockers.

assembled heads, quality valves will already be included), you can take advantage of aftermarket stainless steel valves. The only reason to go with titanium valves is to lighten valve weight. Considering the higher cost of titanium valves, this only makes sense if you plan to race the engine, where valvetrain weight is a consideration for sustained high rpm. For the street, from mild to wild, stainless valves will perform just fine. Of course, if you want to brag to your buddies that you have titanium components, feel free to spend the extra bucks.

OEM Rocker Arm Ratios

LS1: 1.7:1 (intake and exhaust rockers identical)
LS6: 1.7:1 (intake and exhaust rockers identical)
LS2: 1.7:1 (intake and exhaust rockers identical)
L92: 1.7:1 (intake rocker offset)
LS3: 1.7:1 (intake rocker offset)
L99: 1.7:1 (intake rocker offset)
LS9: 1.7:1 (intake rocker offset)
LS7: 1.8:1 (intake rocker offset)

Rockers

GM LS rocker arms feature a 1.7:1 ratio for all LS cylinder heads, except for the LS7, which features an increased 1.8:1 rocker arm ratio. OE rocker arms feature a trunion bearing at the pivot point, which presents a weak point regarding high performance use (they tend to fail under high engine speeds). If you're building a performance-upgraded or racing LS engine, avoid the original equipment rockers in favor of aftermarket units that feature forged/billet high-density alloy bodies and well-oiled pivot bearings or needle bearings. Performance aftermarket roller rockers are designed for extreme use that involves higher spring pressures and higher and/or sustained engine speeds. The GM rockers may be upgraded by replacing the trunion bearings with superior bearings (Katech and others offer this service), but if you're serious about performance, the best avenue is to bite the bullet and buy a set of high quality roller rockers from a reputable aftermarket supplier such as Harland Sharp, Comp Cams, Scorpion, etc. The stock trunion bearing rockers are not suitable for high performance use.

Due to valve angles used in various LS heads, rocker arms may be straight or offset. The LS1, LS6 and LS2 heads use a straight rocker (no offset between valve and pushrod contacts), and both intake and exhaust rockers are identical.

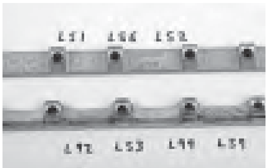
On the LS3, LS9 and L92 GM heads, the intake rocker features an offset (exhaust rockers are the same as used on LS1, LS6 and LS2).

The LS7, as mentioned earlier, features a 1.8:1 ratio. In addition, the intake rocker features an offset.

GM OE rockers are not full roller rockers, as they only pivot, or roll, on a trunion bearing and do not feature a roller tip at the valve contact.

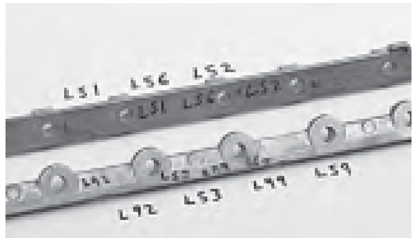
OEM Rocker Arm Pedestal Rails—Two different rocker arm pedestal rail versions are used. One rail is designed for use on the LS1, LS6 and LS2. The other is designed for the L92, LS3, L99 and LS9.

The rail for the LS1, LS6 and LS2 features the



Two versions of the rocker rails exist, one for the earlier LS1, LS6 and LS2 applications (top row) and one for the later LS3, LS9 and L92 heads (bottom row).

This end-view of the two rocker rails shows the early LS1, LS6, LS2 rail at the left and the later LS3, LS9, L92 rail at right.



This underside view of the early (seen at top in this photo) and later rails shows a clear shape difference. Note the later rail (seen at bottom in photo) bolt holes are slightly offset and the hole bosses protrude outward on one side.

pedestals centered (height-wise) on the rail. Each edge of the rail's length is straight. The rail for the L92, LS3, L99 and LS9 locates the pedestals a bit offset, with one side of each pedestal extended out (one edge of the rail features individual pedestal bulges, or radiuses that protrude out from the edge).

The rail for the LS1, LS6 and LS2 features each cylinder's pair of pedestals located 1.901" on center from each other. The rail for the L92, LS3, L99 and LS9 features the pedestal centers located 2.227" apart (center of hole to center of hole). The part numbers on the rails are 12552203 for the LS1, LS6 and LS2 rails and 12600936 for the L92, LS3, L99 and LS9 rails.

This close-up shows the flat-machined bosses. A one-piece cast aluminum rail mounts atop these bosses, with the rails featuring the radiused rocker locations.

The LS7 heads do not require separate rocker rails, since the head casting features machined radiused pockets to directly accept the rockers. Many aftermarket performance LS-style cylinder heads also feature these rocker pedestals, eliminating the need for rocker rails.

The LS7 cylinder heads feature individual radiused rocker stands and do not require the use of a separate rocker arm mounting rail.

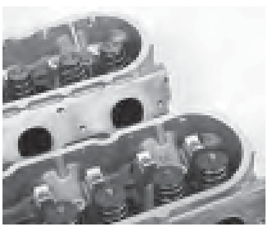
With regard to aftermarket performance cylinder heads, the manufacturers don't necessarily follow these GM design rules. Regardless of the cylinder head engine application, many aftermarket cylinder head makers tend to eliminate the pedestal rails altogether and incorporate cast-in machined pedestals (basically taking the features they like from various GM versions and coming up with a design element combination that works best and that reduces the number of individual parts). The cylinder head manufacturer will provide recommendations for the specific rocker arms that are designed to be used with their heads. For instance, when using a pair of Trick Flow TFS-3060T001-CO2 heads, these require the use of roller rockers. One recommended rocker arm set is Harland Sharp's p/n SLS17. These forged aluminum rockers feature needle bearing trunions, with each pair of rockers bridged together by a common pivot shaft. These bolt directly to the heads with no muss or fuss.

Interchangeability—Aftermarket full-roller rockers are readily available through the performance aftermarket. All LS1/LS6 and LS2 intake and exhaust rockers are interchangeable, but the LS3, LS9 and L92 intake rockers are offset. Exhaust rockers are the same for LS1, LS6, LS2, L92, LS3 and LS9. LS7 rockers are unique, as the intake rocker features an offset, and the LS7 rocker ratio is higher at 1.80:1, as opposed to 1.70:1 for all other LS engines.

OEM Valve Springs

All original equipment-style LS series cylinder heads feature beehive-shaped springs (these feature

Beehive valve springs take advantage of coil shape to minimize unwanted harmonics, eliminating the need for dual damper springs. However, I know several engine builders who prefer to use traditional dual springs, especially where higher spring pressures are desired.



While the LS1, LS6, LS2 and LS3, LS9 and L92 heads feature tapered beehive valve springs (upper head shown here), the LS7 heads feature non-tapered conventional shaped springs (lower head shown here).

smaller diameter upper and lower coils for superior damping of spring harmonics). All OEM spring retainers are steel, even in the LS7. This single beehive spring design eliminates the need for dual springs, and also allows the use of smaller and lighter retainers. There is some debate among engine builders regarding the virtues of beehive springs, as some builders prefer to use conventional dual springs that feature uniform top and bottom spring diameters.

My advice, if you're building for performance, as opposed to simply rebuilding an original engine, is to use conventional single or double-springs (with same diameter top and bottom, not the beehive). Availability and pricing is better, along with the advantage of common retainer diameters. Always base valve spring rates on the camshaft maker's recommendations. You'll see valve spring open and closed pressures and installed height specs on the camshaft data card supplied with the cam. It's not that there's anything really wrong with the beehive design, but I really don't see any big advantage to their use. To help in reducing valve mass (weight), you can take advantage of titanium retainers, which are readily available from any of the leading valvetrain manufacturers. The most important aspect of choosing the springs is to always follow the camshaft maker's spring rate recommendations.

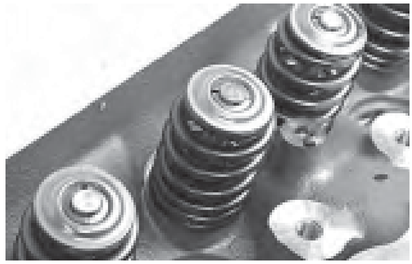
Head Gaskets

Early LS engines featured composite-type cylinder head gaskets. Around 2002, GM switched to multi-layer steel (MLS) cylinder head gaskets.

All remaining gaskets throughout the engines are formed elastic seal type gaskets that are reusable (depending on condition of course).

When buying replacement cylinder head gaskets, choose the MLS type. They provide excellent sealing characteristics and tend to allow a more even distribution of cylinder head clamping. I often refer to clamping loads in every engine-build book. It's important to realize that the act of tightening the cylinder head bolts (or nuts on head studs) results in generating a degree of elastic stretch in the fastener (bolt or stud). This "stretch" creates tension, or compression load, on the head and gasket. Without proper clamping load, the head gasket won't seal, and the cylinder head may be subject to uneven thermal expansion and contraction. Cylinder head fastener torque is simply a means of achieving the desired clamping load.

Note: It is very common (on any engine, not just LS) when using MLS cylinder head gaskets that you may experience a slight external coolant weeping during the initial engine run. This is normal. The MLS gaskets feature a special heat-cured coating that will continue to seal during the initial run. Don't panic if you see a small bit of coolant weeping out between the heads and block when the engine runs for the first time. This coolant weeping won't happen in every case, but it's not uncommon. As long as the deck surfaces have been prepared properly and you've followed correct assembly procedures, this minor leakage should disappear quickly.



The beehive valve springs (seen here) were designed to reduce spring harmonics, but heavier conventional springs were favored for the LS7.

Performance Aftermarket Heads

The performance aftermarket has developed many heads for the LS platform, with new ones seeming to arrive every month. In this section we'll take a look at six current sources, including Dart, Trick Flow, World Products, Edelbrock, AFR and Pro-Filer, but there are many others. As I mentioned earlier, the performance aftermarket basically looks as what GM designed and pushes the envelope in terms of flow characteristics and strives to increase horsepower and torque.

***Intake Port Volume*—**When choosing a cylinder head, pay attention to intake port volume. This is a major factor in the horsepower and torque range, depending on the application. You can basically divide the port volume factor into two groups: street/strip and racing.

The smaller the cross section of the intake port, the more you enhance torque. As you increase port volume, you gain more at wide-open throttle and at top-end. A smaller cross section increases velocity, and a large cross section allows more flow at higher rpm.

Engine displacement also factors in. As engine displacement increases, the more you can take advantage of greater port volume.

Don't purchase a set of cylinder heads based on big numbers. A cylinder head that features large port volume can result in a boggy engine when operated at low rpm on the street. Bigger may be better for racing use, but too-large intake port cross sections on a street application may not allow the engine to produce power where you want it. Choose the head based on the application…you want to maximize power based on how you drive the vehicle. Smaller port volume, more low-end torque. Bigger port volumes, more power as you open then engine up under throttle.

On average, with the correct cylinder head selection, you can expect a horsepower increase in the 20–40 hp range, but that's speaking in very general terms, since other variables come into play, including, as mentioned earlier, displacement and port volume, but also camshaft profile.

***Matched Head Kits*—**Here are a few examples of a matched cylinder head kit (I'll cite a few Trick Flow packaged kits for illustrative purposes (kits include pushrods and Harland Sharp roller rocker arms, along with GM gaskets). When choosing a camshaft to compliment your new cylinder heads, you can refer to these kits as a general guide.

For LS1/LS6 5.7L: The TFS-K306-485-460 kit includes TFS-3060T001-C01 heads with 215cc port volume (intended for the LS1/LS6), along with a camshaft featuring 0.560" intake and exhaust lift, and duration of 216 deg intake and 220 deg exhaust @ 0.050", which will produce 485 hp and 460 ft-lb of torque.

The TFS-K306-500-460 kit includes the same cylinder head, along with a camshaft profile that features 0.575" intake ands exhaust lift and 220/224 deg duration @ 0.050", to obtain 500 hp and 460 ft-lb of torque.

Kit TFS-K306-515-460 kit includes the same cylinder head, with a camshaft that provides 0.585" intake and exhaust lift, and duration of 228/230 deg @ 0.050", for 515 hp and 460 ft-lb of torque.

LS2 Cylinder Head Specifications

GM part number:	12564825
Combustion chamber vol.:	64.5cc
Intake port volume:	210 cc
Exhaust port volume:	70cc
Max. valve lift:	0.570"
Block deck flatness:	0.003" (within 6.0" area; 0.004" overall length max)
Intake manifold deck flatness:	0.0031"
Exhaust deck flatness:	0.005"
Intake port type:	Cathedral
height:	4.732" (deck to rocker cover seal surface)
Valve angle:	15 degrees

OE Valvetrain Specifications

Rocker arm ratio:	1.70:1
Rocker type:	investment cast, roller trunnion
Valve lash net:	No adjustment
Valve dia.:	2.00" int/1.55" exh
Valve guide material:	powdered iron
Valve guide separation:	1.913"
Valve seat angles:	30/45/60 degrees
Valve face angle:	45 degrees
Valve seat angle:	46 degrees
Valve seat runout:	0.002" (max)
Valve seat width (int):	0.0400"
Valve seat width (exh)	0.0700"
Valve stem dia.:	0.315"
Valve stem clearance (int):	0.001–0.0026"
Valve stem clearance (exh):	0.001–0.0026"
Oil seal installed height:	0.712–0.752"
Valve spring free length:	2.080"
Valve spring pressure closed:	76 lb @ 1.800"
Valve spring pressure open:	220 lb @ 1.320"
Spring installed height (int):	1.800"
Spring installed height (exh):	1.800"
Valve guide installed height:	0.682" (from spring seat surface to top of valve guide)
Roller lifter dia.:	0.700"
Valve material:	stainless steel/hollow stems/Na filled exhaust

For the LS2 6.0L, kit TFS-K306-550-470 includes the TFS-3060T001-CO2 heads (225cc port volume). The camshaft features an intake and exhaust lift of 0.595", a duration of 238/242 deg @ 0.050", for a whopping 550 hp and 470 ft-lb of torque.

As far as cylinder head chamber volume is concerned, it should be obvious (all other things being constant) that smaller chambers provide more compression and larger chambers provide less

Project LS2 Heads

While the OE LS6/LS2 cylinder heads are just fine for a stock or mild power build, for Project LS2 build, I chose a pair of fully assembled Trick Flow aluminum GenX street/strip heads, which are fully CNC-ported for optimum airflow. The clever boys at Trick Flow spent quite a few hours developing these heads to maximize horsepower and torque for the LS engine, both in computer mapping and dyno cell testing.

During the development stage of the Trick Flow GenX street/strip CNC-ported cylinder heads, Trick Flow engineers determined that the valve angles needed to change from the stock 15 degrees to 13.6 degrees in order to decrease valve shrouding, increase mid-lift airflow, and to improve rocker arm-to-valve-cover clearance. Testing also proved that relocating the spark plugs in the combustion chambers further enhanced mid-lift airflow and increased rigidity of the casting for extreme horsepower applications. Additional material was also added to the rocker arm mounting points for high-rpm valvetrain stability.

These fully CNC-ported performance cylinder heads feature 215cc (LS1), 225cc (LS2) or 235cc (LSX) intake runners, 80cc exhaust runners, 64cc (LS1), 65cc (LS2) or 70cc (LSX) combustion chambers, 2.040" (LS1), 2.055" (LS2) or 2.080" (LSX) intake valves, 1.575" (LS1/LS2) or 1.600" (LSX) exhaust valves, bronze valve guides and ductile iron intake and exhaust valve seat inserts. Assembled heads include 1.300" dual valve springs (for hydraulic roller camshafts up to 0.600" of valve lift), Viton fluoroelastomer canister-style valve seals, 7 degree machined steel valve locks and 7 degree titanium retainers.

Note: While the official recommended valve lift limit is listed at 0.600", Trick Flow engineers told me that my 0.624" valve lift cam will be fine, providing that I check valve to piston clearance during the build, which I would naturally do as a matter of course. With these Trick Flow heads, the recommended limit of 0.600" is a "safe" figure for novice engine builders who might not think to check their clearances. Beyond 0.600" valve lift, you need to check. Keep in mind that the safe limit for OE LS2 heads is about 0.540" total valve lift in terms of valve to piston clearance.

Project LS2 Cylinder Head Specs

Trick Flow P/N TFS-3060T001-C02

Note: Trick Flow heads TFS-3060T001-C01 has an intake port of 215cc and TFS 3060T001 has an intake port volume of 220cc; otherwise specs are the same as below.

Material:	A356-T61 aluminum
Combustion chamber vol.:	65cc
Intake port vol.:	225cc
Intake port dimensions:	3.250"x1.070" (cathedral)
Intake port location:	stock
Intake valve diameter:	2.055"
Intake valve angle:	13.5 degrees
Intake valve seat:	iron, 2.125"x1.800"x0.375"
Intake valve length:	124.45mm
Intake valve stem dia.:	8mm
Exhaust port volume:	80cc
Exhaust port dimensions:	1.460" x 1.670" oval
Exhaust port location:	stock
Exhaust valve dia.:	1.575"
Exhaust valve angle:	13.5 degrees
Exhaust valve seat:	iron, 1.625"x1.280"x0.375"
Exhaust valve length:	124.45mm
Exhaust valve stem dia.:	8mm (0.314960")
Valve guide material:	bronze alloy (int & exh)
Valve guide length:	2.000"
Valve guide clearance:	0.0012" int / 0.0016" exh
Valve seals:	Viton flouroelastomer canister
Valve seat angles:	37 deg x 45 deg x 60 deg
Valve spring pocket dia.:	1.480"
Valve spring I.D. locators:	1.300"
Valve spring retainers:	7 degree x 1.300" O.D. titanium
Valve stem locks:	7 degree machined steel
Valve springs:	1.300" O.D. double spring 150 lb @ 1.800" installed height 438 lb @ 1.200" open 448 lb per inch rate 0.600" maximum valve lift
Milling specifications:	angle mill 0.008" per cc flat mill 0.006" per cc
Pushrod length:	longer than stock required
Rocker arm type:	roller rocker arms only
Spark plugs:	NGK 4177
Assembled head weight;	24.5 lb

Flow Specs

Lift	Intake Flow (cfm)	Exhaust Flow (cfm)
0.100"	68	55
0.200"	142	115
0.300"	220	185
0.400"	279	230
0.500"	316	251
0.600"	338	259

Trick Flow offers several cylinder head configurations for LS applications. Shown here is their TFS-3060T001-C02 with cathedral intake ports. Actually, this is the cylinder head model that I used for my sample LS build that produced 625.4 hp.

compression. Factors that must be considered include bore diameter and piston dome volume. For specific examples of cylinder head chamber volume in combination with piston dome volume and resulting compression ratios, refer to the JE Pistons specification chart in Chapter 6.

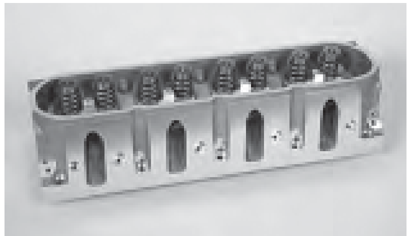
Trick Flow Cylinder Heads

TFS-3060T001-C02—Gen X street/strip CNC-ported cylinder head for LS2. 65cc chambers, 225cc intake runners. Fully assembled. Cathedral intake ports, oval exhaust ports. Valves 2.02" intake and 1.575" exhaust. Maximum valve lift 0.600". Spring O.D. 1.300". Dual springs. Titanium retainers Valve angles 13.50 degrees. Valve seats ductile iron. Bronze valve guides. Steam holes not drilled. This is the head I used in the 625.4 hp Project LS2 build featured throughout this book.

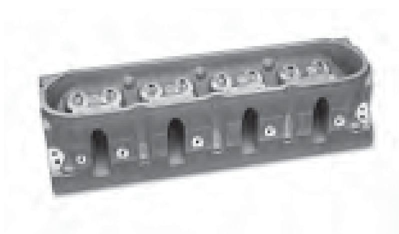
TFS-3061B001-C02—Gen X street/strip head, bare (not assembled) for LS2. CNC-ported with 65cc chambers, 225cc intake runners and 80cc exhaust runners. Cathedral intake ports and oval exhaust ports. 2.055"/1.575" valves. Valve angle 13.50 degrees on both intake and exhaust. Ductile iron valve seats are not machined.

TFS-3061T001-C02—Gen X street/strip head for LS2. Fully assembled. 65cc chambers, 225cc intake and 80cc exhaust runner volumes. Cathedral intake ports. 2.055" intake and 1.575" exhaust valves.

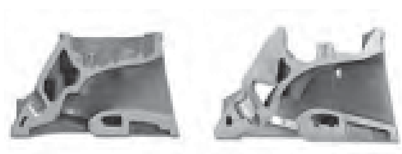
TFS-30500001-C00—Gen X street CNC-ported. For LS1/LS6. 58cc chambers, 205cc intake runners and 80cc exhaust runners. Cathedral intake ports and D-shaped exhaust ports. Valves 2.000"/1.575". Fully assembled. Chromoly retainers. Powdered metal valve guides. Steam holes not drilled.



Dart offers two choices in LS heads: Machined from billet stock or precision as-cast versions. Shown here is the CNC machined billet head. Courtesy Dart Machinery.



Shown here is the as-cast Dart Pro 1 head. The high-precision casting offers high flow and performance without the cost of a billet machined product. Courtesy Dart Machinery.



At left is a cross section of an OE LS1 head intake port. At right is a Dart Pro 1. The big differences are the size of the ports, the shape of the ports (note the step in the OE port near the guide boss) and the amount of material Dart added to the top to strengthen the spring seat area and allow for upgraded valvetrain modifications. Courtesy Dart Machinery.

TFS-3050T001-C00—Gen X street CNC-ported, fully assembled. LS1/LS6. 58cc chambers, 205cc intake and 80cc exhaust runners. Cathedral intake ports and D-shaped exhaust ports. Intake valves 2.000" and exhaust valves 1.575". Titanium retainers, powdered metal valve guides, ductile iron valve seats.

TFS-30510001-C00—Gen X street CNC-ported. For LS1/LS6. Fully assembled. 58cc chambers, 205cc intake and 80cc exhaust runners. Cathedral intake ports and D-port exhaust. Valves 2.000"/1.575". Chromoly retainers. Powdered metal valve guides.

Dart Pro 1

Pro 1 LS1 aluminum small-block cylinder heads. Cast from virgin 355-T6 aerospace aluminum and CNC machined. Cathedral intake ports. Radiused exhaust seats and CNC machined valve bowls. Manganese bronze valve guides. Extra thick walls

Dart Pro 1 Specs

P/N	Material	Port Volume	Chamber Volume	Int/Exh Valve	Spring Diameter	Notes
11010010	Aluminum	205	62	2.02/1.60	n/a	Bare casting
11011112	Aluminum	205	62	2.02/1.60	1.290	Assembled
11020020	Aluminum	225	62	2.05/1.60	n/a	Bare casting
11021122	Aluminum	225	62	2.05/1.60	1.290	Assembled
CNC Pro 1						
11071040	Aluminum	250	68	2.08/1.60	n/a	Bare casting
11071142	Aluminum	250	68	2.08/1.60	1.290B	Assembled
11071143	Aluminum	250	68	2.08/1.60	1.290D	Assembled

Warhawk 12-Degree LS7 Specs

Casting number :	WOR-076A
Material:	355-T6 alloy
Valve seats:	Hardened (int & exh)
Valve guide:	Manganese bronze
Spring seats:	Machined for 1.560" (can be machined to 1.625")
Valves:	Manley stainless steel
Valve diameter:	2.20" int/1.60" exh (5/16" stem)
Rocker arms:	Stock LS7 rockers and integral stands
Intake runner:	285cc, standard port location
Exhaust ports:	106cc, standard location
Combustion chamber:	64cc or 72cc
Spark plug:	14mm, 0.750" reach, gasket style
Valve job:	Multi-angle intake and radiused exhaust
Valve cover rail:	Raised 0.346" for aftermarket valvetrain
Valve angle:	Stock 12-degree
Accessory bolt holes:	Stock locations

Warhawk 12-Degree LS7 Part Numbers

025350	Warhawk 285cc bare head, 64cc, no valve job
025350-2	Warhawk 285cc assembled head, 1.437" dual springs, hyd. roller or solid flat tappet, max lift 0.600"
025350-3	Warhawk 285cc assembled head, 1.550" dual springs, solid roller, max lift 0.700"
025350C	Warhawk 296cc CNC ported vare head, 72cc chambers
025350C-2	Warhawk 296cc, CNC ported assembled head, 72cc chambers, 1.437" dual springs, hyd. Roller or solid flat tappet, max lift 0.600"
025350C-3	Warhawk 296cc assembled head, 1.550" dual springs, solid roller, max lift 0.700"
025400	Warhawk 285cc bare head, 72cc chambers, no valve job
025400-2	Warhawk 285cc assembled head, 1.437" dual springs, hyd. roller or solid flat tappet, max lift 0.600"
025400-3	Warhawk 285cc assembled head, 1.550" dual springs, solid roller, max lift 0.700"

for porting. Additional material above ports allow valvetrain modifications. Intake valve diameters are matched to port volumes (2.02 for 205cc ports and 2.05 valves for 225cc intake ports). Optimized 85cc exhaust ports (15cc larger than stock) and 1.60" exhaust valves for quick scavenging. Accommodates all OE accessories. Assembled heads include stainless steel valves, valve springs, retainers, locks and seals.

The 205cc (intake port volume) cylinder heads are best suited to the LS1/LS6, with the 225 and 250cc heads targeted for 6.0L and larger displacement (the 250cc head would be ideal for the LS7 7.0L). These heads offer bolt-on compatibility, featuring standard valve angles and spacing.

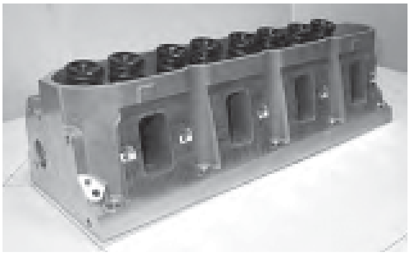
Note: B = beehive spring, D = double springs

World Products Warhawk 12-Degree LS7

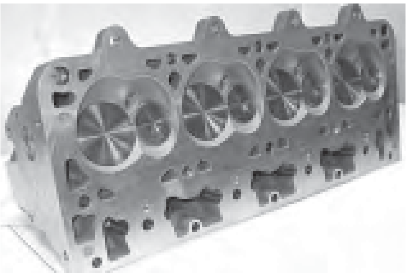
The Warhawk 12-degree LS7 head features gigantic 285cc intake runners and 106cc exhaust runners for outrageous flow. CNC ported versions are also available that feature 296cc intake and 110cc exhaust runners. These heads are available as bare castings or as complete, race-ready assemblies that feature stainless steel Manley 2.200" intake and 1.600" exhaust valves, high performance dual springs and Manley chromoly retainers. The heads can accommodate 1.625" diameter valve springs and valves with an overall length of 5.500". This cylinder head also features two extra bolt holes per cylinder to provide extra sealing/clamping load to suit higher combustion pressures, such as in extreme compression ratios or when used with forced air (turbocharger or supercharger).

Warhawk 15-Degree LS1, LS6, LS2

This head is intended for use with the 5.7L LS1/LS6 and the 6.0L LS2. The larger-than-stock 235cc intake runners provide outstanding flow. A choice of either 64cc or 72cc combustion chambers



World Products offers rectangular intake port LS heads, in addition to cathedral-port versions. Courtesy World Products.



A view of World Products' LS1 combustion chambers. Courtesy World Products.

is offered, depending on your compression ratio intention. This head is also available with full CNC porting and an increased intake runner volume of 255cc for competition use. Heads are available as either bare castings or as fully assembled units equipped with Manley stainless steel valves, high performance springs and chromoly retainers. The 235cc version would be a good choice for street/strip applications, and the 255cc version is likely better suited for competition use.

AirFlow Research (AFR) LSX Mongoose Strip (LS1, LS6, LS2)

With its large port volume, this head is best suited for racing applications. All AFR heads feature the cathedral intake port design. The 245cc head is intended for larger displacement combinations in the 415 to 454 cid range, with a minimum bore diameter of 4.060". This head requires a head gasket bore of at least 4.200". Larger intake valves feature a head diameter of

Warhawk 15-Degree Specs

Casting number:	WOR-075
Material:	355-T6 alloy
Valve seats:	Hardened
Valve guides:	manganese bronze
Spring seats:	machined for 1.560"
Valves:	Manley stainless steel
Valve diameter:	2.080" int, 1.600" exh, 5/16" stems
Rocker arms:	Stock LS1 with stock stands
Intake runner:	235cc, standard port location
Exhaust ports:	87cc, standard location
Combustion chamber vol.:	64cc or 72cc
Spark plug:	14mm, 0.750" reach, gasket style
Valve job:	Multi-angle intake and radiused exhaust
Valve cover rail:	Raised 0.300" for aftermarket valvetrain
Valve angle:	Stock 15-degree
Accessory bolt holes:	Stock locations

Head Flow @ 0.800" Lift
305 int/212 exh (Super Flow 1050)
328 int/229 exh (Super Flow 600)

CNC Ported @ 0.800" Lift
330 int/243 exh (Super Flow 1050)
352 int/229 exh (Super Flow 600)

Warhawk 15-Degree Part Numbers

025150	Warhawk 235cc bare head, 64cc chambers
025150-2	Warhawk 235cc assembled head, 1.437" dual springs, hyd. roller or solid flat tappet, max lift 0.600"
025150-3	Warhawk 235cc assembled head, 1.550" dual springs, solid roller, max lift 0.700"
025150C	Warhawk 255cc CNC ported bare head, 72cc chambers
025150C-2	Warhawk 255cc CNC ported assembled head, 1.437" dual springs, hyd. roller or solid flat tappet, max lift 0.600"
025150C-3	Warhawk 255cc CNC ported assembled head, 1.550" dual springs, solid roller, max lift 0.700"
025250	Warhawk 235cc bare head, 72cc chambers
025250-2	Warhawk 235cc assembled head, 1.437" dual springs, hyd. roller or solid flat tappet, max lift 0.600"
025250-3	Warhawk 235cc assembled head, 1.550" dual springs, solid roller, max lift 0.700"

AFR 245cc Mongoose Strip Specs

Intake port:	Cathedral
Intake port volume:	245cc
Exhaust port volume:	87cc
Combustion chambers:	64cc or 72cc
Valve diameters:	2.160" int, 1.600" exh
Spring pockets:	1.570"
Head deck thickness:	0.750"
Valve guides:	Bronze
Retainers:	7-degree 1.250"
Titanium	
Bead lock keepers:	7-degree
Valve seals:	Viton
Suggested manifold:	LS6 or FAST TPIS
Valve spacing:	Stock
Rocker arms:	Stock
Valve angle:	Stock
CNC ported chambers	
CNC intake and exhaust ports	
Three-angle radiused valve job	

2.160" (exhaust valves remain at 1.600"). Desgined for racing purposes as opposed to street duty, the 245cc head will accommodate solid roller cam operation and will accept larger diameter 0.375" pushrods with no additional clearancing required. Spring pockets are 1.570" in diameter. According to AFR, with an "aggressive" setup, this head is capable of producing in the range of 700 hp while providing plenty of low and mid-range torque.

AFR 225cc Mongoose Strip

This is a max-performance street/strip head (still emission-legal), also applicable to LS1/LS6/LS2 blocks. Ideal for normally aspirated 396 cid to 427 cid builds. According to AFR, this head is also a killer choice for a wild 346 cid build, although some low rpm torque loss may result. Combustion chambers, intake and exhaust ports are fully CNC ported. If you want to absolutely humiliate the local Cobra Mustang, this is a good choice. Assembled heads feature 2.080" intake and 1.600" exhaust valves and titanium retainers. Springs feature a 1.270" diameter seat and will accommodate up to a 0.650" max valve lift.

AFR 215cc Mongoose Street

This cylinder head is designed specifically to maximize 4" bore combinations in the 364 to 408 cid range, and is also recommended for longer stroke applications in the 415 to 430 cid range. This head is intended as a maximum street performance piece as opposed to all-out competition (where 225cc & larger intake runner volume is more applicable). The 215 head, regardless of cylinder bore diameter, requires the use of a head gasket that features a 4.135" gasket bore. In short, if you want to pull away from your local Mustang Cobra pest, the 205cc head will accomplish the task. If you want the Cobra to disappear, go with the 215cc head. By the way, AFR

AFR 225cc Mongoose Strip Specs

Intake port:	Cathedral
Intake port volume:	225cc
Exhaust port volume:	85cc
Combustion chambers	62cc, 65cc, or 72cc
Valve diameters:	2.080" int, 1.600" exh
Spring pockets:	1.250"
Head deck thickness:	0.750"
Valve guides:	Bronze
Retainers:	7-degree 1.250"
Titanium	
Bead lock keepers:	7-degree
Valve seals:	Viton
Suggested manifold:	LS6 or FAST TPIS
Valve spacing:	Stock
Rocker arms:	Stock
Valve angle:	Stock
CNC ported chambers	
CNC intake and exhaust ports	
Three-angle radiused valve job	

AFR 215cc Mongoose Street Specs

Intake port:	Cathedral
Intake port volume:	215cc
Exhaust port volume:	84cc
Combustion chambers:	68cc or 74cc
Valve diameters:	2.020" int/1.600" exh
Spring pockets:	1.250"
Head deck thickness:	0.750"
Valve guides:	Bronze
Retainers:	7-degree 1.250"
Titanium	
Bead lock keepers:	7-degree
Valve seals:	Viton
Suggested manifold:	LS6 or FAST TPIS
Valve spacing:	Stock
Rocker arms:	Stock
Valve angle:	Stock
CNC ported chambers	
CNC intake and exhaust ports	
Three-angle radiused valve job	

recommends the use of the FAST intake manifold (if you retain fuel injection, of course).

AFR 205cc Mongoose Street

This head is designed for use with the LS1, LS6 or LS2 block, and is intended for street performance. The 205cc intake runner volume (same as the stock LS1 head) creates increased port velocity as compared to the OE head. Head deck thickness is a generous 3/4", ideal for nitrous or blown applications. Rocker stud bosses are reinforced for greater valvetrain stability at extended rpm. Basically, this is a little street killer.

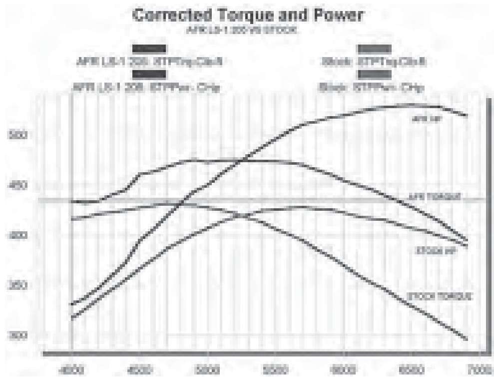
Hydraulic roller cams in LS engines typically experience valve float at about 6600–6800 rpm. If you plan to run aftermarket roller rockers and/or a camshaft that features more than 0.600" valve lift, you'll need to upgrade the valve springs (AFR recommends its #8019 spring or equivalent with a closed pressure of 155 lb and open pressure of 410 or more).

The smaller port volume increases torque for street performance. During a dyno test conducted by AFR, this head (along with a cam and intake upgrade) showed a 102 hp increase over a stock LS1. The baseline engine was a stock LS1 equipped with 1.75" long-tube headers and 3" Flowmaster mufflers. In this form, the engine pulled 428 hp at 5700rpm and 432 ft-lb of torque at 4700 rpm. With the upgrade to the 205cc AFR heads, a FAST intake manifold equipped with a 78mm ported throttle body and a camshaft featuring .581 lift (int/exh) and duration of 224/228 deg, the engine pulled 530 hp at 6500 rpm and 475 ft-lb of torque at 4900 rpm.

Pro-Filer Products LS1/LS6 Racing

Pro-Filer tends to concentrate on serious track applications as opposed to daily drivers that cruise the local ice cream stand. Their LS1/LS6 racing cylinder heads are available with or without water jackets ("solid" heads with no water jackets are intended for drag racing where optimum rigidity is required and where runs are limited to short drag runs). Intake runner volume is offered in either 215cc, 225cc or 235cc. The cylinder head deck thickness features a 1/2" thick mass, to better accommodate nitrous or blown applications.

These heads, though applicable to an LS2, are specifically designed for maximum performance on the LS1/LS6 5.7L versions. By the way, Pro-Filer offers a matching cast intake manifold designed to work with these heads, dubbed their Nitrous Express LS1 that is already set up for individual cylinder nitrous injection. These heads are as-cast and equivalent to CNC ported heads. Both bare and assembled heads are offered. Assembled heads feature bronze guides and seats, stainless steel 2.055" intake valves and 1.600" exhaust valves, steel retainers and high-pressure springs.



This dyno data graph compares a stock LS1 to the same engine equipped with the AFR 205cc cylinder head, along with a camshaft and intake manifold upgrade. This a a good example of how a simple head/cam/intake upgrade can add as much as 100+ hp to an otherwise stock LS engine.

AFR 205cc Mongoose Street Specs

Intake port:	Cathedral
Intake port volume:	205cc
Exhaust port volume:	84cc
Combustion chambers:	66cc or 76cc
Valve diameters:	2.160" int, 1.600" exh
Spring pockets:	1.250"
Head deck thickness:	0.750"
Valve guides:	Bronze
Retainers:	7-degree 1.250"
Titanium	
Bead lock keepers:	7-degree
Valve seals:	Viton
Suggested manifold:	LS6 or FAST TPIS
Valve spacing:	Stock
Rocker arms:	Stock
Valve angle:	Stock
CNC ported chambers	
CNC intake and exhaust ports	
Three-angle radiused valve job	

Pro-Filer Products LS1 Specs

Block use:	LS1 or LS6
215cc intake port volume	
Bronze guides	
215cc airflow at 0.900" lift	
Available in 225cc or 235cc intake port volume	
Equivalent to CNC ported heads as-cast	
Material:	A356 aluminum
Valve angle:	Standard
Bore spacing:	Standard
Combustion chamber:	62cc
Intake port flow:	215cc/308cfm; 235cc/341cfm
Intake valve diameter:	215cc/2.02"; 235cc/2.08"
Deck thickness:	0.500"
Spark plugs:	14mm, 0.750" reach, gasketed
Recommended manifold:	Pro-Filer Nitrous Express LS1
Gasket requirement:	Standard
Valve cover:	Standard
Piston application:	Standard (check valve clearance)
Rocker application:	Standard, Jesel or T&D

Edelbrock RPM Xtreme LS1/LS6/LS2 Specs

Combustion chamber: 65cc
Intake runner: 212cc
Exhaust runner: 76cc
Valve diameter: 2.02" int, 1.57" exh
Valve guides: Manganese bronze
Deck thickness: 5/8"
Valve spring dia.: 1.55"/1.30"
Valve spring max lift: 0.600"
Pushrod dia.: 5/16"
Valve angle: 15-degree
Exhaust port location: Stock
Spark plug: 14mm, 0.750" reach, OE tapered seat

Edelbrock rpm Xtreme LS-series as-cast cylinder head features CNC porting in chambers, intake entry, exhaust exit and intake/exhaust bowls. Courtesy Edelbrock.

Edelbrock Performer RPM CNC

The Performer RPM CNC head was developed jointly by Edelbrock and Lingenfelter. It will provide good horsepower and torque up to the 6500 rpm range. Heads feature extra thick decks for increased rigidity and extra material in the spring pockets for compatibility with high-pressure springs and high-lift cams. This is a good choice for street performance 5.7L LS1 and LS6 engines. The Performer RPM is designed for use with 5/16" pushrods and feature 65cc combustion chambers and 203cc intake runner volume. Fully assembled heads feature 15-degree 2.02" intake valves and 1.57" exhaust valves, and 1.55" valve spring diameters.

Edelbrock RPM Xtreme LS1/LS6/LS2

The RPM X is a hotter, completely CNC-machined head for street/strip applications that delivers improved airflow, hp and torque. The deck is extra thick at a healthy 5/8", and Heli-Coil thread inserts are installed for long-term durability. High-quality beehive springs are secured with steel retainers and locks and will accommodate valve lift up to 0.600". Another feature worth noting is that these heads are machined to accept either center-bolt or perimeter-style valve covers, which is a nice touch. These heads are available bare or fully assembled.

Edelbrock Victor LS-R Series

Adaptable to all LS blocks. Pro-Port Raw cylinder head. Requires CNC porting and full professional preparation. Seats and guides are included but not installed.

The LS-R head was designed for custom-fitting to GM's race LSX block (or comparable aftermarket blocks). Intake runners are raised and valve have been relocated for all-out competition engine applications. This head also requires the use of the SB2 style valve cover because of the head's canted valve layout. Combustion chamber size is a tight

25cc, which can be increased to accommodate individual compression ratio requirements. Valve diameter requirements include 2.25" intake and 1.68" exhaust. These are all-out race heads and are not intended for street use.

Edelbrock LS1 Pro-Port Raw

This is a bare, unported version of the Edelbrock/Lingenfelter LS1 head. Fits 1997 and later LS1, LS6 and LS2 blocks. These are raw castings, requiring full professional machining. This allows a professional engine machinist to create exact chamber volume and port dimensions.

Edelbrock Victor LS-R Specs
24-degree canted valve design
Requires use of GM SB2 valve cover style
Stock exhaust bolt pattern
Raw combustion chamber volume: 24cc
Intake port dimensions: 1.32" x 1.97"
Exhaust port dimensions: 1.55" x 1.30"
Valves: 2.25" int/1.68" exh

Edelbrock LS1 Pro-Port Specs
Raw chamber volume: 38cc
Intake port dimensions: 0.82" x 2.80"
Exhaust port dimensions: 1.41" x 1.02"
Valve sizes: 2.08" int/1.64" exh

Chapter 4

Bore & Stroke Combinations

A crankshaft's stroke dimension refers to the total stroke, from the rod pin's BDC (bottom dead center) to TDC (top dead center) positions. When selecting a stroker combination (crankshaft, connecting rods and pistons), remember that you only factor in one half of the crankshaft's published stroke dimension. The distance from the centerline of the crank rod pin at TDC, plus rod length plus piston compression distance is the length package that must fit within the block's available deck height dimension. Pictured here is a forged 4.000" stroker crankshaft from Lunati. This crank, coupled with Lunati connecting rods featuring a 6.125" length and JE pistons featuring a compression distance of 1.115" was used in a factory LS2 block that was square-decked to a deck height of 9.234" to achieve 403.13 cid with 4.005" cylinder bores. With that stroke/rod/piston combo, our pistons protruded above the decks by 0.006", which was more than compensated for by using cylinder head gaskets with a crushed thickness of about 0.045".

Increasing an engine's displacement is one way to increase power. This can be accomplished by either increasing the cylinder bore diameter or increasing the crankshaft's stroke length, or a combination of the two.

Stroke refers to the travel distance of the crankshaft's rod journal relative to the crankshaft's main centerline. By travel distance, we're referring to the distance the center of the rod journal moves in relation to the crankshaft centerline at both the pistons; top dead center location and the bottom dead center location (full up plus full down). The measured distance from the crankshaft centerline to the rod journal centerline will represent half of the stroke length. This is a common misconception among novice engine builders. When someone buys a 4.000" stroke crankshaft, they may think that the centerline of the rod journals will be positioned 4.000" from the crankshaft main bore centerline. If they attempt to measure the offset distance of the rod journal, misguided folks often assume that they purchased the wrong crank, since they're only seeing about 2.000" of offset. Just remember that the stroke length includes total stroke during a 180-degree rotation of the crank.

Altering stroke length also means that you need to pay attention to connecting rod length and piston compression distance (piston compression distance, or CD, is measured from the centerline of the piston's pin bore to the piston deck). Crank stroke, rod length and piston compression distance all add up to determine where the piston dome will end up at TDC (top dead center) relative to the block deck.

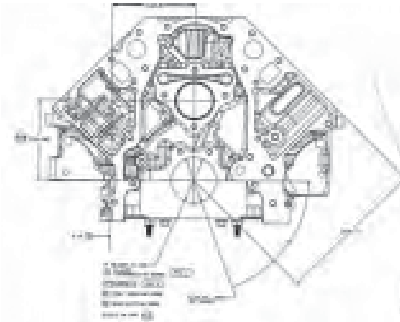
Connecting Rod Length

Connecting rod length refers to the distance from the centerline of the small end (piston wrist pin bore) to the centerline of the big end (crank rod pin bore). In order to actually measure this length, use a long-scale precision caliper. There are several choices of measuring points, but one example is to measure from inside-to-inside of the two bores, then add one-half of each bore's diameter. This is easier than it sounds.

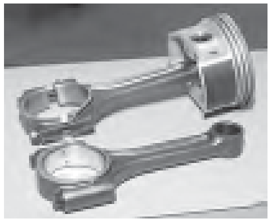
Using an inside caliper, measure from the bottom of the wrist pin bore to the roof of the big end bore (the two points of the bores that are closest to each other). Record this measurement. We'll call this measurement R1.

Next, using a bore gauge, measure the small end bore and divide that diameter by 2. Record this number (this is the radius of the wrist pin bore). We'll call this measurement S1.

Next, using a bore gauge and with the rod's big end cap installed and fully torqued to specification, measure the diameter of the big end bore and divide that number by 2. Record this number. We'll call this measurement B1.



The stroke package must fit within the confines of the block, so you must always consider the block's deck height. Deck height refers to the distance from the main bore centerline to the block's cylinder head deck surface. LS factory blocks are notorious for having unequal deck heights (high/low side to side and/or front to rear), so it's wise to first have the blocks decks surfaced in order to establish equal deck distance from the crank centerline, before choosing your stroker combination. You can probably fudge this and assume that the decks are OK, but if you want absolute precision, correct (or at least carefully measure) block deck height at all four corners (right front, right rear, left front, left rear) before spending money on rods and pistons for a stroker combo.



Factory LS1/LS6 and LS2 connecting rods are manufactured of powder metal, featuring cracked-cap design. These rods are surprisingly strong, but if you plan to build a real bruiser, or if you plan to change stroke, you'll move to an aftermarket connecting rod that features either forged or billet construction.

Today's quality aftermarket connecting rods are generally extremely precise in terms of center-to-center lengths, but it never hurts to check, especially when you're attempting to "blueprint" the build by precisely equalizing all crank-rod-pin-to-block-deck distances.

Now, simply add all three measurements together:

R1 + S1 + B1

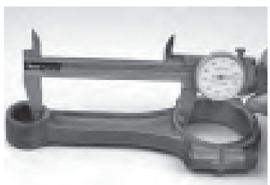
to determine rod length. Again, all we're doing is adding each bore's radius to the distance from the bottom of the small bore to the top of the big bore.

Don't try to measure a rod's length by eyeballing the bore centers in an attempt to taking only one measurement from center to center. You'll never get it right.

Aftermarket connecting rod makers do an outstanding job of making their rods precisely to the required dimensions, so if Lunati, Oliver, Crower, Scat, etc. advertises a rod at, say, 5.700", you can be sure that the dimension is as stated. However, it's always best to be as anal as possible whenever building an engine, so it's always best to double check by measuring components on your own.

Piston Compression Distance (CD)

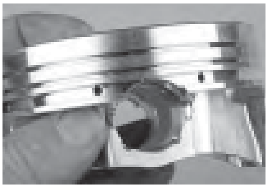
Piston compression distance (also called *compression height*) refers to the distance from the piston pin centerline to the flat surface of the piston dome. To measure this, use a caliper and measure



Using a caliper to measure from the bottom of the wrist pin bore to the top of the big end bore. To determine rod length, we then add half of the small end diameter and half of the big end diameter (wrist pin bore radius and big end bore radius).

Measuring the small end of a connecting rod. Here we use a small bore gauge. The gauge is then carefully removed and measured with a micrometer. Divide the measured hole diameter, which represents the radius.

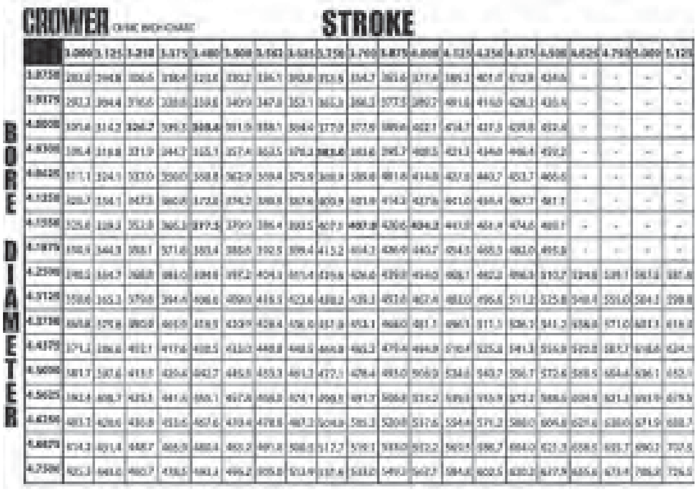
Measuring the diameter of a connecting rod's big end. Divide this diameter by 2. This represents the radius of the hole.



A piston's compression distance (CD) refers to the distance from the centerline of the wrist pin bore to the flat surface of the dome.

Here we measure from the top of the wrist pin bore to the piston dome. Add to this the radius of the pin bore to determine the piston's compression distance.

Here we use a bore gauge, adjusting it to duplicate the piston's pin bore. The snap/telescopic bore gauge is then carefully measured with a micrometer.



As an example, here's a handy bore and stroke chart (this one from Crower). By simply cross referencing the cylinder bore diameter the vertical list to the left) and the stroke (horizontal list at the top), the resulting engine displacement is found. If your particular bore and stroke isn't listed on a chart such as this, it's easy to calculate your combination by simply multiplying bore diameter x bore diameter x stroke x 0.7854 x number of cylinders. As an example using an LS2 with a stock bore of 4.000" and a stroke of, say, 4.125", final displacement would be 414.7 cid (cubic inches of displacement). Courtesy Crower.

from the top of the pin bore to the dome flat. Then, use a bore gauge to measure the pin bore diameter. Then add one-half of the pin bore dimension to the distance from the top of the pin bore to the dome.

OK…now you want to figure out what parts you'll need in terms of crank stroke, rod length and piston compression distance. To determine stroke, rod length and piston CD, you need to know the block deck height.

Block deck height (BDH) is measured from the crankshaft main centerline bore to the block deck surface.

Let's say that you want to end up with a zero deck (where the piston's flat portion of its dome is even with the block deck). You now must consider the variables of block deck height, crankshaft stroke, connecting rod length and piston CD.

In order to achieve zero deck clearance, you must consider half of the crankshaft stroke (since we're only concerned here with the TDC position of the crank's rod journals). Simply add 1/2 of crankshaft stroke to connecting rod center-to-center length plus piston CD. This final figure needs to match the block deck height in order to obtain a zero deck piston-to-block result.

Example: Let's say that we're dealing with a block that features a deck height of 9.240", and you want to stroke the engine while obtaining a zero deck clearance. You simply need to use a combination of 1/2 crank stroke plus rod length plus piston CD that equals that block deck height.

Let's say that, for this block, you'd like to use a 4.000" stroke. Since we're only using 1/2 of the stroke for this calculation, we'll use 2.000" as our stroke reference. Now, we need to come up with a rod and piston CD that together will add up to 9.240". If an available aftermarket rod is offered in a 6.125" length, then we know that the piston CD must be 1.115". The formula is:

BDH = (Stroke ÷ 2) + (rod length + piston cd)
2.000" + 6.125" + 1.115" = 9.240"

Now, let's say that the block, once corrected for deck squareness, leaves you with a block deck height of 9.234". This same combination of stroke, rod length and piston CD will result in the piston dome being placed 0.006" above the block deck. With a head gasket installed at about 0.045" thickness, this places the piston dome about 0.039" below the cylinder head deck, which still provides adequate piston to head clearance, even with a high-lift cam.

Determining Displacement

The formula to determine displacement (cid) is:

bore^2 x (stroke x 0.78540) x number of cylinders

For an example, let's use the factory stock LS2 cylinder bore diameter of 4.00" and 3.622" stroke:

cid = 4.00^2 x (3.622 x 0.7854) x 8
cid = 16.000 x 2.844 x 8
cid = 364.032 cid

The final cylinder bore diameters in the project LS2 block depicted in this book is 4.005", and the stroke of the Lunati crankshaft is 4.000". Plugging them into the formula:

cid = 4.005^2 x (4.000 x 0.7854) x 8
cid = 16.040025 x 3.1416 x 8
cid = 403.13074032

We simply round that off to 403.13 cubic inches of displacement.

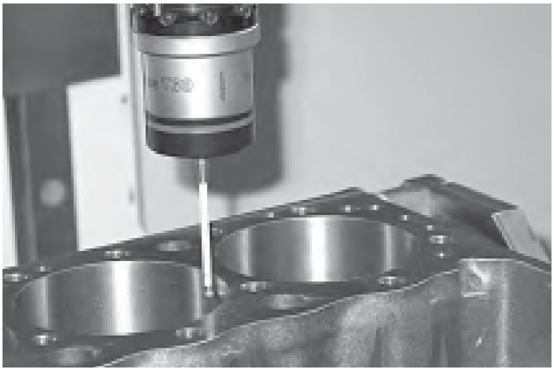
Common Bore and Stroke Combinations

Note: the LS2 block is designed as a 6.0L block, while the LS1/LS6 is a 5.7L block

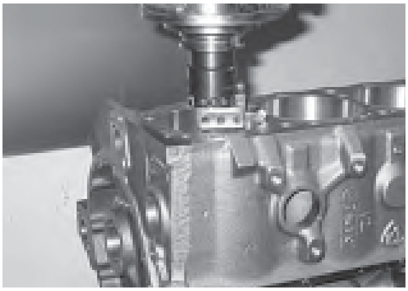
The LS2 block can safely be overbored to a maximum diameter of 4.125". A commonly available and popular stroker crank will feature a stroke of 4.000".

Bore	Stroke	Displacement (cid)
*4.000	3.622	364.12
4.005	4.000	403.13
4.030	4.000	408.18
4.060	4.000	414.28
4.125	4.000	427.65

* Stock OEM figures



If the machining is to be done on a CNC machine, prior to cylinder boring, the machine probes the cylinder wall location and existing diameter. This data is used by the machine to determine precisely where the machining will occur.



If a larger-than-stock piston diameter is selected, the cylinder bores are then machined to the appropriate oversize, less about 0.001–0.0015", with the remaining material (to achieve finished bore diameter) to be removed during cylinder honing. Here a block's cylinders are machined to rough diameter on an RMC CNC machine. By the way, boring on a CNC machine allows the engine builder to not only enlarge the bores to the desired rough diameter, but also allows him to correct the bore centerline location (if the original bore was slightly off center, and assuming the block provides enough meat to allow this…in the case of an aluminum LS block, this will be dictated by the thickness of the iron cylinder liners). Boring on a CNC enables the machinist to easily correct bore diameter, bore centerline and bore angle, correcting any off-tolerances that may exist in a factory casting.

Piston and Connecting Rod Combinations

Note: These JE piston specs are illustrative of offerings by other piston manufacturers

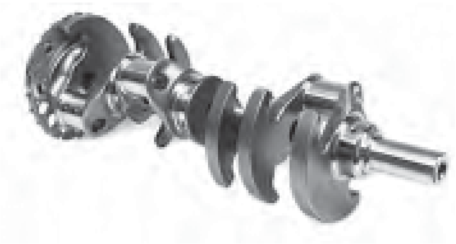
JE Piston Flat-Top

Piston P/N	CID	Bore/Stroke	Rod Length	Block Height	CD Height	Head CR 64cc/66cc/72cc	Dome
243016	403	4.005/4.000	6.125	9.240	1.115	11.6/11.3/10.6	-5.0
243017	408	4.030/4.000	6.125	9.240	1.115	11.7/11.4/10.7	-5.0
243018	427	4.125/4.000	6.125	9.240	1.115	12.1/11.9/11.1	-5.0

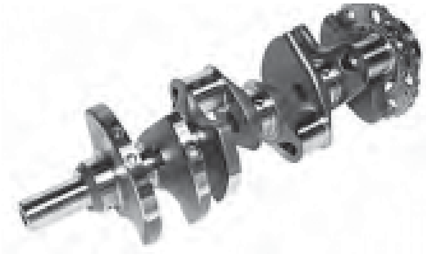
JE Inverted Dome

Piston P/N	CID	Bore/Stroke	Rod Length	Block Height	CD Height	Head CR 64cc/66cc/72cc	Dome
221176	408	4.030/4.000	6.125	9.240	1.115	9.2/9.0/8.6	-29
221178	414	4.060/4.000	6.125	9.240	1.115	9.3/9.18.7	-29
221180	427	4.125/4.000	6.125	9.240	1.115	9.59.38.9	-29
264041	383	3.905/4.000	6.125	9.240	1.115	10.5/10.3/9.7	-10
264042	403	4.005/4.000	6.125	9.240	1.115	11.0/10.7/10.1	-10
264043	408	4.030/4.000	6.125	9.240	1.115	11.1/10.8/10.2	-10

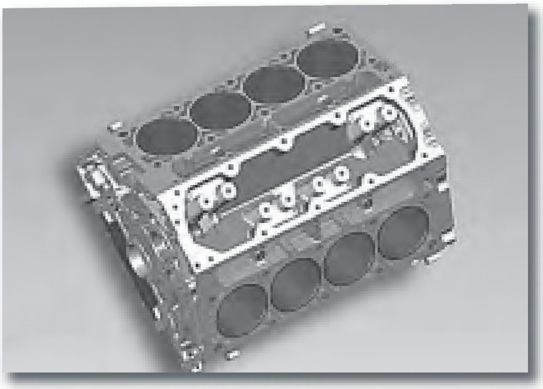
Note: All compression ratios above are calculated using a head gasket thickness of 0.042" and 0.00" deck clearance. The pistons listed above are designed to accommodate 1.5, 1.5 and 3mm rings. The inverted dome pistons shown here are designed to accommodate optimum compression ratios with forced induction applications such as turbocharging or supercharging.



Here's an example of an exotic racing crankshaft from Callies. Specifically for high-buck racing LS applications, Callies offers the Magnum XL in strokes ranging from 2.600" to 4.300", and with rod pin diameters including 2.100" (stock diameter), 2.000", 1.888" and 1.850" (for builders who want to use smaller diameter big end rods for lighter weight and reduced mass). Both LS1/LS6 and LS2/LS7 tone wheels are available. The Magnum XL features radically reduced counterweight mass, weighing in at a mere 34 to 47 lb. That's light. Callies refers to this crank as their "weapon of mass reduction."



When ordering an aftermarket crankshaft, remember that the reluctor wheel (also called a tone wheel) is needed for crank position sensor signaling. The tooth count varies between LS1/LS6 and LS2/LS7/LS3/LS9 applications (24x or 58x).



Overhead CAD engineering illustration of the 6.0L LS2 block. Courtesy GM.

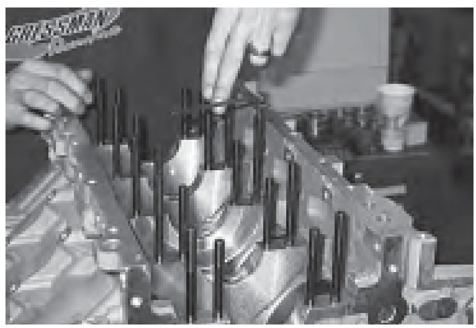
Chapter 5

Cylinder Block Prep

Block preparation begins with a clean bare block. If the block is used, it needs to be thoroughly washed before any machining takes place. This needs to be done in a shop's hot tank or hot pressure washer.

Main bore alignment should be checked first, along with main bore out of round. If corrections are needed, a main bore align honing can easily be accomplished on a main bore honing machine. LS2 main bores should be finished at 2.750–2.751" diameter.

Other block dimensions that must be checked include deck height (centerline of the main bore to the RH and the LH deck surfaces [at both front and rear]), head deck alignment, checking for front-to-rear alignment and inboard-to-outboard alignment. Basically, the head decks need to be parallel to the main bore (front to rear) and 90 degrees to the main bore centerline from inboard to outboard deck surfaces. Cylinder bores need to be checked for diameter (top to bottom, checking for bore taper and out of round), and centerline location as well (bore centerline placed correctly according to "blueprint" specifications). Lifter bores should also be checked, both for bore diameter and bore placement/angle. In addition to simply meeting desired bore diameters (main bore, cylinder bores, lifter bores) and deck flatness, if we're doing a performance build, we want to correct as many deviations as possible that may exist on a factory mass-produced production block.

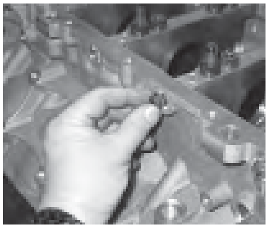


Before checking the main bore, we install the main cap fasteners that will be used for final assembly. Shown here are ARP main cap studs. Decide on the main cap fasteners from the beginning, and stick with them throughout the machining, test fitting and assembly steps, whether you opt for studs or bolts. Try to avoid changing them mid-stream, as this could possibly affect main bore geometry. So, if you currently have old OE bolts but are thinking of upgrading to high performance bolts or studs at some point during the build, don't delay…use the desired main cap fasteners from the very beginning. Here the ARP studs are lightly snugged with a hex wrench to a value of about 4 ft-lb. Don't get carried away and try to tighten studs…they should be finger-tight or lightly snugged only. Studs do not need to be tightened to a high torque value! You'll achieve clamping loads as you tighten the nuts.

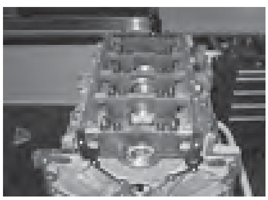
With main studs in place, the main caps are re-installed.

Tighten the main cap side bolts to specified value (the values will differ depending on the use of oil or moly).

With main caps fully installed, main bores are checked individually for size/roundness consistency. This check reveals need for resizing corrections at each main bore location.

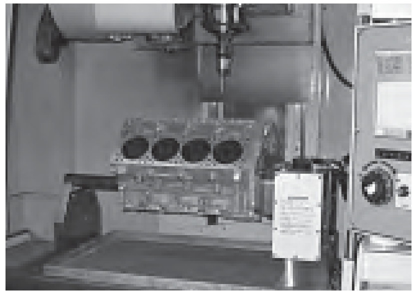


If you're using main cap primary bolts, first coat the bolt threads and underside of the heads with oil or moly. If using studs, apply oil or moly to the exposed stud threads, nut threads and underside of the nuts. Once the primary 10mm main cap fasteners are torqued to value, coat the threads and the underside of the bolt heads of the side cap bolts with oil or moly.



With all main cap fasteners tightened to specified torque value, the block is now ready to be measured and machined.

Scott Gressman of Gressman Powersports finalizes his check of main bore dimensions.



Here the block is mounted to an RMC CNC machine for block machining. This will permit cylinder bore oversizing, and if needed, lifter bore correction, cylinder bore centerline correction, main bore geometry correction and deck height and squareness correction, all in one setup.

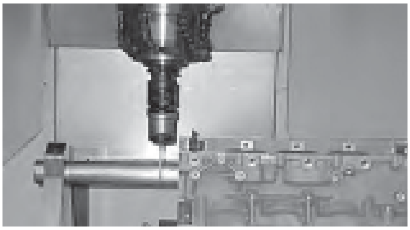
As an example of what you may run into with an LS2 aluminum block, I visited Gressman Powersports, where Scott Gressman decked my brand-new GM LS2 aluminum block, honed the cylinders to size and balanced the Lunati stroker crankshaft.

Scott checked my block on a 5-axis RMC CNC machine. This type of precision machining center makes it relatively easy to both measure and correct block deviations (especially since the machine's computer already has all of the factory specifications in its computer memory).

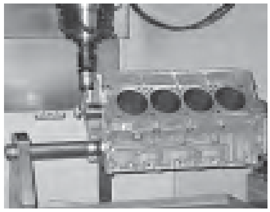
Before beginning your checks, the main caps must be fully installed in order to induce the stresses that the block will experience with the main caps installed. So at this point, you need to decide on which main cap fasteners you plan to use and start with them immediately (OE main cap bolts, aftermarket main cap bolts or aftermarket main cap studs).

Note: The LS blocks feature 100% metric threads in all thread locations. I opted to pitch the OE main cap bolts and installed a set of ARP main studs (p/n 234-5608). The ARP main cap studs are 10mm in diameter. The block engagement threads feature a 2.0 pitch, and the exposed nut ends feature a 1.25 pitch. The side bolts are 8mm x 1.25. After installing the studs finger-tight to the block, the caps were installed and the nuts were tightened to 50 lb-ft at the inboard studs and 60 lb-ft at the outboard studs. The 8mm cap side bolts (included in the ARP kit) were tightened to 20 lb-ft. By the way, you'll need a 10mm 12-point socket for servicing these side bolts).

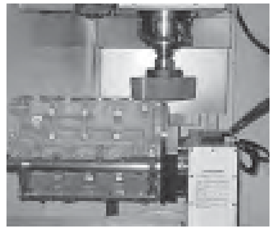
Note: We applied ARP moly lube to all exposed stud threads, nut undersides and side bolt threads and



With a main bore mandrel in place (this creates a main bore centerline reference), the CNC machine's probe begins to plot the block.



With a cam tunnel mandrel in place, the CNC probe measures camshaft bore centerline, referenced from the main bore centerline. The data tells the machine's computer where the cam tunnel is located relative to the main bore.



Here the CNC machine cuts the block decks to correct squareness and height issues. It's typical for LS aluminum blocks to feature slight variations in deck height and angle (one deck higher than the opposite deck, etc.). In order to achieve a precision, equalized and centered block, CNC machining provides an easy solution.

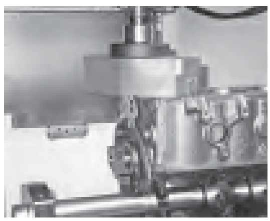
head undersides. The torque specs we followed are recommended by ARP when their moly lube is used.

Note: The LS2 aluminum block, like any other aluminum modular block, likes to move around as components are installed and fasteners tightened. If the main bore is to be align-honed, after installing the main caps and fully torquing all main cap bolts to specification, install and fully torque a pair of cylinder heads (or cylinder head deck plates) to the block, then align-hone the main housing bores. Without stressing the block with the heads in place, it is very possible to end up with as much as 0.002" in main bore distortion.

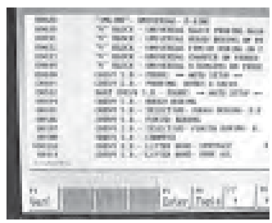
The CNC machine measured decks height from front to rear and from inboard-to-outboard on each deck. While the published GM OE deck height spec is 9.240", example LS2 block seen here had a deck height measurement at the front of the left bank at 9.2402" and 9.2364" (inboard/outboard, indicating a twist), and the rear of the left bank measured 9.2461"/9.2414" (indicating a slant from front to rear and twist). The right bank measured 9.2386"/9.2346" at the front and 9.2453"/9.2409" at the rear.

The lowest spot on the right deck was 9.2346", so Scott cut both decks at a height of 9.234", indexed from the crank centerline, to achieve parallel decks that are equidistant (and square) from the crank centerline. The need to deck a new GM production block isn't unusual, as Scott noted that, in his experience, the LS blocks are usually out an average of about 0.006"–0.008" at the decks. Considering our 4.000" stroke, our 6.125" rods and our piston compression distance of 1.115", our pistons should stick out of the decks by about 0.006". In order to achieve a zero deck clearance, we'll use 0.045" thick Victor MLS cylinder head gaskets to compensate.

Lifter bores diameters were measured at 0.843–0.844", exactly at OE spec. Thanks to the



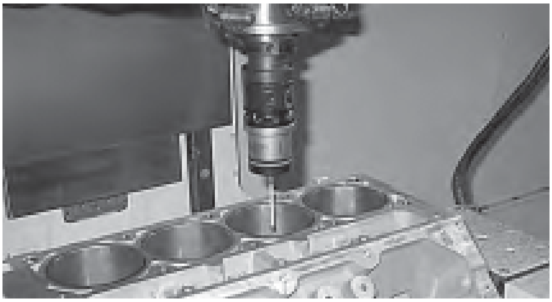
The rotary cutting fixture not only corrects any deck geometry issues, but is able to achieve the desired Ra surface finish all in one process.



The CNC machine's computer is equipped with blueprint programs for specific blocks, and allows the operator to store individual block dimensional data.

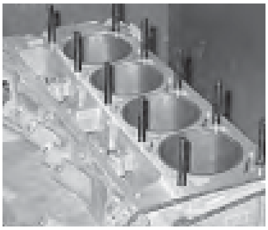
CNC program, Scott was able to quickly measure cylinder bore centerline and lifter bore centerline locations. In our sample block, no corrections were needed. If any bore locations were off-center (for example a lifter bore), the lifter bore could be overbored in order to create the correct centerline, then bronze bushed, with the bronze bushing then honed to the 0.843–0.844" desired diameter.

Before your cylinder bores can be final honed to size, you must have your pistons of choice in hand in order to physically measure the skirt diameters (don't just rely on printed numbers…always measure any OE or aftermarket piston in order to determine the finished cylinder bore diameter).

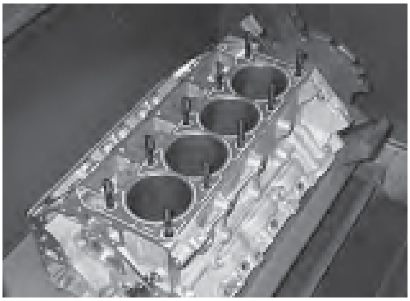


Each cylinder bore is measured for location, diameter and centerline. Here an LS2 aluminum block is measured. Once all cylinder bore dimensions and geometry data is captured, the operator can then decide what, if any, corrective measures need to be taken. This data is used not only from a corrective standpoint, but is also used in preparation of cylinder overboring, if oversized bores are desired.

Since a CNC machine (that is equipped with OEM design block dimensional data) already knows where all bores should be (in terms of centerline, angle and diameter), corrections to out-of-tolerance lifter bores are easily handled (early design Chevy block seen here for illustrative purposes).



Once all block machining has been accomplished, the cylinder bores must now be honed in order to achieve final diameter and desired surface finish. Here an LS2 block is secured in a dedicated honing machine.



All performance blocks (especially aluminum) should be honed with the decks pre-stressed to simulate cylinder head clamping loads, to compensate for cylinder bore distortion and stresses. This is done by mounting deck plates (also called torque plates) to the block decks. However, in order to best simulate the assembled-engine state, a head gasket must be installed between the block deck and torque plate. The head gasket should be a used gasket, already crushed to simulate the installed cylinder head condition. Cylinder head studs should be installed finger-tight (a slight snug of 3–5 ft-lb is OK) but not over-tightened. Make sure that the head gasket is oriented properly and that the decks and both sides of the used gaskets are clean.

The deck plate is carefully set on the block. As with main cap fasteners, the cylinder head fasteners of choice should be employed from this step (cylinder honing) through final assembly. If studs are to be used for final assembly, install the deck plates with the same studs.

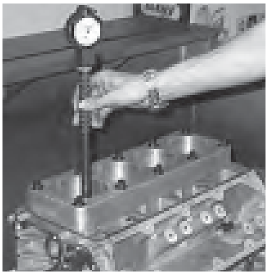
Cylinder Bore Honing

Regarding the example block seen in the photos in this chapter, the CNC machine indicated that the cylinder bores were factory finished at 4.000", so removal of a mere 0.005" was needed to achieve a 0.005" skirt clearance for our 4.000" JE pistons (the skirt clearance specified by JE).

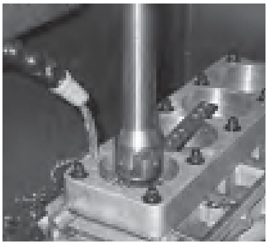
ARP head studs (P/N 234-4317) were installed in the decks finger-tight. With temporary head gaskets in place, a pair of BHJ torque plates were installed, with nuts tightened to a final value of 80 lb-ft, in three equal steps, again using ARP moly lube.

Using his Rottler honing machine, Scott honed all cylinders to a final diameter of 4.005" using 500-grit diamond stones, followed by four strokes with silicon carbide plateau brushes. Plateau honing serves to even out the peaks and valleys left by stone

Deck plates are tightened following specified cylinder head tightening values. Be sure to lube the threads and bolt or nut undersides. Again, remember to follow the proper torque values based on the use of oil vs moly lube. Also, be sure to follow the specified tightening sequence. You need to realize that any block, especially an aluminum block, undergoes metallurgical stresses and distortion once major components (such as main caps and cylinder heads) are fully tightened. In terms of cylinder honing, you want the block as close to a fully assembled state as possible in order to achieve true and consistent bore geometry.

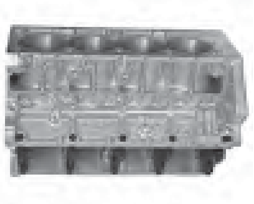


Using a bore gauge, each cylinder is checked for diameter, from the top to the middle and bottom areas, prior to and during the honing process.



Honing is accomplished with abrasive honing stones on a rotating mandrel while a lubricating coolant is applied.

Honing cylinders should be done by alternating bore locations (front bore followed by third bore, followed by second bore, followed by fourth bore) in order to prevent the previously honed bore's elevated temperature (as a result of honing) from affecting the following bore. By alternating bores during honing, you allow the earlier-honed bore to cool.



As a sidenote, CNC machining allows you to reduce block weight (for racing purposes) by machining un-needed exterior block material. Shown here is a billet-machined aluminum block from Dart (their LS billet block). Any block exterior (cast iron or aluminum) can be profile-machined on exterior surfaces, as long as the CNC machine's computer is equipped with that block's specific design software.

honing, providing faster piston ring seating and superior oil retention on the cylinder bore walls. Basically, plateau honing is a final step that "cleans up" the honed walls for enhanced ring performance.

While it is possible to profile/lighten the exterior, this is a very expensive proposition, and should only be considered for a serious race application. For the street, it may look cool, but it really isn't worth the expense. But hey, if your wallet is fat enough, go for it.

Also, never have the crank balanced until after you've checked for crank counterweight to block clearance. If you have a clearance issue and opt to remove a bit of material from a counterweight, this will affect balance. Don't balance until you know everything clears.

Main Cap Tightening Sequence

- Tighten the inside main stud nuts first, starting at #3 cap left, followed by #3 right, #4 left, #4 right, #2 left, #2 right, #5 left, #5 right, #1 left and #1 right.
- Next, tighten the outer main stud nuts in the same sequence as above.
- Finally, tighten the 8mm side bolts in the same cap sequence (#3, #4, #2, #5, #1).

Head Stud Tightening

ARP recommends installing the studs finger-tight. Nuts should be tightened (with all threads and nut undersides lubed with their moly) to a final value of 80 lb-ft in three equal steps.

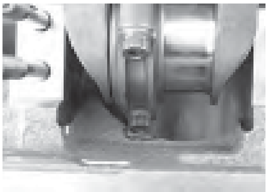
The cylinder head fasteners involve two rows of 11mm fasteners and one inboard row of 8mm fasteners. For purposes of torque plate installation, we only concerned ourselves with the 11mm studs

OEM LS Main Cap Bolt Torque Values

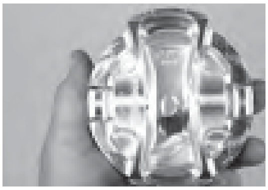
Main cap inner:	15 lb-ft (first pass) plus 80 degrees final
Main cap outer:	15 lb-ft (first pass) plus 53 degrees final
Main cap side bolts:	18 lb-ft

My LS2 Buildup Torque Values with ARP Studs & Side Bolts

Main cap inner:	50 lb-ft
Main cap outer:	60 lb-ft
Main cap side:	20 lb-ft



Either prior to or after cylinder boring and/or honing, test-fit the main bearings and crankshaft, checking for bearing oil clearance, crank endplay and, in the case of a stroker setup, for counterweight to block clearance. If you're using a stroker setup, once the cylinder bores have been final-sized for the pistons that you plan to use, test fit the connecting rods (with rod bearings and pistons but no rings, and with the cylinder bores well oiled) and carefully and slowly rotate the crankshaft to check for connecting rod/rod bolt clearance to the block. In this photo, a 4.000" stroke crankshaft is installed in an OEM LS2 block. Note that the connecting rod bolt head interferes with the block (the interference area is seen here outlined with a black marker). In some cases, only one or two locations may need clearancing, while in other cases, clearancing may be needed at every rod location. You won't know until you test fit and check.



The narrow boss area is required for stroker applications in order to clear the LS reluctor wheel. This is referred to as a side relief design.

(the 8mm studs will be added during final assembly).

The head fastener tightening sequence is as follows:

Center inboard, followed by center outboard, followed by second from front inboard, fourth from front outboard, fourth from front inboard, second from front outboard, first from front outboard, rear outboard, rear inboard, and front inboard. During head installation, this is followed by tightening the far-inboard 8mm fasteners starting at the center, followed by fourth from front, second from front, rear and front.

Remember that the head fasteners should be tightened in three "equal" steps. For our 11mm stud nuts, we started at 26 lb-ft, followed by 53 lb-ft, followed by a final pull to 80 lb-ft.

Note: While ARP naturally used metric sizing for all block engagement locations, they did customers a favor by making their head studs with inch threads at the top (nut end). The head studs, while 11mm x 20.0 for block engagement, feature 7/16" x 20 threads at the nut ends. This makes it easy for users to easily locate replacement nuts (if nuts are lost, etc.), since 7/16" hardened nuts are commonly used in many head stud kits (ARP and others). They did the same with the small far-inboard head studs, which feature the needed 8mm x 1.25 thread for block engagement, but feature 5/16" x 24 upper threads and nuts.

Bearing Checks

In our project LS2 block, the main bores measured at 2.750" (spec is 2.750–2.751"). The installed main bearing (MAHLE Clevite MS2199HK) I.D. measured 2.5605". The crank main journals measured 2.559", which would provide 0.0015" oil clearance, within the OE tolerance range. For higher rpm and higher load applications, we might like to see a bit of additional bearing oil clearance. With our block and crank, we had two potential fixes: either switch to 1X main bearings (which would provide an additional 0.001" clearance for a final 0.0025" oil clearance), or to align-hone the block's main bore by an additional 0.001". Using 1X bearings is obviously the quicker and cheaper way to go.

As far as rod bearing clearance is concerned, with the MAHLE Clevite rod bearings CB663HNK installed in the Lunati H-beam rods (and with rod bolts tightened to a rod bolt stretch of 0.0053"), installed bearing I.D. measured 2.1025". The rod pins measured 2.100", which provides a rod bearing oil clearance of 0.0025".

Note: The ARP rod bolts that were supplied with the Lunati rods are ARP 8740 bolts, featuring a 7/16" diameter and a shank length of 6.100". Per Lunati's specs, these bolts are to be tightened to a stretch value of 0.0052"–0.0056" (or to a torque value of 80–85 ft-lb with 30W oil).

Rod-to-Block Clearance

Whenever you plan to build an engine wherein you deviate from the stock stroke dimension, you need to mock the crankshaft, pistons, rods and camshaft in the block to check for potential clearance issues (crank counterweight to block, counterweights to pistons, connecting rod big ends to block).

Since in this specific LS2 build, stroke increased from the OE stroke of 3.622" to 4.000", it was obvious that I needed to check for rod clearance. With one rod (w/bearings) and piston test-installed (in each bore, one at a time), I carefully rotated the crank and found that the bottom of each cylinder required clearancing to allow the rod outer bolt

This close-up clearly shows the interference location of a rod bolt to the block. After each counterweight and each rod to-block location has been checked and marked, remove the rods/pistons, remove the crank and bearings, and notch the required areas using a die grinder. You don't need to get too carried away. A clearance of about 0.060 to 0.100" is fine. After clearance grinding, thoroughly wash the block and re-test-fit the crank and rods and verify clearances. This is a good example of why (if you plan to assembly the engine yourself) you'll likely need to make several trips to your local machine shop. Especially when using a longer-than-stock stroke, never assume that everything will clear. Take the time to test fit and check every area of potential interference. Just remember that anytime you grind material, the block must be expertly washed/rinsed before attempting further test fitting or assembly.

Either I-beam or H-beam rod styles are fine for street use (as long as they are made by a reputable quality-oriented maker). However, an H-beam design theoretically offers increased strength and is more suited to high-compression, higher horsepower applications. Generally speaking, I-beams are considered OK for up to about 500 hp. Beyond that, H-beams are probably a better choice. This will vary depending on the brand (material, metal treating, rod dimensions, etc.). GM factory LS rods (except LS7 rods, which are made of titanium) are made of powdered metal in an I-beam design. If you're just doing a mild rebuild and are sticking close to stock power output, the OE rods should suffice. However, if you plan to play, you're better off by spending a few bucks and moving up to quality forged aftermarket rods (brand such as Lunati, Scat, Callies, Crower, Eagle, etc.). A Lunati 6.125" length forged H-beam rod is shown here.

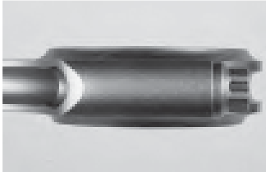
heads to clear the bottom of the bores. Using a mini 3/8" belt sander, I ground a small relief pocket in line with the bolt head at about 0.420" wide x about 0.220" deep. As long as you have more than, say 0.060" clearance, you should be OK.

Eliminating Cylinder Bore Distortion

Even with the best of intentions and preparation, some degree of cylinder bore distortion is likely to occur under dynamic stress (heat & pressure). The

While GM stock rods feature a press-fit to the piston wrist pin, most aftermarket performance rods feature a full-float, or "bushed) design to increase pin oiling and to reduce the heat generated between only the pin and piston pin bore. This also makes rod/piston assembly and disassembly easier, avoiding the need to use a press.

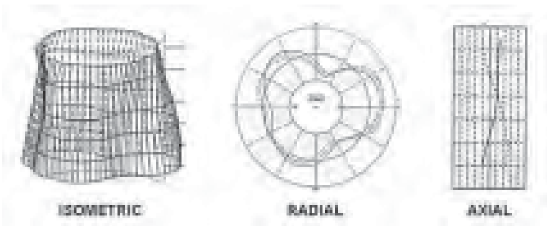
Note the oil feed hole to the rod small end on this Lunati rod.



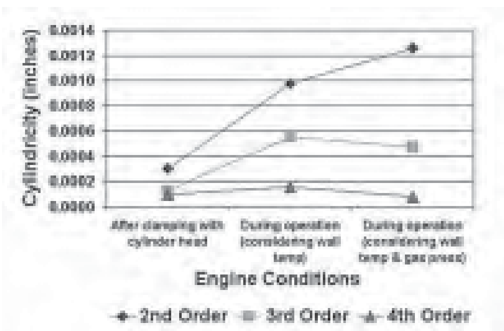
A quality performance rod will feature a high-precision mating surface between rod and cap. When fully tightened, the cap parting line (both exterior and in the big end bore) will not be visible to the eye. It is vital to always keep each rod cap with its original rod, and that the cap remains properly oriented to the rod. If the cap and rod are not already marked, either etch or mark (with a machinist's pen) the cap and rod on one side, and number each rod and cap (cyl. 1, cyl. 2, etc.) to avoid mixing caps. DO NOT use a hammer and punch to place marks on a precision aftermarket rod or cap, since this could result in potential stress risers or rod/cap distortion.

Performance aftermarket rods will usually feature high-quality (ARP, etc.) rod bolts. Most performance rod bolts will feature a dimple at each end (head and tip) to allow the use of a stretch gauge during rod bolt tightening. While builders have a choice of either using torque or tightening while monitoring bolt stretch, the dimples are present for those who opt to use the tightening-by-stretch method.

challenge is to understand how these changes take place and to establish procedures that will minimize these changes. As the block ages and/or is exposed to thermal changes, the casting's molecular structure will change, however slightly, which will affect bore geometry. In addition, distinct changes in bore shape will take place as the block is assembled. The clamping forces that result from the installation of cylinder heads will, in most cases, cause the bores to



Three views of a typical dynamic cylinder bore distortion scenario. Courtesy Sunnen.



This graph illustrates how cylinder concentricity can be affected by cylinder head clamping, operation with regard to temperature and operation with regard to cylinder wall temperature and combustion pressure. Courtesy Sunnen.

morph as the fasteners pull and squeeze metal adjacent to the bores. Sometimes these changes are insignificant, while in other situations, the change can be so dramatic as to cause measurable ring dragging and subsequent loss of power, fuel economy and sealing due to both out-of-roundness and frictional heat. In other engines, these problems may be compounded if the specific block is severely affected by additional distortion that results from clamping forces caused by bellhousing bolts, water pump bolts, motor mount bolts, etc.

Granted, only the more severe cases will be a cause of concern on a street engine. However, if the goal is to produce an extremely efficient racing engine, every factor which can affect dynamic ring shape must be considered.

As noted by Sunnen's Tim Meara, in order to accurately "map" a cylinder bore in order to obtain a clear dimensional picture of how that bore is shaped from top to bottom, a special "PAT" gauge is used. This is an inclinometer that features a shaft and probe. The shaft is affixed to the deck or torque plate and runs vertically through the bore centerline. The probe runs along the shaft vertically and monitors the bore walls radially. This provides a dimensional perspective view of the entire bore, relative to the theoretical bore centerline. Don't expect to run out and buy one of these, as they cost around $175,000 and are primarily used by piston ring and honing equipment manufacturers for analysis applications. This allows plotting the actual shape of the bore in addition to bore diameter. The readings can be displayed radially (viewing the bore from overhead) to show where the bore shifts from the centerline; and in an isometric view (side angle perspective in a variety of view angles) that allows you to see the entire bore in a dimensional manner.

In order to obtain bore diameter readings in your shop without the use of this sophisticated equipment, the cylinder walls can be measured with a bore gauge at four different levels at four clock positions (12, 3, 6 and 9 o'clock). Once these numbers have been recorded, place a honing plate (one per deck) on the block, torque the plate(s), and re-measure the same points to reveal differences that have occurred. However, bear in mind that this will not reveal concentric bore diameter shifts relative to the centerline.

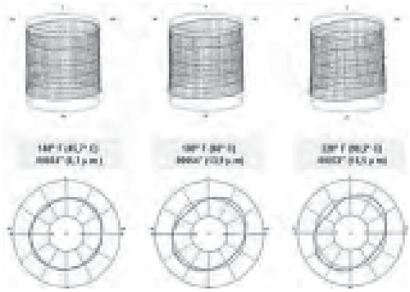
Another variable relating to bore distortion is the cylinder head itself. After measuring the bores (accessing from the bottom of the bores) on a relaxed block (no heads or torque plate), install and torque a cylinder head, and read the bores again from the bottom of the bore to note the changes that have taken place. Next, remove that head and install a different head of the same type and measure the bores once again. If you find a different distortion level/pattern, don't be surprised. Depending on the makeup of the cylinder head, the clamping forces may reveal a different situation due to the structure of the head, especially on cast heads, due to differences in the hard/soft internal makeup of the casting core. If the head pulls down harder or softer in various areas, this will accordingly affect how the block is stressed, resulting in variations of cylinder bore shape.

As mentioned earlier, when measuring a bore for shape, we need to remember that, depending on the instrumentation being used, we may or may not obtain a true bore shape. If we use a bore gauge, we are simply measuring bore diameter (and out of round) in specific height levels of the bore, but since we are not referencing from the true bore centerline, we may be overlooking shifts of the centerline at various height locations. If in doubt, or if we know that the radius of the bore has shifted relative to the centerline, we can use a precision bore-truing fixture to correct the problem (such as those offered by BHJ, CWT, etc.), or take advantage of CNC technology in order to create a "new" bore centerline based on blueprint data from the block manufacturer. The bores can then be "clean-bored" to an oversize, with the cutters referenced from a fixed (and presumably correct) centerline. This will create bore trueness in a static condition, but subsequent changes may still occur when the block is subjected to loads, pressures and temperature.

Keep in mind that when we're dealing with cast-iron blocks, the very nature of the casting process and the material mix can and will create differences from block to block. In other words, if you lined up five blocks with identical casting numbers and identical age, you'll probably find five different variations of bore distortion. Knowing this, we need to temper our view of block analysis. Just because one small-block Chevy of a particular series and casting shows unruly bore distortion in number 3 bore, this does not mean that this condition will be exactly repeated in every block of that vintage and type. Each block casting is its own animal and needs to be treated as such.

MAHLE Clevite's Bill McKnight was kind enough to share bore distortion information that was part of a MAHLE Clevite NASCAR engine builders' seminar presented by Victor Reinz engineer Ernest Oxenknecht, that addressed this very topic. Selected excerpts from that seminar follow.

Primary causes of bore distortion in relation to the cylinder head/block joint include clamping load, cylinder head gasket/combustion seal design, the honing procedure and assembly procedures.



These isometric views show bore shape changes relative to temperature shifts. Courtesy Sunnen.

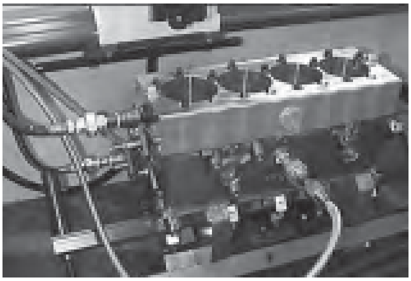
Clamp Load

Bore distortion is generally directly related to clamp load. The clamp load must restrain combustion lift-off force and still provide adequate force for the gasket to do its job. Additional clamp load generally only leads to additional bore distortion. In other words, tightening head fasteners beyond the recommended specification will only hurt. The optimal goal is to minimize clamp load and distribute the clamp load uniformly while maintaining combustion and fluid seals.

Distribution of clamp load affects bore distortion. An equal load distribution is the goal.

One interesting item to note is that the end cylinders are typically overloaded, as they aren't required to share bolt load between cylinders. For custom racing applications, consider smaller diameter studs/bolts for deck-end positions to reduce the tendency of overloading the end cylinder areas. An excellent method of checking this is to perform pressure film studies (carbonless impression paper) to inspect head gasket load distribution, in an effort to equalize loads by possibly using smaller-diameter fasteners at end positions.

Bolt clamp load can be measured by referencing bolt stretch (in terms of length). This is done with a Bidwell Bolt Gauge (formerly known as a Raymond Bolt Gauge), which sends an ultrasonic wave signal through the bolt from the head (or top of the stud). Once this signal travels down to the bottom of the bolt, it then shoots back to the signal sensor. The amount of time that is takes for signal return determines length, or amount of stretch. The bolt is first measured statically to create a reference value, which is then compared to stretched length under installed conditions. The final value can be measured in terms of pounds of clamping load. For example, if a 7/16" bolt is rated at 10,000 lb and the installed reading shows a clamping load of 12,000 lb, it's obvious that the bolt has been stretched beyond its clamp load design. Also, bolt load can be tailored to achieve a uniform distribution of clamp load across all areas of the deck and head gasket by experimenting with monitored bolt loads while using a telltale load indicator such as carbonless impression paper. Determining bolt load knowledge is a critical factor and should be gathered on engines both during assembly and during disassembly.



Hot honing involves not only applying cylinder head clamping load to the block (via a deck plate) but also plumbs heated water through the block to help simulate engine running temperature. Not many shops have a hot honing system, but this process has been the subject of much research in the pro race engine building community. Courtesy Sunnen.

Honing Procedure

Install a deck plate (torque plate) and head gasket to initial assembly load. Next, relax the clamp load to levels actually measured from a conditioned engine. Hone the cylinders at this point. Assemble the engine to exact initial clamp load of the data-bearing engine.

Torque values are not adequate when performing assembly where optimal performance is required, and where exacting bolt/stud load must be accurately measured. Torque and torque/angle methods can result in 25–30% load variations. Instead, measure bolt/stud load with an ultrasonic gauge.

Simulating operating cylinder head load on bores while honing is the most critical factor in minimizing bore distortion. Again, this means going beyond merely using a deck plate with bolts torqued to value. Actual bolt loads must be monitored and achieved at predetermined levels.

How Much is Enough?—Minimum clamp load must be greater than the combination of lift-off force and required sealing force. A general approximation (a good general model) for clamp load is three times lift-off force. This generally results in static sealing stress in the combustion area of 7500 psi. Lift-off force for a 4.25" bore @ 1400 psi peak pressure is 19,861 lb. Depending on the application and number of bolts featured to seal each bore, individual bolt load requirements may be in the 6,165–11,917 lb range. For example, a typical ARP 7/16" stud may be rated at 12,700–15,600 lb load range.

Head Gasket Selection/Consideration—Wire ring style head gaskets may relax as much as 10–25% after initial assembly. By contrast, MLS (multi-layer steel) cylinder head gaskets relax less than 10% after initial assembly, thereby providing additional assurance of maintaining proper clamping load and load distribution.

Wire ring style gaskets require the highest clamp load and can feature high peak loading along the cylinder openings. Again, by contrast, all active (spring function) MLS gaskets have the lowest peak loading along the cylinder openings. MLS gaskets with a built-in "stopper" layer or beaded spacer provide high combustion sealing stress with lower required bolt loading. Active MLS gaskets are designed with formed metal layers featuring contact and air spaces that work as a spring to provide compressive tension that aids in sealing while requiring lower loading. Active MLS gaskets feature an elastic element which absorbs cylinder head motion. Stopper MLS gaskets also feature a layer of "dead stop" that provides a limit to compression. Stopper type gaskets feature rigid combustion seals which bend the cylinder head over the seal as a result of clamping loads. Active MLS offers low hardware distortion, since the gasket "gives" to reduce the chance of distorting bores and head decks. This type also provides good recovery for lightweight hardware. However, it may be difficult to generate high combustion sealing stress with an active type MLS. The stopper MLS type of gasket provides high sealing potential, but has the potential to generate high hardware distortion. Determining which type of gasket to use will be based on research data gathered during engine components, engine test assembly and engine operation (on dyno and/or on-track).

Thermal Considerations During Honing—Another aspect of obtaining a bore that will remain as true as possible during engine operation involves heat. Consider that while a bore may be correctively trued while the block is cold, it stands to reason that bore shape may be affected as temperatures rise and fluctuate. In that regard, does it make sense to hone cylinders at room temperature, or at an elevated temperature that more closely resembles levels experienced in a running engine? Some argue that the change is minimal; or that the act of honing generates surface heat on the walls anyway. However, others are of the opinion that the block should be heated with circulating water in order to replicate the effects of hot coolant flowing through the block (and adjacent to the bores).

While a torque plate affects the upper 1.5" or so of the bore, the dimensional change of an average bore between hot and cold can be twice that of a torque plate, or more. Because of the complex interaction between engine design, casting processes, uneven wall thickness, variations in metal composition and internal metal stresses, dimensional changes of the cylinders within a block can vary significantly. Not only are there thermal dimensional changes, but these changes are far from uniform throughout the bore. The major effect is the gross dimensional change in bore diameter, which can change 0.0005–0.001 of an inch, per inch of bore diameter, at temperatures between 65 degrees F and 210 degrees F. For a common 4" bore, this equals 0.002–0.004" of growth.

The rest of these variations within the bore…thermal distortions—are largely nonuniform and can create critical concerns. These distortions include the local diametric variations in the walls, the barrel or hourglass effect, bores departing from circular and becoming non-round and the bowing or arcing of the bore from a true cylinder. A normal bore gauge can detect all but the last of these distortions.

Since the cylinder walls are not of uniform thickness and the cylinder is captured at each end, thermal expansion of the metal can and does cause distortion of the cylinder walls. A normal cylinder wall will assume a slight barrel shape as the temperature increases, with high and low spots that vary from cylinder to cylinder, causing a non-circular, nonuniform bore as the engine heats.

Temperature is not the only effect on a bore. Under normal conditions, the engine cooling system operates at 10–14 psi. Normal engine pressure forces the cylinder into an hourglass shape. While 10–14 psi may not seem like much, it compresses the cylinder walls in the center around 0.0005". The normal pressure effect from the cooling system tends to partially offset the barrel effect of this thermal distortion. Because of these offsetting effects, hot honing must be done with the block pressurized to achieve the best possible true bore.

While a few attempts at creating a hot honing environment have been seen in previous years, an excellent example of a viable system is KW Products' Hot Hone 2000. This is a completely self-contained system that features a stainless steel cartridge pump, brass tank and armored safety hoses with quick (Kwik) connect couplings. The system includes a fully adjustable electronic thermostat, pressure and temperature gauge, automotive-style filler, soft plug and block adapters for the small-block Chevy. According to KW, the unit is adaptable to all honing machines and uses standard torque plates. Block adapters for other engines are also available or can be fabricated by an individual shop.

Various factors can affect cylinder bore geometry changes:

- The density of the material varies
- Core thickness varies throughout
- Machining tolerances are not within acceptable performance guidelines
- Webs or reinforcement of critical areas are not optimal
- All core sand, ties, stands and machining debris is not removed
- Galleys are not sized or routed optimally
- Water jackets and passages do not allow for even heat transfer
- Flow problems in molds create weakened areas

Note: Some aftermarket blocks (all materials) are just copies of OEM and suffer the same ills. However, there are others that are far superior in most of the above areas.

Torque plates reproduce the stress in the upper 0.5–1.5" of the bore that would otherwise be produced by bolting the cylinder head in place while still allowing access to machining the bore. The actual measured amount of distortion in the areas around the bolt at the top of the block is seldom more than 0.0005–0.001". This is however a significant amount when you consider that the average high-performance engine builder won't accept a bore that is less than 0.0002" straight and true.

It is usually necessary, especially with plain-Jane OE blocks, to torque-plate the block when you bore it if you plan to use torque plates when honing. The hone may jerk from the distortion if it wasn't originally bored with torque plates and sometimes the bore is distorted enough that by the time the machinists straightens the bore, it may be larger than desired.

When a block is heated to its intended operating temperature and the subsequent related pressure, the amount of distortion will vary depending on many factors. An obvious few are temperature, pressure, block material, varying density of material, quality of casting, Siamese bores, sleeved blocks and offset boring.

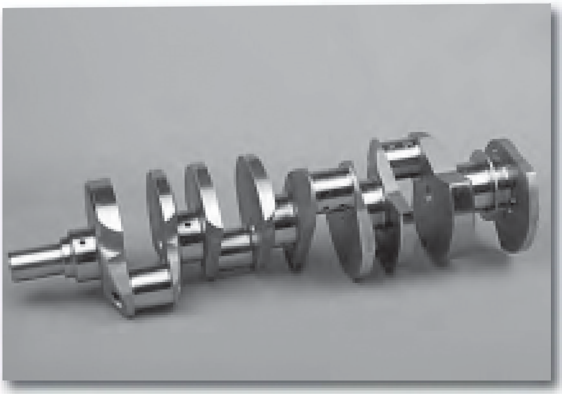
The average change in size of a cylinder bore heated to 190 degrees F from an ambient temperature of 65 degrees F is between 0.003–0.004". This anticipated change is not necessarily linear, as different areas of the cylinder bore may change by varying amounts.

According to research done by KW, in addition to the amount of average bore size increase, the average difference from cylindrical in the heated and pressurized bore seems to be around 0.0015". This change can be several times the change seen with torque plates. These are average figures and the real revelation will be those areas of the bore that move outside of these norms without obvious reason.

Theoretically, with the engine block heated to operating temperature during the honing process, the bores should remain fairly stable and stay on-size throughout the process.

Chapter 6

Crankshafts, Rods, Pistons & Bearings



A forged crank offers vastly increased grain structure and strength as opposed to a casting. Shown here is a Lunati big block Chevy stroker, precision-machine-finished to an incredible degree of accuracy.

In this chapter we'll discuss the rotating and reciprocating assembly. That's just a fancy term for the crankshaft, connecting rods, bearings, pistons and rings. We'll include both OE and aftermarket components, with an emphasis on performance aftermarket offerings.

We'll begin by providing an overview of forged crankshafts. Although the LS cast cranks are certainly well-made components (much better than early generation castings), if you're building the engine from scratch, or if you plan to add more stroke as part of your effort to increase displacement, it just makes sense to upgrade to a quality forged crankshaft that provides additional strength and worry-free durability under increased horsepower and torque conditions.

Forged Cranks

If you plan to build an LS with about 400+ hp, your best bet is a forged crank as opposed to a cast unit.

The Forging Process**—**Individual crankshaft manufacturers often employ their own proprietary formulas, but generally speaking, a steel ingot is heated in an oven to about 2,200 degrees F (at which point the steel is very formable…not yet a liquid, but very easy to move around and shape). The ingot is then placed in a forging die and squeezed into the approximate shape of the desired crank profile. This "squeezing" is performed either by a hammering or pressing process. Either way, the goal is to compress the alloy mix not only to precisely fill the die, but also to increase the strength of the alloy by compacting the molecules and aligning and strengthening the grain structure. Basically, the size of the ingot is much larger than the volume required in the die (generally, a crank maker will start with an ingot that weighs about twice as much as the desired final product). During the forging/compacting process, the excess material is forced out of the die at its mating lines. This excess is later sheared off in a trimming die.

Once a blank casting or forging is made, the crankshaft is then machined to its final state. The process followed by Callies Performance in Fostoria, Ohio, home of one of the leading performance and racing crankshaft manufacturers:

•Machining rough shape…counterweights, snout, rear flange
•Machining for journals
•Gun drilling through rod throws
•Gun drilling through the mains
•Oil feed cross drilling
•Finish grinding main and rod journals
•Crack checking with Magnaflux
•Balancing

Parting Lines—Upon examining a forged crankshaft, you may notice what appears to be a broad "parting line" which may make some folks wonder if the crank is cast or forged. This "parting line" sometimes seen on forged cranks is merely evidence of the excess steel that was forced out of the die during the forging process. This excess steel is sheared off of the crank after forging (performed in a "trimming die"), with dress-up trimming done during crankshaft machining. In some cases, this area (where near-liquid steel has been forced out of the die during hot-hammering or pressing) is machined completely away, with no trace of the trim line, while in other cases the trim area may not have been machined as closely, leaving a slight telltale sign of the trim area (if this evidence exists, this does not indicate any problem whatsoever and is merely cosmetic). In other words, even forged cranks may feature a slight evidence area of the die mating path. This slight trace of the trim area is normal and does not present a problem.

Twist vs. Non-Twist—Forged crankshafts can be made using either twist or non-twist approaches. Since forging requires the use of a die, it's obvious that the die consists of two sections. A twist-forged crankshaft uses a die that places two rod throws to one side and two throws to the opposite side (180 degrees apart). This makes it easier to remove the forging from the die. Once out of the die, the crankshaft is then literally twisted (while hot and formable) to obtain the correct pin geometry. However, in doing so, the grain structure of the steel is interrupted, which creates potential weak spots and stress risers. A non-twist crankshaft is forged in exactly the final shape, but involves a die that is much more complex (in order to make it separable). That's one of the reasons a non-twist forging is more expensive than a twist forging. All of the crank manufacturers we spoke with produce non-twist forgings.

Forged Crank Manufacturers

Although I will briefly outline a few features from some major crank manufacturers, there are literally dozens in the aftermarket. I've listed many of them in the appendix on page 197. I recommend you visit their websites to see what each has to offer. We just don't have the space to list all of their features here.

Crower—Crower uses 4340 and EN30B (an alloy that is often used for billet cranks) for their forgings. The forgings are compacted in a hammer process, with all manufacturing handled in the U.S. The units are heat treated for core hardness to around 36 Rockwell. After machining and finish grinding, they nitride for surface hardness to a depth of approximately 0.002–0.003". Crower's Kerry Novack noted that they don't like to go deeper in surface hardness because they don't want to create potential brittle points.

Scat—Scat employs a press technology instead of a traditional hammering approach. According to Tom Lieb, this press-forging is done in three progressive stages, with the material essentially pushed into shape as the nose and tail is formed to create front and rear main bearing areas. As the center bearing areas are formed, the pressing action creates a wedge of material that is pushed into the counterweight areas of the die, etc. Tom noted that this new technology press-forging is handled in China using the latest German press equipment. As with hammering, excess material oozes out from the die, which is then trimmed off. After tempering and machining, surface hardening is handled via nitriding. "Hardening metal is like baking a cake," noted Lieb. "Ingredients include a lot of different things such as vanadium, manganese, nickel, etc. The heat treatment process is designed around the different elements in the steel mix, and how they react to each other. With chromoly, we heat to about 2,600 degrees F, followed by a dip in a vat of heated glycol. As the metal is control-shocked, all of the elements hold hands and establish a grain structure. We use short-cycle nitriding to create an extremely hard surface that's about 0.002–0.004" deep. You can, of course, case-garden deeper, but that can create brittle fillet areas. If (during the service life of the crank) you need to regrind the journals, simply get it re-nitrided after grinding."

Bryant Racing—Bryant Racing produces mostly billet cranks, but they do offer a line of forged cranks as well. "Ninety percent of what we do are billet cranks," noted Bryant's Joe Squires, "but we do offer a few forged units as well. Basically, we buy raw forgings from Ford and GM (the same forgings previously used in NASCAR). We heat-treat them, finish them and nitride to 0.005" deep. Our billet cranks are made from American Timken 4340 steel (made to order for us, using our own recipes), through-hardened, cryo-stablized, stress-relieved and plasma-ion-nitrided."

Lunati—Lunati makes some killer cranks, 100% made in the USA. Their Pro Series forged crankshafts are machined using 4340 steel and meet aircraft standards for material cleanliness and structural purity. Main and rod journal surfaces are very finely finished to a grade of 5 RMS or better (that's really fine, almost like a mirror). Journal radii are ground to 0.140" for excellent rod big end clearance. Journal roundness is held to a tolerance of 0.0001" or less, and each rod journal is drilled

Finished forged cranks ready for inspection. Courtesy Bryant.

with a 7/8" or 3/4" lightening hole to reduce mass (inertia weight), and their Pro Series also features gun-drilled mains for additional weight reduction. These cranks have been successfully used in applications of 1500 hp and more. Custom strokes are also available on request, as are the long-snout LS7 cranks (to accommodate dry-sump drive systems).

Callies—Callies employs 4340 steel in their forgings, and offers their "Perma-Tough" heat treatment process that "changes the micro-structure of the steel" and penetrates deep into the crankshaft. Callies claims that "even after a 0.030" regrind, these shafts can go directly back into service with complete confidence."

Bullet Racing—Bullet Racing Cams told us that they heat treat their cranks after forging to a range of 32–34 Rockwell. After final machining, their ion nitride surface hardening creates a 62–65 Rockwell surface that's about 0.012–0.020" deep. They use both U.S. and overseas forging plants.

K-1—K-1 Technologies, a division of Carrillo, offers both forged and billet cranks, all made from 4340 steel and nitrided for improved bearing life.

Without exception, all of the performance crankshaft makers we contacted use 4340 steel and produce non-twist style forgings.

Forged vs. Billet Cranks

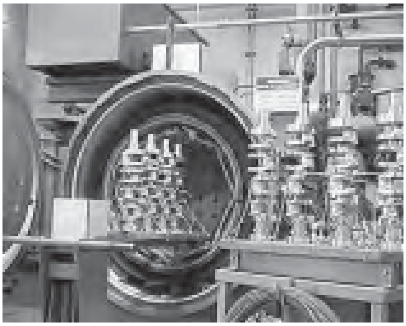
Depending on who you talk to, some say that forgings are stronger than billets and some say just the opposite. We're not going to debate that issue here. One of the indisputable benefits derived from carving cranks from billet bar stock is versatility, since by "simply" writing the appropriate program, you can CNC-machine a billet crank in whatever configuration you want, without being restricted by a die shape. This also eliminates the cost and time involved in having a die made. In other words, billet machining, as opposed to using a forging die, more easily allows creation of any custom crankshaft. In either case, the material has been forged…either as a blank or in approximate finished form.

Surface Hardening

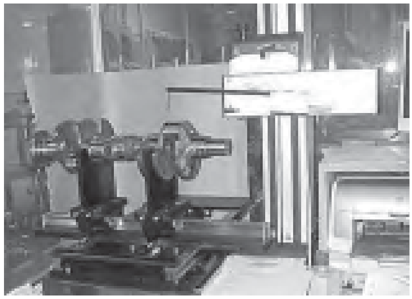
Crankshaft main/pin fillet fatigue strength can be enhanced by induction hardening, ion-nitriding or deep rolling.

Induction Hardening—Induction hardening results in surface hardening and involves heating the component by means of an alternating magnetic field to a temperature within or above the steel's transformation range, followed by an immediate quenching. Induction hardening does not affect the core of the component. Induction hardening isn't widely used by crank makers, in part because it isn't very controllable (hardening depths can vary, and isolated hard spots can be created, which can lead to brittleness and the creation of stress points). Induction hardening can also dig much deeper into the crank than desired and might actually affect the material's core strength. If the crank is heated to the point where the journal is glowing red, this can drastically degrade the strength of the crank's core material. Also, since the crankshaft features a variation of material thickness, if the crank is not cooled in a controlled manner, major stress areas are likely to be created. Basically, induction hardening, at least for crankshafts, isn't a very good idea. This can lead to premature failure or cracking, undesirable flexing and harmonic issues and puzzling uneven main bearing wear.

Nitriding—Nitriding is a hardening process that involves the absorption of nitrogen into the steel. All machining, stress relieving, hardening and tempering are carried out before nitriding. The component is heated in a special container through which heated ammonia and nitrogen gas is allowed to pass. The gas reacts with the carbon on the surface of the steel, penetrating the surface to form nitrides. This results in a much higher surface hardness, making the surface more resistant to abrasion and increases fatigue strength. Nitriding affects the entire crank and isn't isolated to only journal and fillet areas. In other words, the surface hardness is more uniform. The amount of time exposed to the nitriding process is a factor in terms of hardness depth (the longer the crank is exposed to the process, the deeper the hardness). Each crankshaft maker has it's own methodology with regard to surface hardness depth. The increased



Surface hardening such as ion nitriding is done by exposing the cranks to an ammonia/nitrogen mix, where nitrogen reacts with the surface, creating a hardened surface. Hardening depth is controlled and dictated by the specific manufacturer. Courtesy Bryant.



Here a finished crankshaft is inspected for profile using a sophisticated profilometer. Courtesy Bryant.

hardness needs to be deep enough to provide wear and surface strength, but not so deep as to create a potentially brittle crank that might snap under extreme loads. In talking with a sample number of performance crank makers, it appears that hardness depths are ranging from approximately 0.002" to 0.020" (Callies claims a -0.030" regrind possible without losing hardness).

According to Scat, typical cycle time for crankshaft nitriding is 24 hours or more.

Note: The nitriding process is calibrated for each specific alloy steel. If the steel does not actually meet that specification, the crank may bend, break or swell during the nitriding process. It sounds nasty, but that's really a good thing, since it serves as a quality check for the steel alloy.

As far as crank service life is concerned, if a crank's rod or main journals need to be reground, say -0.020", you'll lose the initial surface hardness. While some builders (or customers) may assume that the crank is no longer useable simply because the surface hardness has been lost, in reality this isn't a problem. Simply send the crank out for nitriding after the corrective grinding has been accomplished.

Deep Rolling—Deep rolling is a radially symmetric deformation process used primarily for surface finish, hardness and residual stress control.

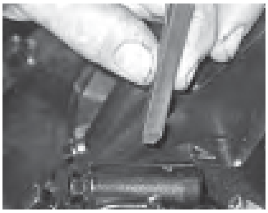
Crankshaft Prep

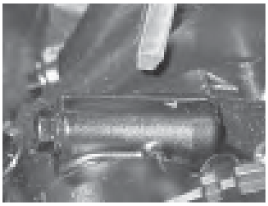
Regardless of which crank you choose, take the time to measure the crank to verify its condition and to decide if it needs any corrective work.

Check Runout—Check the crankshaft for runout. With the crankshaft mounted level to a rotating fixture (resting on the front and rear main journals), set up a dial indicator at the center (No. 3) main journal, placing the indicator probe slightly offset to avoid hitting the oil hole. Preload the indicator by about 0.050" and then zero the dial. Slowly rotate the crankshaft while observing the gauge. Maximum OE-spec allowable runout is 0.00118". Generally speaking, if the crank shows less than 0.001" runout, it's probably fine. If the crank shows more than 0.001" runout, it needs to be either straightened or replaced. Crank straightening is a precision task that should only be handled by a skilled specialist. Not all cranks can be successfully straightened, by the way.

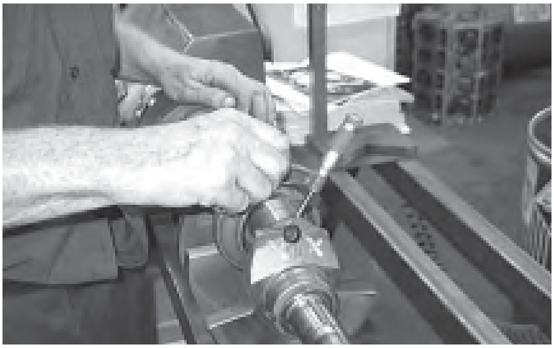
Measure Journals—Measure all main and rod journals with a micrometer. Main journals should measure 2.558–2.559". Also measure each main journal for taper (measure the journal area at two locations…towards the front and towards the rear). Maximum allowable journal taper is 0.0004". Also, be sure to measure each main journal at several radial locations to check for journal out-of-round. Maximum allowable out-of-round is 0.000118".

Next measure each rod journal diameter at several radial locations. Rod journal diameter should be 2.0991–2.0999". Measure for journal taper (at each end of the journal surface). Maximum allowable rod journal taper is 0.0002". Also measure rod journal width (base of fillet to base of fillet), which should be 1.902". If the journal surfaces are damaged (scratched, scored, gouged, burnt), further inspection is required. If the scratches are light enough, the journals may be saved simply by repolishing with 400 grit, followed by 600 grit abrasive paper. If the surface damage cannot be eliminated by polishing, the journals may need to be reground with an abrasive stone wheel on a crankshaft grinder. If one or more main journals



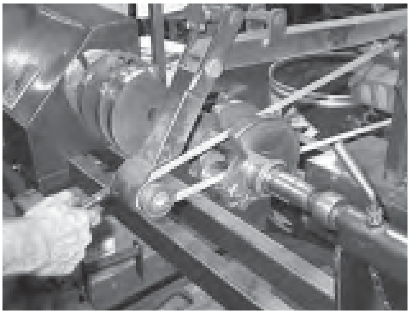


During disassembly of an OE crank, be sure to mark the outboard side of each connecting rod and its cap, to help keep caps matched to their rods. Number each rod and its cap per cylinder location (1, 2, 3, 4, 5, 6, 7, 8). Use a number stamp and a hammer, but only strike hard enough to make the mark. Don't use excessive force.



Once the OE crankshaft has been removed and cleaned, use a micrometer to measure each rod journal diameter. Measure each end of each journal as well, to check for journal taper. LS rod journals should measure 2.0991–2.0999". Maximum allowable rod journal taper is 0.0002". Main journals should measure 2.558–2.559". Maximum allowable main journal taper is 0.0004". Record your diameter readings for each main journal; and for each rod journal. If diameters are incorrect/and/or excessive taper exists, the journals may be reground to an undersize (various bearing makers offer specific undersize (smaller ID) rod and main bearings. By the way, there's nothing wrong with a crankshaft that has been undersize-ground, providing the job is done correctly.

needs to be reground to an undersize, then all five main journals should be ground to the same undersize. The same goes for rod journals. Never grind only select journals to an undersize. Either do all mains, or all rod pins, or both rods and mains (depending where the damage exists). Main and rod bearings are available in common undersizes including –0.010, -0.020 and –0.030". If a crankshaft's mains, rods or both are reground to an undersize, the crankshaft should be labeled to easily identify any undersizing by stamping or etching the undersize on the forward face of the front



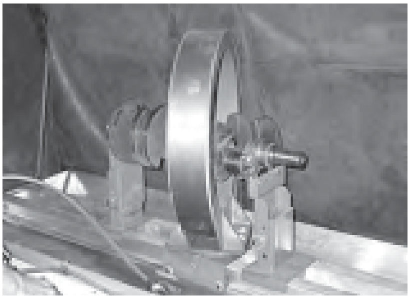
Once an OE crank checks out OK and you intend to reuse it, each journal can be polished on a crankshaft belt polisher, using 400 grit, stepped up to 600 grit. Small surface scratches can also usually be eliminated by polishing. Note: Different equipment makers may specify different grit-grade abrasives for polishing. The journals should not be "mirror" polished, since microscopic scratches are needed to provide oil cling.

counterweight. For example, if the main journals are fine but the rod journals are reground to, say, 0.010" undersize, the stamping or etching should say "ROD 010," OR "R –10", etc., to clearly identify the rod journals as having been undersized by 0.010". A negative symbol (-) preceding the number makes it clear that the regrind factor of 0.010" has been removed.

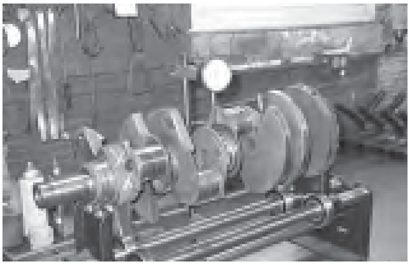
Inspect Fillets—Also make sure to inspect all fillets (the shoulder area where the journal surface blends into the counterweight or throw area). A journal should NEVER be ground to create a sharp corner, since this can lead to an eventual stress riser, which can result in crank failure.

Inspect All Holes—Inspect all threaded holes (the center hole in the front snout and the flywheel holes in the rear flange). Make sure that the threads are clean and are not damaged. A chaser tap (as opposed to a cutting tap) can clean these threads without cutting and removing too much thread material. Inspect all main and rod journal oil feed holes to make sure that they're drilled through, and that they're not plugged up with debris.

Grinding Undersized—If any beyond-tolerance areas are found in terms of journal diameter, taper, width or out of round, this can be corrected by re-grinding on a crankshaft grinding machine. In order to correct journals, you'll end up moving to an undersize (smaller diameter than original), in which case you can easily purchase a set of undersized-I.D. main and/or rod bearings. Just



The crankshaft should be checked for cracks/flaws. One method involves the use of a magnetic particle inspection. Here an LS crank is mounted on a DCM magnetic particle inspection station. A large diameter magnet will pass over the crank as the technician inspects the crank using a blacklight.



The crankshaft should also be inspected for runout (bend). The crankshaft is placed on level V-blocks or on a crankshaft polishing station. With a dial indicator mounted at the center (No. 3) main journal, the crankshaft is slowly rotated to check for runout. Any runout under 0.001" is generally deemed acceptable. If runout is 0.001" or greater, the crank must either be straightened or replaced.

If a crankshaft (rod and/or main journals) is to be reground to an undersize, this is done on a dedicated crankshaft grinder, using specific-width abrasive stone wheels. When main journals are ground, the crankshaft is mounted and rotated "straight" with zero runout. When rod journals are ground, since they are offset from the crank centerline, the crank is adjusted on the machine to run at an offset, with the rod journals positioned at zero. Cooling fluid is applied during grinding to cool and clean the journal surfaces.

OEM LS Crankshaft Specs

(Applies to all LS crankshafts)

Rotation:	clockwise (viewed from front)
Runout:	0.00118" (max/production)
Main bearing clearance:	0.0007–0.00212"
Rod pin dia:	2.0991–2.0999"
Rod pin taper:	0.0002" (max)
Rod pin width:	1.902"
Crank end play:	0.0015-0.0078"
Main journal dia:	2.558–2.559"
Main journal taper:	0.0004" (max)
Reluctor wheel runout:	0.01–0.028" (max)
Flywheel bolt base circle:	3.110"
Stroke (OE):	3.622"
Main seal I.D.:	4.527"
Thrust wall width:	1.029–1.032"

OE Crankshaft Strokes

LS1/LS6:	3.622"
LS2:	3.622"
LS7:	4.000"
LS3:	3.622"
LS9:	3.622"

remember that bearing size needs to be uniform…if one main journal must be reground to then accept an undersize main bearing, then all five main journals should be ground to that same size. The same holds true for rod bearings. If even only one rod journal needs to be undersized, then all rod journals need to be brought to the same size.

Always check with your bearing supplier to first find out what undersize bearings are available (-0.0005", -0.005", 0.010", 0.020", etc.). This will determine the diameter of the regrind.

Also, it's always a good idea to inspect the crankshaft for flaws/cracks. This is best done on a magnetic particle inspection station. (Commonly known as a Magnaflux machine even though Magnaflux is a brand name. Other equipment makers, such as DCM, make magnetic particle inspection equipment.) The crank is mounted horizontally on the inspection bench and passes through a large diameter circular magnet and inspected with an ultraviolet ("black") light. Any cracks are easily found, visible as whitish lines. If a crank is cracked, don't even debate the issue—just replace it.

If you purchase a new crankshaft and the reluctor wheel is not already installed, you'll need to install the wheel, but placement and method of installation is critical. Don't attempt it if you don't know what you're doing, as you can ruin the wheel.

Here's an example of an aftermarket performance crankshaft from Callies, with the reluctor wheel already installed. The wheel (also called a tone wheel or tone ring) sends crankshaft position signals to the ECU via the crankshaft position sensor that's mounted on the rearward right wall of the block.

Here's a Lunati 4.000" stroke forged crank that I bought, with the reluctor wheel separate (Lunati will gladly install the wheel as well).

Reluctor wheels are available in both 24-tooth (Gen III) and 58-tooth (Gen IV/LS2). Selecting the tooth count all depends on your ECU (if you plan to use an OE harness and computer) or an aftermarket timing control module. The two need to match—if you have a 24-tooth wheel, you need a controller for a 24-tooth wheel. The same goes for the 58-tooth wheel (where you'd need a 58-tooth controller). If you have your controller, then you need to buy the correct tone wheel to match up to the controller.

Crankshaft Reluctor Wheel

LS engines feature a toothed reluctor wheel (also called a tone wheel or tone ring), which is press-fit onto the rear of the crankshaft. This toothed wheel is used by the crankshaft position sensor for ignition timing. There are two styles of wheels. The LS1/LS6 engines originally used the 24-tooth reluctor wheel, while the 2006 and newer LS2/LS7/LS3/LS9 engines featured a 58-tooth wheel. This is important to note for those who plan to use an aftermarket timing control unit, such as MSD's 6LS timing control module. MSD's 6LS module part number 6010 is designed for use with the 24-tooth wheel, while their part number 6012 is designed for the 58-tooth wheel.

If you opt to buy an aftermarket performance crankshaft (let's say you're building a stroker engine, for example), the crankshaft may or may not include a reluctor wheel. In either case, pay attention to the number of teeth on the wheel. If you plan to use the factory engine management computer, you'll need to stick with the same version (24 or 58 tooth) of wheel that the engine originally used. If you plan to use an aftermarket controller, it really doesn't matter, as long as you buy the correct timing controller that matches your wheel's number of teeth.

Removing Reluctor Wheel—The reluctor wheel (also referred to as a timing wheel) is interference-fit onto the rear of the crankshaft, with no key or other registering device. If for some reason you need to remove the wheel (if the wheel is damaged, which is rare; or if the crank journals are to be reground or repaired and the wheel is in the way), first mark the wheel and the crank to create matchmarks. The position of the wheel is critical. Do not attempt to remove the wheel with a puller, since you'll bend/distort the flimsy wheel. Instead, carefully and evenly heat the wheel with a torch to roughly 200 degrees F. As the wheel expands as a result of heat, it can easily be pulled off by hand (obviously you'll need to wear heavy welder's gloves).

Installing Reluctor Wheel—The reluctor wheel features a series of teeth that provide crankshaft position signals (via a sensor) to the ECM. The wheel press fits to the rear of the crank, immediately forward of the No. 5 main bearing. The wheel features about a 0.007" interference fit. While an OE LS crank is already fitted with this timing wheel, an aftermarket crank may or may not be provided with an installed wheel. If you need to install the wheel yourself, be advised that the clock position is critical for proper timing reference.

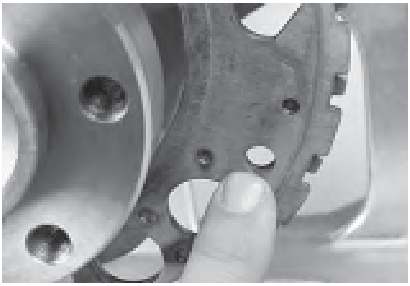
One source for a reluctor wheel installation tool is Goodson Shop Supplies. Their reluctor wheel installation tool (Goodson refers to this as their RRJ-350 Reluctor Ring Jig) indexes to the 8mm hole in the reluctor wheel, allowing for an easy and precise installation to the crankshaft.

An internal dowel (inside the tool body) engages into the crankshaft's rear flange dowel hole.

Here's the dowel pinhole in the crank's rear flange. The tool's internal locating pin fits this hole very precisely.

The reluctor wheel interference-fits onto the smooth outer surface of the crankshaft's rear flange. Make sure that the crank flange is clean and free of burrs. Do not attempt to make the job easier by grinding material from either the crank flange or the inside edge of the wheel's center hole.

This close-up shows the installer tool's outer dowel pin engaged into the tone wheel's 8mm indexing hole.



Here's a close-up of the reluctor wheel's indexing hole.

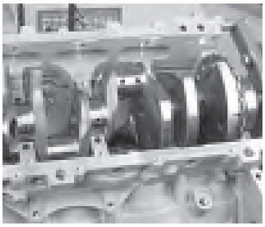
Since LS cranks feature no keyway or other index point (thanks a lot, GM), how do you know where to locate the wheel? Goodson Shop Supplies has the answer. They offer a very handy indexing and installation tool for LS reluctor wheel mounting. The RRJ-350 Reluctor Ring Jig (for Chevy 350 type applications) is a short steel tube that's equipped with two indexing pins. An external tang secures a threaded stud, with the stud tip turned down to 8mm diameter. This pin engages into the sole 8mm hole in the reluctor wheel. An internal guide pin (a threaded stud with the tip turned down to 11mm) engages into the 11mm blind dowel hole in the crank's flywheel flange. This jig orients the reluctor wheel precisely in the correct timing position. The two dowel studs feature jam nuts, to allow depth adjustment (you simply want to make sure that the 8mm dowel passes through the wheel's 8mm hole, and that the 11mm dowel project out far enough to engage into the crank flange dowel hole).

Before attempting the installation, I lightly chamfered the entry hole of the reluctor wheel, and lightly chamfered the edge of the crank's reluctor wheel flange. Goodson's instructions advise this chamfering to ease installation. The instructions also state that the wheel may be pressed onto the crank or heated to 450 degrees F for a slip-on fit. I admit that I did try to cold-press the wheel onto the crank, but maintaining a square alignment of the

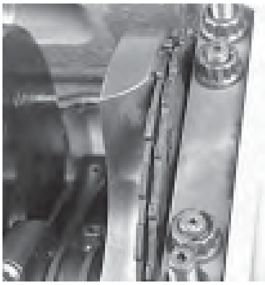
With the reluctor wheel heated (convection oven or very carefully torch-heated) and installed to the tool, the tool and tone wheel, as an assembly, will slip onto the crank flange. Do not whack the tool or the reluctor wheel with a hammer.

Here's the reluctor wheel installed onto the crank, with the installer tool removed.

As you can seen here, the reluctor wheel is positioned on the crank with the two "arrowhead" shaped holes at 90 degrees to the first rod pin, with the series of large holes in the wheel positioned opposite from the first rod pin. That's only a rough description. DO NOT attempt to install a reluctor wheel by eyesight. You MUST have the proper installation tool. If you don't have the tool, take the crank and ring to a local engine builder who is experienced in tone wheel installation.



Here's a view of a Lunati 4.000" stroker crank paid onto the block's upper main bearings. Notice the reluctor wheel at the far right in this photo.



This view shows how tight a fit you'll have with the reluctor-wheel-equipped crankshaft. With all main bearings lubed and main caps fully installed, carefully rotate the crank to check reluctor wheel runout. If you have more than about 0.002" runout, the reluctor wheel is probably bent, in which case you'll probably need to replace it.

wheel to the crank was difficult. Ultimately, I took the easy way out and heated the reluctor wheel's I.D. lip with a torch, slipped the wheel onto the Goodson jig, and the wheel slid onto the crank as easily as a rock drops into water. My advice: install the ring by pre-heating it, instead of potentially ruining the ring by cold-pressing.

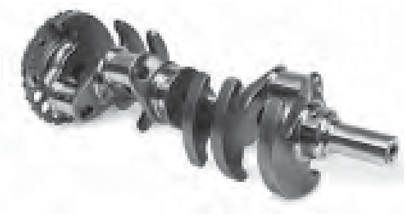
Caution: The ring is made of two plates riveted together. If you cock it out of alignment and continue to press, the plates can begin to separate. If this happens, you can pinch the plates together with C-clamps and carefully tack-weld it back together at the rivet hole locations. Just be careful to avoid creating a warp/runout condition.

Again, because the jig indexes to both the wheel and to the crank, misalignment isn't an issue. If you expect to build LS engines, I highly recommend buying this jig. It takes all of the guesswork and time-consuming measuring out of the equation. Don't even try to press it on cold. Simply heat the ring, seat it onto the jig, and place the jig and wheel onto the crank. With heat and the right tool, it's easy.

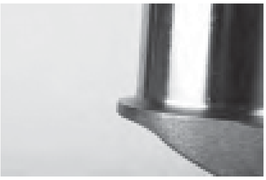
Note: If you plan to convert your LS engine to run with a carburetor and a distributor, you won't need the reluctor wheel at all.

***Reducing Rotating Weight*—**Reducing weight in a race car is generally a good thing, since making a race car lighter frees horsepower and can improve handling and braking. When we consider the weight of the engine as a system, removing weight benefits overall vehicle poundage. When we also consider the weight of specific engine components, this not only affects vehicle static weight, but engine response and durability as well.

While lighter may always sound better, we need to recognize one critical factor: we still need to balance the crank. If we remove too much weight from the counterweights (more than our bobweight factor), we'll need to reintroduce weight (via Mallory metal) to the crank, which defeats the purpose of initially achieving a lighter component. Lightening any crank must revolve around the balancing issue,



For a drastic weight/mass reduction, superlight crankshafts for high rpm racing applications can feature severely scalloped counterweights. This Callies Magnum XL is a good example of a no-holds-barred racing crank that features reduced mass while maintaining race-level durability. Courtesy Callies.



This close-up of a Lunati LS crank shows a nicely rolled fillet on a rod pin. This gentle radiused transition adds strength and eliminates any potential for stress raisers.

which is covered in detail in Chapter 7.

While several methods of weight removal are available, each method has its own effect. Drilling a hole through the centerline of the main (most commonly referred to as gun-drilling or rifle-drilling) serves two purposes: this removes static weight from the engine and race car, and it promotes vacuum and scavenging in the crankcase. For example, if an oil pan features a scraper system, this may isolate the crankcase cylinder-to-cylinder. Gun drilling can equalize crank case pressure and vacuum, transferring air back & forth to improve the scavenging. This is applicable to both wet and dry sump layouts. As an example, Tom Lieb at Scat told us that when GM was developing the LS1, the case was so excessively pressurized that initially uncontrollable external leaks occurred at numerous locations. As a result of Scat's involvement with the program, they were able to solve the problem by strategically gun drilling the crank.

The rod pins can be drilled as well (which reduces overall weight and aids in matching bobweights when using light rods and pistons). Pin drilling is done with regard to oil passage locations, which often require specific angle drilling to clear oil holes. This makes it easier to balance the crank (the weight removed by drilling the rod pins can generally equal one or two slugs of heavy metal). Gun drilling can, depending on crank stroke, remove 3–4 lb on a typical small-block Chevy, or 4–6 lb on a big-block Chevy, and without reducing crank strength.

Undercutting (machining the counterweights thinner at predetermined locations) and profiling the counterweights via knife edging and bullnosing are also effective ways to reduce weight, again, keeping in mind the final balancing scenario. According to Tom Lieb, when billet cranks are produced, since the entire crank will be CNC machined anyway, Scat profiles the counterweights in the process. When a forged crank is produced, "excess" material exists as a natural by-product of the forging process in order to remove the crank from the forging die. If an end-user simply rounds off the counterweight edges (in an effort to bullnose), this might result in a weight savings of 0.75–1 lb. If the counterweight radius is reduced (on a lathe), plus profiling by knife-edging, the weight savings can translate into removal of 4–5 lb. In terms of balancing, as opposed to drilling holes in the counterweights, opposite a rod throw position, the same result can be accomplished by instead reducing the radius of the counterweight. Again, the amount of weight removed must be driven by the bobweight factor.

"A lot of guys spend big money for a lightweight crankshaft," notes Lieb, "and then turn around and install an 8-inch diameter, 12-lb damper, defeating the purpose of buying the lighter rotating mass crank." A handy formula to note is that rotating mass is equal to the square of the distance from the centerline multiplied by weight.

For instance, using an 8-inch damper that weighs 12 lb as an example, the damper's radius (distance from the centerline) is 4 inches. This radius squared (4x4) equals 16. When you multiply 16 x 12 (the damper weighs 12 lb), you find that the damper features a rotating mass of 192 lb. Simply by moving to a 6-inch diameter damper that weighs about 8 lb, you reduce this rotating mass to 72 lb.

A critical benefit of using lighter rods and pistons (aside from quicker acceleration) is that you impose less stress on the crankshaft. In a typical engine with a redline of 6500 rpm, the piston may effectively generate a force equal to almost 12,000 lb when the rod tries to stop it at the end of the exhaust stroke. As piston and rod weight is reduced, this weight goes down, resulting in less stress on the crank. And anytime you can remove stress from a racing crank, you've made huge strides in crank longevity and reliability.

Lunati Forged Crankshafts

P/N	Stroke	Rod Pin	Main	Rod	Weight
JH711ER	3.622	2.100	2.559	6.125	50–51 lb
JO711ER	4.000	2.100	2.559	6.125	50–51
JL711ER	4.185	2.100	2.559	6.125	50–51
JU711ER	4.125	2.100	2.559	6.125	50–51
JP711ER	4.250	2.100	2.559	6.125	50
JQ711ER	4.500	2.100	2.559	6.125	50
JC711ER	4.600	2.100	2.559	6.125	50

Aftermarket crankshaft damper and pulley applications are available from aftermarket firms such as ATI (seen here). The ATI system features a hub (center) that interference-fits onto the crank snout, a damper (right) and a bolt-on pulley.

Aftermarket Crank Dampers

Aftermarket performance crank dampers (also referred to as balancers) should be considered when building a performance LS engine. If you plan to build the LS featuring a "conventional" LS accessory drive system (water pump, power steering pump, etc.), you'll need to stick with a serpentine belt setup. One notable aftermarket damper supplier is ATI. Their Serpentine Super Damper features grooves for serpentine belts machined into the outer damper shell. The dampers come standard with six outer grooves (as standard in OEM drive systems) but are also available with eight or ten grooves for supercharger applications.

The dampers are available in OEM 7.5" diameter, 6.75" diameter for 10% underdrive, and 5.5" outer shell diameters. Crank hubs may be fitted with a grooved serpentine pulley to drive external oil pumps or other vehicle accessories. The dampers are available in steel or lightweight hard-coated aluminum and feature laser-engraved timing marks.

Note: The LS1 in Camaro/Firebird (1998–2002) do not use the same hub offset/accessory drive offset as the LS1/LS6/LS2/LS3 and LS7 in the 1997–2009 Corvette. The Corvette uses an offset that is closer to the engine. The Camaro/Firebird is a bit further out. The Camaro/Firebird offset is also shared by the 2004–2006 GTO. The Corvette offset is also shared by the 2004-2007 Cadillac CTS-V (LS6 and LS2).

The difference in the offset between the Corvette and the Camaro can cause problems with some accessory drive components. For example, the 2005 and newer LS2 Corvette GM water pump won't work with the F-body (Camaro/Firebird) accessory drive because the pulley doesn't extend far enough forward for belt lineup.

Eagle Crankshafts

P/N	Stroke
434636226100	3.6220
434736226100	3.6220
434640006100	4.0000
434740006100	4.0000
442740006100	4.0000
434641006100	4.1000
434741006100	4.1000
442741006100	4.1000
434641256100	4.1250
434741256100	4.1250
442741256100	4.1250
434642506560	4.2500
434742506560	4.2500
442742506460	4.2500
442743756460	4.3750
434743756460	4.3750
434643756460	4.3750

Note: Internal balance; target bobweight of 1800g; rated for 1500 hp

Performance Aftermarket Crankshafts

(Examples listed here include Callies, Lunati, Eagle and Scat. Refer to the appendix for additional crankshaft manufacturers.)

All LS crankshafts listed here feature the OE 2.559" main diameter, which accommodates all standard LS block main bores.

Connecting Rods

Rods should be inspected for center-to-center length, big end bore diameter, small end bore diameter, big end bore out-of-round, rod bend, rod twist and for cracks.

LS engine connecting rods (except for LS7 and LS9, which are forged titanium) are made of powdered metal, featuring "cracked cap" construction. The big-end rod bores should

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Scat Crankshafts
(forged 4340 standard weight)

P/N	Stroke	Rod length	Rod pin	Reluctor wheel teeth
4-LS1-1-4000-6125-24	4.000	6.125	2.100	24
4-LS1-1-4000-6125-58	4.000	6.125	2.100	58
4-LS1-1-4125-6125-24	4.125	6.125	2.100	24
4-LS1-1-4125-6125-58	4.125	6.125	2.100	58
4-LS1-1-4250-6125-24	4.250	6.125	2.100	24
SCAT Crankshafts (forged 4340 Lightweight Pro Comp)				
4-LS1-1-4000-6125-24-2	4.000	6.125	2.100	24
4-LS1-1-4000-6125-58-2	4.000	6.125	2.100	58
4-LS1-1-4125-6125-24-2	4.125	6.125	2.100	24
4-LS1-1-4125-6125-58-2	4.125	6.125	2.100	58
4-LS1-1-4250-6125-24-2	4.250	6.125	2.100	24
SCAT Crankshafts (forged 4340 Superlight)				
4-LS1-1-4000-6125-24-3	4.000	6.125	2.100	24
4-LS1-1-4000-6125-58-3	4.000	6.125	2.100	58
4-LS1-1-4125-6125-24-3	4.125	6.125	2.100	24
4-LS1-1-4125-6125-58-3	4.125	6.125	2.100	58
4-LS1-1-4250-6125-24-3	4.250	6.125	2.100	24

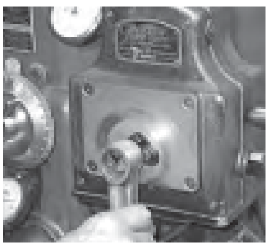
Callies Forged Crankshafts

P/N	Stroke	Pin dia.	Main dia.	Model
APH317-CS	3.625	2.100	2.559	Compstar
APH347-CS	3.625	2.000	2.559	Compstar
APO317-CS	4.000	2.100	2.559	Compstar
APO31N-CS	4.000	2.100	2.559	Compstar
APO347-CS	4.000	2.000	2.559	Compstar
AWO317-CS	4.000	2.100	2.559	Compsar
APZ317-CS	4.100	2.100	2.559	Compstar
APU317-CS	4.125	2.100	2.559	Compstar
APP317-CS	4.250	2.100	2.559	Compstar
APO31R-CL	4.000	2.100	2.559	Compstar
APH31V-DS	3.625	2.100	2.559	DragonSlayer
APH34V-DS	3.625	2.000	2.559	DragonSlayer
APO31V-DS	4.000	2.100	2.559	DragonSlayer
APO34V-DS	4.000	2.000	2.559	DragonSlayer
APU31V-DS	4.125	2.100	2.559	DragonSlayer
APZ31V-MG	3.622	2.100	2.559	Magnum
APC31V-MG	3.900	2.100	2.559	Magnum
AWO31K-MG	4.000	2.100	2.559	Magnum
APZ31V-MG	4.100	2.100	2.559	Magnum
APZ34V-MG	4.185	2.000	2.559	Magnum
APP31V-MG	4.250	2.100	2.559	Magnum
APQ31K-MG	4.500	2.100	2.559	Magnum
AWQ34V-MG	4.500	2.000	2.559	Magnum
AWZ31K-MG	4.600	2.100	2.559	Magnum
APZ39V-XL	3.025	1.888	2.559	Magnum XL
APZ3DV-XL	3.185	1.850	2.559	Magnum XL
APU31V-XL	4.125	2.100	2.559	Magnum XL

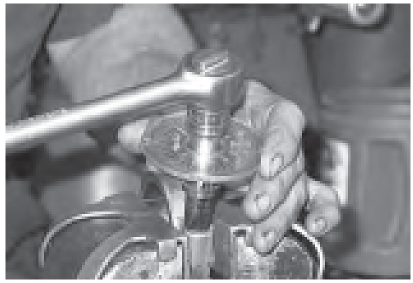
In order to separate a rod cap on a previously fully tightened rod assembly, loosen the rod bolts while holding the rod steady. The safest method is to clamp the rod big end in a dedicated rod vise as shown here, or to use a soft-metal liner in a bench vise. You simply need to avoid damaging the rod (gouges, twisting, etc.).

With the cap fully installed onto its rod, measure the rod big end. LS rod big-end diameters should be 2.224–2.225". Check in several axis, including from the bottom center to the top center to determine if the rod bore has been pulled out of round. If out of round by 0.002" or less, the rod big end may be honed 0.002" to correct, and then fitted with +0.002" OD rod bearings. If an OE powder metal connecting rod features more than 0.002" out-of-round, discard the rod and replace it.

OE rod small-ends are interference-fit to the piston wrist pins. This requires the use of a hydraulic press to push the wrist pin out of the rod in order to separate the piston from the connecting rod.



OE rod small-end diameter should be 0.9436". If using aftermarket performance full-floating rods, diameter will be based on oil clearance to the wrist pins.



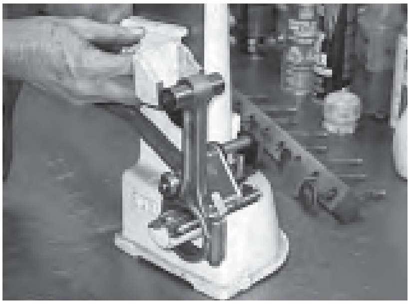
When tightening connecting rod bolts (when reinstalling the caps in order to measure the rod big end diameter), the OE 9mm rod bolts require a torque-plus-angle tightening method (15 ft-lb plus 65 degrees; or 15 ft-lb plus 75 degrees, depending on which version [early or late] rod bolts you have). An easy method is to use an inexpensive plastic angle gauge tool (available for about $6). Simply zero the gauge, hold the outer wheel steady with your fingers, and tighten the rod bolt until the dial hits the appropriate number of degrees. If you're using aftermarket performance rod bolts, no angle tightening is needed.

Using a connecting rod alignment checker, inspect each connecting rod for bend (with the rod placed onto the tool centering fixture, a feeler gauge can be used between the wrist pin surface and the upper checking base).

measure (OE spec) from 2.224" to 2.225". When measuring the big end bore for diameter and out-of-round, the cap must be fully installed, with rod bolts fully tightened (the OE rod bolts are 9mm bolts and are designed for torque-plus-angle tightening. There are two versions…the first design, which is tightened to 15 ft-lb plus 65 degrees; and the second design, which is tightened to 15 ft-lb plus 75 degrees. The LS2 should have the second design, but if you choose to use OE rods and OE rod bolts, check to see which bolts you have. If you're using aftermarket rods and rod bolts, follow the maker's specs for bolt tightening.

If the rod big-end bores are out of round by less than 0.002", the bores may be honed +0.002" oversize, since +0.002" oversize-O.D. rod bearings are available. If the bore is more than 0.002" out of round, toss the rod and replace it. Cracked cap rods cannot be reconditioned in the traditional manner (grinding mating surfaces flat, reinstalling the cap and honing to original diameter).

***OE Rods*—**All OE rods (except for LS7 and LS9) feature I-beam, powdered metal (PM) construction w/ cracked cap design. Premium aftermarket rods will be forged steel or machined from a forged billet. Aftermarket rods are also available in either I-beam or H-beam.



Also check each rod for twist (small- and big-end bore centerlines at different planes). While I could not find an official GM factory tolerance, generally speaking, rod bend or twist should be less than 0.001" for every inch of rod length. With that said, it can be assumed that the LS2 60.098" connecting rod should not have more than 0.006" bend or twist. However, given the tighter tolerances that the LS engine family tends to feature, I'd say that maximum bend or twist should be limited to no more than about 0.004–0.005". If greater, toss the rod and replace it. You can't fix rod bend or twist, and it's not even worth the effort to try.

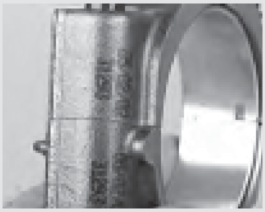
The OE rod and piston assembly. The connecting rods are I-beam style, and made from highly compressed powdered metal (sort of a high-density pressure casting). Rod small ends feature a 0.0008"–0.0017" press fit to the wrist pins.

Rod Specs

LS7/LS9: Forged titanium construction w/machined cap mating
Bearing bore dia:: 2.224–2.225" (applies to OE and aftermarket)
Rod bearing clearance: 0.0009–0.0025" (OE and aftermarket)
Bearing width: 0.9449" (OE and aftermarket)
Side clearance: 0.00433–0.0200" (OE and aftermarket)
Center to center: 6.098" (OE length only)
Piston pin bore dia 0.9436 (OE and possible aftermarket, depending on piston pin diameter and if press fit or full float bushed)
Piston pin boss width: 0.9449" (OE and aftermarket)
Piston pin press: 0.0008–0.0017" if press fit (OE and some aftermarket)
Rod bolts: 9mm x 10.0 X 43mm (OE—Aftermarket rods may feature 3/8" or 7/16" bolts)

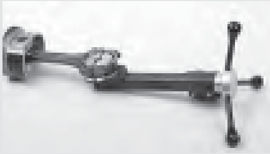
The OE rod bolts are 9mm in diameter with a 10.0 thread pitch, and the shanks are 43mm long. A thin metal dowel centers the bolt shank in the rod cap. These are torque-plus-angle bolts and should not be reused. If you plan to use OE rods, buy new OE rod bolts. If you buy new rods, the bolts will already be included.

Powdered metal connecting rods are pressure-cast as one piece. The cap is then separated by literally snapping it off of the rod's main body. This may sound crude, but the resulting uneven mating surfaces then perfectly align, with no chance of minutely moving the cap. This is a very precise method of achieving cap alignment. The downfall is that you can't resize the big ends in the traditional manner (which would involve grinding material from the mating surfaces, reinstalling the cap and then honing the bore back to original diameter).



This close-up shows the irregular mating surface between cap and rod, created by the fracture process. This cap has been finger-installed to its rod.

As you begin to tighten the rod bolts, the once-noticeable separation crack begins to disappear. Once fully tightened, you cannot see the mating line at all. Powder metal construction with cracked caps are nothing new and are not unique to LS rods. This OE-only design has been around for many years.



Once a rod cap has been fully tightened to its rod (for checking/measuring purposes, for example), a safe method of separating the cap is with the use of a dedicated rod cap splitter tool. This draws the cap from the rod without the need to hold the rod upside down and bang on the loosened rod bolts.

Aftermarket performance connecting rods are available in both I-beam (similar in shape to the OE rod beam) and H-beam (seen here). Generically speaking, I-beam type rods are OK for anything up to about 400 hp. Beyond that, H-beam rods are recommended due to their greater design strength.

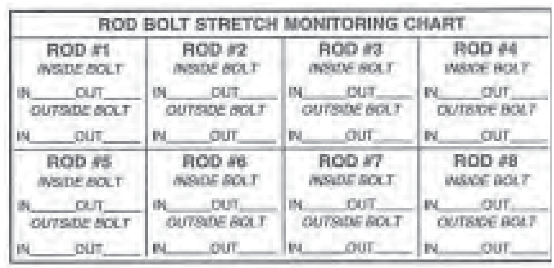
Even when using the best aftermarket rods, always check big- and small-end bore diameters, just to be sure.

As noted earlier, the OE connecting rod small ends are interference-fit to the piston wrist pins. The pin floats inside the piston's pin bore, but remains locked to the connecting rod. Performance aftermarket rods and pistons offer full-float design, where both the piston and the rod pivot (float) with an oil clearance between both piston pin bore and rod pin bore.

High-performance aftermarket connecting rod bolts feature a dimple on each end (see shank tip here).

Here we see the dimple on the rod bolt head. These dimples allow the use of a rod bolt stretch gauge to monitor rod bolt stretch during tightening. The gauge features tapered tips that nestle into these dimples.

Lunati I-beam style forged rods are completely machined to final shape. In terms of both dimension and weights, each rod in the set are absolutely identical. Courtesy Lunati.



ROD BOLT STRETCH MONITORING CHART

ROD #1	ROD #2	ROD #3	ROD #4
INSIDE BOLT	INSIDE BOLT	INSIDE BOLT	INSIDE BOLT
IN_____OUT_____	IN_____OUT_____	IN_____OUT_____	IN_____OUT_____
OUTSIDE BOLT	OUTSIDE BOLT	OUTSIDE BOLT	OUTSIDE BOLT
IN_____OUT_____	IN_____OUT_____	IN_____OUT_____	IN_____OUT_____
ROD #5	ROD #6	ROD #7	ROD #8
INSIDE BOLT	INSIDE BOLT	INSIDE BOLT	INSIDE BOLT
IN_____OUT_____	IN_____OUT_____	IN_____OUT_____	IN_____OUT_____
OUTSIDE BOLT	OUTSIDE BOLT	OUTSIDE BOLT	OUTSIDE BOLT
IN_____OUT_____	IN_____OUT_____	IN_____OUT_____	IN_____OUT_____

Most performance aftermarket connecting rod makers will supply a chart. This allows you to create a record of each rod bolt's stretch.

You have a choice of two methods for rod bolt tightening (when using performance aftermarket rods and rod bolts): torque or stretch. Rod (and rod bolt) makers will provide both specs. The stretch method offers a more accurate way to monitor and achieve desired bolt clamping load, since the torque factor is eliminated (by monitoring only tightening torque, the variable of thread and bolt underhead friction can result in slight inconsistent bolt tightening. Each engine builder has his own preference (torque or stretch). Shown here is a Gearhead Tools stretch gauge that features a handy finger hole for holding the gauge.

Aftermarket Connecting Rods

While OE rods for most LS engines are made of powdered metal (PM) featuring a cracked-cap parting design, with the exception of the LS7 and LS9 which use forged titanium rods, all aftermarket performance connecting rods are high-density steel forgings (yes, exotic aluminum billet and titanium rods are also available, but these are strictly custom applications for high-horsepower race applications).

A number of excellent sources exist for performance LS rods, including Lunati, Scat and Eagle. Remember, the formula to determine rod length:

RL = BDH – Stroke ÷ 2 – CD
where RL = rod length, BDH = block deck height and CD = piston compression distance.

***Lunati*—**Lunati offers both fully machined I-beam and H-beam connecting rods, all forged from aircraft grade 4340 steel. Rods are heat treated, stress relieved, shot-peened and Magnaflux checked. Each set of rods is weight matched within +/- 1.5 grams, so no additional weight-corrections are needed at either small or big ends. All rods are outfitted with ARP rod bolts. Lunati LS rods are available in a 6.125" length and in a newly released 6.300" length. The 6.300" rod is specially designed for large-displacement racing blocks that feature 9.500" to 9.750" deck heights.

Complete Rotating Assemblies

Several crankshaft manufacturers also offer complete rotating assemblies, which include a matched system of the crankshaft, connecting rods, pistons, piston rings, main bearings and rod bearings. Based on a zero deck dimension (where the flat of the piston dome meets the block deck at TDC), and the standard OE cylinder head combustion volume, the pistons will be selected to achieve specific compression ratios. These kits are generally available in a balanced or unbalanced condition. In kit where the crankshafts are already balanced, the manufacturer factors in the pistons, connecting rods, rings and rod bearings for the individual kit, based on your bore, stroke and

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Lunati Rod Specs

P/N	Type	Length	Journal dia.	Small End dia.	Weight (g)
6125HL3	H-beam	6.125	2.100	0.928	605
6125H3	H-beam	6.125	2.100	0.928	680
6125FM3	I-beam	6.125	2.100	0.928	609
6300-8	I-beam	6.300	2.100	0.928	645

Eagle Rod Specs

P/N	Type	Length	Journal dia.	Pin dia.	HP Rating	Weight (g)
SIR6125BBLW	I-beam	6.125	2.100	0.927	500	600
SIR6200BBLW	I-beam	6.200	2.100	0.927	500	610
SIR6250BBLW	I-beam	6.250	2.100	0.927	500	615
CRS6100L3D	H-beam	6.100	2.100	0.927	750	650
CRS6100M3D	H-beam	6.100	2.100	0.945	750	650
CRS6125BLW	H-beam	6.125	2.100	0.927	600	550
CRS6125O3D	H-beam	6.125	2.100	0.927	700	620
CRS6125O3D2000	H-beam	6.125	2.100	0.927	1100	620
CRS6125O3DL19	H-beam	6.125	2.100	0.927	1400	620
CRS6200O3D	H-beam	6.200	2.100	0.927	700	650
CRS6200O3D2000	H-beam	6.200	2.100	0.927	1100	650
CRS6460H3D2000	H-beam	6.460	1.889	0.927	1100	640
CRS6460H3DL19	H-beam	6.460	1.889	0.927	1400	640
CRS6460O3D2000	H-beam	6.460	2.100	0.927	1100	640
CRS6460O3DL19	H-beam	6.460	2.100	0.927	1400	640
CRS6560H3D2000	H-beam	6.560	1.889	0.927	1100	650
CRS6560O3D2000	H-beam	6.560	2.100	0.927	1100	650

SCAT Connecting Rods

P/N	Wrist pin fit	Length	Rod pin dia.	Wrist pin dia.	Big end width	Weight (g)
I-Beam, Premium Pro Comp 4340 w/ 7/16" rod bolts						
2-ICR6100-927	Bushed	6.100	2.100	0.927	0.940	595
2-ICR6100-944P	Pressed	6.100	2.100	0.944	0.940	600
H-Beam Premium Pro Comp 4340 w/ ARP 8740 7/16" rod bolts						
2-LS1-6100-2100-927	Bushed	6.100	2.100	0.927	0.940	
2-LS1-6100-2100-945	Bushed	6.100	2.100	0.945	0.940	
2-350-6125-2100	Bushed	6.125	2.100	0.927	0.940	
H-Beam Premium Pro Comp 4340 w/ ARP 2000 7/16" rod bolts						
2-LS1-6100-2100-927A	Bushed	6.100	2.100	0.927	0.940	
2-LS1-6100-2100-945A	Bushed	6.100	2.100	0.945	0.940	
2-350-6125-2100	Bushed	6.125	2.100	0.927	0.940	

An example of a complete rotating assembly. Once you've determined the bore and stroke combination that you want, a matched and already balanced system can be ordered under a single part number. This will include the crankshaft, connecting rods, pistons and pins, piston rings, main bearings and rod bearings. Several crankshaft manufacturers offer such complete assemblies. Courtesy Scat.

compression requirements. If you don't feel like calculating your required piston compression distance and connecting rod length, these rotating assembly kits provide an easy way to obtain your desired bore and stroke combination in a ready-to-install state (obviously, cylinder bores must be sized for the pistons and the block may require slight clearancing depending on the stroke).

As an example, Scat offers both street/strip and competition rotating assemblies, balanced or unbalanced. Piston domes, depending on compression ratio, will be either flat-tops (with valve relief pockets) or dished.

Crankshafts will also be already fitted with the reluctor wheel. Two choices of reluctor wheels are offered, including 24-tooth and 58-tooth (LS1 and LS6 uses the 24-tooth wheel, while LS2 and later versions use the 58-tooth wheel). If you're planning to use an aftermarket timing control module and not a stock OE controller, you can use either tooth count, as long as you purchase the appropriate controller for the wheel's tooth count.

If you want to piece the assembly together yourself, once you have determined your final bore and stroke combination based on the displacement you want, you'll need to determine connecting rod length and piston compression distance in order to retain a zero deck clearance at TDC. Rather than dwell on the steps involved here, refer to Chapter 4 for a simple explanation regarding these measurements.

With the exception of LS9 forged aluminum pistons, all LS OE pistons are hypereutectic (cast aluminum with a high silica content). While not as strong as a forged piston, this type is stronger and lighter than old-school cast pistons, and is used in probably the majority of OE engines (and most car maker brands as well). If you plan to build a hot monster (say over 400 hp), and especially if you plan to use nitrous or forced induction, toss these slugs and move up to quality forged pistons. Note that the LS piston skirts are factory-coated with an anti-friction material (most likely moly or Teflon). This coating reduces operating noise when the engine is cold (re piston slap) and provides a bit of added insurance against dry scuffing.

Pistons

OE hypereutectic pistons (commonly used by all automakers and on all factory LS engines except the LS9, which is factory equipped with forged pistons due to the use of a supercharger) are cast alloy with a high silica content. Basically, this means that they don't expand and contract (change diameter) during heat cycles as much as a cast piston, so the automakers can maintain tighter piston-to-wall clearances for improved efficiency and reduced emissions. Hypereutectic pistons are stronger than cast pistons, and they're fine for unmodified engines and even mildly hot-rodded engines. If you're going to stick with GM OE pistons, and if you're dealing with an LS1 that's not going to be overbored, the OE LS6 pistons are probably a better choice. Both the LS1 and LS6 use hypereutectic pistons, but the metallurgy of the LS6 piston is a bit stronger, due to a higher content of nickel and copper. They won't grow as much under temperature as the LS1 pistons, so piston slap (when cold) and oil consumption is slightly reduced. Any of the hypereutectic slugs that were originally used in the LS series should be able to handle just shy of 500 hp, as long as the engine is not outfitted with nitrous injection or any form of forced induction.

However, if you plan to play hard by increasing cylinder pressure (nitrous, supercharging, turbocharging) or decide to boost compression ratio, or plan to bore and/or stroke the engine and need to buy new pistons anyway, don't mess around. Purchase quality aftermarket high-performance pistons that are made from dense alloy

The OE pistons are flat-top. If you plan to run a cam with more than about 0.544" valve lift, you'll need to either notch the OE domes or buy new forged pistons that feature valve relief pockets, to avoid valve-to-piston contact.

This side view of an OE LS piston and ring package shows the 1.5mm top ring, 1.5mm second ring and 3mm oil ring package. When building a stroker engine, you may need a piston that features a shorter compress distance (centerline of the wrist pin to the dome) to avoid raising the piston too far above the block deck.

The OE pistons feature a small dot in the dome. During assembly, remember that this dot must face towards the front of the engine.

forgings/billet stock. Quality forged pistons either start off as semi-shaped dense forgings and are then CNC-machined to final shape, or they begin life as a dense forged chunk of billet alloy and are fully formed by CNC-machining (depending on the route the individual piston maker takes). Most true custom pistons that are made to order are machined from billet slugs.

Dome Shape—As far as dome shape is concerned, there's no need to get carried away with anything exotic. You'll use either flat-top or dished pistons. Flat-top pistons are just that…the domes are cut flat, with no positive protrusions. However, the flat-top slugs will feature valve relief pockets to accommodate valve head travel. Whenever you look at a flat-top piston that features valve reliefs, the larger pocket will be for the intake valve and the smaller pocket is for the exhaust valve (since intake valves are larger in diameter than the exhaust valves).

Dished pistons are essentially flat-tops with a large center relief that creates a "dish" on the dome area. Dished pistons, as compared to flat-tops, simply create more combustion volume, thereby lowering the compression ratio. A variety of dish volumes are available, depending on the manufacturer and desired compression ratios. Depending on your specific needs in terms of static compression, either a flat-top or dished piston will fill the bill. For instance, if the cylinder head combustion chamber is relatively small, and a flat-top would result in, say, 12:1 compression ratio, a move to a dished piston might drop this to 11:1 (this is just a hypothetical example). Dished pistons are often selected to drop static compression for an engine that will be equipped with forced induction, such as a supercharger or turbocharger (since under dynamic conditions, the forced induction will increase cylinder pressure).

As an example, let's say that you're building a 408 cid LS engine, starting with, say, an LS2 6.0L block. This build would involve a cylinder bore diameter of 4.030" and a stroke of 4.000". Achieving the compression ratio of choice will now be based on the cylinder head combustion chamber volume and the piston dome volume.

In this example, let's say that you have a cylinder head that features a 64cc combustion chamber. Using a flat-top piston that features –10cc (the volume generated by the valve pockets) would result in about an 11.1:1 compression ratio. If you plan to run a turbo, this is going to be a bit high, so choosing a dished piston that features a –290cc volume would drop compression to the 9.2:1 area.

If you run a cylinder head with 66cc chambers, a –10cc flat-top would result in about 10.8:1 compression, and a –290cc dished piston would drop this to about 9.0:1.

If you run a cylinder head with 72cc chambers, a –10cc flat-top would give you about 10.2:1, while a –290cc dished piston would change this to about 8.6:1.

These are only examples, but you can see how the piston dome volume will affect the compression ratio, in conjunction with the combustion chamber volume.

Piston Compression Distance (CD)—When selecting or ordering custom pistons, one of the dimensions to be aware of is the piston's CD, or compression distance (also referred to as compression height). This is the distance from the centerline of the piston's wrist pin bore to the outer top surface of the piston dome (if we're dealing with a flat-top piston, this is simply the distance from the pin bore center to the dome surface). The location of the pin bore dictates where the dome will be located at TDC, relative to the small end of

GM OE LS Pistons

Engine	P/N	Bore	Oversize	Rod	Pin	CR	Chamber
LS1/LS6	88984245	3.898	std	std	pressed	n/a	65
LS1/LS6	88984246	3.908	+0.010	std	pressed	n/a	65
LS2	89017478	4.000	std	std	floating	10.9	65
LS2	89017479	4.020	+0.020	6.098	floating	10.9	65
LS7	12602624	4.125	std	6.067	floating	11.0	70
LS7	89018171	4.145	+0.020	6.067	floating	11.0	70

the connecting rod. If the piston CD is too short, the top of the piston dome will be too far below the block deck. If the CD is too tall, the piston dome will stick up above the block deck. At TDC (top dead center), OE pistons generally stick out about 0.006– 0.008" above deck, and you'll end up with about 0.005" to about 0.008" with aftermarket pistons (this will vary). When calculating piston CD, it's easier to consider a zero deck, since slight variation will likely occur as a result of reconditioning the block (during deck checking and resurfacing).

Remember that in terms of where the piston will be at TDC, we're considering four individual variables: block deck height, crank stroke, connecting rod length and piston CD. When you're creating a stroker engine (with a longer stroke than factory), we need to consider these four dimensions as a coordinated package.

The block deck height is the distance from the crankshaft main bore centerline to the block deck surface. Crank stroke is the distance of total linear movement of the crank's rod pin, from bottom-dead-center to top-dead-center. The connecting rod length is the distance from the centerline of the rod's big and to the centerline of the rod's small end. The piston CD is the distance from the pin bore centerline to the piston dome.

When determining your stroker package, here's a simple formula to determine block deck height (BDH):

BDH = (Stroke ÷ 2) + (connecting rod length + piston CD)

Note: We consider only half of the crank's stroke because at TDC, we're only seeing half of the stroke.

Note: When you're building a stroker LS engine, you need to be aware of a possible interference issue between the No. 8 piston and the crankshaft's reluctor wheel. In order to address this issue, aftermarket piston makers design a side relief into their pistons, reducing the boss area to prevent the toothed wheel from hitting the underside of the piston. If you decide to over-stroke your LS, make sure that the pistons you choose feature this relief!

Let's do a for-instance: let's say that your block deck height is 9.240" and your stroke is 4.000". Now let's say that your rods have a center length of 6.125". Given those dimensions, let's figure out your required piston CD.

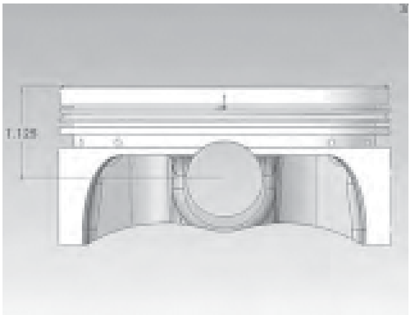
Piston CD = (4.000 ÷ 2) + 6.125"
Piston CD = 8.125"

Since we have a deck height of 9.240", we know that we need a piston CD of 1.115" (subtracting the 8.125" from the 9.240" deck height).

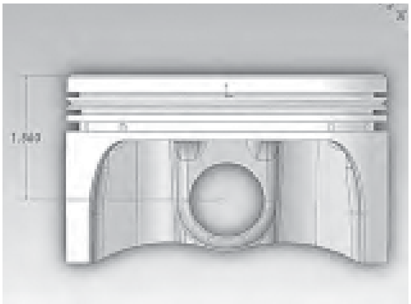
If your block features a block deck height of 9.240" (the factory deck height for LS1, LS6, LS2, LS7, LS3 and LS9), the crank stroke, rod length and piston CD need to be packaged together so that the piston dome is theoretically flush with the block deck.

By selecting the rod length to match up with your piston CD, or choosing piston CD to match up with your rod length, you'll be able to achieve the desired distance package.

Piston Coatings**—**This is a good time to mention piston coatings. There are two areas of the piston to consider regarding specialty coatings. The skirts may be coated with a thin impregnated film of a moly graphite type material. This is an anti-friction coating that helps to protect both the piston skirt and the cylinder wall from scuffing issues. Scuffing can occur when the piston rocks during its transition between upstroke and downstroke, especially if oil delivery/oil performance becomes an issue, or in the case of cold startups before the piston has a chance to thermally expand to its proper running dimension. The anti-friction coating provides a bit of a fail-safe protection in those situations. While skirt coatings were once in limited use among high-end racers, today these coatings are commonplace and have even been adopted by the OE makers. When you purchase aftermarket performance pistons,



This illustration shows the piston compression distance (CD). This piston's CD measures 1.125" from the pin bore centerline to the dome. Courtesy JE Pistons.



For comparison, here's a piston with a CD of 1.560". Courtesy JE Pistons.

depending on the maker and the specific piston part number, a skirt coating may be standard equipment, or may be available as an added option. If you have a choice, go with the coated skirts. You don't need to compensate for the coating thickness during cylinder bore prep, since these skirt coatings are extremely thin…don't worry about it.

The other type of coating that applies to pistons is a dome coating. This is generally a thermal barrier coating that helps to deflect heat and reduces the amount of heat that soaks into the piston (reducing heat-soak will reduce the piston's diameter growth, allowing you to operate with a more consistent piston-to-bore clearance). However, the main benefit of a thermal barrier coating is to create a more efficient combustion burn, allowing the heat to travel more efficiently out the exhaust instead of hanging around and affecting the piston. With that said, you really don't need a thermal barrier coating for street operation in a naturally aspirated engine. However, for a racing engine (where every fraction of power counts) or for an engine that creates higher combustion heat and pressure, such as in forced induction setups, this thermal barrier coating is definitely worth considering. If properly applied, it won't hurt and it'll probably help. I mention properly applied for a reason. Since most thermal barrier coatings feature a ceramic-based material (and ceramic is tough and abrasive), it must be applied carefully to achieve proper adhesion (it should actually bond to and become part of the piston dome). If a ceramic coating starts to lift and flake off, the loose debris will cause havoc in the bores, bearings, etc. It's best to rely on a skilled service facility that specializes in these coatings and that have experience in the automotive performance

JE FSR Pistons

For my Project LS2 engine build, I chose JE's FSR (forged side relief) pistons, P/N 243016. The pistons I chose to accommodate my particular block are sized for a bore diameter of 4.005".

These pistons are flat-top 15-degree slugs (meaning that the valve relief pockets accommodate heads that feature 15-degree valve angles), designed for use with our 4.000" stroke and our 6.125" connecting rods. Since my chosen camshaft featured a valve lift of 0.624" (with the stock rocker arm ratio of 1.70:1), the valve pocket volume is 5cc. Compression height is 1.115", and piston weight is 402 grams. JE included rings, including 1.5mm top, 1.5mm second and 3mm oil rings (with spacer rails). The full-float wrist pins are P/N 927-2250-15-51C. The pin locks are P/N 927-073-MW. The oil ring support rails are P/N RA4000-183.

Due to the need for clearance between the rear-mounted crank timing reluctor wheel and No. 8 piston, all pistons feature a box style, with a narrow pin boss area. This is a common requirement for LS engines that feature a crankshaft reluctor wheel. The potential interference occurs at No. 8 piston only, but naturally all eight slugs need to feature the same design from a balance standpoint.

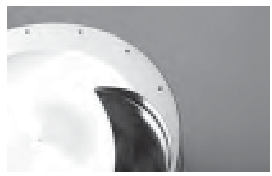
Note: While GM recommends that maximum valve lift that can be used with stock-style flat-top pistons can be no more than about 0.570", Katech told me that in reality, a maximum of 0.595" valve lift can be used with the stock pistons without the need to fly cut reliefs. Beyond 0.595" valve lift, you'll need to fly cut stock flat-tops or purchase flat-top forged pistons that already feature intake and exhaust valve relief pockets.

While GM stock pistons are just fine for stock engine applications, if you plan to play, (overboring, running higher compression, changing compression ratio, accommodating a longer stroke, adding nitrous, using a supercharger, etc.), toss the factory cast hypereutectic pistons in the trash and invest in a set of quality forged pistons. They're stronger than the hyper pistons, and you have a multitude of choices in terms of bore diameter, dome height, dome shape, dome volume, weight, etc. Shown here is a set of 4.005" bore pistons from JE for a +0.005" LS2 application. High-quality forged piston sets such as those offered by JE and other leading pistons makers are CNC machined to exacting tolerances and are usually very closely weight-matched as sets. This set for the Project LS2 buildup featured all eight pistons that weighed within 0.03g of each other, which meant that no weight correction was needed.

These JE pistons provided reduced weight, with excess material removed from areas where material reduction would not affect piston strength.

View of a typical flat-top LS forged piston. Notice the intake and exhaust valve relief pockets. This piston features an anti-friction moly type skirt coating. A skirt coating is always a good idea on any piston, whether for the street or for racing. Courtesy JE Pistons.

Here's an example of a dished piston (notice the dish relief across the entire dome) with valve reliefs. This particular piston is JE's newly introduced LS7 forged piston. Courtesy JE Pistons.



The small holes seen at the outer dome area are gas ports which allow pressure to be directed to the top ring, providing improved top ring sealing and forcing the ring down on its land to eliminate flutter. This is a race option on some pistons.

and racing industry. Prime examples include Swain Tech Coatings and Polydyne. I've had racing pistons coated by both of these firms over the years (both skirt coatings and thermal barrier coatings), without a single problem.

If you really want to do things right, and you're going to have the piston domes ceramic coated anyway, it's an excellent idea to finish the package by also having the same coating applied to the cylinder head combustion chambers, the face and throat of the exhaust valves, and to the cylinder head's exhaust ports. This will make a difference in terms of power increase and a more efficient fuel burn and scavenge. It makes the combustion process more efficient. For the street though, you really don't need to have this done.

OE wrist pin bore diameters (in the piston) are 0.9436" and are press-fit to the small end of the connecting rod with an interference of about 0.00027 – 0.00086". Floating piston wrist pin diameters (where the pin floats in both the piston and rod with no interference fit) are fairly constant in the LS series, usually in the 0.927 – 0.928" range for aftermarket pistons and pins (when you buy pistons, they'll include the matching pins). There's really no magic involved in selecting pins for the average builder, since they're packaged along with the aftermarket pistons. We could devote pages to piston pin technology, discussing materials (chromoly, titanium, etc.), but you really don't need to fuss over the issue. Buy quality pistons and use the pins that are included.

A press-fit pin stays in place because it's interference-fit to the rod. A full-floating pin needs a way to secure it in place, to prevent it from walking out and digging into the cylinder wall. This is handled at the ends of the piston's pin bore. Each end of the piston pin bore will feature a groove that accepts either a wire lock or a spiral lock (different piston makers use either design, and in the case of spiral locks, two locks per end may be needed. But this really isn't a concern, since the appropriate locks will be included with the pistons.

A wire lock is a circlip made of tensioned round wire that is compressed and snapped into the lock

Probe Forged Aluminum Pistons

P/N	Bore sizes	Stroke	CD	Rod length	Pin dia.	Rings	Dome
14509	4.000/4.030	3.622	1.295	6.125	0.927	1.5/1.5/3mm	Flat top –30.0cc
14510	4.000/4.030	3.622	1.295	6.125	0.927	1.5/1.5/3mm	Reverse –160.0cc
14512	4.000/4.030	3.900	1.155	6.125	0.927	1.5/1.5/3mm	Reverse –8.5cc
14513	4.000/4.030	3.900	1.155	6.125	0.927	1.5/1.5/3mm	Dish –22.4cc

Note: Figures are based on stock 9.240" deck.

JE Forged Pistons

P/N	CID	Bore/Stroke	Rod length	Block deck height	CD	Compression Ratio 64cc/66cc/72cc	Dome volume	Wt. (g)
221176	408	4.030/4.000	6.125	9.240	1.115	9.2/9.0/8.6	-290.0	395
221178	414	4.060/4.000	6.125	9.240	1.115	9.3/9.1/8.7	-290.0	400
221180	427	4.125/4.000	6.125	9.240	1.115	9.5/9.3/8.9	-290.0	425
264041	383	3.905/4.000	6.125	9.240	1.115	10.5/10.3/9.7	-10.0	382
264042	403	4.005/4.000	6.125	9.240	1.115	11.0/10.7/10.1	-10.0	407
264043	408	4.030/4.000	6.125	9.240	1.115	11.1/10.8/10.2	-10.0	418
Flat-Top (w/ side-relief)								
243016	403	4.005/4.000	6.125	9.240	1.115	11.6/11.3/10.6	-50.0	402
243017	408	4.030/4.000	6.125	9.240	1.115	11.7/11.4/10.7	-50.0	410
243018	427	4.125/4.000	6.125	9.240	1.115	12.1/11.9/11.1	-50.0	440

Note: The pistons listed here are forged side-relief off-the-shelf stocked pistons. Custom pistons are also available. Side-relief refers to extra clearance at the pin boss sides to enable No.8 piston to clear the reluctor wheel. To keep weight matched, all eight pistons feature this side relief design. Inverted dome design to accommodate forced induction.

Note: Compression ratio calculated with 0.00" deck clearance and 0.042" head gasket; rings are 1.5/1.5/30.0mm.

Ross Forged Aluminum Pistons

P/N	Bore	Stroke	CD	Rod length	Pin dia
99171	4.125	4.000	1.110	6.125	0.927
99173	4.125	4.000	1.110	6.125	0.927
99172	4.125	4.000	1.110	6.125	0.927
99174	4.155	4.000	n/a	6.125	0.927

Note: Figures are based on 9.240" deck, 64cc chamber, with 0.050" piston to head clearance (deck and gasket combined…pistons listed here include oil ring support rails).

groove. A spiral lock is a tensioned flat-stock with overlapping layers. Either style isn't really difficult to install, once you get the hang of it. Once fully installed, the lock sits in the bore groove and blocks the wrist pin from walking out of its bore.

Aftermarket Pistons

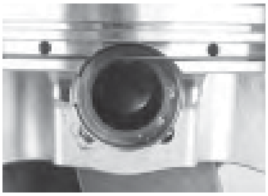
***Diamond Pistons*—**Diamond pistons are custom made to order. Contact Diamond. Pistons are CNC machined from forged billet stock. Diamond technicians will discuss your piston requirements with you and will help you to determine the specific piston configuration for your engine. They'll start off with a chunk of dense billet forging and will create the piston by CNC machining. This allows you to obtain whatever piston diameter you want, along with whatever dome volume and valve relief setup your build requires. Basically, they'll make anything you want.

***Katech Pistons*—**KAT-4855B-4125 Katech forged LS1/LS2 pistons. 4032 aluminum. For rod length of 6.100". Bore size 4.125". 110.0:1 compression with stock heads. Katech offers a full range of pistons for all LS engines, in a variety of bore diameters, dome configurations and compression heights.

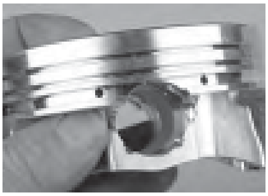
***GMPP LSX Pistons*—**GMPP performance upgrade pistons. Lightweight forged 4032 aluminum. Anti-friction skirt coating. Forced pin oiling. Pistons include wrist pins and rings. LSX376 Piston 19166957: 4.065" bore, flat top, no valve notches. For use with stock connecting rods only. Weight-matched to stock LS3 piston weight, LSX376 Piston 19244016:4.065" bore, 14cc dish lowers compression to approx. 9:1 with most

This view shows the small bump (male dimple) on the underside of the oil ring support rail. This provides a positive stop in case the support rail begins to rotate, preventing the support rail gap from entering the void.

Today's thinner piston rings also help to accommodate shorter ring land areas in short-CD pistons. For LS applications, the 1.5mm, 1.5mm, 3mm top-second/oil layout is typical.



This side view shows the oil ring support rail in position. This is installed prior to installing the oil ring package.



Due to the short CD on this piston (1.115"), the pin bore is positioned high enough that it intersects the oil ring groove. In this situation, a special oil ring support rail is needed (the piston maker widens the oil ring groove to accommodate the addition of the support rail).

standard LS cylinder heads. Optimized for supercharged or turbocharged applications. Use with stock-type connecting rods only.
LSX454 Piston 19166958: 4.185" bore, dished with valve reliefs. Must be used with LSX connecting rods. Features 0.866" wrist pin.

Piston Rings

While most original LS pistons use a 1.2mm top ring, 1.5mm second ring and a 2.8mm oil ring, aftermarket forged performance pistons will feature ring thickness based on the piston maker's research and development for their piston. Generally speaking, most aftermarket pistons for the LS will likely call for a 1.5mm top ring, 1.5mm second ring and 3mm oil ring package. Many aftermarket piston makers either supply the correct rings with their pistons or recommend a specific brand, size and part number. Don't reinvent the wheel. Follow the piston maker's recommendation.

As far as ring materials are concerned, the top ring is where the choices primarily exist. A ductile iron plasma moly coated top ring is just fine and dandy for any naturally aspirated LS street/performance engine (plasma moly refers to a plasma-sprayed moly coating that improves ring lubricity and resistance to heat).

The factory LS aluminum blocks feature relatively soft ductile iron liners, so the softer ductile iron plasma moly rings tend to seat and seal better as opposed to harder steel tops rings.

Top Rings—If you plan to add boost with a forced induction system, you need to move to gas-nitrided steel top rings…that is, when used with forged pistons. Installing steel top rings on hypereutectic pistons is probably a waste of money, since if extreme cylinder pressure occurs, as with a forced induction, the piston is more likely to give up before the top ring. The harder steel top rings will hold up to extreme cylinder pressures better than plasma moly ductile iron. Ring seating time (break-in) may take a bit longer with steel rings, but assuming the cylinder bore is properly finished (ideally finished off with a plateau brush at the end of the honing job), ring seating really shouldn't be a major concern. Scott Gressman at Gressman Powersports in Fremont, Ohio, tells me that he generally uses plasma moly ductile rings whenever he builds a street LS engine. But when he builds one for a forced induction setup, he always moves

GM OE LS Rings

Engine	P/N	Bore	Oversize	Thickness
LS2	89017484	4.000	std	1.2/1.5/2.5mm
LS7	89017776	4.125	std	1.2/1.2/2.0mm
LS7	89017777	4.145	+0.020	1.2/1.2/2.0mm

This set of Diamond racing pistons also included a matching set of pins, pin locks and a complete ring package. Many high performance piston makers prefer to select and supply rings with their pistons to assure proper styles (and naturally, size) that work best with their pistons.

to a steel top ring. His favorites are Speed Pro's Hellfire rings or Total Seal's TNT rings.

Basically, if the engine will produce under 500 hp and it won't see any nitrous or forced induction, you're probably fine with ductile iron plasma moly top rings. Otherwise, go with steel top rings that are either nitrided or plasma moly coated (nitriding is a surface treatment that hardens the ring surface for better wear resistance while maintaining compatibility with the cylinder wall surface).

When using steel top rings, the cylinder wall requires a rougher surface finish in order to provide ring sealing. The harder the ring face, the rougher the cylinder wall. While honing machine loads can vary depending on brand, Scott generally finishes bores that will use plasma moly rings with a 400 diamond stone (roughly equivalent to a 240 grit abrasive stone) at 40% load, then finishes the surface with a silicon carbide plateau brush for four strokes at 30% load. Again, these steps can vary depending on the brand of honing machine due to differences on motor loads. For plasma moly rings on a GM block, Scott achieves a 12-16 Ra finish. For steel tops rings, the finish will be rougher, at about 22–26 Ra.

Steel top rings, as opposed to ductile iron, provide increased tensile strength, higher yield strength, greater fatigue life and added hardness while offering a decreased ring mass (thickness and weight). Today's steel rings are getting thinner, which not only decreases mass but provides better conformity to the cylinder walls. The result is less friction, less blowby, better efficiency and (although not a big consideration for performance folks), slightly improved fuel economy and tighter emissions.

The use of thinner rings goes hand in hand with improved cylinder wall finishes and the increased popularity of synthetic oils.

Second Rings—The second ring doesn't need to be as advanced, since it isn't as exposed to combustion heat. Second rings continue to be made from cast iron, or in higher-horsepower application ring sets, ductile iron. Second-ring design has changed somewhat though, moving from the traditional profile (barrel face, reverse bevel) to a Napier style. The Napier style features a slight undercut (often called a "hook" style) that provides a bit of oil reservoir for scraped oil (second rings are primarily for oil control). GM uses the Napier style second ring as OE on the LS pistons. Most aftermarket performance ring sets will likely feature this style.

Ring Packages—Oil ring packages for the LS engines (usually 3mm in aftermarket sets) feature reduced tension, primarily by slightly decreasing the radial depth (how far the ring sits in the groove). The reduced tension decreases ring friction (freeing up power) but actually loads against the cylinder wall a bit more for increased oil control.

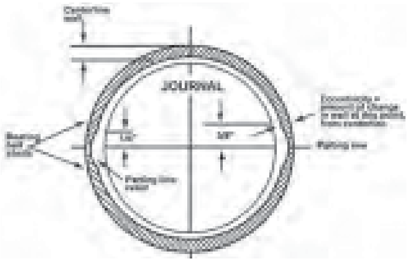
This info is primarily offered for background education. In a nutshell, the top ring is what's going to determine your buying selection. Again, if you purchase new aftermarket performance pistons, follow the piston maker's recommendation, which will be based on your intended application (horsepower level and naturally aspirated versus forced induction).

Note that, especially in a stroker combination where piston CD is on the short side, the ring package is crammed together more closely. Depending on the piston CD, it is very common for the oil ring groove to actually intersect the piston's pin bore. In those cases, the oil ring package will include a lower support rail. This is an additional rail (installed first, before the 3-piece oil ring package) that sits on the bottom oil groove land to provide oil ring support over the open areas that hit the pin bores. Support rails will feature a small male bump. This small male dimple needs to be located over the pin bore. This prevents the support rail from rotating too far, eliminating the possibility of the support rail gap moving over the open pin bore relief.

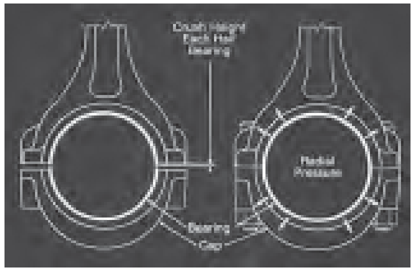
Bearings

Six criteria that must be considered in terms of high-performance bearings include bearing construction and materials, proper housing and shaft geometry, proper bearing geometry, proper surface finishes, sufficient supply of clean oil and adequate oil viscosity.

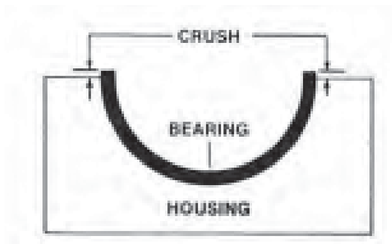
In terms of construction, cast bearings provide superior strength as opposed to sintered bearings produced from powdered metal. Sintered bearings lack the continuous copper phase which is needed for strength. A high performance bearing produced



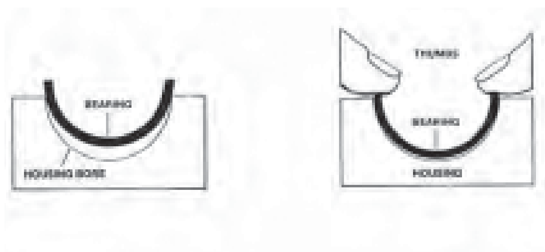
Installed bearing sets create a slightly eccentric bore, which promotes oil film capture and enables the rotational movement of the shaft to generate a hydroplane of oil film around the circumference.



Bearing crush is critical to hold the bearing in place. With the cap installed, this exerts radial pressure, forcing the bearing backs outward radially.



Both rod and main bearings must feature a specified amount of crush area in order to achieve bearing lock-in within the housing.



The bearing shell outer edges (approaching the parting line areas) are larger than the saddle, which adds to the lock-in placement of the bearing shells.

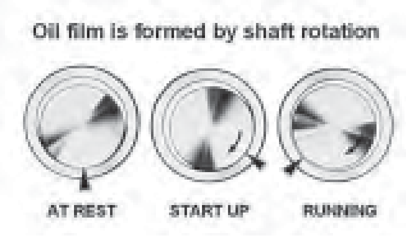
using a steel back, a cast copper-lead primary layer, a nickel dam (laid on top of the copper-lead mass), and a lead/tin/copper overlay provide the best performance for bearings used in high-stress applications.

In short, all high performance bearings are of the cast copper-lead type.

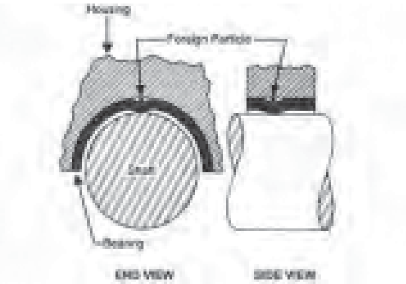
Main and rod bearing shells feature a slight projection area when installed in the saddle or cap. When the cap is installed and fully tightened to specification, this crush height forces the bearing shells to attempt to expand outward, applying radial pressure concentrically around the bearing housing. This creates the proper geometric shape of the bearing I.D. and locks the bearing in place, preventing bearing movement relative to the bearing housing. Contrary to popular belief, the small locating tangs/grooves featured adjacent to bearing parting lines are not responsible for locking the bearings in place. These tangs and grooves serve to locate the bearings during assembly only. The installed radial pressure is the primary force responsible for locking the bearings in place. Bearing shells are also slightly larger across the open end as compared to the housing (saddle/cap). When forced into the housing, this slight interference fit also holds the individual bearing shells in place during the assembly process.

Bearing shells are slightly tapered (thinner) approaching and at the parting line. This creates an eccentric I.D., which promotes a pressurized oil film as the shaft rotates (allowing the oil film to compress and expand as the shaft rotates. This creates a hydroplaning effect, providing an oil film to quickly establish between the journal surface and the bearing. This is the reason that rod bearings are not grooved…because you want to create a hydroplaning effect for maximum oil travel between the bearing and journal. This bearing I.D. eccentricity also dictates how an installed bearing I.D. is to be measured. The "tightest" areas (in terms of minimum clearance between the bearing and journal) will always be at the top and bottom (12 o'clock and 6 o'clock) positions, so bearing I.D. must be measured between these two points.

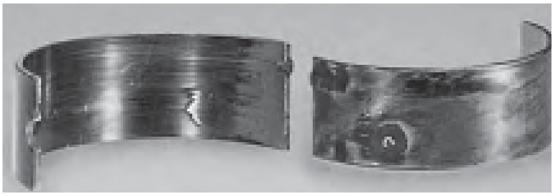
Performance bearings use a maximum amount of crush. If you over-compress the bearing, you'll



Oil film is formed during shaft rotation. As rotation begins, the oil film is generated, which travels around the circumference of the shaft, literally lifting the shaft into a centered location.



Dirt particles or embedded blasting shot left behind in the housing face can push the bearing inward, creating a high spot between the bearing and shaft, which leads to damage of the bearing's outer layers. This will restrict oil clearance and can cause localized overload, friction, heat and will lead to bearing failure.



This view shows the damage that results from trapped particles behind the bearing. Note the bearing wear on the face (left). A metal chip that was trapped behind the bearing during assembly distorted the bearing wall inward against the shaft, causing wear through the overlay into the copper-lead base.

create a thick spot on the bearing wall, possibly minimizing clearance and oil travel. If you have insufficient crush, the bearing will be loose, resulting in bearing surface polishing or fretting (metal transfer).

According to Clevite's John Havel, if you're faced with slight geometry problems regarding journal geometry or misalignment, a good choice is their V-series bearing, which features a 0.0010" lead/indium overlay and no nickel dam. This bearing offers a "softer" surface edge which will be more forgiving if you're dealing with slight misalignment (the P-series features a 0.0005" lead/tin/copper overlay. The H-series rod bearings feature a 0.0005" lead/tin/copper overlay, and the H-series main bearings feature a 0.0010" lead/tin/copper overlay).

General Clearance Recommendations—Start with 0.0010" of clearance per inch of journal diameter. For example:

2.100" journal dia x 0.0010
= 0.0021"

For high-performance applications, add 0.0005". If, for example, initial clearance is determined to be 0.0021", add 0.0005" for a final clearance of 0.0026". From this point, tighten clearance as your experience dictates in specific applications.

Note: Use of a dial bore gauge is always the recommended method of measuring oil clearance. Instead of measuring journal diameter and then measuring installed bearing diameter, zero the bore gauge at the actual journal diameter. When you measure bearing diameter, you'll obtain a direct clearance reading without the need to perform math procedures, avoiding potential math mistakes.

John Havel emphasized that if clearance modification is needed, do not increase or decrease clearance by modifying housing size outside of tolerance limits. An undersize housing will over-crush the bearing; and an oversize housing will reduce crush and bearing retention.

Currently, Clevite utilizes finite element analysis computer modeling to examine the elastic deflections of all bearing-related areas. EHL, or Elasto-Hydrodynamic Lubrication, allows engineers to more accurately determine the effects of dynamic forces in relation to forces and oil clearances. This understanding of loads, metal deflection and effects on clearance has allowed a more precise view of what the bearings are subjected to, and furthers engineers' ability to develop bearings that will function properly in high-stress dynamic racing applications.

Clearances vs. Cavitation—Cavitation erosion of a bearing occurs when rapid movement of the shaft away from the bearing surface causes vapor bubbles to form in the oil film. When these bubbles break, the resulting force causes erosion of the bearing soft overlay layer. Appearance and location of cavitation erosion will differ with operating conditions due to varying load patterns in different engine applications. According to John Havel, the nickel dam in the H-series and copper-indium

Clevite and other high-performance bearing manufacturers today offer their bearings with a special moly or moly graphite type anti-friction coating, as either a standard feature or as an option. If you have a choice, choose the coated versions. Pictured here is a set of Clevite-coated rod bearings.

intermetallic compound in the V-series helps to resist further penetration. Prolonged exposure will eventually result in erosion of the nickel or copper-indium dam. H-series bearings feature a thicker nickel dam to resist cavitation longer. Eventual penetration of the nickel dam causes copper particles to break loose, enter the clearance gap and become embedded into the bearing surface.

So far, the most effective means of controlling cavitation erosion seems to be a reduction in bearing clearance. This has worked in IRL and NASCAR applications. As an example, Aurora IRL engines running 0.0028" rod clearance experienced cavitation erosion, but those running a slightly decreased clearance of 0.0020" showed little or no cavitation erosion.

Bearing Coatings—Several race engine builders have tested cryogenic treatments on main and rod bearings, but the consensus seems to be that cryo treatment has its place in other areas, they haven't seen a benefit in terms of treating bearings. The new coatings being used by top bearing makers today is far superior to the original generation of coatings, and holds up very well. Oil clearances have definitely become tighter, with 0.0011" to 0.0015" now becoming commonplace, especially due to smaller journal sizes and the use of synthetic oils (depending on the application, they're running 0-10 up to 20-50 weights, with the majority using 10-30 and 10-40). Depending on the application, today's race engines are running less oil pressure, and with less parasitic drag (builders often take advantage of today's oil shedding coatings to help reduce drag).

As far as crank oil holes are concerned, simply deburr the holes to break off any sharp edges. It was commonplace for years for builders to radius-sweep the holes, but you get too much bleed-off doing that, so it's better to simply deburr the holes, removing as little material as possible.

In order to provide adequate oil delivery, some high-end race engine builders sometimes drill extra oil holes in the bearings and partial-radius grooves in the housing or saddle area of the mains to create multiple oil supply points. This is especially important in engines that use smaller bearings and will experience higher loads (don't try this at home).

Higher Load Clearances—As far as bearing clearances are concerned, for street engines that see higher loads, some builders tend to run somewhere around 0.003" for mains and around 0.0025" for rods.

For engines that will see lots of heat for extended periods, such as endurance engines or marine engines, tighter bearing clearances are the norm, to compensate for the fact that clearances will loosen under hot conditions.

In a high-speed, high-load race engine application, experienced builders tend to run a fairly high crush (where bearing shells mate together), while maintaining this within an acceptable range. Considering bearing load and journal and housing deflection, you want to make sure that the bearing is securely held in place. Where you have oil films that are in the tenths of thousands clearance, the bearing gets very hot. If you don't have adequate crush, you won't get enough heat transfer. Avoid taking housings to their maximum size, to avoid inadequate heat transfer.

When a builder opts for smaller journal diameter crankshafts (to reduce mass) they sometimes modify the crankshaft journal oil holes in order to drive more oil to the rods. As you shrink the rod journal diameter, the load goes up. In order to get extra oil to the rod bearings, they create a slight teardrop groove to the crank main oil holes. The leading edge (attack side) of the oil hole is slightly grooved. As the crankshaft rotates, this slight teardrop-shaped cavity fills with oil and is then force-pumped into the oil hole, increasing boost pressure. This can cure problems with rod bearings that were otherwise seeing too much load. This can be done with a grinder, but is best performed on a CNC machine. However, you need to pay strict attention to the dimensions of the teardrop groove, in terms of width, length and depth. Generally speaking, this teardrop groove is usually around 0.300" to 0.400" in length. If the groove is too aggressive, you could start starving the mains for oil. The specific profile of this groove controls the

Race Bearing Tech

The bearing gurus at Clevite share insight regarding current and future rod and main bearing development.

When big bucks and series championships are on the line, every nuance is considered. Bearings are no exception.

According to MAHLE Clevite's Bill McKnight, top NASCAR Cup teams are carefully selecting bearings and measuring each. They will typically order about 500 bearings and check each individual bearing shell for height (in terms of crush factor) and thickness, etc…they'll carefully categorize each bearing as tight, loose or intermediate, which then allows them to pick and choose bearings depending on the specific engine application.

The trend among the Cup teams is to run tighter clearances, creating higher oil film pressure.

McKnight also noted that some teams are buying Clevite bearings from a proprietary facility in Scotland whose technicians painstakingly measure and package sets guaranteed to be exact matches. "These measured and matched bearings are rather expensive, costing around $30 each, so only teams with very healthy budgets are taking advantage of this. NASCAR engine developers are also currently testing cryogenic treatment of bearings to determine if this offers any benefit, but the jury is still out with regard to this. All teams are definitely taking advantage of bearing surface coatings, which is no longer considered a questionable approach. The use of anti-friction and oil-embedding coatings have definitely proven their worth."

Bill McKnight noted that Clevite's first effort at cryogenically treating race bearings for drag applications was made during the summer of 2007 for the top fuel and funny car teams, the hardest users of bearings we have. Tests continue, improvements look to be small, perhaps 5–7%, but when you're using all we've got in a bearing and still asking for more, that may be enough. The treatment consists of freezing finished product at well below -300 degrees F for 7–8 hours.

In the NASCAR series, a few changes have been instituted. Standardizing on a minimum size of 1.850" for the rod pins and 1.999" for the mains is now completed. Clevite has numerous choices for these engines, including both H series and V series materials, 2.000" main sets, main sets allowing teams who ran a 2.017" main journal last year to use those same blocks with a 2" crank (0.017, 0.018, 0.019"-under sets) narrowed rod shells, dowel holes in some sets, extra clearance sets and inventory on the older sizes still used by some teams (1.770" rods and 2.300" main, RO7 blocks).

As NASCAR teams continue to narrow the rod bearings in search of less friction and more horsepower, the locating lug on the bearing insert has been placed very close to the edge of the bearing, creating what might be considered a stress point. Clevite is currently in phase-two testing of a new "indentless lug" insert for those applications. This provides a smooth, uninterrupted surface at the parting line.

Also for drag racing applications, pro teams, many of whom are using off-the-shelf race bearings, are starting to take a look at what the NASCAR teams have been doing. Reduced mass, lower friction and coatings are all subjects being talked about at the track. One way to look at it is" If your engine bearings look really good at teardown for refreshing the motor, you're probably leaving something on the table in terms of performance improvements.

amount of oil pressurizing into the rod. Again, this is nothing for the weekend builder to mess with, and is certainly not necessary for street applications.

Fine-Tuning Bearing Clearance on Undersized Cranks—In an effort to aid engine builders in fine-tuning their bearing clearances, MAHLE Clevite recently introduced half-size H-series performance bearings. New part numbers include 0.009", 0.011", 0.019" and 0.021" rod and main bearings. These special-size bearings offer greater latitude in choosing bearings for performance engines that feature an undersize-ground crankshaft. By taking advantage of these new bearings, builders can easily achieve specific bearing clearances of +/- a half-thousandths of an inch. For example, using a pair of 0.009" bearings will reduce bearing clearance by 0.001" compared with normal 0.010" bearings. Similarly, clearance can be increased by 0.001" by using a pair of 0.011" bearings. It is also possible to use one 0.009" bearing shell in combination with a regular 0.010" shell to reduce clearance by 0.0005", etc. These special half-size bearings are currently available for a wide range of Chevy, Ford and Chrysler applications. All bearings feature Tri-Armor construction and MAHLE Clevite's unique moly graphite coating that's distributed in a PTFE (polymer) carrier.

Chapter 7
Engine Balancing

LS crankshafts are internally balanced. This means that any corrective weight issues are handled at the crankshaft counterweights (as well as equalizing static weight of pistons and rods). An internal balance job does not require that the crank damper and/or flywheel to be attached to the crankshaft during balancing. An internally balanced crank will accept zero-balanced front and rear components. Shown here is an ATI Super Damper crank balancer, mounting hub and belt pulley. These components are already zero-balanced as manufactured. This means that if the engine is internally balanced, you can change the crank damper and flywheel at a later date without affecting balance (as long as the damper and flywheel are individually zero-balanced). A crankshaft that is externally balanced requires that the damper and flywheel must be mounted to the crank during spin balancing, and those components are then dedicated to that crank.

A properly balanced engine will operate smoother and with less dynamic strain. The results can include slightly better fuel economy, smoother operation throughout the rpm band, and most importantly, less life-draining and power-robbing harmonic vibration and avoidable stresses. In other words, a properly balanced engine will last longer and will have the potential to produce more horsepower (eliminating harmonic imbalance that can prevent the engine from realizing its potential).

The purpose of balancing, in a nutshell, is to match the crank's geometric centerline axis to the mass centerline axis. The geometric centerline is an unchanging point of reference. This is the static center of rotation of the crank's main journals. The mass centerline is the axis that can change, as rotating and reciprocating forces act on the centerline under dynamic conditions.

If the crank's mass dynamic centerline is too far out of alignment from the geometric centerline, these two centerlines constantly fight each other. In other words, the crank's mains are being forced to rotate in an eccentric path. This ongoing creation of an offset pressure point can squeeze the oil film out from between bearings and journals. Naturally, the result of a severe imbalance is eventual main and rod bearing failure. Don't think that an engine must only exhibit wild vibration for this to be a problem. Even small forces, though possibly not felt by the driver, can magnify and over time, and can lead to shortened engine life. Balancing will optimize the operational conditions and is a prime factor in obtaining maximum engine life.

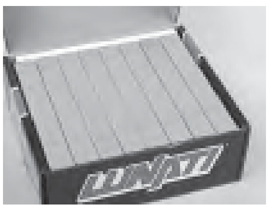
Types of Weight Balanced

Rotating Mass—This is the material that rotates on a single fixed axis, including the crankshaft, flywheel and harmonic damper. Also included is the clutch assembly or torque converter. Weight will be removed from or added to the crankshaft counterweights, harmonic damper and flywheel, as needed.

Reciprocating Mass—The material that is connected to the crank but reciprocates (running up and down the cylinder bores) at angles relative to the crank's centerline. This includes the connecting rods, rod bearings, pistons, piston pins, pin locks (if used), piston rings and lubricating oil that clings to these parts. Weight will be removed from pistons and connecting rods as needed. Piston pins, piston rings and rod bearings are never modified during the balancing process.

Even the finest high performance crankshafts should be checked for balance. Cranks are factory balanced to a point, but the variables of piston, rod, rings and rod bearing weight can affect assembled dynamic balance. Also: understand that balancing is a different issue as opposed to blueprinting. Just because a crank has been balanced, that does not mean that the engine has been blueprinted. Too many people misunderstand this. Blueprinting is a complex procedure of optimizing the entire engine assembly in terms of dimensions, geometry and clearances. Balancing is simply one aspect of blueprinting.

High-performance premium connecting rods (such as the Lunati forged rods shown here) have been factory-weighed, with average small end, big end and total weight marked on the box. However, even the highest quality rods should still be checked to verify weights.



These Lunati H-beam connecting rods weighed in right on the money, as weighed and labeled by Lunati. No weight corrections were needed at all. But it still makes sense to check by weighing each rod on a scale simply to verify.

Clevite rod bearings shown here, featuring their Tri-Armor design and a moly coating for reduced friction. When balancing the crankshaft, you'll need to bring the rod bearings, since they're part of the reciprocating weight factor. But you don't need to bring the main bearings to the balance shop, since they have no affect on rotating or reciprocating balance weight issues.

Balancing Equipment

- A digital weight scale (to weigh reciprocating parts)
- Bobweight sets (to create facsimiles of your reciprocating parts)
- Spin-balancer machine with computer control
- Drill press (for removing weight from crankshaft counterweights). This can be a separate unit, but it's much more efficient to purchase a built-on drill press as part of the spin balancer bench. This eliminates the time-consuming act of carrying the crank back and forth between the balancer and a stand-alone drill press.
- Flywheel adapter hub (to allow separate spin balancing of flywheel when zero-balancing of flywheel is required)
- Set of bobweight cards (to ease recording of all weights)
- If you plan to spin-balance items such as flywheels, impellers, boat propellers, fans, etc., make sure you purchase a balancer that offers a segment mode that allows single-plane balancing.

Their weight is simply determined on a platform scale to allow the creation of total reciprocating weight. Even though you won't remove or add weight from/to these parts, you still need to know how much they weigh so that you can determine what the total reciprocating mass will be on each crank throw.

Creating a Typical Bobweight Card

A bobweight is simply a reproduction of reciprocating weight, in a practical form to allow safe and accurate spin balancing. After all, you can't bolt up complete rod/piston assemblies to the crank and then spin the entire assembly in order to measure balance. The rods would flop around, make lots of noise, and would rotate out of their intended angle positions relative to the crank. You could never achieve an accurate reading, and this gyrating mess would pose more danger than you could wave an OSHA injunction at. We use bobweights to duplicate the weight and position of the rod/piston assemblies in a safe and controlled fashion. Bobweights are special aluminum clamps that secure to the crank's rod journals. The weights are either composed of lead-shot-filled tubes or graduated assortments of weight discs.

To create a bobweight on a 90-degree V8, we consider 100% of the rod throw's rotating weight (the big end of the rod and the rod bearing) and 50% of the reciprocating weight, which includes the pistons, small rod ends, rings, pins and locks (don't get the rotating weight of the rod confused with the

Each connecting rod is weighed for small end weight (shown), big end weight and total weight. A special hanging fixture is used to weigh small and big ends. When weighing either end of the rod, the centerline of each end (small and big) should be kept level. Pistons, pins, rings are also weighed separately.

crank centerline rotating mass). For other engine configurations, different percentages of the reciprocating weight may be required for use. The balancing equipment maker will usually provide a reference chart, or will have this information programmed into its computer software.

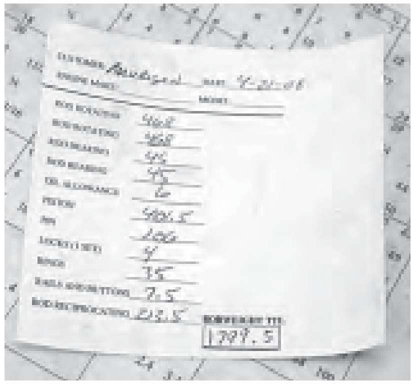
Once the total bobweight is determined, the weights are assembled to duplicate the real-life reciprocating mass.

Sample Bobweight Card

(90-degree V8)
Piston: 694.0 g
Piston pin: +195.0 g
Pin locks: +-0-
Piston rings: +63.5 g
Rod (small end): +293.0 g
Total: 1245.5 g
Multiply by number of pistons per throw: 2
Reciprocating weight per throw: = 2491.0 g
Multiply by 0.50 or 50%
Reciprocating factor: = 1245.5 g
Rod (big end): 609.5 g
Rod bearing: + 46.0 g
Total: 655.5 g
Multiply by number of rods per throw: 2
Total: 1311.0 g
Oil (anticipated oil weight on big end): +4.0 g
Total rotating weight per crank throw: 1315.0 g
Reciprocating factor (weight found on other half of bobweight card: +1245.5 g
Total bobweight: 2560.5 g

In this sample V8 situation, each bobweight will be assembled to weigh exactly 2560.5 grams.

In order to balance the pistons and rods (this must be done before establishing bobweight numbers),



Once all components (rod bearings, rods, pistons, pins, rings and pin locks), the bobweight card is filled out, allowing the balance operator to determine the required bobweights needed to check crankshaft balance.

the digital platform scale is used to weigh individual components. This is a very easy procedure with no nasty surprises.

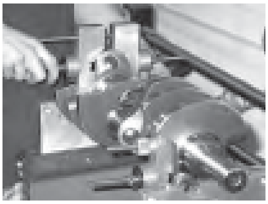
Weigh each piston and record individual weight (note the weight on the dome with a magic marker). Then weigh each pin and record those weights. Next, match pins to pistons lessen the difference in weights between piston/pin sets. Note the combined weight of each piston & pin set (you can erase the previously noted number and record a new set weight on the piston dome). Now determine which piston/pin set is the lightest. This now becomes your index...your target weight for the rest of the piston/pin sets. Begin to remove material from each piston until you match the weight of the index set. Material may be removed from the dome underside or pin boss underside using a milling bit, but exercise care to avoid creating weak spots.

Next, weigh each connecting rod small end and follow the same procedure. Find the lightest (this becomes your target weight), and remove stock from all other rod small ends until you match the weight of the index. Repeat this procedure with the rod large ends. Material may be removed from rod bosses, but be careful to avoid creating stress-raisers. Don't create sharp edges, burrs or rough grind marks.

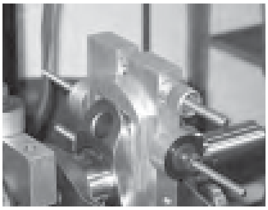
Weigh one set of piston rings (one top ring, one second ring and one oil ring set) and record this weight. Considering their light mass, we can safely assume that all ring sets will provide equal weight.

Weigh and record the weight of one complete rod bearing insert. Weigh and record one pair of piston pin locks or pin buttons (if these are to be used).

Once the bobweights are installed onto the crank, the assembly is spun on the bench balancer in the same manner as a tire & wheel assembly is spin-



The crankshaft is checked for main and rod journal cleanliness, and mounted on the crankshaft balancing machine's clean (and oiled) nylon V-blocks. The bobweights are then attached to the rod journals. The bobweights will simulate the weight of the components that were previously weighed.



Bobweights need to be centered (fore/aft) on each rod pin. Here Scott Gressman temporarily installed a custom-made aluminum spacer which allows him to quickly center the bobweight without taking the time to measure.

checked. Heavy and light points are located by the balancer's computer, and the operator is clearly directed to either add or remove weight at a specific point on a specific counterweight. Removal is handled via drilling into the outer edge of the counterweights, while weight addition is accomplished by press-fitting and weld-sealing tungsten (heavy metal) into an existing or a freshly drilled hole. Making a change at one end of the crank will likely create a new imbalance at the opposite end of the crank, so the operator may have to continue to make a few minor adjustments to achieve final balance.

Balancing Tips

• Perform all machining to the crankshaft, flywheel, pistons and rods before balancing. Alterations to these parts after balancing will negate your balancing work, and you'll have to start over. For instance, if connecting rod beams are to be smoothed and polished, do this before the balancing work begins.

• If you find a gross difference in crankshaft spin-up weight from front to rear of the shaft, chances are good that the crank is bent. To avoid wasting time, always check the crankshaft for runout before taking the time to spin balance the crank. With the crank laying on the balancer's twin V-blocks, set up a dial indicator and check runout on the main journals.

• By the same token, when a crank is ground, it's imperative that the stroke doesn't change from rod throw to rod throw. The centerline of the rod journals should be identical (centerline of main to centerline of each rod journal). Also, and this is especially critical if the ignition system is crank-fired, the index of each rod journal must be correct. Although the stroke may be OK, if the index is out of whack, the engine's timing will be grossly out of position. Just remember that crank grinding can affect balance, if the stroke or index is altered.

• If the crankshaft was stored improperly, or if the crank was chucked off center in the crank grinder, or if it was chucked under tension, the axis of the crank mains could be untrue. Also, the effects of heat can create small deflections in the crank, so make sure the crank reaches room temperature before performing a spin-balance reading.

• Replacement oversize pistons are not necessarily lightened to match the weight of the OE piston, so never assume that the balance won't be affected even though you're changing a complete set of pistons from old to new. This is why the balancer was invented...to verify what you're dealing with and allow you to correct any mass problems!

Replacement pistons are usually boxed by the maker as a matched set (weighing within X-grams of each other). However, you should never assume that all pistons of the same part number will weigh within that acceptable match range (although today's performance aftermarket forged and CNC-finished pistons are typically extremely well weight-matched). Forged and hypereutectic pistons will likely be more closely matched in weight from the start.

• Weigh the pistons and pins separately. You can then match pistons to pins to "even out" the piston/pin set weights, thereby reducing the time needed to machine weight from pistons (match the lightest piston with the heaviest pin, etc.).

• Try to maintain piston/pin weights to within one gram, from cylinder location to cylinder location. There's really no need to make yourself crazy by trying to create a tighter tolerance range. A 1-gram tolerance is perfectly acceptable (we say this not to make it easier, but because it's impractical to try to achieve tight-number tolerances. When you consider the changing forces that act upon the engine during operation, with oil slinging around, clinging to areas in a sometimes random pattern, you'll simply drive yourself nuts for no additional benefit if you try to create ultra-tight gram matching).

• LS crankshafts are internally balanced—that means that weight corrections are made on the crankshaft itself, without regard to damper or flywheel. The damper and flywheel for an internally balanced crankshaft should be zero balanced independently. If the engine is externally balanced (where the flywheel is an integral part of the crank's balance), consider future flywheel replacements. This is especially important with race motors that will routinely be rebuilt or repaired. Once the assembly is balanced, remove the flywheel and spin this up separately, and document the state of balance of that flywheel. In this way, future replacement flywheels can be balanced to those exact specs (duplicating the first flywheel), without the need to rebalance the crank!

• When removing weight from a piston, don't blindly remove stock from the underside of the dome. Measure the dome thickness first.

As far as balancing is concerned, here's what you need to know: if the engine is an internally balanced design (where all of the crankshaft balancing occurs at the counterweights and the damper and flywheel are zero-balanced on their own), the viscous damper itself is already balanced, so there's no need to perform any balancing work on the damper at any time. If the engine is an externally balanced design (where the front damper and the flywheel are integral components of crank balance), the viscous damper will consists of two parts...an outer damper ring and a center hub. Disassemble the damper to separate the ring from the hub. Mount only the hub to the crank snout (along with the flywheel at the rear crank flange) for crankshaft balancing. Do not attach the viscous damper ring to the hub for balancing!

In short, never install a viscous-type damper or damper ring to a crank for spin-balancing, since the centrifugal internal action of the damper's fluid will serve to mask some of the crank's harmonic disturbances, and will result in a false spin-balance reading.

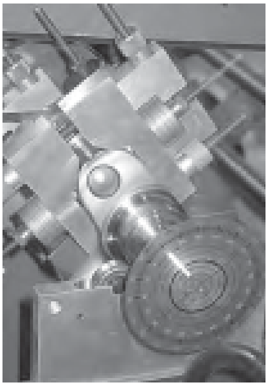
During the balancing of my LS2 Lunati crankshaft, the JE pistons weighed in at a consistent 401.5 grams, and each piston pin weighed 106.0 grams. There was no need to remove weight from any of the pistons in order to create a matched set.

My Lunati connecting rod big ends each weighed in at 468 grams and small ends at 213.5 grams. Again, no need to correct. JE and Lunati did a superb job during manufacturing. Thanks to the current technology being used by high-end aftermarket component manufacturers today, it's rare to find a set of forged pistons or connecting rods that actually require weight corrections.

Once the bobweights were created (following our bobweight card), bobweights were attached to the crankshaft, with each set placed 90 degrees from each other to better represent operational centrifugal force. It's important to center the bobweights on each rod journal. This can be done using a feeler gauge or with a pre-made aluminum spacer that is inserted between the fillet cheek and the bobweight (the spacer is used only to index the bobweight centered on the journal…the spacer is then removed).

The crankshaft is then spun (on the crankshaft balancing machine). Heavy or light areas are indicated by the machine's computer. Heavy spots are corrected by grinding or drilling material from the specific crank counterweight. If weight must be added, a hole is drilled into the counterweight. A piece of heavy metal (tungsten…often called Mallory metal) is then press-fit into the hole and tack-welded into place. After each modification, the crank is spun again to re-check. Weight correction is chased until acceptable.

Note: When weight must be added to a counterweight, it's best to drill the hole through the counterweight (fore/aft, parallel with the crank length). If the hole is drilled into the outer edge of the counterweight and heavy metal is added, you run the risk (however small) that the weight could potentially be thrown out by centrifugal force.



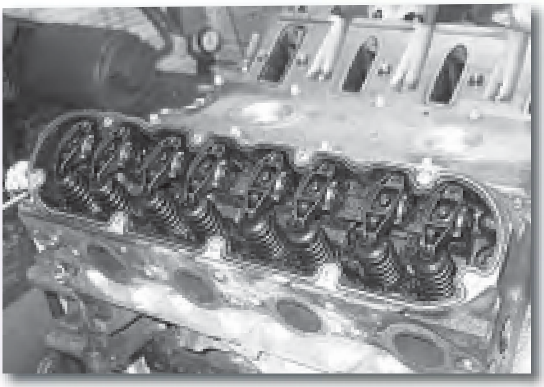
Sometimes the operator gets lucky and nails it on the first try, while in some cases, weight correction must be "chased" several times. If adding heavy metal is needed, the options are to drill a hole and install the tungsten slug on either the outer edge of the counterweight or 90 degrees (through a counterweight). Whenever feasible, the drill-through method is preferred, since this eliminates the remote possibility of the weight ever being slung out during engine operation. Either way, if a tungsten slug is added, balancing shops generally secure the slug with a small tig weld.

Project LS2 Bobweight Card

Rod rotating:	468.0
Rod rotating:	468.0
Rod bearings:	45.0
Rod bearings:	45.0
Oil allowance:	6.0
Piston:	401.5
Piston pin:	106.0
Locks (1 set):	4.0
Ring set:	35.0
Support rail:	7.5
Rod reciprocating:	213.5
Bobweight Total:	1799.5g

Chapter 8

Cylinder Head Reconditioning & Rebuilding



If you expect to reuse the original rocker arms and valves, keep them organized per position due to wear patterns established at the rocker to valve contacts.

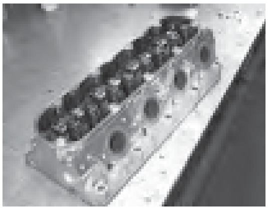
Inspection

If you plan to use stock GM LS6/LS2 cylinder heads (same head), don't just wipe off the gunk and slap them back on. Invest the effort to inspect them to avoid problems down the road. If removing the heads from a stock engine, don't worry about saving the OE head bolts. Toss them and replace them with either new OE bolts, high-performance aftermarket head bolts or high-performance aftermarket head studs. When removing the heads, don't forget the smaller 8mm "pinch" bolts, especially the ones at the inboard corners. If the head is gunked up with crud, it's easy to miss them. If you miss one, you'll end up ruining the head (and maybe the block deck) as you frustratingly try to pry the head loose. With all head bolts removed (the 11mm and the 8mm bolts), the heads should pop off rather easily.

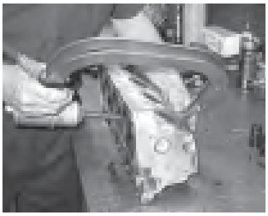
Note: If you plan to reuse the OE rocker arms and valves, try to keep them in order due to the wear patterns on the rocker-to-valve-tip surfaces.

Disassemble Head—Once the heads have been removed, use a valve spring compressor tool to slightly compress each valve spring in order to remove the valve keepers, retainers and springs. Before compressing, give each valve stem tip a single whack with a plastic mallet. This will break the keeper locks from their set positions, making it easier to remove them once the spring is compressed. I wouldn't worry about

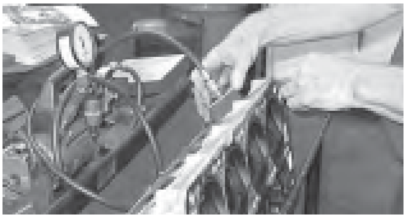
If the original heads are to be reused, during teardown, don't worry about cylinder head bolt locations. The head bolts should be replaced anyway.



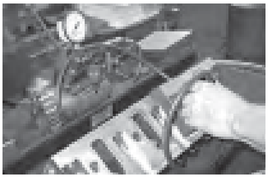
Once the OE heads have been partially disassembled and vacuum tested, they'll be cleaned in a hot tank or pressure washer.



Use a valve spring compressor to compress the springs, allowing removal of valve spring keepers and retainers and springs.

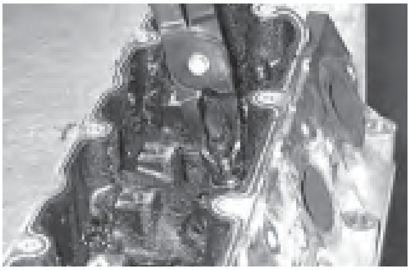


With valve springs removed, vacuum test each valve location. Here the exhaust valves are checked for sealing.



Here the intake valves are checked for sealing. The tester's vacuum gauge will indicate if you have any leaking valve-to-valve seat problems. Any leakdown indicates the need to reface or replace valves and to reface valve seats.

Once the leakdown test has been completed, remove the intake and exhaust valves.



Use a pair of valve seal pliers to remove all valve seals.

keeping the springs in order, since you'll need to pressure test all of them (or replace them) anyway.

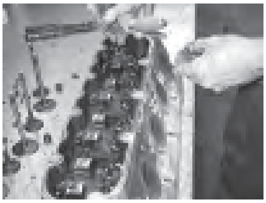
With the springs removed, perform a vacuum test on each intake port and each exhaust port. This check will tell you if any of the valves are not seated properly. If a closed valve won't hold vacuum, it's a leaker and must be addressed (refacing the valve, remachining the seat, replacing the valve and/or replacing the seat). Make a record of the vacuum reading of each valve location, and mark each head for later identification.

Once all valves have been checked for sealing, remove the valves (if you plan to reuse them, keep them in order. A handy organizing method involves a pair of cheap wooden yardsticks with eight 3/8" holes drilled in each yardstick. Label each yardstick for cylinder head (LH/RH) and label the front (engine front). This will help you to keep track of each valve's original location.

Using a pair of valve guide seal pliers, remove all valve stem seals (wiggle and pull) and pitch them. Never reuse valve seals.

Next, remove all eight steel valve spring seats (at the base of each guide boss). A pencil magnet works

Aluminum cylinder heads will always feature steel spring seats (to prevent the springs from digging into the softer aluminum).



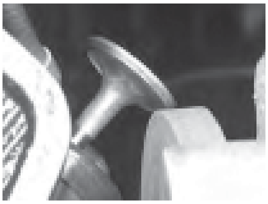
Use a pencil magnet to remove all spring seats.

fine for this. All aluminum cylinder heads require the use of steel spring seats to prevent the springs from digging into the sifter aluminum. If you plan to use the stock diameter beehive valve springs (or aftermarket valve springs of the same base diameter), keep these spring seats.

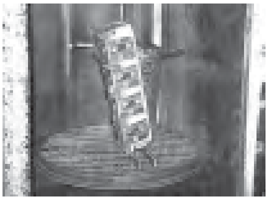
Inspect each intake and exhaust valve. Using a micrometer, measure the valve stem near the top (just below the lock groove) and further down within the area of the stem that runs inside the

Use a micrometer to measure each valve stem. Measure the lower area of the stem that rides through the valve guide and record the diameter.

Also measure the valve stem near the top. This non-wear area will provide a reference regarding stem wear on the guide area. The OE valve stem diameter specification is 0.315". Intake valve head diameter should be 2.00" and exhaust valve head diameter should be 1.55".



After the valve is checked for runout, the valves may be reused by refacing. Matching valve seat angles are 30/45/60 degrees.



Once the cylinder heads have been completely disassembled, they should be cleaned in a hot tank or heated pressure-washer to remove oil and contaminants.

A Rodex cleaning brush can be used to quickly final-clean the intake and exhaust decks. Don't dwell on isolated areas to avoid creating uneven surfaces.

A nice way to final-clean the head surfaces is to tumble-blast the head in an enclosed blasting cabinet using a soft cleaning media such as walnut shell particles.

valve guide. The OE specification for valve stems is 0.315".

If you found any leaking valves during the vacuum test, those valves should be refaced (or replaced). If you're going to reface or replace one valve, it's best to do this to all of the valves. That way, you know they're all fresh. Check each valve for runout (straightness) as well. Any runout is cause for replacing the valve.

Once the cylinder heads have been completely disassembled, clean them again in a hot pressure washer. It's a good idea to follow this up by tumbling the heads in a media blaster that uses a softer-than aluminum media, such as crushed walnut shells. After a tumble-blast cleaning (or glass beading if you prefer), carefully wash the heads again to remove all media particles. Inspect after washing to make certain that no media has been trapped inside oil or water passages or in blind threaded holes.

Once the heads are clean, check the decks for flatness (measuring for deck warp). Using a precision machinist's straightedge and a feeler gauge, inspect the cylinder side deck, the intake manifold deck and the exhaust deck. **Note:** You must use a precision-ground straightedge. You cannot perform an accurate check using any old ruler or piece of scrap metal that happens to be lying around your garage or shop. Just because it may look straight, that doesn't mean that it is straight.

Check Deck Flatness—You'll need to check the cylinder deck in at least three planes. First, lay the straightedge on the head's deck lengthwise, front to rear, about centered over the combustion chambers and use a feeler gauge to see if it will easily slip between the straightedge and the deck. While the OE specification tolerance is 0.003" for any given 6.0" distance or 0.004" for total length, I don't like to see any gaps. If gaps as slight as 0.0005" are found, the deck should be resurfaced to achieve perfect flatness. While OE makers tend to tell you that their heads should be replaced if any warp (beyond their published tolerance) is found, you can safely resurface to the tune of about 0.005" without a problem.

Next, lay the straightedge in a diagonal, from one corner to the opposing corner and perform the same check. Then lay the straightedge across the remaining corners (corner to corner) and check for gaps. Again, the OE spec allows as much as 0.003" warp for a 6.0" length, or 0.004" for total length. If it's warped, resurface. If you can't save the head deck by removing about 0.005", then I'd consider replacing it. When resurfacing, the deck should be cut on a calibrated resurfacing machine to the

With the cylinder decks clean, use a machinist's precision straightedge and a feeler gauge to inspect deck flatness. Don't use just any ruler or piece of "straight" metal that may be lying around your garage. In order to obtain an accurate reading, a precision-ground straightedge is mandatory. With the straightedge positioned along the length of the deck (front to rear, centered over the combustion chambers), the acceptable limit for warpage (out of flat) is 0.003" within a 6.0" area, or 0.004" overall length. Record your findings.

Next, position the straightedge diagonally across the cylinder deck (corner to opposing corner) and measure for flatness. The OE specification calls for a maximum warpage of 0.003" within a 6.0" area or 0.004" overall.

Next measure flatness with the straightedge positioned at the other two opposing corners. The OE tolerance is the same as before. If the cylinder-side deck of the head is warped (uneven) beyond the specified limits, the cylinder head can either be resurfaced to regain flatness, or replaced. While an OE spec may call for replacing the head if any beyond-limit warpage is found, you can generally cut about 0.005" to clean up the deck without a problem.

proper surface finish. Your machinist can obtain the desired finish. Generally speaking, the finish must be very smooth with no scratches that can be felt by dragging your fingernail across the deck.

Perform the same flatness check at the intake deck. The OE specification calls for a maximum allowable deviation of 0.0031". The exhaust deck specification is an allowable maximum of 0.005".

Check new or used valve springs with a valve spring tester. The OE valve spring specifications include a free height (uncompressed) of 2.080". When compressed to the specified installed height of 1.800", spring pressure should be 76 lb. When the valve spring is compressed to a length of 1.320" (simulating valve open), spring pressure should be 220 lb. Note: Spring installed height is 1.800" for both intake and exhaust valve spring locations. If aftermarket valve springs are to be used (as would be the case with a performance camshaft change), the camshaft manufacturer will specify recommended valve spring heights and corresponding pressures. This information will be included on the new camshaft's specification card.

Inspect Valve Springs—Inspect all valve springs (new or used). Measure valve spring free height (uncompressed). The OE beehive springs call for a free height of 2.080". With the spring placed on a calibrated valve spring tester, compress the spring to the installed height of 1.800" (this is the spring height as installed in the head with no rocker). The OE specification calls for a spring pressure of 76 lb at the 1.800" installed height. Next, check the spring for open pressure (this is the pressure the spring should provide when the rocker pushes down on the valve to open the valve fully). The OE specification calls for a spring pressure of 220 lb when the spring is compressed to a height of 1.320". Height (free, installed and open) is the same for both OE intake and OE exhaust springs.

Note: If you're doing a camshaft swap, the camshaft maker will specify the recommended valve spring pressures for that particular camshaft, based on lift and anticipated operating engine speed. The valve spring specifications will be listed on the camshaft's data card.

Before performing cylinder head assembly, inspect the head for cracks and signs of coolant leakage (which could be the result of a crack or casting porosity). Depending on the fault (crack or porosity), the head may be rescued by a skilled cylinder head shop using tig welding and/or vacuum resin impregnation. Depending on the extent of the damage and the estimated cost of repair, you'll need to make a judgment call to decide if the head should be repaired or replaced.

If valve seats require refacing, the valve seat angles of 30 degrees/45 degrees/60 degrees must be maintained.

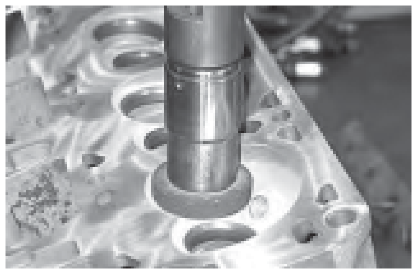
Inspect combustion chambers for burrs or other sharp spots. These can lead to hot-spots during engine operation, resulting in detonation (preignition). If any sharp edges are found, lightly smooth these out.

If valve seats require refacing, the proper seat angles must be retained (30/45/60 degrees). This can be accomplished with angle grinding or angle cutting, depending on the type of seat & guide equipment available.

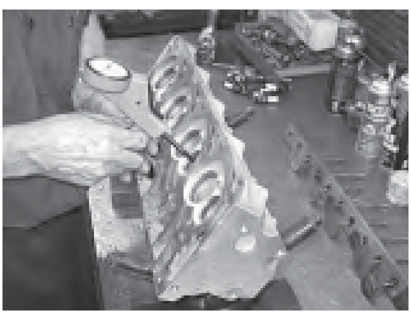
OE valve guides are made of powdered iron. If worn, these can easily be replaced with bronze guides.

Valve seats should be checked for runout (the uniformity of the circumference relative to the centerline of the valve guide). If any measurable runout is present, the seats must be either refaced or replaced and faced at the proper angles.

All intake and exhaust valve seat and guide locations must be inspected.



Here a valve seat grinding stone cuts one of the seat angles.



Using an inside bore gauge, measure each valve guide for diameter and taper (measure at three equidistant locations in the length of the guides). The OE valve stem clearance calls for a rather tight minimum of 0.001" to an allowable maximum of 0.0026". Some aftermarket heads feature in the range of 0.0012" for intakes and about 0.0016" for exhaust valve stem clearance. An absolute maximum to consider would be about 0.0015" for intakes and about 0.0026" maximum for exhaust.

Valve Seat Runout—Valve seats should be checked for runout, using a valve seat runout gauge. This checks for concentricity of the seat relative to the centerline of the valve guide. While the OE specification allows for a maximum of 0.002" valve seat runout, any runout greater than 0.001" should be deemed unacceptable.

Valve Guide ID—Check valve guide inside diameter for both diameter and taper, using an inside micrometer valve guide bore gauge. Based on the diameter of the valve stems that you intend to use, the OE specs note that valve guide inside diameter should allow for 0.001–0.0026" for both intake and exhaust valve locations. Aftermarket performance cylinder heads (citing Trick Flow as but one example) may call for 0.0012" for intake valve stem clearance and 0.0016" for exhaust valve stem clearance. These clearances are a bit tighter than the 0.0015" intake and 0.0020–0.0025" clearances used by many race engine builders on other engine applications.

If the powdered iron OE valve guides are worn, these can be drilled/reamed out and replaced with bronze guides which are then reamed to achieve final desired stem clearance.

While you may be tempted to "port and polish" the intake and exhaust ports, don't monkey around with this on your own. The surface finish on today's precision castings is already acceptable (a mirror finish won't gain anything and can actually hurt. Port shape and volume are the big improvement factors, not surface finish). If you want more go-power, don't mess with the OE heads. Buy a pair of performance aftermarket heads that were already developed and dyno tested for honest power increases. Cylinder head manufacturers such as Trick Flow, Edelbrock, AFR and others have made big strides in developing kick-butt heads for the LS platform.

Valves

If you want to gain a better understanding of the high performance/racing intake and exhaust valve designs and materials that are available, the following information should be of some help. Choosing the optimum valve for a specific application can sometimes be confusing, considering the various choices available today. Here we attempt to explain the various materials and designs in an effort to better understand today's valve offerings.

Stainless Steel—Although stainless steel valves may be offered in varying grades/alloy recipes, high performance stainless steel valves are most commonly made of material referred to as EV8 (a more expensive heavy-duty stainless alloy material), and are made from a one-piece forging. In addition, some valve makers offer a stronger stainless steel formula that offers higher heat resistance (Manley's XH-428 is an example). Some makers use EV8 only for their exhaust valves, while others utilize this material for both intake and exhaust valves. High quality performance stainless valves should feature hard stellite tips (since stainless is not hardenable, a hardened tip must be welded onto the stem) and hard chrome plated stems (not cheap flash chroming) to reduce guide wear. Undercut stems contribute to slight weight reduction and benefit flow characteristics.

Note: If a particular brand of stainless steel valves does not feature a hard tip, the use of lash caps will be required.

Titanium—Titanium (chemical symbol Ti) offers the highest strength-to-weight ratio of any known metal. In an unalloyed condition, Ti is as strong as some steel materials but about 45% lighter. When used to manufacture automotive valves, titanium is alloyed with small percentages of various materials, including copper and

OE valves feature stainless steel valves (hollow sodium filled exhaust valves). Aftermarket valves will commonly be stainless steel as well.

High-performance racing intake and exhaust valve technology is far more advanced than you might first think.

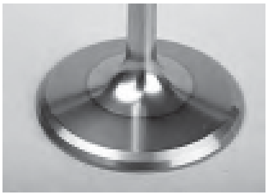
molybdenum. Titanium is a fairly hard material and can be challenging to machine, as it can gall if tooling isn't hard and sharp enough, and if the material isn't cooled properly during machining.

Many titanium valves are generally produced by starting with a forging, then machined to final shape, but some are produced using a two-piece inertia-welded design.

Three styles of valve tips are generally available, which includes a hardened steel tip or a ceramic-coated tip (ceramic tips are to be used in conjunction with lash caps) and thin-film technology such as a PVD coating.

As we noted earlier, titanium is a relatively soft material, requiring a protective contact surface at the stem tips, usually requiring hardened lash caps. Valve maker Xceldyne notes that when valves feature stem diameters smaller than 5/16" (7mm or less in diameter), a specialized hard coating is applied to the stem tip in order to protect the tip from lash cap friction.

The ceramic coating is a durable hard coating intended to protect the titanium from the friction caused by the lash cap. Other coatings such as a



The telltale ring on the valve throat indicates the transition between the chromium nitride (CrN) coating (applied to the seat area and majority of the head) to the stem base, which is "bare" titanium.

Applying a hard coating such as TiN to the stem tip and lock groove protects the titanium material from galling damage from a lash cap and retainer locks.

PVD (plasma vapor deposition) treatment, a CrN (chrome nitride) treatment, CVD (chemical vapor deposition) or DLC (diamond-like carbon) or other highly specialized protective application may be applied to the tips. This hardened feature at the tip prevents material transfer or galling between the tip and lash cap.

Hollow titanium valves are also available, either with hollow stems or with a combination of hollow stems and hollow heads. Hollow stem designs reduce valve weight by about 10%. The hollow head design is a proprietary process that removes an additional 6 to 8 grams of weight (of course, depending on valve size). As part of the proprietary process, the inside of the valve head may be reinforced to provide a support structure for strength and rigidity.

A commonly used lock design for titanium valves is the "super 7" style, commonly referred to as a 7-degree lock, which is actually closer to 8 degrees. Lock grooves are square grooved or radiused for superior lock engagement as well as reduced potential for stress risers. Xceldyne notes that they apply a specialized thin-film PVD coating to the locks and retainers to prevent material galling between titanium/titanium materials. Scott mentioned that lock-to-retainer interface is perhaps the biggest galling-potential issue that must be addressed. Some precautions concerning the handling and use of titanium valves include:

- Do not touch the valve surface with your bare hands, since fingerprint acids may affect the coating). Use gloves or coat the valve with oil before handling.
- Never use a lapping compound, or any abrasive material when the valve is coated with a PVD style coating.
- Valve seats should be replaced during each and every rebuild in order to insure a proper valve-to-seat contact. The width of the contact zone (valve face to valve seat) should be at least 1mm.
- New valve seats should be a relatively soft material, such as bronze or nodular iron (heat treated to Rockwell RC32 or less).
- Unless directed otherwise by the valve maker, always use hardened lash caps on titanium valves. Some makers offer valves built with friction-welded hardened tips. Bare, unprotected titanium tips are relatively soft and will mushroom when exposed to rocker arm forces.

If the titanium valve features a stellite tip (stellite tipped valves don't require lash caps), during valve service, the stellite tips can be ground, with caution. You should be able to safely remove approximately a maximum of 0.015" to 0.020".

As far as valve seats are concerned, again keep in mind that titanium is a relatively soft material. A traditional cast or hard seat can beat a groove into the valve face, so a nickel bronze seat material is recommended.

Titanium valves are extremely lightweight and are designed for applications where valvetrain weight needs to be reduced, for high-rpm and extended high-rpm applications, since titanium valves allow for higher engine speeds and will accommodate highly aggressive camshaft profiles. The lighter weight contributes to minimized wear on rocker arms and improved valve spring life. As valve weight is reduced, lighter springs can be used. As spring force is reduced, this reduces frictional loads between the lifters and cam lobes. So, the use of titanium valves offer both higher engines speeds, quicker engine acceleration, and reduced friction throughout the valvetrain. While lighter weight and the resulting ability to achieve higher engine speed is of obvious benefit in any form of racing, the ability of the engine to produce quicker acceleration is extremely beneficial in a drag racing application.

It should be obvious that titanium valves are designed for higher engine speeds, which is fine for higher top-end power. However, for extreme temperature situations (blown, turbo, nitro engines), titanium may not be the ideal choice. Also, for many street applications, titanium may not be a good choice for an engine that doesn't need to rev as highly, and for an engine that will be buttoned up and not torn down and serviced regularly. In other words, it's probably best to reserve the use of titanium for naturally aspirated race or inlet-side forced induction applications where valvetrain weight and sustained high-rpm use is paramount.

Iconel Valves—Inconel is a registered trademark of Special Metals Corporation, referring to a family of nickel-based superalloys. Inconel alloys are oxidation and corrosion-resistant materials designed for use in high-heat environments. Inconel retains strength over a wide temperature range. As opposed to steel or aluminum, Inconel doesn't creep as much (change dimension) under high-heat use. Inconel is commonly used in high stress aircraft applications such as high-speed airframe and jet engine components.

Five "grades" of Inconel are in common use, including 600, 625, 690, 718 and 939. As an interesting sidenote, a special Inconel X material was used in the makeup of the skin for the legendary X-15 rocket plane.

Basically, the benefits of Inconel include light weight, extreme resistance to temperature, high strength and resistance to thermal dynamics.

Inconel alloy makeup (depending on the specific alloy mix) can include carbon, manganese, silicon, phosphorous, sulfer, nickel, cobalt, chromium, iron, aluminum, molybdenum, titanium, boron and copper, with the heaviest material concentration accounted for with nickel and chromium.

Inconel valves offer extremely high thermal resistance and are designed for high heat applications as found in turbocharged, supercharged and nitrous applications.

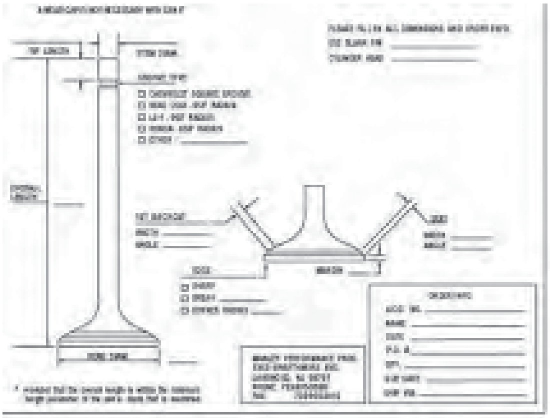
Nimonic 90—Nimonic is a nickel-chromium alloy. A specific grade of this material, Nimonic 90, is used by some makers for producing high-performance valves. Nimonic 90 is a super alloy comprised of nickel-chromium-cobalt, which offers high strength and especially an ability to withstand extremely high temperatures, reportedly well within the 2000 degree F range, without distortion. This material is also widely used in aerospace industries for applications such as valves in turbo motors and blades and discs in gas turbines. Manley reports that they've seen success in such extreme applications as nitromethane and high-boost turbo applications such as multiple-turbo tractor-pull engines.

Stellite—Stellite is a hard coating applied to valve stem tips and faces to provide a hard surface, to minimize wear. Stellite alloy is a non-magnetic and non-corrosive cobalt-chromium alloy that may also contain a tungsten element. It resists embrittlement and annealing at higher temperatures. Interestingly, the term Stellite was derived from the name of a Scottish racehorse (yeah, I know…who cares?). Stellite is often applied to steel or stainless steel valves.

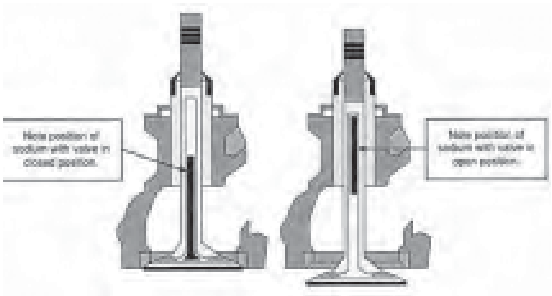
Sodium Filled—Sodium-filled valves feature stems that are precision-gun-drilled and filled with a specially formulated sodium. This achieves weight reduction (the result of the gun-drilling to create a hollow stem) and better heat dispersion. There is some debate concerning the efficiency of this heat transfer, due to concerns that the heat transfer to the guides increases guide wear. Even with these concerns in mind, it's interesting to note that the Chevy LS7 engine features sodium-filled exhaust valves (along with titanium intake valves).

The hollow space in the head/stem of a sodium-cooled valve is filled to about 60% of its volume with metallic sodium, which melts at about 206 degrees F. The inertia forces that result during valve opening cause the liquid sodium to migrate upwards inside the stem, transferring heat to the valve guide and subsequently to the water jacket.

Hollow Stem—Hollow-stem stainless steel or titanium valves (no sodium-fill) features gun-drilled stems to create hollow stems, strictly for weight reduction (this reduces valve weight by approximately 10% as compared to a comparable solid-stem valve). Citing Ferrea as an example, their hollow stem valves are gun-drilled and micropolished, and feature friction welded tips, shot-peened and rolled lock grooves, "avionics" chrome plated stems, and feature face hardness up to 42 HRc. This micropolishing reduces the risk of stress risers in the I.D. walls of the stem.



This custom-order chart is an example of the data required when ordering custom valves. Variables include stem diameter, overall valve length, lock groove type, head diameter, type of head edge, width and angles of mating face area and seat margin. Courtesy Manley.



Sodium (in a gun-drilled sodium-filled valve stem) moves upward as the valve enters the open position, theoretically transferring heat to the guide for improved heat dissipation. Illustration courtesy Manley.

Valve Selection

Since valve weight in particular naturally relates to valve spring force and cam profile selection for given race applications, I contacted the folks at Comp Cams for their input on selecting the right valve for the cam being used.

For the majority of street engines, a quality stainless steel valve is recommended. Billy Godbold of Comp Cams noted that they prefer titanium for most race applications, but that some engine builders that specialize in turbocharged applications prefer a high nickel Inconel valve. "We have to leave the final decision up to the engine builder, but it does limit the cam designs we can choose from when going to a heavy valve."

Hollow stem valves tend to work great on the intake side, but they are much more difficult to manufacture and to inspect for defects on the I.D. surface. Many of the upper-tier engine builders shy away from hollow valves for that reason in endurance (NASCAR or 24-hour style) racing.

Comp's Thomas Griffin noted that stainless steel valves are most common in street and mild-performance racing. Titanium is used when valve weight is important and when budget is not a consideration. Inconel is used when exhaust gas temps get really high. Stainless steel (for street performance) has much better durability characteristics than titanium, and the street guys won't usually see the real benefits of titanium. In racing, use titanium when you want to lose weight and spend a lot of money. If durability is a concern and you're already making as much power as you want and are already turning the engine as high as you want, then you need to use a stainless steel material. If you're running nitromethane, then an Inconel exhaust valve material will be your best bet if you want to finish a race. NASCAR engines use a variety of titanium materials because of the temperature and impact-related issues associated with their severe applications.

Godbold noted, "On the exhaust side, sodium-filling is the best way to increase the head capacity of a hollow exhaust valve. If stock diameter steel valves are required, but a valve weight is not mandated, going to a hollow intake and sodium-filled exhaust is certainly a major advantage."

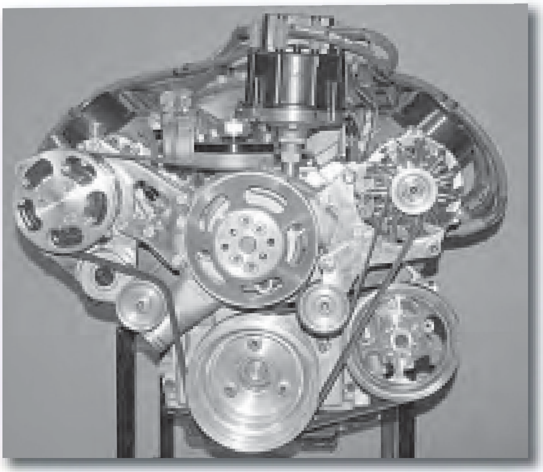
To prevent excessive tip wear on titanium valves (especially the small O.D. non-hardened tip variety), using a lash cap provides an excellent wear surface for the roller tip, sliding contact or cam follower. While you always want the rocker to push down on the section of the cap directly over the stem, using a lash cap certainly gives you a better sense of safety as you approach the edge of the valve in high lift applications with a very small (5 to 7mm) stem.

Griffin noted that since engine builders and cam designers push limits, the stems get smaller and the lift gets higher. As a result, lash caps are used with smaller valves to better distribute the load across a larger area than the base stem tip area. They are also used with higher lift because when the lift is increased, the rocker arm sweep length usually increases across the valve or lash cap as well, compounding the issues caused by the smaller valve stem diameter.

As a quick summary, high-quality EV8 stainless steel valves are a good choice for street and naturally aspirated race engines, while titanium valves benefit high revs in race engines that don't experience extremes in temperatures, and Inconel (and other similar nickel content) valves are suggested for extreme cylinder pressure/extreme temperature applications (primarily exhaust). For extreme-temperature applications such as very high cylinder pressure nitromethane, blown or supercharged use, a combination of titanium intake valves and Inconel or Nimonic exhaust valves are used.

Chapter 9

Engine Assembly



After all the reconditioning, parts selection, prep and research, it's time to bolt it all together. With the end so close, it is easy to rush and make mistakes. But take the time to perform all the preassembly checks and clearances before final assembly.

This chapter details the assembly of a modified LS2. However, the assembly procedures are similar for all LS engine models. For the sake of simplicity, we've grouped all of the instructional text into one section. It is recommended that you read through it first. This section is then followed with a detailed photo sequence, which is organized from left to right, top to bottom.

Note: *The procedures that follow apply both to test-assembly for blueprinting and final assembly.*

Prep Block

Once the block has been prepared, in terms of sizing the cylinders for the pistons of choice and checking rotating mass clearance (making sure that the crankshaft counterweights clear the block, making sure the connecting rod big ends and the rod bolts clear the block), checking main and rod bearing clearances, and checking lifter-to-lifter bore clearance, you're now ready to begin final assembly

The first step in any final assembly is to wash the block. This doesn't mean just rubbing the block with a damp rag…the block must be absolutely clean inside and out. The block should be hot-tank or jet-washed (this must be done at an engine shop) to remove the majority of metal particles that were produced during block machining and cylinder honing.

Final Wash—Have your local shop wash the block and lightly coat the cylinder bores with a light oil to prevent surface rust. Bag the block in a sealed plastic bag for transport. Once the block is in your assembly location, remove the bag, mount the block to your engine stand, and begin to wash the block by hand. Use hot water and a good detergent soap (household dishwashing liquid or something similar works well). Using a clean long-handled soft-bristle brush (non-metallic), scrub the block exterior, the main saddles, the cylinder bores and the decks. Using long "rifle" brushes, clean out all oil passages. Basically, soap the heck out of the block and soap-scrub all surfaces to remove all traces of oils, dust, etc. Then, using a garden hose or better yet, a power washer, thoroughly rinse the block (including all oil and water passages) with hot water.

When you've rinsed the block thoroughly, use clean compressed air to dry the block. It's best to use a blow gun with a rubber tip to avoid gouging any metal surfaces. Blow out all bolt holes, plug holes, oil passages and water jackets, etc. Once the block is dry, immediately apply a light coat of lubricating oil (WD40 or similar is OK) to the cylinder walls to prevent surface rust. If you're working on an aluminum block, only the cylinder walls must be oiled to prevent rust from starting. If you're using a cast-iron block, you should coat the cylinder walls and lifter bores with a light oil, and you should apply a light coat of paint or etching primer to the block exterior (bare cast iron will begin to oxidize/rust very quickly, so don't delay). When applying a light oil to the cylinder walls, make sure that you use clean, lint-free towels.

Note: Once the block has been washed, rinsed and dried, and especially once oil has been applied to cylinder walls, you're now committed to maintaining cleanliness…immediately move the block to your final assembly location, in an enclosed area. If your assembly location is your home garage, this means that once the block is there, you should not open the overhead garage door. Keep the room as sealed as possible to prevent airborne particles from contaminating the block. Anytime you leave the block (before or during the stages of assembly), place a clean lint-free cover over the block. Also, don't smoke in the assembly area, to prevent ashes from contaminating the block.

Install Bearings—With the clean block positioned upside down on your engine stand, the upper main bearings are installed into the block saddles. Remember, the upper main bearings are installed to the block's bearing saddles and the lower main bearings are installed onto the main caps.

Even though you've washed the block, don't consider this as a guarantee of cleanliness throughout the assembly. Before installing the upper main bearings, carefully wipe each main bearing saddle with a clean lint-free cloth to make absolutely certain that there are no dirt or dust particles on the saddle surfaces. Do not apply anything on the saddles before installing the bearings—the saddles must be clean and dry (do not oil the saddles).

On a clean workbench, organize your main bearings. Remember that the LS engine's thrust bearing will be located at the center (No. 3) main saddle location. Carefully inspect each bearing shell, since upper and lower bearing shells will be identified as such. The upper bearing shells will feature an oil hole (this aligns to the main bearing oil feed hole in each block saddle) and the lower main bearing shells will feature no oil holes. Pay attention to this. If you mix up the bearings (uppers and lowers), you'll block off oil feed and this would not be good (translation: destroyed engine). I feel the need to mention this because some folks tend to get confused when the block is upside down. Just remember that upper bearings install to the block and lower bearings install to the main caps.

Install the thrust bearing first, at the center (No. 3) main saddle. Depending on the brand of main bearings, fore/aft orientation may be specified, so read the instructions that are included with your bearings. In the build shown here, I used Clevite 77 main bearings.

The Clevite thrust bearing (at No. 3 main cap) feature two thrust face oil grooves on one side and three grooves on the opposite side. The three-groove side must face the rear of the block.

Inspect the bearing before installing it (both sides) to make sure that there are no particles of dirt, dust, etc. Install the bearing shell dry (no oil). The bearing shell features a locating tang that will align to the tang notch in the block saddle. With clean hands, insert the bearing shell into the saddle. Use your fingertips to gently but firmly push the ends of the bearing until both ends are flush with the main cap mating surface. Install the remaining upper bearings in the same manner (check each for cleanliness and install all bearings dry).

Check Bearing Clearances—If you haven't already pre-assembled to check bearing clearances, read the next section. If you've already checked main bearing clearance, proceed to crankshaft installation on page 108. In order to check main bearing clearance, install all lower main bearings into the main caps (same procedure as you followed with the uppers, remembering to position the lower center thrust bearing with the three-groove side facing rearward).

Carefully install the main caps. Place each main cap (pay attention to location and direction—each cap is marked for bearing location (1, 2, 3, 4, 5) and for direction (arrow towards front). Position a main cap as closely as you can by eye. If you're using main cap bolts, lightly lube the bolt threads (or upper stud threads) and then loosely install the four primary (10mm) main cap bolts, engaging by a few threads. This will help guide the cap into proper register (if you're using main studs, the studs should already be in place, which will guide the main caps). Once each cap is aligned (via the fasteners), push the cap against the block, tapping with a clean plastic mallet to roughly seat the cap. If using bolts, apply lube to the underside of the bolt heads. If using studs, apply lube to the lower threads and to the underside of the nuts. Begin to tighten the main cap fasteners. Initially snug each cap's inner 10mm fasteners to about 5 ft-lb, the tighten the outer 10mm fasteners to about 5 ft-lb, simply to settle each cap in register (tightening until each cap appears to be mated flush).

Always follow the recommended tightening sequence when tightening the main cap fasteners. Refer to the main cap tightening sequence on the next page, and the illustration on page 134.

Torquing Main Cap Bolts—Torquing the main cap bolts must be accomplished in multiple passes in order to evenly distribute clamping load. The torque values will differ depending on what fasteners are being used. If you are using new OE main cap bolts, you'll follow a torque-plus-angle method

during tightening:
• Inner 10mm (vertical) bolts: 5 ft-lb (first pass) plus additional 80 degrees rotation
• Outer 10mm (vertical) bolts: 15 ft-lb (first pass) plus additional 53 degrees rotation
• 8mm side bolts: 18 ft-lb

Note: Torque-plus-angle tightening involves first tightening, using a torque wrench, to a specified torque value. This is then followed by continued tightening by a specific number of degrees of rotation. You can monitor this by placing a small dot (marker or paint) on one side of the bolt head and an aligned mark on the cap, where both dots are aligned. Then, as you continue to tighten, you can see how far the bolt head rotates with regard to the mark on the cap. If you do this by eyeball, you'll have to estimate when you reach 53 degrees or 80 degrees, etc. Or you can use an angle gauge. This is a simple dial gauge attached to a socket wrench. Place the socket onto the bolt head and zero the gauge. As you slowly rotate clockwise to tighten, you can clearly see how many degrees you've moved the bolt head.

Note: If you're using new OE main cap bolts, use engine oil as the thread and underhead lubricant. OE tightening specifications are based on the use of oil.

The reason this method is used by the original equipment manufacturers is to achieve the proper bolt stretch and resulting clamping force that the engineers have determined as needed for specific applications, using the OE bolts that are designed for this method.

If using ARP main cap studs, you'll follow a three-step torque-tightening procedure:

Inner 10mm nuts:	20 ft-lb (first pass)
Outer 10mm nuts:	20 ft-lb (first pass)
Inner 10mm nuts:	50 ft-lb (second pass)
Outer 10mm nuts:	60 ft-lb (second pass)
8mm side bolts:	20 ft-lb

Note: ARP tightening specs are based on the use of their moly assembly lubricant)

Check Bearing Diameter—Using a quality bore gauge, carefully measure each installed main bearing inner diameter and record the measurement (No. 1, 2, 3, 4 and 5). When measuring bearing diameter, measure with the bore gauge contacting the bearing fairly close to the 12 o'clock and 6 o'clock positions (avoid hitting the oil feed hole in the upper bearings). Don't measure at or close to the mating surfaces, since bearings are slightly thinner at the mating surfaces in order to promote an oil wedge during crankshaft rotation, and you'll get an erroneous larger reading there.

Measure Crank Journal Diameter—Once all five bearing diameters have been recorded, use a micrometer to carefully measure the diameter of each crankshaft main journal (the crankshaft journals should be clean and dry). Record the measured diameter of each crankshaft journal (No. 1, 2, 3, 4 and 5) and record each journal's measured diameter.

The difference between the installed bearing diameter and the crankshaft journal diameter is the oil clearance. Simply subtract the journal diameter from the bearing diameter. According to published OE specs, acceptable main bearing clearance is 0.0007 to 0.00212", making an "ideal" oil clearance of about 0.0013 to 0.0015".

However, some experienced builders prefer a bit more clearance, to the tune of about 0.002 to 0.0025". If your measurement of main bearing oil clearance is, say, 0.0015" and you want a bit more clearance, MAHLE Clevite offers a 1X main bearing size (their part number MS2199HK 1X), which would provide 0.0025" clearance.

In the example Project LS2 build shown in this book, my installed main bearing diameters measured 2.5605" and my Lunati crank main journals measured 2.559". In order to achieve 0.0025" oil clearance, I went with the MAHLE Clevite 1X bearings. That provided an easy fix, as opposed to align-honing another 0.001" from the block's main bores.

Once you're happy with main bearing oil clearance, remove the five main caps. First remove the 8mm side bolts, then remove the 10mm vertical fasteners in reverse order from the tightening sequence. You'll need to wiggle each main cap to dislodge it from the block. Just use your fingers and

OE Main Cap Tightening Sequence

Here's the tightening sequence, in order of tightening. The view is looking at the block upside down. LH (left hand) refers to the driver side of the block and RH refers to the passenger side of the block:

1	cap 3, inboard LH	16	cap 2, outboard RH
2	cap 3, inboard RH	17	cap 5, outboard LH
3	cap 4, inboard LH	18	cap 5, outboard RH
4	cap 4, inboard RH	19	cap 1, outboard LH
5	cap 2, inboard LH	20	cap 1, outboard RH
6	cap 2, inboard RH	21	side bolt cap 3 RH
7	cap 5, inboard LH	22	side bolt cap 3 LH
8	cap 5, inboard RH	23	side bolt cap 4 RH
9	cap 1, inboard LH	24	side bolt cap 4 LH
10	cap 1, inboard RH	25	side bolt cap 2 RH
11	cap 3, outboard LH	26	side bolt cap 2 LH
12	cap 3, outboard RH	27	side bolt cap 5 RH
13	cap 4, outboard LH	28	side bolt cap 5 LH
14	cap 4, outboard RH	29	side bolt cap 1 RH
15	cap 2, outboard LH	30	side bolt cap 1 LH

wiggle while you pull. Don't use any type of prybar.

If the block has been used (a previously run engine), the main caps may be a bit tight due to the clamping force of the 8mm side bolts as the block heated/cooled during operation. GM offers a spreader bar that is inserted between the block walls and extended (basically a turnbuckle deal) to ever-so-slightly spread the block walls apart to ease main cap removal. Chances are you won't need it. Just wiggle and pull and while some may be stubborn, they'll eventually loosen. If you're using main cap bolts, you can re-insert two bolts (one at each side, without engaging threads), and use these as mini leverage handles to wiggle the cap fore/aft.

If you prefer to make life easier and don't mind spending about $200 or so, RHS and Weld Wheels both make LS main cap puller tools that slide the caps neatly out of the block. The RHS tool part number is 549106.

Once the main caps have been removed, recheck all bearing locations to make sure that none of the bearing shells have moved. Verify that all upper and lower bearings are seated properly. Carefully, once again, wipe each bearing with a dry, lint-free towel. Next, apply a liberal coating of engine oil or engine assembly lube to the exposed bearing surfaces on both upper and lower bearings, and make sure to also lube the front and rear thrust bearing faces. My favorite assembly lube is Royal Purple's Max Tuff. This is a super-slippery and super-sticky synthetic lube that is great for coating bearings.

Install Crankshaft

Closely inspect the crankshaft again to verify cleanliness. Make sure that the entire crank is clean. Pay special attention to the journals surfaces and the oil holes. If needed, carry the crank out of the assembly room and give it another wash with hot soapy water, running a rifle brush through each oil hole. After a thorough rinsing, blow compressed air through all oil holes and dry the entire crank. Carry the crank back to the assembly area, stand it upright on a clean workbench and once again go over all journal surfaces with a clean lint-free rag.

Even though you already lubed the main bearings, apply a coating of oil or assembly lube to the journals, making sure that you smear the lube onto the journal fillets.

Wash your hands (so that they're not slippery). With the block secured on the engine stand (engine stand head tightened to prevent accidental block rotation), pick up the crank by the front snout and the rear flange. CAREFULLY lay the crankshaft onto the upper bearings (pay attention to alignment to prevent nicking a journal). Once the crank is seated onto the upper bearings, don't rotate it at this point.

Tip: If you're using main cap studs, consider removing the studs before laying the crank into the block. With the studs in the way, you'll need to lift the crank higher to clear the studs, which creates a greater chance of bumping into the studs. Once the crank lays onto the upper bearings, you can re-install the studs. Install the main caps. When tapping the caps down, be careful not to dislodge the lower bearings from the caps.

Final-Install Caps—The caps must be installed in proper orientation. Each cap is number stamped for location, as is the adjacent pan rail surfaces of the block. The side of the cap that features the number stamp must be placed adjacent to the number stamp on the block (place cap numbers closest to block numbers). This will orient the small curved tangs on the caps facing rearward, except for No. 5 cap, where the tangs face forward (the number stamps for No. 1, 2, 3 and 4 are located on the left side of the block, while No. 5 is stamped on the left side).

During my assembly, with the crankshaft carefully laid onto the upper bearings, I then installed the ARP main studs (I applied a light coat of ARP moly on the block-side threads) finger-tight. The caps were then hand-installed, paying attention to cap angle, nestling the caps into position as evenly as possible. I then lightly snugged each stud using a hex wrench to about 3 to 5 ft-lb preload (basically just making sure that they were fully seated).

The aluminum block is very alive, so any forces applied (such as main cap fastener tightening) will cause the block to move around. Keep this in mind when tightening the mains. Don't be tempted to try rolling the crank after partial tightening. The main bores won't straighten out until all primary main cap fasteners are fully torqued. Since I used ARP main studs instead of the OE bolts, I ignored the OE torque/angle spec, and tightened the stud nuts using the straight torque values recommended by ARP. Following the proper sequence, I tightened the stud nuts (with ARP moly on threads and nut undersides) to a final value of 50 ft-lb at the inboard stud locations (closest to the crank) and 60 ft-lb at the outboard studs. However, instead of simply chasing full value all at once, I opted to tighten in stages. I started by carefully drawing the caps down by tightening the nuts to about 10 ft-lb. I then continued by tightening the inboard stud nuts to 25 ft-lb, followed by tightening the outboard stud nut to 25 ft-lb. This allowed the caps to settle and provided an even baseline of clamping. I then tightened the inboards to their final value of 50 ft-lb, followed by final-tightening the outboards to 60 ft-lb. At this point, the crank rolls like butter. Don't be tempted to try tolling the crank until all of the 10mm vertical main cap bolts have been fully torqued. Otherwise, you'll probably freak out if the crank feels tight. Remember…I mentioned that the aluminum block moves around. The main bores were machined at the factory with the main caps fully tightened. Main bore geometry will change when the main caps are removed or are not fully tightened. Wait until all ten 10mm primary main cap fasteners are fully tightened to value before attempting to rotate the crankshaft.

Once the primary stud nuts were fully tightened, I then installed the ten (five per side) 8mm side bolts (threads and head undersides coated with ARP moly), tightening to 20 ft-lb. These are tightened in sequence, starting at No. 3 main cap, followed by No. 4, No. 2, No. 5 and No. 1 cap locations.

Check Crankshaft Endplay—Once the main caps have been fully tightened to value, check crankshaft endplay/thrust. Using a plastic mallet, gently tap the crankshaft on the snout, rearward. Then tap the crank forward from the rear. This helps to seat the crank thrust area. Position a dial indicator at the crankshaft nose or rear flange (pick a convenient spot). If using a magnetic-base indicator stand on an aluminum block, you should be able to stick the magnetic base onto the face of the front main cap. Using a clean screwdriver, gently pry the crankshaft rearward (placing the screwdriver between a main cap and a counterweight), adjust the dial indicator with about 0.050" preload, and zero the indicator gauge. Then gently pry the crankshaft forward and note how far the crank has moved. Repeat this a couple of time to make sure that you obtain a clean reading. The LS crank should have about 0.0015" to 0.0078" thrust play (my LS2 build featured a measured 0.005" endplay). If too tight, you can remove the main caps, remove the crank, and remove the upper and lower halves of the No. 3 thrust bearing. Clean the bearing of all lubricant. Using a caliper or micrometer, measure the outside width of the thrust bearing faces (front to rear) and record. Holding the two (upper and lower) thrust bearing shells together, place the thrust faces onto a clean piece of emery cloth that has been placed on a glass surface, and rub the bearing faces against the emery cloth to remove a bit of thrust face material. Take a few swipes, clean the bearing and re-measure the width, noting how much material has been removed. If the crank endplay was noted at, say 0.002" but you want 0.005", you'll want to remove 0.003" from the thrust face. Don't try to whack off a bunch at one shot, slowly creep up, cleaning a re-measuring after each swipe. Thoroughly clean the thrust bearings, reinstall the bearings, crank and caps and recheck endplay.

Camshaft

Like every aspect of a build, you need to spend some time to make sure that the camshaft is absolutely clean. Using a wax and grease remover (such as Prep-Sol) or lacquer thinner, wipe all journals and lobes to remove any packing grease/protectant and wipe dry using a lint free rag. Blow with compressed air to remove any remaining particles, rag fibers or other debris.

Both camshaft journals and lobes need to be lubricated. Since this is a roller type camshaft, we don't face the same critical break-in issues as compared to a flat tappet camshaft. I coat journals with Royal Purple Max Tuff, and I coat the lobes with either the lube that was supplied with the cam or with Max Tuff.

Install Camshaft—Inserting the camshaft into the block must be handled with care to avoid nicking or scratching the cam bearings. A fore/aft scratch in a cam bearing can result in a reduction of oil pressure. In order to safely insert the camshaft, always install a temporary handle to the camshaft nose. Installation handles are readily available at good auto parts stores, or any speed shop. Using an extended handle at the snout provides leverage control that will greatly help to keep the camshaft straight during installation. As you feed the camshaft into the cam bore, you can take a brief rest whenever a camshaft journal inserts into the front cam bearing, if you need a little break. As you insert the camshaft, take advantage of the installation handle as a leverage aid to keep the rear of the camshaft from dropping on its own weight. If you feel resistance at any point, DO NOT try to force the cam further. If the cam stops at any point, that means you're not aligned. Gently and slowly wiggle to achieve alignment and slowly continue. Once fully inserted, the camshaft should rotate easily with your fingers.

The Project LS2 engine buildup used a steel roller cam (Crane's P/N 144HR00162, grind No. HR-256/367-2S-14). I coated the journals and lobes with Royal Purple Max Tuff assembly lube and slid the stick into its bore.

Note: If your roller cam is supplied with an assembly lube, (or if the cam maker recommends a specific assembly lube, it's best to follow their recommendation. For a flat tappet cam, it's critical to use a high-pressure assembly lube/paste to prevent premature lube wear. For a steel roller cam, this isn't as critical an issue. A good assembly lube (such as Max Tuff) will suffice.

Project LS2 Cam Card
Crane Part No. 144HR00162
Grind No. HR-256/367-2S-14

Lift
Intake @ cam 0.367"/Exhaust @ cam 0.367"; Intake @ valve 0.624"/Exhaust @ valve 0.624"
Rocker arm ratio: 1.70

Cam Timing @ 0.004 Lift
Intake opens 44 degrees BTDC; closes @ 89 degrees ABDC
Exhaust opens 96 degrees BBDC; closes 45 degrees ATDC
Advertised intake duration is 313 degrees; exhaust duration is 321 degrees

Cam Timing @ 0.050" Lift
Intake opens 17.5 degrees BTDC; closes @ 58.5 degrees ABDC
Exhaust opens 69.5 degrees BBDC; closes 14.5 degrees ATDC
Max Intake Lift: 109 degrees ATDC
Max Exhaust Lift: 119 degrees BTDC
Intake Duration: 256 degrees
Exhaust Duration: 264 degrees
Firing Order: 1-8-7-2-6-5-4-3

Install Cam Retainer Plate—Once the camshaft has been fully inserted, install the camshaft retainer plate. This is secured to the block face with four 8mm x 1.25 bolts. The retainer plate features a printed silicone seal on the block side, so no further sealant is needed. A center hole in the plate allows the stepped-down nose of the camshaft to pass through the plate, providing a thrust-stop for the camshaft.

Note: If you buy a new plate and new GM bolts, you may notice that the plate's bolt holes are slightly chamfered, indicating the need for flat-top (countersunk) bolts heads. However, the new bolts will feature flat-underside hex heads. GM had a running change with these retainer plates. Even if your plate had chamfered bolt holes, it's OK to go ahead and use the hex-head bolts. Apply a drop of medium-strength thread-locking compound onto the retainer plate bolt threads and tighten these four retainer plate bolts to a value of 18 ft-lb.

Install Timing Set—At this point, the timing set may be installed. Don't try to install the oil pump yet, since the timing gear must be installed prior to pump mounting.

If you're using an aftermarket crankshaft, it may or may not already feature a snout key to engage the crank gear. If not, you'll need to install the key now if you haven't already done so.

In Project LS2, I initially tried to install a GM OE crank snout key, but it was way too tall for the Lunati crank snout's key groove (it's not unusual for aftermarket cranks to feature a different keyway depth or length). The 1.5" radiused Lunati key (P/N CS001) that was provided with my crank however, fit perfectly. This is simply a tidbit I wanted to pass along. Don't assume that the OE key will fit all aftermarket cranks, so make sure that you obtain a key from the crank maker (actually, Lunati supplied a key, but I have to admit that I forgot about it until I attempted to install the GM key. Hey, I never said I was smart). Using a brass blunt-nose drift and a hammer, seat the key so that it's centered fore/aft and level (top surface of the key parallel to the crank snout).

Before attempting to install the timing set, rotate the block on the engine stand upright (normal in-vehicle position).

Instead of using a stock timing set, I chose a Performance Billet Gear Set P/N 5623T, sourced from GM performance distributor Scoggin Dickey. This kit includes a double roller chain, cam gear, adjustable crank gear (with timing adjustment from 0 - +/- 4 degrees), a Torrington-type bearing that is placed between the cam retainer plate and cam gear, two spacer shims to move the oil pump out for the timing system clearance, and a drive gear for the stock type oil pump.

Note: While you're messing around with installing the crank gear, it's a good idea to soak the new timing chain in clean engine oil for an hour or more.

The crank gear featured about a 0.001" interference fit to the crank snout. I easily tapped it into place using a thick-wall aluminum tube to prevent marring the gear. Using a soft-metal tube (aluminum or brass) as a driver is a much better choice as opposed to trying to bang the gear into place by whacking it directly with a hammer.

Rotate the crankshaft so that the timing dot on the crank gear is at the top (12 o'clock position). This will place the crankshaft snout's key at about the 2 o'clock position.

Check Camshaft Endplay—Before installing the timing chain, temporarily install the camshaft gear onto the camshaft nose and tighten the three cam gear bolts to 20 ft-lb.

Place a dial indicator onto the face of the cam gear. Push the camshaft rearward until it stops. Preload the dial indicator at about 0.050" and then zero the indicator gauge. Using your fingers on the cam gear, pull the cam forward (towards you) and note camshaft endplay. In Project LS2, I recorded 0.0035" endplay. An acceptable range is 0.001–0.012".

Note: An aftermarket cam gear may include a thrust bearing, which installs to the rear of the cam gear. Make sure that this bearing spacer is installed on the cam gear before checking camshaft endplay.

Once cam endplay is verified, remove the cam gear. Rotate the camshaft to place the cam's dowel pin just below the 3 o'clock position (as you face the block). Install the timing chain onto the camshaft gear. Engage the chain onto the bottom of the crank gear. Draw the cam gear and chain toward the cam, aligning the cam dowel pin to the cam gear's dowel pin hole. This will likely be frustrating at first, since the timing chain isn't about to "stretch" to make the job easy. Be patient. Once the cam gear is placed onto the cam, the timing dot at the bottom of the cam gear should face 6 o'clock and should align to the 12 o'clock position dot on the crank gear.

Once the timing set has been positioned, apply a dab of medium thread locker onto the cam gear bolts, install the bolts and tighten to specification. OE cam gear bolts are tightened to 26 ft-lb.

There are plenty of camshaft profiles from which to choose for the LS format. Following are the specifications of the specific camshaft I chose for my sample LS2 build.

Note: This is a fairly radical cam profile, with a healthy valve lift of 0.624" (requiring notching OE pistons or changing to forged pistons that feature valve reliefs). I'm only showing this camshaft car information as a reference of my particular build.

Install Oil Pump

Once the timing set has been fully installed, the oil pump may be installed. This is a gerotor-style, crank-driven pump that is driven directly by the crankshaft snout. For Project LS2, I chose a high volume/high pressure crank-driven unit from Melling, P/N 10296, but installation is the same for an OE pump.

Note: The OE crank gear is integral with the snout-mounted toothed oil pump drive. My aftermarket timing set featured a separate crank gear and oil pump tooth drive gear. Before installing the oil pump, insert the external-toothed drive gear into the oil pump's central drive gear. This external toothed gear (supplied with the timing set) serves as an adapter that is key-driven by the crankshaft snout. The external teeth on the adapter slides into the female-toothed gear in the oil pump. Apply oil or assembly lube to the teeth and carefully slide the adapter into the oil pump, engaging the male-to-female teeth (it's a close fit but will easily install by hand).

While pump spacers are not required if you're using an OE timing set, in order to provide clearance for the thicker-then-stock timing chain setup on my build, I installed the supplied spacer plates between the oil pump and the block face. I applied a bead of RTV to each side of these plates in order to provide a seal. All four oil pump mounting bolts were tightened to 18 ft-lb, with a drop of thread locker applied to each bolt's threads.

Note: The OE oil pump installation procedure calls for centering the pump to the crank snout. Mount the oil pump to the block, tightening the four mounting bolts to a mere 45 in-lb. Then center the pump by nudging it around until you achieve an even 0.002" clearance around the entire drive gear (stick a 0.002" feeler gauge at one side and another 0.002" feeler gauge 180 degrees from the first gauge). Once it's centered, tighten the four mounting bolts to their final 18 ft-lb value. Follow this procedure regardless of your oil pump's brand.

Install Block Plugs

You can install most of the block plugs at any time, but a few must be installed before installing the front and rear engine covers.

A 16mm cup-style expansion plug needs to be installed on the front of the block, on the left side (driver side), next to the oil pump. This hole is open to oil (a factory-drilled hole for oil passage machining). Apply a smear of RTV to the outer wall of the plug and tap the plug into the hole until flush with the block face (concave side facing out). All remaining threaded plugs (whether being reused from a core engine or purchased new as part of a new block's completion kit) can be installed now as well. All threaded water jacket plugs feature a straight metric thread design and are sealed with Teflon thread sealant.

An oil relief plunger (white plastic with an O-ring) installs into the left rear of the block, with the O-ring towards the rear (oil the plunger, slip the bare white end into the hole, and seat until the O-ring end of the plunger is flush with the block's rear face.

Check Piston Ring Gap

Before installing the pistons and connecting rods, address the piston rings. If you have standard bores, standard replacement rings should be fine, but you should still check ring fit/gap to make sure. If you've enlarged the bore diameter, you'll definitely need to check, even if you purchased rings that are part numbered for your specific bore diameter.

On a clean workbench, organize all of your new rings, by cylinder, with top ring at the top, followed by second compression rings, followed by your oil ring packages.

Using a clean, lint-free towel or rag, wipe each cylinder clean to remove oil/dust etc. Start with the

OE Piston Ring End Gaps	
Top:	0.008–0.0160"
Second:	0.015–0.027"
Oil Rails:	0.009–0.031"

top compression rings. One cylinder at a time, carefully compress the ring and insert the ring into the bore, about 1/2" below the deck. You must now "square" the ring in the bore (the ring must be placed evenly and equidistant around its entire circumference, relative to the block deck). To do this, you can use a dial caliper. Extend the caliper's rule (the end that you would use to measure depth) to about 3/4" or so and tighten the caliper's setscrew. Walking around the perimeter of the ring, gently push the ring down until the caliper's body contacts the deck. You get the point. Just use something to push the ring down evenly so that the ring isn't crooked in the bore. I recommend the ring-squaring tool available from Summit Racing. It's adjustable for bore diameter and is stepped. Simply loosen the setscrew, slide it apart to fit the bore diameter and tighten the setscrew. Now the tool is ready to measure all eight cylinders. Place the tool into the bore. The lower portion of the tool contacts the ring, and when the upper shoulder contacts the block deck, the ring is squared. Remove the tool, and using a feeler gauge, carefully measure the ring gap. You need to measure ring gap for the top ring, second ring and both oil ring rails. You don't need to check gap for the oil expansion ring.

OE and aftermarket ring gaps may vary, depending on piston and/or ring source. If an off-the-shelf ring isn't available for your specific bore diameter/piston, or if you prefer to custom-fit rings anyway, slightly oversized "file to fit" rings are available that allow you to custom-tune ring end gap.

File-Fitting Rings—In my Project LS2 build, I opted to file-fit rings for my LS2 block's 4.005" bores. The rings (which were included with my JE pistons) include JE Pro Seal top rings S14000-5-1.5DMR ductile plasma moly. I filed these to achieve an end-gap of 0.018". The second rings, JE Pro Seal J24000-3-1.5IPC iron rings were file-fitted with a gap of 0.020". For a high-performance street/strip application, JE recommends a top ring gap of bore x 0.0045"; and a second ring gap of bore x 0.0050". Minimum gap for oil rings is 0.015", which were good to go.

I file-fitted each ring to its assigned bore, to accommodate any variance in bore diameter. A diameter variance from one cylinder to the next changes the end gap of the rings in that cylinder by a factor of pi (3.1416). For example, a cylinder that is 0.001" larger in diameter will increase the ring end gap by 0.001 x 3.1416, or 0.003". It's critical to always fit each ring for the specific cylinder into which the ring will be installed.

I filed all of the top and second rings using Summit Racing's rotary ring filer. It may not be as cool as an electric filer, but the diamond wheel cuts fast and clean, and it's a bunch cheaper. An alternative is to use a thin, narrow fine file and file by hand.

Be advised that you need to file squarely (don't create an angle to the gap), and you need to creep up on the desired gap. Count your strokes as you file, and always file in a direction from the inside of the ring towards the outside of the ring…don't reciprocate the file back and forth. After every few filings (around every 7), clean the metal debris from the ring, place it back into its assigned cylinder and measure gap again. After a few rings, you'll get a feel for how many file strokes are needed. Remember to take your time…you can always file more, but you can't add material if you file too much. Once you're satisfied with the ring gap, carefully deburr the gap edges using a fine file.

Whether you've had to file your rings or if the gaps measured good out of the box, keep the rings organized by cylinder location.

In addition to checking ring gap with each ring in its respective cylinder bore, you can also check how the rings fit in your pistons.

When checking ring radial back clearance for top and second rings, with the ring set in its groove and side clearance (ring face radius protruding out) at 0.001–0.002", radial back clearance should be at least 0.005".

Since our JE pistons feature a pin bore that intersects the oil ring groove (due to the short compression height, where the pin bore is so close to the oil ring groove that it actually intersects the oil ring groove), an oil ring support rail is necessary to complete the floor surface area for the oil ring package. This is very common whenever you choose a short piston compression distance. The support rail provides a complete "footprint" for the oil ring package, covering the void let by the intersecting pin bore. The support rail installs at the bottom of the oil ring groove, with the rail's anti-rotational locking detent facing downward. When installing the support rail, rotate the rail until the detent falls into the void at the wrist pin hole.

Note: Do not install the support rail until the pistons are assembled to the rods, since the rails will block the pathway for the wrist pins.

Assemble Pistons & Rods

Now you're ready to assemble the pistons to the connecting rods. However, before you begin to install the pistons to the rods, the connecting rod caps must be removed from the rods (if not already done). If the rod caps are still connected to the rods, you need to separate and remove the caps. When loosening the rod bolts, use care to avoid damaging the rod. You can lightly secure the rod big end in a bench vise, but make sure that the rod is padded to prevent gouging. Loosen each bolt, backing both off until the bolt is engaged only by about 5 or 6 threads. Then remove the rod from the vise. Hanging the rod big end with one hand (fingers holding the cap section only), tap each rod bolt with a clean plastic hammer. One or two strikes on each bolt head will usually pop the cap loose from the rod. Do this over a workbench to prevent accidentally dropping the rod onto the floor. Once the cap is separated from its rod, remove the rod bolts and the cap. Organize all rods on a clean workbench, and keep each cap and its bolts with each rod. DO NOT mix up caps and rods!

A cleaner, safer method involves the use of a special rod vise. This bench-mounted vise features plastic/composite jaws that allow you to clamp the rod big end without damage. The vise holds the rod at the big end to allow bolt loosening without fear of bending or twisting the rod.

Once the bolts are loosened and removed, then the rod is moved to a bench-mounted rod cap splitter. This is a specialty tool that features a two-piece mandrel that expands in one direction, cleanly drawing the cap from the rod without the need to bang on the rod bolts while trying to hold the rod with one hand.

Installing Piston Pins—If you're using OE components, the piston pin floats in the piston's pin bore, but is press-fit to the connecting rod's small end bore. The best method of assembly for a press-pin is to heat the rod small ends in a special rod heater (allowing the rod small end bore to expand, which allows the installer to slip the pin through the one side of the piston's pin bore, through the rod small end bore, into the opposing side of the piston's pin bore, centering the pin onto the rod.

However, if you've upgraded to aftermarket performance connecting rods and pistons, chances are you've purchased "full floating" rods. This design does not feature a press fit of the pin to the rod. Instead, the rod small end bore is larger in diameter, allowing the pin to fully float in both piston and rod. When a full-floating setup is used, you need a method of securing the pin to prevent the pin from sliding out and contacting the cylinder wall.

The setup shown in the photos includes a full floating system that involves JE pistons and pins and Lunati forged H-beam bushed connecting rods. The JE full-floating wrist pins are secured with the supplied wire locks (either wire locks or spiral locks are common). Depending on the piston maker's locking groove design in the piston pin bore ends, either the wire lock or spiral locks will be provided with the pistons.

Install the end of one lock at 90 degrees from the pin lock groove. Use a stiff small blade screwdriver, inserting the tip into the pin lock groove while you wedge the lock into the groove. As you walk the lock clockwise, you can insert a small screwdriver into the lower right access groove (two of these grooves are featured along the lower circumference of the pin bore). Using the screwdriver as a lever, pivot the screwdriver inboard to engage part of the wire lock into its groove. Then insert the screwdriver into the lower left access groove and finish levering the wire lock into place.

An option is to use Lockintool's W-927 wire lock installer. This tool features a step-faced head that allows you walk the wire lock into place by working the tool in an angle and "rolling" the wire in a clockwise path into its groove. I will admit that it took me a while to get the hang of the technique, but it does work well with a bit of practice.

After installing one wire lock, place the wrist pin against the lock and, using a brass drift, hit the lock to insure full seating. Lube the wrist pin and assemble the connecting rod to the piston. Install the second wrist pin wire lock. JE recommends hitting both sides of the pin with a brass drift to insure proper wire lock seating. Perform these lock-seating steps on a soft pad to avoid piston damage.

Note: Each piston must be installed onto its respective connecting rod in the proper orientation. If the piston features valve relief pockets, the pockets must be oriented at the top section, closest to the lifter bores, as installed in the engine block.

The connecting rods will feature a slight chamfer on one side of the big end bore. This chamfer provides clearance at the crankshaft journal fillets. Using a marker (Sharpie, etc.), label each rod and piston for their assigned cylinder bore location. Just remember that the rod's big end bore's chamfer must face its crank journal fillet (each end of each rod journal will feature a slight radiused fillet), and the piston's valve pockets must be oriented at the top as the piston sits in its bore (the deepest part of the valve pockets will be closest to the top of the block). Unless you're experienced at engine assembly, take the time to figure this out for each cylinder location and use a marker to note cylinder number, and to help further, mark an arrow on the piston dome to indicate which side of the piston faces toward the front of the block. These reference marks will help you to avoid orientation mistakes during assembly.

***Installing Piston Rings*—**Once the rods are assembled to the pistons, install the oil ring support rail (if your pistons require these support rails), making sure to place the rail's small male dimple facing down, and positioned over the pin bore void.

The oil ring package is then installed (expander ring, followed by the lower oil ring rail followed by the upper oil ring rail), followed by the second and top rings. Pay attention to the expander ring, making sure that the ends remain butted and do not overlap.

Ring makers provide a reference mark to indicate which side of the ring must face upwards. Usually, top and second rings feature a small dimple dot. If you see a dot, the dot must face upwards when installed. If no dot is provided, the ring is probably not orientation specific. ALWAYS read the instructions supplied with your rings, since some rings may not feature a dot, but may feature a slight bevel at one edge that dictates up/down orientation.

The JE second rings I used in this sample build feature laser-etchings on the top of the ring and the top rings feature a small dimple at the top. Just remember that the inside bevel on the second ring must face down, and the top ring's bevel must face up.

JE's recommendation for gap location is as follows: when viewing the bore from overhead, with the front of the bore at 12 o'clock, the bottom oil ring package rail gap is at 11 o'clock. The top oil ring rail gap is at 7 o'clock. The second ring gap is at 9 o'clock facing engine left, and the top ring gap is at 3 o'clock facing engine right.

Once the rods have been assembled to the pistons and the piston rings packages have been installed, next install the new rod bearings. Carefully wipe each rod big-end saddle and cap with a lint-free rag, and make sure that each saddle is clean and dry (do not apply any lube to the saddles or to the back of the bearings). Install the rod bearings, aligning the bearing tangs to the tang notches in the cap and rod saddle. The bearing shells should be fully seated, with the bearing edges flush with the mating decks of the rod and cap.

Once the bearings have been installed, apply engine oil or assembly lube to the exposed bearing faces. Again, I prefer Royal Purple Max Tuff assembly lube. This stuff sticks to the bearings without dripping off later (a nice feature of the engine won't be fired for a while), and it's super slippery and provides outstanding bearing protection during initial engine firing.

Install Piston/Rod Assembly

Regardless of how clean you think the cylinder bores are, clean them again to remove all particles, dust and oils. Use a white lint-free rag and wipe each bore until you can wipe with a white rag without seeing any dark marks on the rag. Once each bore is CLEAN, lubricate each bore with clean engine oil (30W non-detergent engine oil is a fine choice). Don't use a synthetic oil on the cylinder bores, since a super-slick synthetic oil can impede piston ring seating during initial engine operation. Even though I love Max Tuff, it's a super-slick synthetic, so it's a no-no for cylinder walls.

If you plan to use cylinder head studs instead of head bolts, do not install the studs at this time, since they'll be in the way during piston installation. So if you've jumped the gun by installing your head studs, yank them out now and set them aside.

With the rod bearing saddles and rod cap saddles clean and dry (and the rod bearings clean and dry), install the upper rod bearings into the rod saddles and the lower rod bearings into the rod caps. Pay attention to rod bearing locations. The rod bearings are marked for "upper" and "lower" locations and must not be installed improperly. The upper rod bearings are to be installed to the connecting rod saddles, and the lower bearings are installed to the rod caps. The upper and lower marks are stamped on the backside of each bearing shell.

Next, you need to lubricate the piston skirts and the entire piston ring package. As with the cylinder walls, 30W non-detergent engine oil is a good choice. You can either prepare a clean can or tub filled with oil and dunk the piston, or you can apply the oil to the skirts and rings using a clean oil can. Basically, you want to drown the skirts and ring package with oil (oil the wrist pins while you're at it as well). This is a messy job, but it's the nature of the beast. Keep plenty of clean towels handy to wipe off your hands when you're done.

Double-check all ring end gaps to make sure that they're in the proper positions. The critical thing to remember is to avoid allowing any of the ring gaps to align with each other.

In order to install the piston/rod assemblies, orient the engine block on your engine stand so that the right deck is straight up at 12-o'clock, or slightly angled toward you. You can begin with any cylinder you choose, but in order to stay organized, it's best to start with number one cylinder (first cylinder on the block's left/driver side). Rotate the crank to place number one/two rod journal at or about BDC (bottom dead center). Bringing the rod journal down this far gives you easier access with regard to rod cap placement and rod bolt access).

Note: Cylinder numbering is the same as on older generation Chevy engines. Left side: (driver side, from front to rear): 1–3–5–7. Right side: (passenger side, from front to rear): 2–4–6–8.

In order to install the rods and pistons, you'll need to compress the piston ring package in order to squeeze the package into the bores. I know this is obvious, but for the benefit of those who haven't assembled an engine before, I need to discuss this. You'll need a special piston ring compressor in order to squeeze the ring package into a small enough diameter to enter the bore.

Instead of using an old-school barrel-type ring compressor, I used Summit Racing's tapered aluminum ring compressor. Machined from billet aluminum stock, this type of ring compressor features a slightly tapered inside wall (bigger at the top entry and smaller at the block deck side, for easy ring compression). This type of ring compressor is commonly offered in one-piece design, with a specific part number for each specific cylinder bore diameter.

The Summit tool features a split in the barrel wall and a captive worm drive clamp, which makes it adjustable from 4.000" to 4.090" (other range sizes are available as well, but for the sample LS2 build that I show here that features a 4.005" bore, this size works out great). I simply adjusted it to 4.005" to match our bores. I slid the rod and piston through the compressor (inserting the piston from the bottom of the compressor). With a bit of skirt exposed below the compressor, I inserted the assembly into the bore, using the skirts to square the piston in the bore. Using a closed fist, a smooth push against the piston dome slid the assembly into the bore easily and smoothly, with no hang-up interruptions. This is a nice ring compressor design, and since it's adjustable, it's more versatile than a dedicated one-size billet piece, and a bunch easier to use than a barrel (rolled steel band) adjustable type compressor.

When inserting the piston through the ring compressor, make sure that the bottom of the compressor remains flat and flush with the block deck. If you feel a dead stop, that means that a ring has expanded out between the bottom of the compressor and the block deck, so stop. Pull the piston back up, re-fit the piston to the compressor and try again. When the compressor is adjusted properly, you should be able to either push the piston into the bore with your fist, or with a gentle tapping on the piston dome with a clean plastic or rubber hammer handle butt. If it argues with you, don't force it. Reexamine and try again. If you trap a ring onto the block deck and try to force it, you can easily bend or break a ring.

While inserting the piston and rod package, keep an eye on the orientation of the rod big end to make sure that it's in line with the rod journal. Avoid cocking the assembly, as the rod big end can snag onto a crank counterweight.

Once the top ring enters the cylinder bore, the compressor can be removed.

With one hand on the rod big end to guide it, push or tap the piston down until the rod big end bearing makes light contact with the rod journal. Keep an eye on the rod big end as it approaches the rod journal to avoid the rod big end saddle edges from nicking the crank's rod journal!

Install Rod Caps & Bolts**—**Once the rod's upper rod bearing contacts the journal, install the rod cap by hand and begin to install the rod bolts (coat the rod bolt threads and underside of the rod bolt head with oil or assembly lube first). Lightly snug the rod bolts until the rod cap is squarely seated to the rod (tighten to about 5–10 ft-lb).

At this point, don't rotate the crankshaft a bunch until both rods are installed onto the same journal. Next, install the same rod journal's companion piston/rod assembly. At this point, each rod's bolts can be fully tightened.

Rod bolt tightening can be handled either with the application of monitored torque (using a torque wrench), or by the stretch method. The stretch method ignores torque value and instead relies on the stretch of the rod bolt (during tightening and while beginning to create the needed clamping load, the bolt will slightly stretch…this occurs with any high-clamping load fastener. The only difference is the manner in which you monitor this clamping load). The stretch method is theoretically more accurate because it eliminates the variable of friction (at threads and at the bolt head contact), and instead allows you to achieve the predetermined amount of bolt stretch specified by the bolt maker. Tightening rod bolts with the stretch method is more time-consuming, but for many professional builders, this is the preferred method. Refer to the chapter on torque values for more detailed information on both fastener torque and the stretch method.

The Lunati 7/16" rod bolts that I used in the Project LS2 build (made by ARP for Lunati) call for a stretch of 0.0050"–0.0054", or a torque value (with oil) at 80–85 ft-lb. I opted for the stretch method, using the Gearhead Tools billet-bodied stretch gauge. After initially tightening the rod bolts to a mere 10 ft-lb (enough to locate the rod cap but not enough to begin stretching the bolts), I placed the stretch gauge onto a bolt (using the gauge's pointed anvils to nestle into the dimples at each end of the bolt. I then zeroed the gauge. I then began to tighten, using a torque wrench, up to 70 ft-lb, at which point I measured about a 0.003"–0.0035" stretch (each bolt varied, but that's an average). I continued to tighten bit by bit, rechecking as I went, until I reached a bolt stretch within the 0.005" to 0.0054" specified stretch. It's time-consuming, but what I like is the fact that you're actually measuring (and recording) exactly how far each bolt stretches, instead of only using torque (in which case some bolts might stretch by as little as 0.004", or in an even worse case, the bolt might stretch beyond the spec). Tightening by monitoring stretch is definitely a more accurate method of both achieving proper clamping load, and knowing how far the bolt has stretched, instead of guessing.

Note: If you plan to tighten your rod bolts with a torque wrench only, pay attention to published torque values listed by the rod bolt maker, since torque values may differ depending on the type of thread lubricant (oil or moly). This is important, since if you apply moly but follow a spec for oil, you may overtighten the rod bolts! If you're tightening by using the stretch method, either lube is OK, because you're not factoring in frictional losses. I prefer to use moly because it reduces friction and provides a more consistent tightening, regardless of the tightening method.

Check Rod Sideplay—Once each crank rod journal's pair of rods are fully installed, check rod sideplay (also called rod side clearance. This is the amount of freeplay that the rod big end can move fore/aft on the journal). Using your fingers, push a rod big end as far as it will go, away from the other rod or away from the fillet area and measure this gap with a feeler gauge. GM's OE rod sideplay spec calls for 0.00433–0.0200" (pretty healthy range). In Project LS2, I noted 0.011" sideplay at each rod location. Basically, it's important to have some side clearance to avoid rod to rod friction during operation. In my Project LS2 build, this consistency is yet another illustration of the precision with which Lunati and other select crankshaft and connecting rod makers produce their premium products. I noted no deviation at all from pin to pin. If you experience a too-tight rod side clearance issue (less than 0.00433"), the easiest fix will involve removal of that journal's rods and pistons, disassembly of those rods and pistons, a surface grinding those rod big ends by the required amount in order to achieve the desired side clearance.

Once you have fully installed one rod journal's pair of rods/pistons, you may then rotate the crankshaft to check for smooth rotation. I suggest checking crank rotation after each pair of journal rods are installed. If there's a problem, you'll be alerted at that point instead of discovering a problem after all eight cylinder assemblies have been installed.

Install Head Deck Dowels

If you haven't done this already, go ahead and install the cylinder head dowels into the block decks. Two dowels per deck (one front and one rear) are needed to register the cylinder head. Don't rely on only the head bolts (or studs) to accurately register the heads. You must install dowels. Each block deck features two bolt holes with counterbores. These counterbored locations accept the dowels. Don't get cheap at this point. Use new dowels instead of trying to save the old ones that were probably deformed during removal.

Install Lifters Before Head Gaskets

Be aware that the roller lifters and lifter buckets MUST be installed before installing the head gaskets, since sections of the gaskets are located above the lifter buckets.

Lifter installation will be the same regardless of your choice of OE or aftermarket lifters.

In Project LS2, I used Crane's hydraulic roller lifters, P/N 144536-16. These roller lifters are specially designed for use in Gen III engines. They incorporate a specially designed body with relocated oil passages that allow the lifter to retain full oil delivery even with extreme lift cams. According to Crane, this model lifter will handle lobe lifts up to 0.412" (0.700" valve lift with 1.7 ratio rockers), even on reduced base circle cams.

I first soaked the lifters in 30W engine oil for about 20 minutes. The lifters were then installed to the plastic lifter buckets. Simply orient the flats of each lifter body to the flats of the plastic bucket, and snap the lifter into the bucket. With four lifters attached to the plastic bucket, you can then ease the four-lifter bucket assembly into place, easing the lifters as a group into their respective bores. The lifter bucket is then secured to the block with a single 6mm bolt, which I tightened to 125 in-lb (I first placed a drop of medium-strength Valco thread locker onto the bolt threads). Once the lifter bucket is secured, you can then use a pushrod to gently push each lifter down for cam lobe contact. The lifters remain engaged in the buckets for proper lifter orientation (preventing lifter rotation). Remember: a flat-tappet setup requires that the lifters be allowed to freely rotate within the lifter bores, whereas a roller lifter's body cannot be allowed to rotate, since the roller tip must remain in a fixed plane relative to the cam lobe. That's why all roller lifter–equipped engines will feature some sort of method to prevent lifter rotation. In the LS family, the plastic buckets register the roller lifters to prevent rotation.

In our particular application, Crane's roller lifters are a tad longer (to allow for higher lift cams) and require the use of a 6mm spacer washer between the lifter bucket and the block. The spacers were provided with the lifters. To prevent the spacers from sliding down while trying to align the lifter bucket bolt hole, I dabbed a bit of Max Tuff lube onto the back of the washers, which prevented them from sliding out of place.

The clever aspect of the buckets is that this design allows you to perform a future cam change without the need to yank the intake manifold or the lifters. Simply loosen the rockers, remove the pushrods, and turn the camshaft one full revolution. This will nudge the lifters back into the buckets to the point where they'll stay "stuck" in the bucket bores and away from the cam lobes. The cam can then be changed without the need to remove the lifters & buckets.

Cylinder Head Installation

After installing the cylinder deck dowel sleeves (two per deck…just make sure that the dowel holes in the block deck are clean, and tap the new dowels into the recessed dowel holes with a clean plastic mallet until the dowel bottoms out), I finger-installed the ARP cylinder head studs (kit P/N 234-4317). The set includes ten primary studs and five 8mm upper studs per side. All head bolt holes are blind and not open to water, so there's no need for a thread sealant. I applied a light coat of ARP moly to the lower threads, just for the heck of it (to permit easy future servicing).

Note: While the bottom (block-end) of the ARP head studs are 11mm to accommodate the 11mm threaded holes, ARP designed their LS head studs with 7/16" upper threads instead of 11mm. This is a nice touch—if you lose a nut, it'll be easy and quicker to locate another 7/16" nut (since this is a common size, any engine shop will probably already have a few ARP 7/16" nuts lying around the shop from old jobs). This makes life easier than trying to find an 11mm nut at midnight while you're scrambling to get an engine back together.

LS1 engines originally used composite style head gaskets, while the LS2 was fitted with MLS cylinder heads gaskets at the factory. When buying head gaskets, make sure that they're MLS (multi-layer steel).

During my assembly, the Victor MLS cylinder head gaskets P/N 12589227 were positioned on the decks. Both head gaskets are marked "FRONT" at one end (actually, they're marked for front orientation on both sides, which is helpful). If the gaskets you choose are not marked, it's easy to flip them end-for-end and to create a cooling system problem. If your gaskets are not marked, just remember that the large cooling passages on each gasket must be placed at the rear of the decks.

Torquing Heads—With studs and gaskets in place, the heads were lowered onto the decks. Since we're dealing with aluminum heads, hardened washers must be placed under the nuts. Installing the primary head inboard washers is made easier with the use of a pencil magnet (these locations are recessed, with no room for your fingers). I coated all nut threads and undersides with ARP moly. All ten primary stud nuts were then tightened, in sequence, in three steps to a final torque value of 80 ft-lb (I started at 25 ft-lb, then stepped up to 55 ft-lb, then to 80 ft-lb). Once all primary stud nuts were tightened, I then tightened the upper five 8mm stud nuts to 22 ft-lb. These values are specified by ARP with the use of their moly lube. If using 30W oil instead of moly, values are slightly higher (85 ft-lb for the 7/16" nuts and 28 ft-lb for the 8mm nuts).

Install Front Coolant Crossover Pipe

This one-piece tube assembly connects the left and right side upper coolant vent ports of the heads (located at the top front of the heads). This tube assembly serves to equalize coolant pressure between the heads, and provides a handy bleed-off feature (the passages in the cylinder heads are commonly referred to as "steam holes"). This assembly attaches to the front of the heads with a pair of 6mm x 1.0 x 30mm bolts. Sealing is accomplished either with oval gaskets (supplied in our Victor engine gasket set) or with built-in O-rings. Our crossover pipe's blocks already featured O-rings, so we didn't need to use the individual gaskets. The T-pipe of the crossover tube can connect to the upper coolant hose to allow a coolant air bleed. The same coolant vent ports located at the rear of each head are simply blocked off using GM block-off caps. Actually, you can just block off all four (two front and two rear) steam holes using GM block-off plugs, especially if you're going to run a carb setup.

Install Front Timing Cover

The front (timing) cover is a cast aluminum piece that features a front hub seal and a cam position sensor. The gasket is a metal-reinforced unit that requires no additional sealant.

Since the front cover is viewable, and since I can't abide boring-looking stuff, I applied a thin coat of etching primer, followed by a coat of aluminum cast

Cylinder Head Tightening Sequence

Cylinder head fastener tightening sequence of the ARP 7/16" nuts is as follows:

1. center upper
2. center bottom
3. second from front upper
4. second from rear bottom
5. second from rear upper
6. second from front bottom
7. front bottom
8. rear bottom
9. rear upper
10. front upper

Once all 7/16" nuts have been fully tightened, the top row of five 8mm stud nuts are tightened as follows:

1. center
2. second from rear
3. second from front
4. rear
5. front

blast engine paint, just to dress it up a bit and to prevent the bare aluminum from scuzzing-up down the road. The front cover is secured with eight 8mm x 1.25 x 30mm bolts (and two 6mm x 1.0 x 20mm bolts to secure the cam position sensor to the cover). I pitched the OE hex head bolts in favor of a set of tasty-looking ARP stainless 12-point fasteners (with stainless flat washers), P/N 434-1502. All 8mm front cover bolts are to be snugged to 18 ft-lb in a crisscross pattern.

Install Crank Damper

Our ATI damper hub features an interference fit. Using a small convection oven, I heated the hub to 200 degrees F (I monitored temperature of the hub with an infrared pyrometer). With a light coat of anti-seize on the hub I.D., I was able to slip the hub onto the crank snout (aligning the key pin I installed on the snout earlier).

Using ARP's damper bolt, and with ARP moly applied to the bolt threads and both sides of the washer, I tightened the bolt to a value of 235 ft-lb (I did this in three equal steps). Note that the OE instructions advise tightening the OE bolt to 110 ft-lb, then back off one turn, then retighten to 35 ft-lb, plus an additional 110 degrees. I spoke with ARP, and they advised me to simply use the 235 ft-lb value (with their moly lube), when installing their damper bolt.

The ATI Super Damper (featuring an integral crank pulley) was then installed onto the hub using six flat-top 5/16" x 18 x 1" screws, each treated to a dab of thread-locking compound. Using a T40 torx bit, these six screws were snugged to 16 ft-lb.

Note: If you expect to run an A/C compressor on the engine, you must first slip the ATI A/C pulley onto the hub before pressing the hub onto the crank. Once the damper is installed, the A/C pulley is then secured (behind the crank pulley) with three 3/8" bolts and washers.

Cylinder Block Rear

As mentioned earlier, before installing the rear cover (which seals the rear cam area and features a one piece rear crank seal), an oil control plunger must be installed in the lower left of the block rear face. This plunger features a white plastic dumbbell shape with an O-ring at one end. Lube both ends of the plunger and insert into its oil passage hole, with the O-ring end facing the rear of the block. Insert until the face of the O-ring end is flush with the block surface.

Rear Main Seal—The one-piece rear main seal features two sealing lips (one facing forward and one rearward). The rear main seal is first installed onto the rear cover. The cover and seal will install to the crank and block as a single unit.

When installed onto the crank, the rear lip must face outward and the front lip must face inboard, towards the engine front. In order to position the front lip forward, insert a nylon seal installation ring into the seal opening (installing the ring from the rear cover's face, towards the inside of the cover, which will push the front lip forward).

Note: Install the rear main seal dry…do not apply lubricant to the seal lips. It may seem natural to oil the seal, but in the case of the LS rear seal, it's designed to install dry. If you lube the seal, you will probably create a leak.

Carefully position the rear cover, with installer ring in place, onto the crank flange and gently push the cover into place. The trick is to keep the cover, seal and ring square to the crank flange. Once the seal slides over the crank flange, the white nylon installer ring will fall out. This may take a few tries, since the installer ring has a habit of popping off before the seal is started on the crank flange. Before fully seating the rear cover, inspect (using a small penlight) to make sure that the front seal lip is angled forward around the circumference of the crank flange.

If the rear seal is installed with both seal lips angled rearward, you'll have a nasty rear seal oil leak.

The cast aluminum rear cover features a metal-

Installing a Key Pin in the Crank Snout

The LS design normally uses an interference-fit damper with no keyway register (just a tight press fit). If you want to insure that the damper won't slip and rotate during engine operation, ATI's LS1 Crank Pin Drill Fixture P/N 918993 allows you to install a 0.187"diameter dowel pin that will engage into the ATI Super Damper's female keyway.

Slip the fixture onto the crank snout. Measure the exposed snout length from the snout tip to the face of the oil pump gear so that you can readily reference the maximum depth location for the fixture. Then removed the oil pump and mark a line on the snout at that point.

Using a small square, draw two lines parallel with the crank key and extend those lines to the front edge of the snout (plan to drill the hole in-line with the keyway). Remember that the oil pump gear features a single I.D. keyway. If you position your new pin too close to the block, the pin must perfectly align with the key, otherwise you won't be able to service the oil pump in the future without knocking the pin out. There's not a lot of available real estate on the LS crank snout once the pump is in place, so unless you've precisely aligned the pin with the existing key, more than likely you'll need to remove/reinstall this pin whenever oil pump service is called for.

With the drilling fixture slipped onto the snout, rotate the fixture until the fixture's drill hole is in line and centered between the keyway lines.

Install a spare damper bolt to secure the fixture in place (to prevent rotation). By the way, the reason to use an old or spare damper bolt is to prevent accidentally drilling into the bolt shank of the damper bolt that you plan to use for final installation. Granted, you won't easily drill into this bolt, but there's no sense in nicking this high-torque bolt when you can avoid it.

Then install the 11/64" drill pilot and secure it from rotating with the kit's lock-down screw. Using the 0.1690" drill bit supplied in the kit, drill a hole all the way through the snout wall, into the snout's center bore.

Next, the hole must be reamed to 3/16", using the kit's reamer on a low-speed drill (one in/out pass only).

After cleaning the surfaces (and the crank snout bore), install the oil pump if not already in place. Next, a 0.187" diameter dowel pin (supplied with the kit) is inserted into the hole and carefully tapped into place until 0.093" remains exposed on the snout outer surface. Once the timing cover is installed, the damper adapter hub can be press-fit onto the crank snout while aligning the hub's keyway with the newly installed locating pin. Installing this pin is really not necessary…it's an option for a naturally aspirated engine, but highly recommended for a supercharged, turbo and/or nitrous setup. I installed a pin in my crank both because I thought it was a good idea, and to illustrate this for the benefit of the readers.

Note: Drilling the Lunati snout took awhile (it's tough stuff). If you plan to use a cordless drill, be sure to have a few spare batteries charged up.

reinforced gasket. I installed a Victor rear cover gasket, included in their gasket set P/N CS5975. The rear cover is secured with twelve 8mm x 1.25 x 20mm bolts. Instead of using the OE hex-head bolts, I installed ARP's rear cover bolt set P/N 434-1504, which include 12-point stainless steel bolts (hey, they're ARP, and they look cool, so why not?). The cover is positioned and the bolts are tightened to 18 ft-lb in a crisscross pattern. Finger-install the bolts and made sure that the rear seal is properly centered on the crank (and use a straightedge across the bottom of the cover and the block's oil pan rail on each side before gradually snugging the bolts, first to 60 in-lb, then to 10 ft-lb, followed by final clamping at 18 ft-lb.

Windage Tray, Oil Pickup and Oil Pan

Windage Tray—The Moroso windage tray that I used (along with the Moroso aluminum oil pan) secures to the main cap studs, requiring six 10mm x 1.25 nuts and loc washers. Since the windage tray mounting holes and relief holes were likely designed to accept the OE 8mm studs, I drilled the windage tray's mounting tab holes out to 0.410" for the larger diameter ARP studs. I also opened up the relief holes in the tray itself to allow sufficient room for socket wrench access to these nuts.

Once the windage tray is installed, the oil pump pickup may be installed (again, because of the ARP stud diameter, I drilled out the pickup tube's mounting bracket hole to 0.410" in order to secure the bracket to one of the ARP studs). No big deal.

Obviously, if drilling is to be done, do this well away from the engine, and make sure that the drilled items are thoroughly cleaned of all debris.

Oil Pickup—The oil pickup connects at two points: the attachment to the oil pump and the pickup tube bracket towards the rear of the engine. When installing the pickup, be sure to first install the appropriate O-ring onto the pickup tube exit, where the tube engages into the pump. The mounting tab that secures the pickup tube to the oil pump requires a 6mm x 1.0 x 20mm bolt. For extra security, I applied a drop of Loctite 242 thread locker to the bolt threads.

Oil Pan—The Moroso oil pan installs to the block using eleven 8mm x 1.25 x 20mm bolts and three 6mm x 1.0 x 20mm bolts at the rear engine cover area. You can probably get away with using bolts as long as 30mm as well (a cast aluminum OE pan requires longer bolts, length of which varies depending on he specific OE pan). However, the Moroso pan features a pair of 90-degree –10 AN tubes on the left side (to plumb to a remote oil filter). Between the lower tube and the pan rail, there isn't enough clearance to insert a bolt, so in this single location, you'll need an 8mm x 1.25 stud and nut. The stud should protrude no more than 0.750" from the block's rail surface. Be sure to install the stud to the block's rail before positioning the pan.

Rockers

Instead of using the OE rockers, I opted for a far superior full-roller rocker set from Harland Sharp, their P/N SLS17. These are high-strength forged aluminum rockers with needle-bearing trunions and roller tips. Each rocker pair is bridged together by a common pivot shaft. Each rocker is mounted to the rocker pedestal area on the cylinder head with an 8mm x 1.25 socket head cap screw (supplied in the kit), with a flat-head spacer that determines the installed rocker height.

Be aware that on LS cylinder heads, it's very common for the threaded bolt holes in the cylinder head's intake rocker mount locations to be tapped through and open to oil. If this is the case, apply a small dab of thread sealant to the intake rocker's mounting bolt threads. In Project LS2, I used a dab of Hylomar sealant paste to each intake rocker bolt.

With pushrods in place and oiled, I installed the Harland Sharp rockers while each pair of lifters were on base circles (essentially unloaded and zero lash), and tightened the mounting bolts to a value of 22 ft-lb.

The Harland Sharp rockers we chose are 1.7:1 full-rollers, designed to directly replace the OE rockers. In addition to the rockers we used, Harland Sharp also offers adjustable 1.7:1 rockers for race applications (requiring shorter pushrods), as well as 1.8:1 versions.

Pushrods

The OE LS2 pushrod length is 7.400". Since I never blindly follow an OE spec and assume pushrod length, I determined pushrod length using an adjustable pushrod checker. Also, Trick Flow notes that their heads are 0.100" taller than stock, so checking was worth the time.

Once the cylinder heads have been installed (with gaskets), choose one cylinder location as your reference. Rotate the camshaft to place the intake lobe at its base circle (the lowest section of the lobe, opposite its peak). Using a checking pushrod (an adjustable mock pushrod), install the checking pushrod and its rocker arm. Adjust the pushrod until the rocker achieves zero valve lash. Carefully remove the pushrod and measure its overall length. Perform the same task at the exhaust lobe. Take these measurements a couple of times to make sure that your measurements are correct. The LS pushrods feature ball ends at each end, so they're easy to measure using a long caliper. Custom length pushrods (if needed) are readily available, either in-stock from a speed parts retailer or ordered direct from the pushrod manufacturer.

After careful measuring on both intake and exhaust locations, the Harland Sharp roller rockers showed a nicely centered contact patch on the valve stem tips at a pushrod length of 7.500". I then selected a set of 5/16" one-piece forged pushrods, Trick Flow P/N TFS-2140750.

Water Pump

Since I wanted to illustrate what performance aftermarket parts are readily available for LS engines, I chose Edelbrock's aluminum LS water pump, P/N 8896. This pump mounts to the block with six 8mm x 1.25 x 80mm bolts, just like the OE pump. ARP's water pump bolt kit P/N 434-3202 includes these bolts in polished stainless, with 12-point heads (requires the use of a 12-point 10mm socket wrench), and a pair of 6mm x 1.0 x 20mm thermostat housing bolts. If you test-fit the pump to the block without gaskets, you'll find that the pump's upper left rear body hits the upper left timing cover bolt head. Not to worry…with pump gaskets in place, clearance will be fine. Either the ARP bolt and washer, or an OE bolt (with built-in washer flange) will clear. If you're planning to use a different bolt, simply be aware that the total height of the bolt head and washer can't be greater than 0.363" before it'll hit the pump. If you need more clearance, you can easily use a spot-face drill to create a shallow relief on the rear of the pump body.

In order to seal the pump to the block, I chose Victor Reinz's stainless steel seal-printed gaskets (the Victor set thoughtfully offers both cut gaskets and the metal gaskets, providing a choice). I tightened all six water pump mounting bolts to a value of 18 ft-lb.

The Edelbrock water pump pulley P/N 8898 was then installed onto the pump using four 5/16" x 24 x 5/8" flat-top hex-drive screws (provided with the pulley). Use a 3/16" hex wrench.

Note: If you plan to run a carburetor and a distributor on an LS, be prepared to spend some hefty dough. While it's easy to run a carb, it's a more involved and much more expensive deal to run a distributor. In order to run a distributor, you need the GM distributor adapter P/N 88958679 ($419 at Scoggin Dickey, a special water pump to clear the distributor housing, and a host of special pulleys for the entire front of the engine). The only water pump source that I'm aware of for a carb/distributor setup is Wegner Automotive at 920-394-3557 (actually developed by both Wegner and EMP Stewart, and made by Stewart). Gary at Wegner told me that this special billet pump tags at about $350, plus you'll need a complete pulley setup based on your specific needs. The carb/distributor deal was initiated as a result of NASCAR Camping World Series late-model rules in which teams run LS2 engines, but were forced to run carbs and distributors. So, a water pump and pulleys are available, but it'll cost ya.

Note: I feel the need to compliment MAHLE for their Victor gasket set. The set that I used was incredibly complete, including all of the gaskets that you'd expect, and more. The rear seal included a nylon installer tool already fitted to the seal, fuel injector O-rings were included, unique LS style valve cover rubber grommets, oil pan gasket, front and rear engine cover gaskets, top valley cover gasket, exhaust gaskets, water pump gaskets, oil pump O-ring, valve stem seals, formed silicone valve cover seals, etc. The gasket kit was very well thought-out, and was definitely LS-specific, and not just some generic catchall set.

Knock Sensor

The knock sensor (required if you're running computer management) screws into the left side of the block and is secured with a mounting tab. Instead of obtaining this from GM, I saved a couple of bucks and bought a Standard brand, part number KS211, from a local auto parts store.

Crank Position Sensor

The crank position sensor (GM P/N 12560228) installs into the block's right side, in line with the reluctor wheel. Lube the sensor's O-ring lightly with oil and insert until seated. The sensor's bracket tab is then secured with an 8mm x 1.25 x 10–15mm bolt (this is a blind hole, and the bolt will bottom out at a depth of about 19mm).

Coolant and Oil Senders

The oil pressure sender screws into the tall bung stand at the valley cover's left rear. The coolant temperature sender screws into the left cylinder head, towards the front, just ahead of the No. 1 exhaust port. Remember to plug the water port on the right head (rearward of the No. 8 exhaust port). This requires a straight-thread 12mm x 1.5 plug. Unfortunately, this plug is not available individually from GM. Apparently you need to buy a complete head in order to get this piddly little plug. My solution was to use a 12mm x 1.5 x 15mm bolt, with the addition of Teflon sealant on the threads and a crush washer under the bolt head.

By the way, even though this is supposed to be an all-metric engine, the coolant temperature sender hex requires the use of an 11/16" wrench (it's in between 18 and 19mm).

Rocker Covers and Coil Brackets

Instead of using a pair of boring OE rocker covers, I opted for a pair of Moroso welded aluminum cuties. These beautiful TIG-welded covers accept the OE type formed gasket seal (each cover features a CNC'd groove on the mating surface). Each cover is secured to the head using OE type mounting bolts and sealing grommets. One of the covers features a handy threaded oil fill cap with a knurled lid and sealing O-ring, so you can place the fill port at either the right front or left rear. I placed mine at the right front, adjacent to the dipstick.

The Moroso aluminum covers are available with or without coil pack mounting bungs. I chose the version with bungs, to allow coil pack mounting in the OE position (if you want to remotely mount the coil packs you can select the cover version without the bungs).

In OE trim, the coil packs (which mount to brackets that attach to the covers) are always in the way with regard to valve cover service. Moroso designed a very cool hinged coil pack bracket that allows you to swing the entire bank of coils out of the way, allowing easy access to the valve cover bolts. Due to the sliding-pin hinge design, with the upper coil bracket hinged open, you can also easily slide the coil bracket rearward about a half-inch and remove the entire coil assembly (with wires disconnected, naturally).

The valve covers I chose are listed as P/N 68355 and the hinged coil brackets are P/N 72396. The brackets are CNC-machined from billet aluminum and are treated to satin black anodizing (very attractive and pro-looking). All mounting hardware is stainless steel and is thoughtfully included to assemble and install these brackets (the kit even includes socket head cap screws to mount the coils to the upper brackets), so you won't need to hunt down any additional fasteners.

By the way, the hardware kit includes both 1/4x20 and 6mm x 1.0 stainless button-head bolts. Don't get these mixed up. If you rush without paying attention (or not reading the instructions), you can cross-thread.

The four 1/4x20 button heads thread into the lower coil brackets (two per lower bracket, installed from the bracket underside, so that the threads point upwards to serve as studs). Once these 1/4x20 "studs" are installed, a 0.425"-tall black anodized aluminum spacer drops over each stud to provide parallel spacing between the lower and upper brackets. When the upper bracket is laid in position, these studs will pass through attaching holes in the upper brackets (the upper bracket is then secured with washers and nyloc nuts). The eight 6mmx1.0 button heads are used to attach the lower coil brackets to the valve covers (four per side). Each cover's four bracket attachment threads are 6mm x 1.0 in order to accommodate the use of OE valve covers, so this bracket kit works with either OE or Moroso covers.

Install the female hinges and the 1/4x20 button heads to the lower bracket, and install the lower bracket to the valve cover with four 6mmx1.0 button heads. Then install the male-pin hinges to the upper bracket. Once the coil packs are installed to the upper bracket, slip the hinges together, drop the top bracket over the lower bracket, and secure with the nyloc nuts. It's easy, clean and hassle-free.

This is a very well-thought-out design and beats the heck out of the OE set-up, and since all of the fasteners are stainless, you won't feel the urge to replace cheesy hardware store junk with the good stuff, 'cause it's already included. It's obvious that these brackets were designed by seasoned race-prep folks who knew what they were doing. I definitely recommend buying these brackets, whether you use OE valve covers or aftermarket covers.

Note: If you opt to set up your LS engine with a carb and distributor and no computer control, you won't need the eight individual coil packs. The coil packs are necessary with either an injected setup or with a carb setup that uses a timing control module.

Coil Pack Connections

In order for the MSD timing controller to fire the coils, you'll need two GM AC Delco coil harnesses P/N 12582190, which sell for about $75.49 each (one for each bank). Pay attention to the MSD wiring instructions when connecting these coil harness connectors, since it's easy to flip the end-for-end (mixing cylinders 1 and 7, for instance).

Each coil harness connector features four wires. Each connector uses a pink wire (12-volt), brown wire (sensor ground) and black wire (ground). The fourth color indicates connector-to-coil cylinder location.

Cylinder	Wire Color
1	Violet
3	Light Blue
5	Green
7	Red
2	Red
4	Green
6	Light Blue
8	Violet

Top Valley Cover

An aluminum top cover bolts to the block, independent of the intake manifold, secured with eleven 8mm bolts. It is not necessary to disturb this cover when servicing the intake manifold. Some blocks, such as the LS2, feature eight oil towers in the valley used for the active cylinder-on-demand selective firing system. If you're not using this system (and for a performance engine, why would you?), you'll need the valley cover that features sealing O-rings that are built into the underside of the cover.

Air/Fuel Options

You face a few choices with regard to air, fuel and ignition when building an LS. You can stick with the OE fuel injection, you can install an aftermarket performance fuel injection system, or, if you prefer the simplicity and looks of a carburetor setup, it's easy to convert to a carb. If you plan to use a carb instead of fuel injection, you also have a choice of ignition setups, which involves using either the eight individual coilpacks and a timing controller, or going to a front-mount distributor (with built-in HEI coil) and eliminating the eight coilpacks. Here, we'll address all three aftermarket approaches.

Carb Setup

As I mentioned, you can switch over to a carb setup if you prefer, in one of two formats: one option involves the use of a four-barrel intake manifold, a carburetor, a distributor adapter and a distributor. A typical setup includes an Edelbrock Victor Jr. intake manifold P/N 29087 or the Super Victor Jr. intake manifold P/N 28097, a GM distributor adapter P/N 88958679, and Performance Distributors Ford small-block (yes, Ford small-block) distributor P/N 31820 and Performance Distributors plug wires P/N C9076. The GM adapter serves as both a timing cover (taking the place of the original cover) and features a housing that accepts a Ford small-block distributor. A short camshaft stub with distributor gear (part of the adapter set) bolts to the existing camshaft, providing a means to drive the distributor.

Another (and more readily available) option uses the Edelbrock Victor Jr. or Super Victor Jr. intake manifold with the stock-type timing cover, no distributor, eight coilpacks and an MSD timing control module. The module uses signals from cam and crank timing sensors.

Note: Other setups are also available. For example, a Victor Jr. intake manifold drilled to accept fuel injectors. Instead of a conventional carb, a downdraft throttle body is used to regulate intake air.

First, let's address mounting the carbureted intake manifold. We chose an Edelbrock Super Victor Jr., P/N 28097. While you can use an OE plastic type intake manifold gasket set (the gasket body measures 0.200" thick), you'll need longer mounting bolts than are provided with the manifold. The bolts packaged with the manifold are 6mm x 1.0 x 50mm. If you use the plastic body gaskets, you'll need bolts that feature a shank length of 55-60mm.

However, the Edelbrock instructions specifically tell you to use Fel Pro gaskets P/N 1312-3. These gaskets measure 0.063" thick. While the provided bolt length of 50mm is fine, we ran into an interference issue when using the thinner Fel Pro gaskets, between the bottom inboard surface of the intake runners and the engine's top valley cover plate. The runners hit the outer edge of the plate, preventing full mating of the manifold decks to the heads. The solution would be to either grind reliefs on the inboard bottom of the runners or to chamfer the edges of the valley plate. I opted for the latter. With the manifold mocked in place, I marked the cut areas on the valley cover for each of the eight cuts. I would have preferred simply chamfering the entire length of each side of the cover plate, but the chamfers would have then interfered with the manifold bolt washer footprints.

Using a Bridgeport mill, Jeff Lance at Alan-M&S Machine in Wadsworth, Ohio cut eight chamfer reliefs on the top edge of both the right and left sides of the valley plate. The cutting of the angle reliefs removed 0.193" from the horizontal surface and 0.190" from the vertical surface of the plate edges. Each of our mill chamfer cuts are about 2.280" long.

Note: In order to chuck the cover plate on the mill, the plastic PCV housing (mounted to the underside of the plate) had to be removed. In addition to the 5mm bolts that secure this housing, the housing is gasketed to the plate with some tough RTV. If you try to pry it off, you'll break the plastic, so it must be separated with a thin scraper or a razor. Once the plate was machined and repainted, I reinstalled this plastic housing with Permatex "The Right Stuff" black RTV to serve as the sealing bead.

Once this interference issue has been resolved (really no big deal), I torqued the intake manifold bolts to a value of 11 ft-lb (per Edelbrock's instructions), following Edelbrock's bolt tightening sequence.

The Edelbrock Performer four-barrel carb P/N 1412 was snugged to the intake (using ARP stainless steel carb studs and nuts) to 90 in-lb.

Carb Setup Ignition Control (with Coilpacks)— Now for ignition control. In order to utilize a carb (with coilpacks and no distributor) on the LS, the MSD Timing Control P/N 6010 is required. The kit includes the ignition controller, Pro-Data+ software (on a mini CD), wiring harness and individual plug-in timing modules. Optional accessories include MSD's hand held monitor P/N 7550, and a wiring harness for intake manifold mounting (if you opt to mount the box on the intake).

Note: If you have a carburetor setup, you only need the MSD timing controller kit and the coilpacks, an OEM coilpack wiring harness, the crank sensor, cam sensor and optional MAP sensor. You do not need an ECU. If you're using this MSD timing controller with an EFI setup, then you do need to retain an ECU. So, you can use a carbureted LS engine in any vehicle (street rod, race car, etc.), with no need for a central ECU.

MSD's 6010 ignition controller is designed for GM Gen III engines that have been retro-fit with a carburetor and carb manifold. The controller can also be used in stock EFI applications by using harness P/N 8886.

The controller is supplied with a wiring harness that connects to the factory connectors. A shorter harness, mentioned above, is designed for mounting the controller on the intake manifold, under P/N 60101.

The MSD controller offers several programmable features that allow rpm and timing adjustments.

Project LS2 Intake Manifold & Carb

The Edelbrock Super Victor Jr. carbureted intake manifold P/N 28097 features an operating range of 3500–8000 rpm. This is a high-rise single plane intake, capable of supporting over 600 hp. This manifold accepts a square bore carb. The Super Victor offers greater air flow potential than previous LS manifolds. The carb mount pad is 1.12" taller than the Victor Jr. LS1, and the port exits have been increased to1.08" x 2.74". This manifold has already been accepted by NASCAR for use in the Grand National division/Busch North spec engine series. Carb pad height is 60.07".

We followed Edelbrock's recommendation for the carb choice. The Performer Series P/N 1412 (800cfm, manual choke) is recommended for displacements greater than 6.0L and/or vehicles that will experience frequent track time. FYI: their recommendation for a 6.0L street driven application is the Performer Series 1407 (750cfm, manual choke) or 1411 (750cfm, electric choke).

This can be achieved by using the supplied Pro-Data+ software (and connecting a PC-type computer to the controller with the supplied PC harness), or with the optional MSD handheld programmer 7550.

Timing adjustments and selections can also be made by using the supplied plug-in modules.

The controller kit is supplied with six timing curve modules (small two-pin plug-ins) that plug into a port on the side of the controller. The modules are labeled Curve 1, Curve 2, etc. (See chart above). By using one of these modules, the timing curve will be set with a pre-programmed curve that was mapped out by the MSD engineers, tailored for different camshafts, final drive gearing and vehicle weight. So, you can plug in a curve module of your choice, or you can create your own custom program by using their software and a PC.

Note: Any updates that are made using the PC software will be overridden if a plug-in module is left plugged in during power-up of the controller. So, if you plan to create your own program, don't leave a module plugged in.

The controller allows you to program two rev limits: one for an over-rev safety and another that provides a low limit for use as a hole shot or two-step limit. The RevLo is the low rpm limit that is designed to be used while staging at the starting line. It is activated when the blue wire is connected to 12 volts. When 12 volts are not present on this wire, the High Rev Limit is active. It is adjustable in 100 rpm increments from 2,000 to 12,500 rpm.

The RevHi is the over-rev rpm limit. It is active whenever the blue wire (RevLo) is not connected to 12 volts. The RevHi is also adjustable from 2,000 to 12,500 rpm, in 100 rpm increments.

A step retard (Sw retard) will provide an adjustable amount of retard at a specific moment. This is ideal when using nitrous oxide injection. The amount of retard is adjustable from 0 to 15 degrees, in 1 degree increments. The retard is activated when the pink wire is switched to 12 volts. The default retard is 10 degrees.

The programmable instructions (included in the controller instruction booklet) are actually not that complicated. We won't discuss them here due to space constraints, but it's not as bad as you might initially fear. The MSD software walks you through it, and rest assured that you don't need to be a computer whiz to handle this. You can program the controller at your office desk (it connects to your PC via the supplied cable), or you can use a laptop computer while the engine is on the dyno or in the car. You can easily create your own custom timing curve (a really cool advance chart and timing map appears on the computer screen), and you can re-program any time you want. But remember: you don't absolutely have to create your own program. You can just plug in one of the curve modules and go. This is great, since MSD gives you a choice of using one of their six programs, or enabling you the option of custom mapping.

The controller instructions also clearly list the purpose of each harness wire. For example, on the 3-pin crankshaft sensor connection, the orange/yellow wire is for crank sensor signal; the brown wire is for sensor ground; and the pink wire is for the 12-volt supply. This makes troubleshooting easier, and allows you to make up a custom harness if you so desire. Wire identification is provided for the crankshaft sensor, camshaft sensor, optional MAP sensor and coil connectors (for each cylinder).

The MSD controller box may be mounted in any convenient location underhood (firewall, inner fender, etc.), as long as it's placed away from high heat sources; or it can be directly mounted to the right rear side of the intake manifold itself (MSD offers a mounting bracket for this purpose, as well as a short wiring harness). Or, for those of us who prefer to be different, it could be mounted in the vehicle interior.

Carb with Distributor (No Coilpacks)—The next carb type setup involves the same intake manifold and carburetor, but with a twist: get rid of the eight individual coilpacks and mount a distributor at the front of the engine. GM Performance offers a distributor adapter kit, P/N 88958679. This includes a cast aluminum LS front distributor drive cover (this replaces the OE front cover), designed to accept a Ford (yes, Ford) small-block distributor. The kit includes a stubby camshaft front extension that bolts to the existing cam, and

Timing Control Module Curves

Curve 1	Curve 2	Curve 3	Curve 4	Curve 5	Curve 6
RPM/Deg	**RPM/Deg**	**RPM/Deg**	**RPM/Deg**	**RPM/Deg**	**RPM/Deg**
0/0	0/12	0/12	0/15	0/15	0/22
1000/20	1000/22	500/20	1000/28	800/30	800/32
2000/26	1700/27	1700/28	2000/29	2000/32	4500/32
4200/33	4300/29	4300/29	4300/29	4200/34	6700/36
6000/35	6000/36	6000/36	6000/36	6000/36	6800/36
6100/35	6100/36	6100/36	6100/36	6100/36	6900/36

Edelbrock refers to the timing control modules as follows:
Curve 1: Stock or mild camshaft & heavy or low ratio gear
Curve 2: Stock or mild camshaft & medium or standard gear
Curve 3: This is the default curve. For stock or mild camshaft & light or high gear ratio
Curve 4: Z06 or Edelbrock 2215 camshaft (some overlap) & medium or high ratio gear
Curve 5: Z06 or Edelbrock 2215 camshaft (some overlap) & light w/standard ratio or high ratio gear
Curve 6: High overlap cam such as Edelbrock 2216 & light w/high ratio gear
Note: Low ratio = approx. 3.20–3.50:1. Standard = approx. 3.40–3.73:1.
High = approx. 3.90–4.11:1 or higher)

provides a drive gear for the distributor.

Performance Distributors offers a way-cool Ford small-block distributor, already fitted with an HEI coil. Remove the OE front cover, install the GM cam adapter and cover, drop the distributor in, set your timing and go. No computer, no timing module…just a carb and an electronic distributor. Performance Distributors even offers a ready-to-install set of spark plug wires for this setup. By the way, the distributor housing also provides a mounting location for a mechanical fuel pump, to the engine-right of the distributor.

Since the distributor housing is, well, large, it's obvious that the OE design water pump won't fit anymore. Wegner Motorsports, in cooperation with Stewart, makes a unique LS water pump that is designed to work with this setup. The GM distributor housing kit runs approximately $350 to $400+, and the special water pump will run around $400 or so. In outward appearance, is essence, it kinda resembles an OE style pump with longer legs to clear the distributor housing. In addition, because the water pump pulley now sticks out further from the block, you'll also need a special pulley system (also available from Wegner…call 920-394-3557).

The GM adapter kit is listed on page 275 in the 2008 GM Performance Parts catalog.

By the way, I only recently learned that the distributor adapter kit is actually made by Wegner for GM, so apparently you can buy one direct from Wegner. Because of the added cost in executing a carb/distributor conversion, you've really gotta want this setup to justify the expense.

Injection Setup

To serve as but one example of a multi-port direct-injection setup, I chose a Professional Products Power+Plus Typhoon intake manifold kit, P/N 52063, which includes a satin-finish cast aluminum manifold, a pair of red-anodized aluminum fuel rails, a –6 fuel transfer hose assembly (already assembled and ready to connect the two fuel rails at the front), intake gaskets, 6mm x 1.0 x 90mm intake manifold cap screws and washers, extension hose assembly, fuel inlet fitting, 90-degree fittings, a reducer fitting, along with a variety of additional fasteners. Basically, the kit includes everything you'll need to install and plumb this manifold.

By the way, this intake manifold also features blank bosses that can be drilled and tapped to 1/8" NPT in order to accept nitrous injection nozzles.

This intake manifold will accept a 96mm LS2 type throttle body (stock or aftermarket).

When tightening the intake manifold bolts, Professional Products recommends that you make two passes. The first pass involves tightening the bolts to a value of 44 in-lb. The second pass is at 89 in-lb. Once the engine has been run and has reached operating temperature (and has cooled), retorque to 89 in-lb. The torque sequence must be followed during each tightening pass. The supplied 6mm manifold bolts are cap screw style, so you'll need a

5mm hex wrench bit for your torque wrench.

Follow the manifold's instruction sheet for remaining connections for sensors, fuel, vacuum and coolant lines (since this manifold may be installed on either an LS1 or LS2, some differences exist in terms of OE connections. For instance, for an LS1-equipped vehicle, the MAP sensor installs to the front of the manifold. On an LS2-equipped vehicle, the MAP sensor is located on the rear of the manifold). Our manifold features a MAP sensor installation port on the front right side, just behind the throttle body location. The sensor is secured with a single 4mm x 0.5 x 5mm-long screw (supplied in the manifold kit). The MAP sensor location is easily changed if needed. If the vehicle harness requires the sensor at the rear of the manifold, simply drill a 0.440" hole in the blank boss on the manifold's rear wall and drill & tap a 4mm x 0.5 thread pitch screw hole. The front MAP sensor hole can easily be plugged.

Note: When installing the fuel rails, the manifold kit features L-brackets that secure the fuel rails to the manifold. Pay attention to these. The longer bracket leg features a long slot hole. This long-slot leg must be positioned onto the manifold (the short leg installs to the fuel rail). If these brackets are installed incorrectly, you will place an off-angle load at the injectors, which may result in a fuel leak.

Injection Manifold Tightening Sequence

1. Center on left side
2. Center on right side
3. Second from front, left side
4. Second from rear, right side
5. Second from rear, left side
6. Second from front, right side
7. Front, left side
8. Rear, right side
9. Rear, left side
10. Front, right side

Injector Sizes—If you're building an LS2 engine from scratch and you don't have a donor assembly to start with, be aware that fuel injector sizes differ between the LS1 and LS2, in terms of physical dimensions. For example, the injector bores in the intake manifold are 13.9mm in diameter on an LS1 manifold, but 14.7mm on an LS2 manifold. Also, injector body overall length differs. The LS1 takes a long injector (about 77.35mm overall length), and the LS2 takes a short injector (about 65.90mm overall length). You can swap between the two, since various companies offer conversion kits that include O-rings, fuel rail bracket spacers and/or shorter brackets and harness connector adapters.

Stock injectors for an LS1 will work, but will require a Katech adapter kit KAT-A4096, which includes longer fuel rail mounting bolts, bolt spacers and larger LS2 type lower O-rings (this kit sells for about $40 and is available from a number of outlets, including Katech or Scoggin Dickey). Or, you can use injectors part numbered for a 2005-2006 LS2 Corvette (Bosch P/N 0280-156-049 or AC Delco P/N 217-1627). Either provides about 30 lb pressure at the injector. For higher horsepower demands, you'd then likely want to step up to larger injectors during the tuning process (maybe 39 lb or higher, which can always be tuned by adjusting injector duration via computer adjustment. For example, 0280156117 injectors are the short LS2-style, capable of 60 lb, which can be "dialed down" by injector duration adjustment).

The injectors we installed are Bosch P/N 0280156127 (rated at 39 psi) which is the EV6 style (a tick over 3" long). The LS2 injectors (such as the 30-lb rated 0280156049) are about 2.5" long with a fatter lower O-ring). If you have an LS2 manifold, either injector will work. LS2 injectors will drop right in, while LS1 injectors require the LS1-to-LS2 adapter kit, which is made by Katech and available through several suppliers, including Scoggin Dickey. The kit is P/N KATA4096 and sells for about $25. The adapter kit includes four .500" tall fuel rail bracket spacers, four 6mm x 1.0 x 30mm bolts and a full set of larger-diameter LS2-style lower O-rings, which measure about 0.586" in O.D. (remove the injectors' original lower O-rings and install the kit's larger O-rings). O-ring sizes are as follows: Original O-rings on the LS1 style injectors feature an outer diameter of about 0.563" and a thickness of about 0.137". The large LS2 O-rings that fit the LS2 manifold feature an O.D. of about 0.586" and a thickness of about 0.155".

Just for length comparison, the Bosch 0280156 049 (originally a GM LS2 injector), measures 2.575" in overall length. The Bosch 0280156127 injector measures 2.917" in overall length.

The issue of injector selection can get pretty hairy if you're not an injection tuner specialist, but this at least gives you a starting point. If you're planning to make around 500–600 hp, LS2 OE 30-lb injectors are probably a bit on the light side, so 39-lb-rated injectors would be a better choice. Of course, if you're a tuner and know what you're doing, you can always manipulate injectors via programming to achieve various output pressure rates.

Fuel Rails—The Professional Products EFI manifold, like many aftermarket units, will not accept stock OE fuel rails. The supplied performance aluminum fuel rails supplied in the kit must be used. When installing the injectors, be sure to first lubricate the upper and lower O-rings with oil or silicone spray. Once seated in the manifold and fuel rails, gently rotate each injector to verify smooth rotation.

The subject of fuel injector selection can be quite daunting to engine builders who are not seasoned "tuners" of electronically controlled fuel injected engines.

Note: While physically interchangeable, LS1 and LS2 intake manifolds differ in terms of fuel injector bore size (the hole into which the injector seats). LS1 style intake manifolds feature an injector bore diameter of 13.9mm, while the LS2 manifold features a larger 14.7mm bore size.

One thing to remember: just because the injector physically fits the application, that doesn't mean that it will perform properly. Injectors must be selected based not only on the injector's own pressure rating, but in conjunction with the system flow pressure, which takes into account the fuel pump, the intake manifold volume, etc.

Pulley/Belt Setup

In order to the serpentine belt, you'll need a belt tensioner and tensioner pulley. I've heard many complaints about the OE GM tensioner. Apparently, the belt likes to jump off of the tensioner pulley at high rpm. Luckily, Comp Cams has recently introduced a very cool CNC billet machined and adjustable LS belt tensioner, with an already-installed pulley (Comp P/N 54021). This tensioner mounts onto the right side of the water pump (in the OE location). The tensioner includes two 1"-long aluminum spacers that may be used if needed. For installation without the spacers, you'll need a pair of 10mm x 1.5 x 40mm bolts. For installation with the spacers, 55–60mm length is fine.

Once I test-mounted the Comp Cams adjustable serpentine belt tensioner (w/pulley), I knew that I had screwed up early on, since the tensioner pulley and crank pulley weren't even close to aligning (the crank pulley was about 1.5" too far forward for correct belt line-up). That's when I discovered that I had inadvertently ordered the wrong damper hub. As it turns out, our original hub was part numbered for an LS engine in a truck/SUV application (ATI P/N 916430A). A quick call to ATI remedied the situation. The correct damper hub for this application is P/N 916032 (Corvette application). The difference in length of each hub (from the hub's damper contact face to the rear end of the hub) was 1.58" (the 916430A hub is 4.350" long, whereas the 916032 hub is 2.770" long). So, if you're using a Camaro or Corvette tensioner (or an aftermarket tensioner, most of which are designed for the passenger car fitment), you'll need the shorter P/N 916032 damper hub. Our final setup required no spacers (tensioner mounted directly to the pump body's bosses).

Since I wasn't planning to add any driven accessories (I only needed to run the water pump on the engine dyno), the proper fitting serpentine belt for the Project LS2 application is a 43.5"-long belt (I chose a Goodyear Poly V Gatorback, P/N 4060435). In combination with our ATI damper/pulley, our Edelbrock water pump's pulley and my Comp Cams tensioner/pulley, this length worked out perfectly, placing the adjustable tensioner at about the half-way point in its adjustment range. Again, this length was ideal for driving only the water pump for the dyno run. Naturally, once you add an alternator, power steering pump, etc., a longer belt would be needed.

Plumbing the Remote Oil Filter

My Moroso P/N 20141 oil pan features –10 fittings to accommodate a remote-mount oil filter. I plumbed a temporary remote filter just for the dyno use, using a Perma-Cool P/N 1701 oil filter mount. This mount features 1/2" NPT port threads and a 3/4" x 16 filter thread size (to accept a Fram PH8A or hp-1 or equivalent filter). I installed a pair of –10 male to 1/2" NPT male fittings to the filter mount, and plumbed with –10 hose and –10 hose ends. All hose end tightening was done using our Fragola –10 aluminum AN wrench, from my Fragola AN wrench set. Always use an aluminum AN wrench whenever servicing aluminum hose ends to prevent marring the hose ends.

Note that the correct oil-flow routing is as follows: the forward –10 tube at the oil pan is the engine-OUT location, which connects to the remote filter adapter's IN port. The filter adapter's OUT port plumbs to the pan's rear-most IN tube

(The pan's forward tube is ENGINE OUT and the pan's rear tube is ENGINE IN.)

Keep this in mind when plumbing a remote oil filter in the engine bay.

Final Prep and Dyno

After a few minor preparation steps, the Project LS2 engine ran on an engine dynamometer. How's 625.4 hp and 534.6 ft-lb sound?

Whenever I build an engine, regardless of my confidence in terms of fitting and assembly detail, I'm always a bit apprehensive when it comes time to light the fire. But when things go picture-perfect and you hit high numbers without a single glitch, it's a feeling that's better than just about anything else (I'm sure you know what I mean). The Project LS2 build proved to be a total success.

Oil Pressure Sender—In addition to hooking up our MSD wiring harness and the two coil harnesses, I needed to allow for an oil pressure sender connection on the dyNo. Since I wasn't running a complete OE wiring harness and had no provision for simply plugging into the OE sensor, I removed the OE oil pressure switch from the rear of the valley cover plate. After obtaining a spare 16mm straight-thread plug (the same as used on the forward left side of the block to plug an oil galley, (GM P/N 11588949), I drilled the center of this plug using an 11/32" drill and tapped the hole to 1/8" NPT. This allows easy adaptation to a common NPT-thread pressure sender. Since the plug head O.D. is round, you'll either use a pair of pliers to install it, or grind a couple of shallow flats on opposing sides of the plug's head for adjustable wrench use. Don't flatten the edges of the plug head too far though, since the crush washer O.D. is very close to the plug head outer edge.

The Dyno Run—I delivered the engine to Gressman Powersports, in Fremont, Ohio (my favorite dyno shop), to run this LS2 on their Superflow engine dyNo. We added 8 qts of 15-40 Rotella oil to the 7 qt Moroso sump and the remote oil filter. We attached the dyno's oil pressure sender to the 1/8" NPT fitting that I previously added to the valley cover. The cooling system was filled with water via the dyno's cooling tower, and the system was bled. Using the dyno's fuel cell and fuel delivery system and Sunoco 92 octane gasoline, we connected the dyno fuel line to the Edelbrock 800cfm carb.

We plugged the MSD timing control module to the MSD harness. Instead of using one of the pre-programmed curve modules, Scott Gressman opted to utilize the MSD software to program the timing curve on his laptop computer. Scott started with a mild setup at 28 degrees total timing (the control module ramped timing initially from zero to about 12 degrees, then moving to 28 degrees total). The engine fired on the first try (always a nice feeling). After allowing the engine to reach operating temperature, it's first pull showed 537 hp at 6330 rpm, but we hit the built-in rev limiter. Scott reprogrammed to move the limiter, with the next pull hitting 560 hp (again hitting the limiter). After adjusting again, she hit 610 hp at 28 degrees, but again cushioned by the rev limiter. He then bumped her up to 30 degrees total and hit 618 hp at 30 degrees.

Finally, Scott bumped total timing to 31 degrees for the final pull, which resulted in an impressive 625.4 hp at 6800 rpm and 534.6 lb-ft of torque at 5200 rpm.

Project LS2 Dyno Test Results

EngSpd RPM	Torque lb-ft	STPPwr CHp	Fuel A* lb/hr	Fuel B* lb/hr	A/F Ratio	Air scfm	Volumetric Efficiency
4000	453.4	345.3	79.6	77.4	12.26	421	94.5
4100	453.7	354.2	78.3	76.3	12.42	419	91.9
4200	463.6	370.8	79.4	77.1	12.44	425	91.0
4300	472.3	386.7	81.2	79.1	12.37	433	90.5
4400	488.5	409.3	83.3	81.3	12.59	453	92.5
4500	503.0	428.6	86.3	83.9	12.73	473	94.5
4600	511.7	448.2	89.0	86.3	12.94	495	96.8
4700	523.4	468.4	93.3	90.4	13.09	525	10.5
4800	528.5	483.1	98.2	95.3	12.92	546	102.2
4900	529.9	494.3	101.8	98.8	12.75	559	102.5
5000	531.7	506.2	105.6	102.3	12.59	572	102.8
5100	531.7	516.3	109.2	106.2	12.41	584	102.9
5200	534.6	529.3	115.2	111.5	12.16	602	104.0
5300	534.1	539.0	118.6	115.6	12.06	617	104.6
5400	533.2	548.2	120.9	117.1	12.02	625	104.0
5500	532.2	557.4	123.6	119.9	11.96	636	103.9
5600	533.2	568.5	125.3	120.6	12.11	650	104.4
5700	531.7	577.0	126.7	121.4	12.20	661	104.2
5800	530.5	585.9	127.5	122.4	12.29	671	103.9
5900	528.4	593.5	129.4	125.2	12.33	686	104.4
6000	526.0	601.0	131.2	127.2	12.38	699	104.8
6100	520.5	604.5	135.9	131.6	12.22	714	105.2
6200	513.7	606.5	139.7	134.8	12.16	729	105.6
6300	507.5	608.8	141.4	137.3	12.11	737	105.2
6400	501.3	610.9	144.6	139.3	12.04	747	104.8
6500	496.2	614.1	147.1	141.7	12.01	757	104.7
6600	491.4	617.5	148.2	142.8	12.02	764	104.0
6700	486.8	621.0	149.5	143.7	12.16	779	104.5
6800	483.1	625.4	151.4	145.7	12.15	788	104.2
6900	475.6	624.9	151.5	145.3	12.32	799	104.0
7000	464.3	618.9	152.5	145.5	12.40	807	103.6
7100	455.4	615.6	152.9	145.6	12.42	810	102.5

*__Note:__ add Fuel A and Fuel B to determine total fuel.

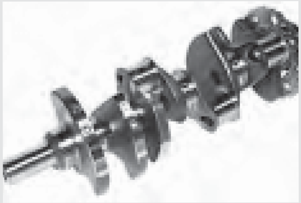
Dyno Reference Data

The final pull was at 30 degrees timing. During all runs, dyno atmospheric data was as follows:

Air Temp (deg. F)	72.0
BaroP inHg	29.53
VapPrs inHg	0.33
AirDens lb/cFt	0.072
AirCor ratio	0.954

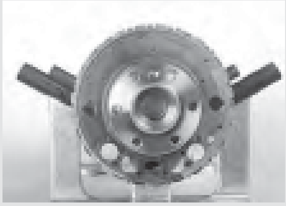
Bear in mind that I only dyno'd this engine with a carburetor setup. With a fuel injection system, the horsepower and torque results will likely differ, but should remain close to the results I obtained. Also keep in mind that different engine dynamometers in different geographic regions (due to calibration) will likely differ by a few numbers up or down. It's rare to find two dynos that will read exactly the same numbers; even the same dyno may provide different numbers on different days.

Note: A complete list of every part, brand and part number for this 625.4 hp LS2 can be found in the appendix on pages 194 and 195.

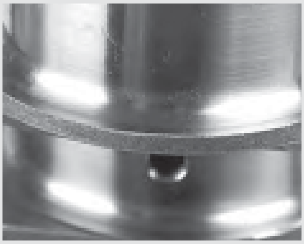


1. Just a reminder: LS crankshafts feature a reluctor wheel (also called a tone wheel) to provide crankshaft position for the crankshaft position sensor. Seen here is a Callies forged crankshaft with a tone wheel.

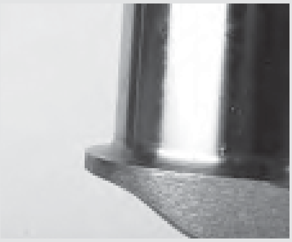
2. When planning to run electronic fuel injection, or even if you plan to run a carburetor, coil packs and a timing controller, you need the reluctor wheel. This must be press-fit onto the rear of the crank.



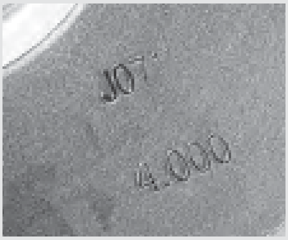
3. The Goodson reluctor wheel installation jig is an absolute must for installing LS crank tone wheels. The tone wheel must be indexed properly. Refer to Chapter 5 for the procedure.



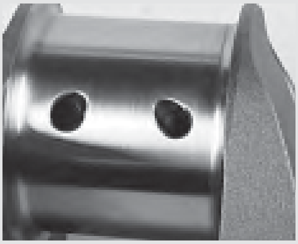
4. Before installing any crankshaft (whether for test fitting or final assembly), the entire crankshaft must be absolutely clean. Carefully clean the entire crankshaft, paying special attention to all main and rod journals.



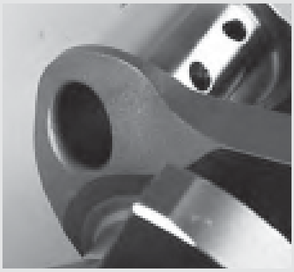
5. Make sure that the journal fillets (where the journal surface radiuses) are clean. This is nothing to be taken lightly. Dirt particles on the crank journals can easily scar new bearings during test fitting or final assembly.



6. An aftermarket performance crankshaft will most likely be stamped on the face of the front counterweight with the stroke dimension. This Lunati crank is clearly identified as having a 4.000" stroke.

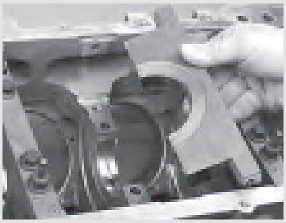


7. When cleaning the crankshaft, make certain that all oil feed passages are clean. Run a clean rifle brush (soaked with solvent) through all oil passages and blow dry with compressed air. Then wash the crank again with hot soapy water, rinse and blow dry.

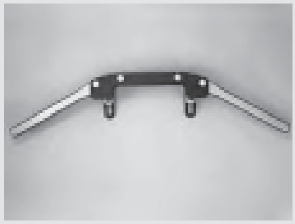


8. Also clean any rod pin lightening holes. Never assume that holes are clean.

9. Make sure that all main caps are marked for position and forward orientation before removing them from the block.

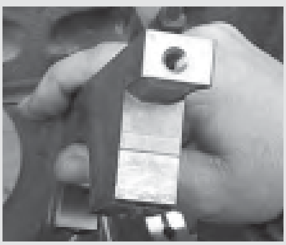


10. LS caps are fairly snug but can usually be removed by hand from a new block. Once the caps have been fully torqued (including side bolts), the block may have squeezed together a bit. Use a block spreader tool to gently spread the block rails apart just enough to release the main caps.



11. For stubborn main caps, specialty main cap puller tools are available, such as this one from RHS.

12. With main caps removed, make sure that the block's main bearing saddles are clean and free of oil. Do not use an abrasive (such as sandpaper, emery cloth, etc.) to clean the aluminum saddles. And NEVER use Scotchbrite pads, as these pads, although very effective, can easily leave fine abrasive particles behind.



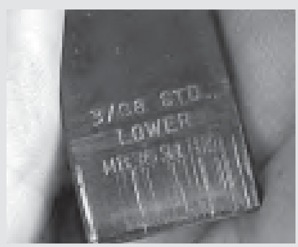
13. Also inspect the main cap side bosses for cleanliness and burrs.

14. Carefully inspect the block's side bolt bosses (on the inboard side of the block walls). These bosses must be free of contaminants and burrs. Don't get carried away by trying to file these bosses. Material removal will destroy main cap alignment.

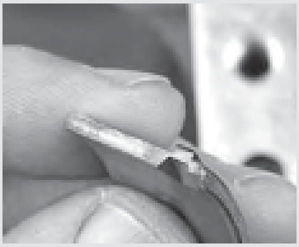
15. Keep the main bearings packaged until ready to measure and/or use.

16. Bearing makers (such as Clevite) offer coated bearings as an option. This is a moly graphite coating that adds an extra bit of anti-scuff protection during initial startup, cold startups and during high load operation. These coatings are extremely thin, so you really don't need to compensate for the coatings with regard to bearing oil clearance.

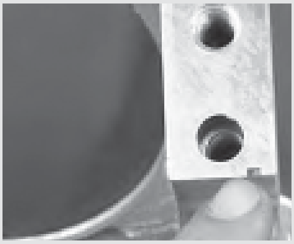
17. Always inspect each main bearing shell for size and orientation. LS main bearings are marked for upper (to the block saddle) and lower (to the main cap) location. This bearing is clearly marked for upper (block saddle) installation.



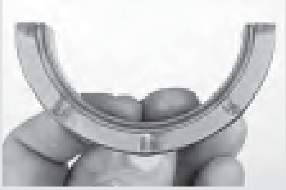
18. This bearing is marked for lower (cap) location. Pay attention to this.



19. Each main (or rod) bearing will feature a tang. This registers into a tang pocket in the block saddle and in the main cap. This locates the bearing during installation in terms of fore/aft location.

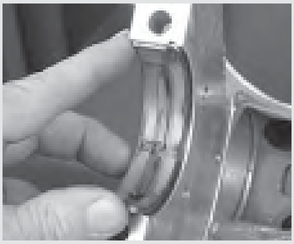


20. Here's a close-up of a bearing tang pocket in an aluminum LS2 block's main bearing saddle.

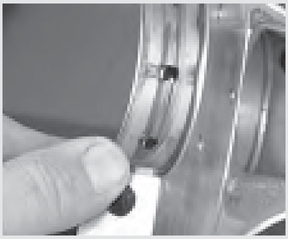


21. The LS engine features the thrust bearing in the center (No. 3) main bearing location, unlike early Chevy engines. The Clevite main thrust bearing features three grooves on one thrust face and two grooves on the opposite thrust face. The three-groove side must face toward the rear of the block.

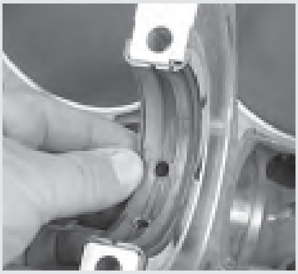
22. The two-groove side of this Clevite thrust bearing must face toward the front of the block.



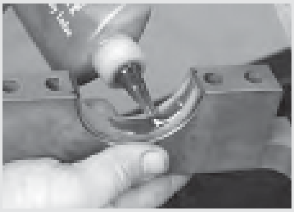
23. Install the bearing shell with the registration tang mated into the saddle's tang cutout, and press both ends of the bearing shell into the saddle with your fingers.



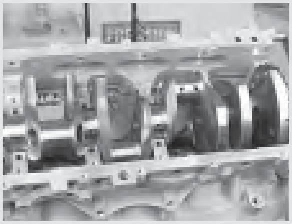
24. Make sure that the bearing edges are reasonably flush with the cap mating surfaces.



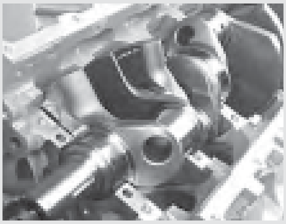
25. The thrust bearing is installed at the No. 3 main bearing location. Again, make sure that the 3-groove side of the thrust face aims toward the rear of the block.



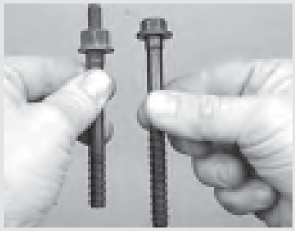
26. With all upper main bearing shells installed into the block saddles, apply a clean lubricant to the entire face of each bearing shell (including the faces of the thrust bearing). You may use clean engine oil, white lithium grease or my favorite, Royal Purple's Max Tuff engine assembly lube.



27. Carefully lay the crankshaft into position. Use extreme care to prevent nicking crank journals and to prevent damaging the upper main bearings. Once the crankshaft is lowered onto the block's main saddles, do not rotate the crank.



28. If you rotate the crankshaft at this point, it is possible to slide one or more upper main bearing shells out of position. Also, rotating the crankshaft will push lubricant out onto the main cap mating surfaces. Do not attempt to rotate the crankshaft until all main caps are in position and snugged tight.



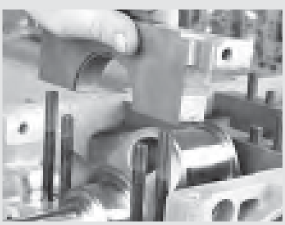
29. OEM main cap bolts on the LS2 (the 11mm verticals) are used in two lengths. The shorter bolt that features the threaded tip above the hex head is installed at the outboard area of the main caps (the extended threaded tips accept a windage tray).

30. Using quality main cap studs like ARP's provide more accurate and consistent main cap torquing, since the threaded stud upper portion threads into the block and remains stationary, with all clamping load being applied via rotation of the nuts. This eliminates the variable of thread friction in the block's threaded main bolt holes, especially in an aluminum block, since the softer aluminum threads in the block aren't disturbed or worn-out during test fitting, engine service, rebuilding, etc.

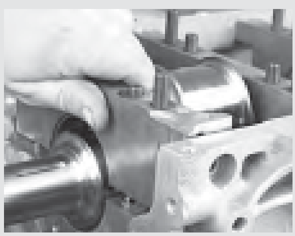
31. Aftermarket main cap studs often feature female hex drives. This makes them easy to install and remove, eliminating the need for double-nutting. NEVER install any stud with a lot of force. It only needs to be finger-tighten. The main cap torque spec only applies to the nut or bolt, not the stud. If you over-tighten a stud, you may cause a splayed condition, making cap installation and removal more difficult.

32. Before installing the main cap fasteners, coat the threads with either 30W engine oil or a moly lube. ARP's moly lube reduces thread friction far better than oil (allowing a more accurate clamping load). FOLLOW the fastener maker's torque spec!

33. It's best to install main cap studs after the crankshaft has been laid onto the upper main bearings, to avoid nicking the crank journals.



34. With the main cap studs in place (if you opted to use studs instead of bolts), carefully slip the main caps onto the studs and lower the cap into position. Be careful not to nick the bearing with the stud tips.



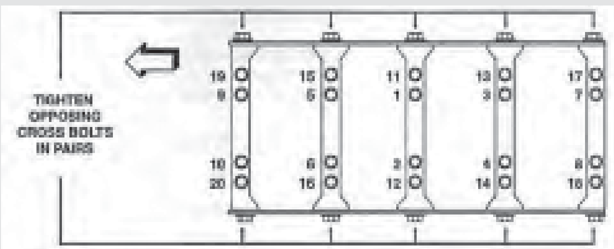
35. Seat each main cap with your hands. Once seated as far as possible with hand pressure, gently tap the main cap with a clean rubber or plastic mallet, to assure full seating.

36. Remember to apply lubricant to the faces of the No. 3 thrust bearing before installing the center main cap.

37. Remember to apply lubricant to the faces of the No. 3 thrust bearing before installing the center main cap.

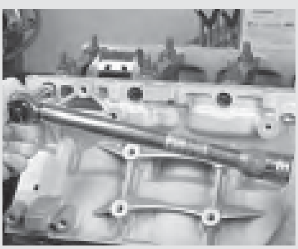
38. If using main cap studs, apply a bit of lube to both sides of the washers (or nuts flange, depending on fastener style) and to the threads and underside of the nuts. Here I apply ARP's moly lube.

39. Granted, moly lube will be messy to handle, but make sure that your hands are CLEAN of dirt, dust, hair, etc. before handling the fasteners.

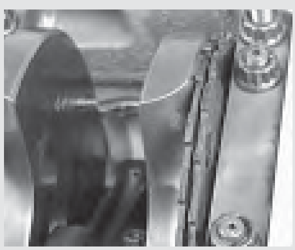


40. This tightening sequence for the main caps must be followed to ensure even distribution of clamping load. This is especially important when using an aluminum engine block.

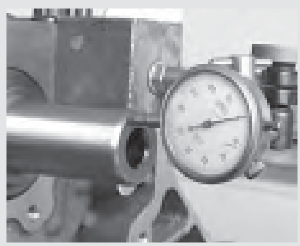
41. Once the 11mm (vertical) main cap fasteners are tightened, apply apply lubricant to both threads and underhead surfaces of the 8mm main cap side bolts.



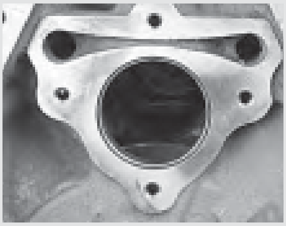
42. Tighten each main cap bolt slowly and smoothly, using a calibrated torque wrench. Take your time and apply smooth, slow force when using the torque wrench. And also make sure that your torque wrenches are properly calibrated.



43. Notice the tight location of the reluctor wheel. As long as the wheel doesn't scrape on the No. 5 main cap, you're okay. You'll usually find about 0.100" or more clearance here. Just make sure it isn't bent.

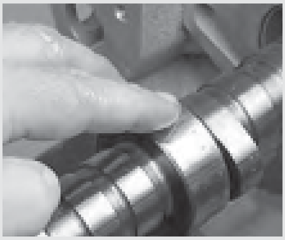


44. Once the main caps have been fully tightened to value, check crankshaft endplay/thrust.

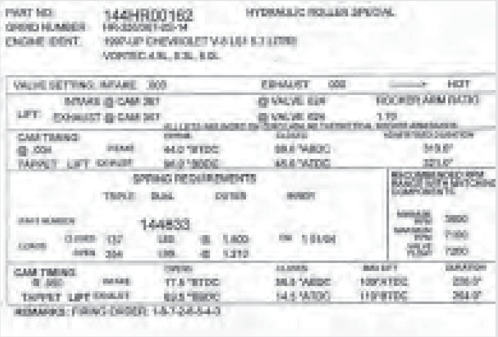


45. The cam bearing tunnel should be cleaned again. While it's nice to precoat the cam bearing faces before installing the cam, if you haven't done this, coating the cam journals will suffice to provide lubricate between the bearings and journals.

46. A wide variety of camshaft profiles are available for the LS engine family. I chose a custom grind from Crane. All LS cams are the roller type (usually made from steel billet). It's generally best to use the same make roller lifters .



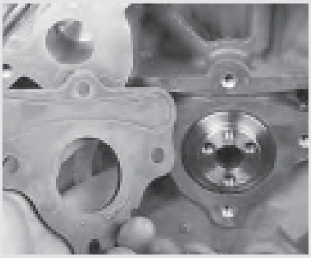
47. Apply a generous amount of lubricant to the camshaft journals and lobes. Start by lubricating only the rear two journals and the rearmost lobes. As the cam is carefully inserted into the first two bearing locations, you can then continue to apply lube. This makes the cam easier to manuever. Use extreme caution when installing any camshaft to avoid nicking or gouging the cam bearings. The camshaft must be kept perfectly aligned to the cam bores. If you feel any resistance, do not force it. Gently wiggle the cam to engage the journals into the bearings as you proceed.



48. This is the cam card from the Crane hydraulic roller camshaft I used in my Project LS2 build. Note that lift is 0.624" at the valves.

49. The camshaft is secured in the block via a camshaft retainer plate. This plate is secured to the block with four screws. The nose of the camshaft is stepped. The smaller diameter nose section will pass through the retainer plate center hole. Be sure to apply lube to the cam nose (the step shoulder) before installing the retainer plate. Also, apply thread locking compound to all four screws. Tighten the four retainer plate screws to a value of 18 ft-lb.

50. The rear of the camshaft retainer plate features a formed-in-place seal. If this seal is damaged, you can carefully apply a thin bead of RTV in the same pattern, or purchase a new retainer plate.



51. Make sure that the mating surfaces (block and rear of retainer plate) are clean and dry.

52. Make sure that the crank snout keyway is clean and free of burrs. Also check the key and make sure that it's free of burrs as well. Place the key into position, centering the key lengthwise in the slot.

53. Using a clean brass blunt-nose drift, tap the key into the slot, making sure that it's level (you don't want the front or rear of the key to stick up higher than the opposite end). Use a soft metal drift such as brass to avoid deforming the key or creating burrs.

54. Make sure that the crank snout and the crank timing gear are clean. Lightly lubricate the crank snout with oil or other lubricant (I use Royal Purple Max Tuff). Slip the crank timing gear onto the snout as far as you can with your fingers. You should be able to slip it on far enough to engage the rear key into the gear's keyway. Using a clean aluminum or brass tube that slips over the snout, lightly hammer the tube against the gear to fully seat the gear.

55. This performance aftermarket crank gear features choices of zero, 2 or 4 degrees advance or retard for cam timing. In this build, I selected the zero timing mark. You can always go back and change cam timing at a later date (retarding will move the power band towards the top rpm end, while advancing will move it towards bottom-end).

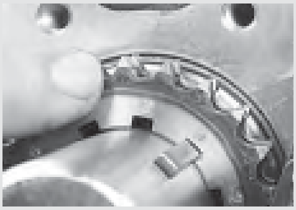
56. If you're building a performance engine, get rid of the wimpy single-roller stock timing chain setup and buy a quality double-roller timing kit.

57. The LS camshaft nose features a stepped face. The smaller diameter passes into the retainer plate hole and the larger diameter shoulder prevents the camshaft from exiting its home.

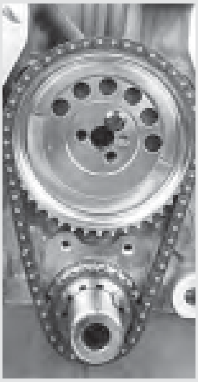
58. The double roller timing from SDPC features a Torrington bearing that installs to the rear of the cam gear and rides against the face of the cam retainer plate.

59. Here the cam gear's bearing is fit to the rear of the timing gear. This is a lightly pressed-on fit that is accomplished by hand.

60. Apply thread-locking compound to the three gear bolts and install the cam gear to the camshaft nose. Tighten to 26 ft-lb. Next, set up a dial indicator and check camshaft endplay. The factory spec calls for 0.001–0.012". My endplay was 0.005". If the endplay is less than 0.001", the cam may bind when subject to heat during operation.



61. When installing the timing chain, ignore the location of the crankshaft snout key. The crank gear has a small stamped 0 on one of the teeth. Rotate the crankshaft to place this zero mark straight-up at 12 o'clock. The camshaft gear also features a small stamped zero mark, which should be placed down at 6 o'clock so that the two zero marks (crank and cam) are closely aligned.

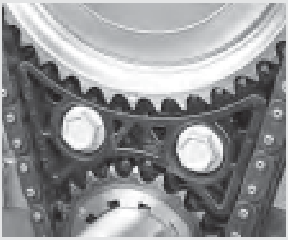


62. Here's a view of the installed timing set. Note that the camshaft's dowel pin at the cam gear is just below the 3 o'clock position.

63. This close-up shows the zero mark of the crank gear slightly to the left of the zero mark on the cam gear. Carefully rotate to obtain an exact lineup of the two zero marks.

64. Once the timing set has been properly installed, install a plastic timing chain damper. This is a factory part (I'm not aware of any aftermarket sources).

65. Orient the damper block with the larger radius facing the cam gear and the smaller radius facing the crank gear.

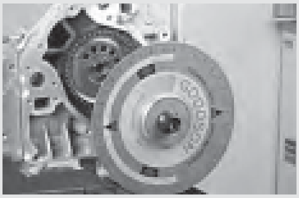


66. Install the chain damper between the two gears, tightening the two mounting bolts to 18 ft-lb.

67. This lifter bore indicator gauge can be used to accurately locate the camshaft base circle, and for measuring cam lobe lift. This gauge tool is made by Foster Tools. This allows you to easily verify the total cam lobe lift.

68. The tool's plastic plunger is inserted into the lifter bore, making contact with the cam lobe. As the tool's body collar is rotated, the collar expands to secure itself in the lifter bore.

69. With the gauge in place (and a slight preload adjusted onto the cam base circle, you can rotate the cam to locate exact base circle. Once zeroed at the base circle, rotate the cam to read total cam lobe lift.

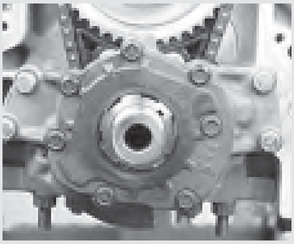


70. Degreeing the camshaft verifies its profile, while including the variables that may be found in the timing set and crank/rod/piston reciprocating assembly. Refer to the cam manufacturer's website for cam degreeing procedures. If using a reputable cam manufacturer, degreeing really isn't necessary for the average street engine.

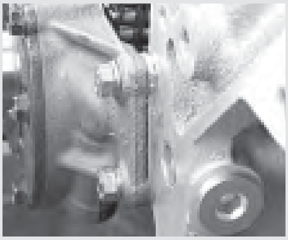
71. The oil pump mates to the front of the crank. This is a gerotor style pump, with its gear driven by the crank snout's gear key. The oil pump cannot be installed until after the camshaft gear and timing chain system has been fully installed.

72. Quality aftermarket oil pumps are readily available, offering choices of high pressure, high volume and high pressure/high volume. Melling is an excellent source, as is Katech.

73. While the OE crank gear is integral with the oil pump drive gear, aftermarket timing sets (such as the set used here) may feature the crank chain gear and the crank snout-mounted oil pump drive gear as two separate pieces. The pump drive gear is slotted on its I.D. to engage to the crank snout key.



74. Once the timing set has been fully installed, the oil pump may be mounted. Apply thread locker to the four pump mounting bolts and tighten the four pump-to-block mounting bolts to 18 ft-lb.



75. When using a double-roller timing set, additional clearance may be required between the chain and pump. The timing set I bought from SDPC included two spacers (one for each side of the pump mounting).

76. The block's left front wall features an oil passage that must be plugged with a 16mm expansion plug. Whether you're dealing with a new bare block or a block that has been rebuilt, make sure to install this plug. I applied a very light coat of RTV around the perimeter of the plug and tapped the plug flush with the block using a flat-faced brass drift.

77. Make sure that the oil plug is flush with the block surface.

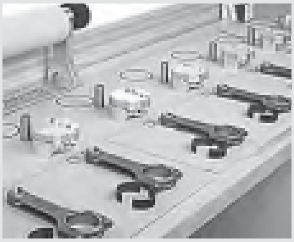
78. The oil control plunger installs into the lower left rear face of the block, with the blue O-ring end of the plunger facing rearwards.

79. Apply a bit of clean engine oil to the O-ring and slip the plunger into its bore with your fingers.

80. The oil control plunger is fully seated when the rear face is flush with the block surface.

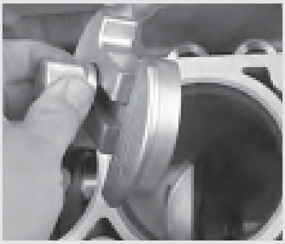
81. All block water jacket plug locations feature metric straight thread (not tapered NPT). Apply thread sealant and tighten using hex wrenches.

82. New threaded block plugs feature preapplied thread sealant. If reusing old plugs, clean the threads and apply fresh Teflon thread compound.



83. For piston and rod assembly, organize all pistons, wrist pins, piston rings, connecting rods, rod bolts and rod bearings on a clean workbench. Use a per-cylinder-location system (cylinder 1, cylinder 2, etc.). Things always goes smoother when you organize all of your parts.

84. To check piston ring fit in the cylinder bores (checking top ring, second ring and oil ring rails), place one ring into it's assigned bore by slightly compressing the ring by hand.



85. The ring must sit squarely in the bore to measure ring gap. A quick way to do this is to use a ring-squaring tool such as this one from Summit Racing. The tool features a stepped design. The smaller diameter step enters the bore and contacts the top of the ring.

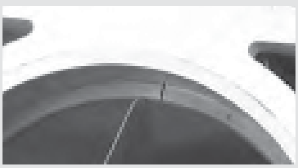
86. The larger diameter shoulder rests on top of the block deck. The tool is adjustable for bore diameter. By gently pushing down on the tool until the shoulder rests flush on the deck, the ring is pushed down and squared so that it sits evenly in the bore (same distance from block deck to ring all the way around the ring).

87. Once the ring is seated squarely in the bore, remove the tool and measure the ring gap using a feeler gauge. Required ring end gap is dictated by the ring or piston maker, so check the maker's instructions.

88. If the measured ring gap is too tight, the ring may be filed to increase the gap. You can do this by hand with a fine flat file or you can use a ring filer like this one from Summit Racing that features a diamond abrasive wheel. File each end of the gap a few strokes at a time, clean the ring and recheck ring gap with the ring placed squarely in the bore. Don't get carried away, since it's easy to remove too much material, in which case the ring cannot be used.

89. After filing to increase ring gap, use a small flat fine file to carefully remove burrs from the filed areas.

90. Carefully inspect the ring end gap areas for burrs. Remove any sharp raised areas.



91. Recheck end gap. The gap should be even (ends parallel, with no taper in the gap). After each ring is confirmed for end gap, clean the ring to remove any particles and keep it organized in a per-cylinder grouping. Don't assume that one cylinder bore can be used as your end gap fitting for all rings. Keep a top, second, and oil ring rail grouping for each cylinder.

92. If the rod caps are still attached to the rods, you'll need to separate them. A dedicated rod vise is a very handy tool. This can mount directly to your workbench or be secured in a bench vise. This one is from Gearhead Tools, and features plastic jaw liners to prevent gouging the rod big end.

93. With the rod big end captured in the rod vise, loosen the rod bolts. With the rod's cap parting line captured in the jaws, this prevents the possibility of twisting the rod.

94. If the rod cap won't easily pull off by hand, back the rod bolts out by about 1/4", and hang the rod big end in one hand while tapping on the rod bolt heads with a plastic hammer. However, a rod splitter offers an easy, controlled method of separating rod caps from rods. Place the rod big end onto the split mandrel (with rod bolts backed out about 1/4" to 1/2") and slowly turn the tool's handle.

95. As the mandrels expand, the cap is precisely separated from the rod in a controlled manner.

96. The OE factory connecting rods are attached to the pistons with an interference fit between the wrist pin and rod small bore. A hydraulic press is required to disassemble/assemble OE pistons and rods.

97. The OE wrist pin "floats" in the piston's pin bore, but is firmly press fit to the rod.

98. The OE hypereutectic pistons feature a small dimple on the dome. This dimple indicates piston orientation in the cylinder bore, with the dot facing towards the front of the block.

99. If you're using aftermarket full-floating pistons and rods (where the wrist pin freely rotates within both the piston pin bore and rod small bore), lubricate the wrist pin prior to assembly. My favorite lube for this is Royal Purple Max Tuff, although engine oil works fine as well.

100. Aftermarket performance forged pistons offer greater strength for higher cylinder pressures, and offer a wide array of choices in terms of diameter, compression height (important when building a stroker engine) and dome configuration (regarding compression and valve to piston clearance issues).

101. When using a full-floating pin design, the wrist pins must be locked in place to prevent them from walking out one side of the piston. Both spiral-wound and wire style locks are available, depending on piston design. Shown here is a wire lock. This will be inserted into the piston pin bore, one at each side of the wrist pin.

102. Inserting a pin lock can be frustrating at first (until you get the hang of it). Applying finger pressure while walking the lock around the bore with a small screwdriver is one method.

103. Using a dedicated pin installation tool is another method. By angle-walking the tool against the lock, the lock will slip into its groove easily. Again, a slight learning curve is needed to become accustomed to the procedure.

104. Small access notches are featured at the outer edge of the piston's pin bore for access by a pick or small screwdriver. Once the lock is in its groove, lightly tap the opposite end of the wrist pin to verify that the lock is properly seated.

105. As you can see in this photo, this performance aftermarket piston features the pin bore higher than the stock location (because of the desired compression height needed for a stroker combination). Because the pin bore cuts through the bottom of the oil ring groove, a separate oil ring support rail is needed in order to retain a full-circumference "footprint" for the oil ring package.

106. The support rail will feature a raised dimple. This dimple must face down, at an open area above the pin bore. This dimple serves as a stopper to prevent the support rail from rotating. This is to prevent the support rail gap from ever entering the pin bore void area.

107. Install the oil ring support rail (if needed) by inserting one end into the oil ring groove, then gently spiraling the rail fully into the oil ring groove.

108. Once the support rail has been installed at the floor of the oil ring groove (if a support rail is needed), you may then begin to install the oil ring package. First install the oil expander ring. This ring is very flexible. Simply wind it into the oil ring groove, allowing it to rest on top of the support rail (if present).

109. Next install the lower oil ring rail. This will be placed at the bottom of the expander ring. The expander ring features a small shoulder at top and bottom to accept its rails. Keep the expander ring's ends butted against each other while the rail is being installed. Do not allow the expander ring ends to overlap. Once the lower rail is in place, this will prevent the expander ring from separating.

110. Next install the upper oil ring rail. Install this in the same manner. Once both rails have been installed, hold the expander ring in place and gently rotate each rail to position the rail end gaps about 45 to 90 degrees away from each other. Gently rotate the entire oil ring package as a group to verify that it freely rotates within the oil ring groove.

111. Next, install the second ring (this is often referred to as the oil control ring or second compression ring). Do not attempt to spiral-install this ring by hand. This ring is much less flexible than the oil rings and can easily break if over-stressed. Always use a quality piston ring expander tool to gently expand the ring just enough to slip it over the piston. Once the ring enters the second ring groove, release tension on the expander tool. Always check the ring maker's instructions for ring orientation. In most cases, the ring will feature a small dot on one side. In most cases, that dot must face upwards. Confirm that the ring rotates around the groove freely without binding.

112. Next, install the top compression ring. Again, check ring orientation and use a ring expander tool to spread the ring just enough to slip over the piston.

113. Rod bearings will be labeled for position. Pay close attention to this! The bearing shell seen here is marked "UPPER," and must be installed to the top of the rod big end bore, not to the rod cap.

114. This bearing is marked "LOWER" and must be installed to the rod cap.

115. Make sure that the rod big end saddle and cap saddle are absolutely clean and free of particles, lint or lubricants. The saddles and the bearing backs must be clean and dry. Finger-install the upper rod bearing into the rod big end saddle, aligning the locating tang to the rod's tang notch. Push down on the bearing edges with your fingers to fully seat the bearing so that the ends are reasonably flush with the rod cap mating surfaces.

116. Install the lower rod bearing into the cap's bearing saddle. Again, the saddle and bearing back surfaces must be clean and dry.

117. Once the rod bearings have been fully seated, apply a generous amount of lubricant only to the exposed bearing surfaces. 30W engine oil is fine, but I prefer something stickier and more slippery, such as Royal Purple Max Tuff.

118. Before installing the piston/rod assemblies, final-clean the cylinder walls. Wipe with a lint-free rag until it wipes clean. Also carefully check each rod journal for cleanliness. Remove all traces of particles, lint, hair, etc. The cylinder walls and rod journals must be as clean as possible. This is another reason to perform the final assembly in a clean, dust-free area.

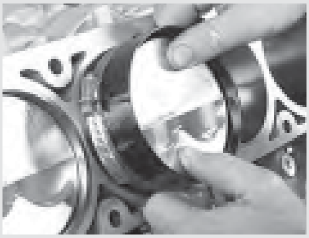
119. Apply a healthy smear of clean 30W engine oil to the entire cylinder wall surface area. A non-detergent oil is preferred. At this point, for assembly and in preparation of the engine's first firing, you need lubricity and you don't need additional cleaning agents. Arrange your ring gaps (you can follow the OE specs or just move your gaps around so that they don't align—the gaps will likely rotate around a little bit during engine operation anyway). I usually just place my top and second ring gaps about 70 or so degrees apart, keeping gaps away from the thrust side of the bores. Check the instructions provided by your piston or ring maker, as they may have their own gap location preferences. Once your gaps are adjusted, douse the entire ring package with clean 30W engine oil, along with piston skirt areas. For this application, I use oil instead of Max Tuff, since a synthetic lube may be too slippery for rings and may hamper ring seating. Also squirt some oil to the entire wrist pin area. Don't worry about getting oil on the piston domes…you can wipe that off later. Just lube the heck out of the piston walls and rings.

120. Rotate the crankshaft to place the intended rod pin in the bottom-dead-center area (placing the rod journal far away from the block deck). This makes it easier to guide the rod toward the journal, and offers better access to the rod big end for alignment and for cap and rod bolt installation. Insert the rod and piston through the ring compressor (enter the rod big end through the top of the compressor), inserting the piston skirts into the compressor.

121. To install the pistons, you'll need a ring compressor. There are several styles, with the spiral-wrapped band clamps the most common. I prefer the type cast or machined from aluminum that features an inside taper that allows the rings to compress gradually as the piston is pushed through. That type is available as a one-piece, dedicated per specific bore size. Or you can choose a tapered ring compressor that's adjustable within a specific range. The compressor shown here is from Summit Racing, adjustable within a bore diameter range from 4.00"–4.09", which works out great for a stock 4.000" LS2 bore up to a slight oversize. My bore diameter is 4.005".

122. Carefully compress/nudge the rings enough to enter the compressor until all rings are captured inside the compressor. Don't push the piston so far as to pop the oil rings out of the compressor bottom. Leave a bit of exposed piston skirt sticking out of the bottom of the tool.

123. Orient the connecting rod so that the chamfered edge of the big end aims at and aligns to the crankshaft's rod fillet, carefully insert the rod into the cylinder bore. Avoid scraping the cylinder wall.

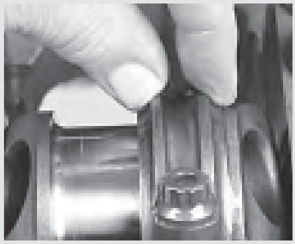


124. With the piston skirts inserted into the bore and the compressor tool's bottom resting flush and flat on the block deck surface, apply pressure to the piston dome and begin to insert the piston. As the piston travels through the compressor, the rings will continue to compress. If you feel solid resistance, stop and reassess. Pull the assembly slightly out of the bore and make sure that the rings are still captured inside the compressor and try again. Depending on the adjustment of your compressor tool, either hand pressure or light/gentle tapping with a clean plastic mallet will allow the piston rings to compress enough to slide into the bore. Once the top ring has entered the bore, remove the compressor tool.

125. Always monitor the location and alignment of the connecting rod relative to the crankshaft while drawing the piston into its bore. It is critical to avoid nicking the rod journal with the connecting rod mating ends. While guiding the rod big end, push the piston deeper into its bore until the upper rod bearing gently seats onto the rod journal.

126. Apply lubricant to the rod bolts (either engine oil or a moly type assembly lube) per bolt maker's recommendation. If you plan to tighten the rod bolts using applied torque, fastener makers such as ARP will offer two torque value levels: one based on oil and the other on moly lube.

127. Be sure to lube both the bolt threads as well as the underside of the bolt head.



128. Once the rod upper bearing is seated at the rod journal, install the rod cap (with lower bearing) and finger-tighten the rod bolts. Be sure to orient the cap so that it's chamfered edge faces the journal fillet. Do not rotate the crank at this point.

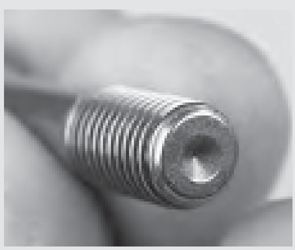
129. Snug the rod bolts, tightening to about 10 ft-lb. Tighten evenly (alternating bolt to bolt). Once the next rod on that same journal has been installed, tighten both adjoining rods' bolts to specification (using a torque-plus-angle method for OE rods; torque-only or by monitoring rod bolt stretch).

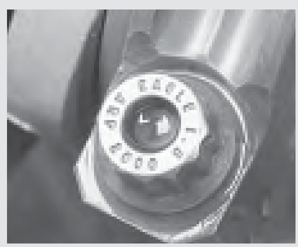
130. OE connecting rods are made of powdered metal and feature a cracked cap design, where the rod cap has been fracture-snapped from the rod. A cracked cap rod cap mating surface is very irregular, as a result of the cap being broken off of the one-piece casting. While this may seem crude, it actually provides a precise cap-to-rod mating, since the cracked surfaces mate together perfectly. While you should never mix caps with rods of any style, you definitely cannot mix powdered metal rods and caps.

131. When a cracked cap rod big end is partially assembled, the irregular crack remains very noticeable.

132. As the rod bolts are tightened, the crack begins to disappear. Once fully tightened the crack completely disappears due to the precise mirror-image mating of the two surfaces.

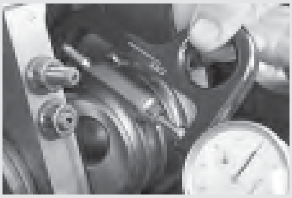
133. OE rod bolts are 9mm in diameter with a 1.0 thread pitch and a shank length of 43mm. The OE rod bolts feature a collar that helps to center the rod bolt in the cap. These are torque-plus-angle design bolts. I'm not certain if they are also torque-to-yield bolts, but I would not recommend reusing them. If using stock type rods, always replace used rod bolts.



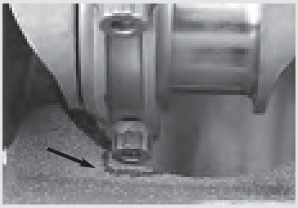


134. Aftermarket high performance rod bolts feature a dimple at each end. These dimples allow the use of a stretch gauge, if the builder prefers to tighten rod bolts by monitoring bolt stretch instead of tightening by torque value. Here we see the gauge dimple at the tip of the rod bolt shank.

135. Rod bolt stretch gauges allow you to monitor each rod bolt's amount of stretch as the bolt is tightened. The bolt maker has predetermined the bolt's clamping load, based on bolt stretch. This eliminates the variables that you can encounter if tightening only by torque (friction at threads and bolt head underside). First place the rod bolt in the stretch gauge (pointed anvil heads engaged into the bolt's dimples). Preload the gauge a bit, by about 0.050" or so. Then zero the indicator gauge. You now have a baseline in terms of that bolt's free stage without being stretched. When the bolt is installed and tightening commences, the gauge will allow you to monitor how far the bolt stretches.



136. After tightening the bolt a bit, place the gauge onto the bolt again to see if and by how much the bolt has stretched. Continue to tighten the bolt in short stages and recheck length until the stretch specified by the bolt maker has been achieved. This may be a longer process than simply tightening with a torque wrench, but it is much more accurate.



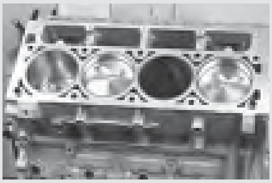
137. During your early preassembly fitting and checking phase, which is important with any crankshaft that provides a longer stroke than the OE crank, you may have found a clearance issue at select rod-bolt-to-block areas. Shown here is a clearance problem (arrow) on an LS2 block fitted with a 4.000" stroke crank.

138. Again, this was done during the test-fitting stage. During test fitting, the block is clearanced by using a die grinder or a mini belt sander. Minimum clearance between the block and counterweights and/or rods is generally considered safe at 0.060" or more clearance.

139. Once both rods are installed onto a common rod journal, rod sideplay can be checked with a feeler gauge. The OE specification calls for a minimum of 0.00433" and a maximum of 0.0200".

140. Once the pistons/rods have been installed, wipe any excess oil from the piston domes and the block deck.

141. LS engines generally feature a slight above-deck piston location (at TDC), to the tune of about 0.005"–0.006" or so. This is common. While stock LS pistons feature flat-top domes, if you plan to use a camshaft that provides more than about 0.544" valve lift, you'll either need to notch the piston domes for valve clearance, or upgrade to aftermarket pistons that feature valve reliefs. Since the camshaft used in Project LS2 features a valve lift of 0.624" at both intake and exhaust, flat top pistons with 5cc reliefs were needed.



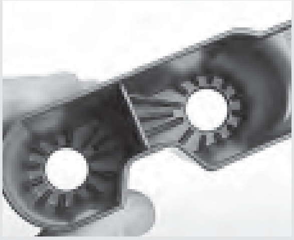
142. With all pistons/rods fully installed, check crank rotation. Things are bound to be a bit snug at this point because the rings haven't seated yet, but you should be able to easily rotate the crank with a wrench placed on the crank snout bolt. Depending on the rings and other variables, it should not require more than about 20 or 25 ft-lb to rotate the assembly at this point.

143. Before you can install the cylinder heads, you need to install the dowel sleeves (two per deck) to the block deck at the lower front and rear counterbored head bolt locations. Make sure that the counterbore is clean and that the dowel sleeve has not burrs. It's always best to use new dowel sleeves, since originals may have been distorted during removal.

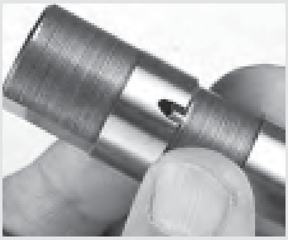
144. Tap the dowel sleeves into the counterbores until they bottom out. Instead of whacking the dowels directly with a hammer, place a driver onto the sleeve and tap the driver with a clean mallet. A clean socket wrench is one choice, as long as its outer diameter is greater than the dowel's outer diameter.

145. Each OE plastic lifter bucket guides a package of four lifters. Each bucket is secured to the block with a single 6mm screw. The lifter bucket bottom features flat-sided guides that engage the roller lifter flats to prevent lifter body rotation and to keep the lifters in plane to the cam lobes.

146. This close up shows the flats that guide the lifters and the center holes that allow pushrod to lifter contact.



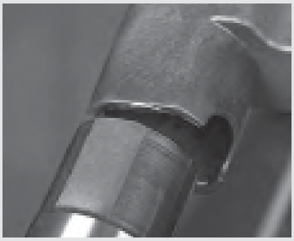
147. The top side of the lifter bucket features oil channels to divert draining oil to the lifters.



148. Note the angle-drilled oil bleed hole in this Crane roller lifter.

149. Aftermarket performance roller lifters feature the same flat sides as the OE lifters for registration to the OE style lifter buckets.

150. Quality high-performance aftermarket performance roller lifters feature extra heavy-duty trunions and hardened roller bearings.

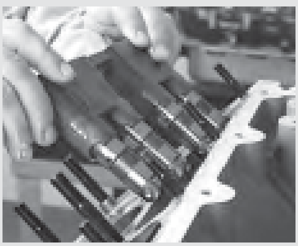


151. Each lifter is installed into the buckets from the bottom of the buckets, aligning the flats on the lifter body to the flats in the bucket lifter guides.

152. Lube the lifter with oil and insert into the bucket.

153. Push the lifter full up into the bucket. It will gently "click" in the up position.

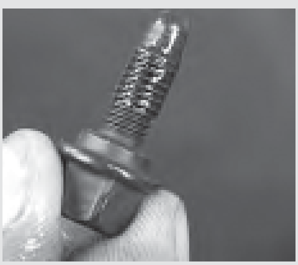
154. With four lifters fully installed into a lifter bucket, the group of four lifters can be installed into the block.



155. With all lifters fully lubed with oil and installed into their respective lifter buckets, gently install the lifter bucket, aligning the lifters to the lifter bores.

156. Some performance roller lifters may be taller than the OE lifter. If so, the lifter maker will provide spacer washers to move the lifter buckets up slightly. If so, the spacer must be placed on the block surface, centered with the lifter bucket mounting bolt hole before the lifter bucket is installed. If these spacers are needed, apply a dab of assembly lube onto the bottom of the spacer first to prevent the spacer from sliding off before the lifter bucket bolt is installed.

157. With the group of four lifters entering their respective lifter bores, allow the bucket to rest onto the block mounting surface.



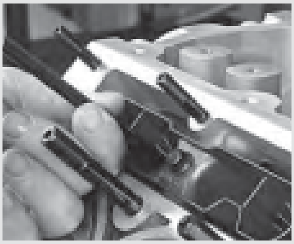
158. Apply thread-locking compound to the lifter bucket 6mm bolts.

159. Tighten each lifter bucket mounting bolt to a value of 125 in-lb.

160. A lifter bucket fully installed. Note that the molded shape of the bucket allows installation to the block in only one direction.

161. This view shows the lifter in the full-up position, held in place by the mild grip by the lifter bucket. The lifters are easily pushed out of the locked position and onto the cam lobes by simply using a pushrod to pop each lifter out of its full-up location. If the need arises to change a camshaft, there's no need to remove the lifters. With the pushrods out of the way, simply rotate the crank and cam. At peak lift, the lifters will engage into the buckets and will remain clear of the camshaft's path.

164. If using OE head bolts, just to be safe, I'd advise using new ones, since the OE spec calls for torque-plus-angle tightening. For a high performance build, however, use either aftermarket bolts or studs. Studs (shown above) offer advantages, including being able to achieve more accurate clamping loads, since the threads in the block remain stationary. Other advantages: For future service (as in an often-rebuilt race engine), the studs provide a nice guide for removing and installing the heads, and you completely avoid placing wear on the softer bolt threads in the aluminum block.

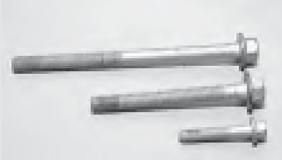


162. Use a pushrod to pop the lifters out of the grip area of the lifter buckets, allowing the lifters to slide down onto the cam lobes.

165. The ARP cylinder head studs feature a distinct "stopper" tip at the bottom, allowing a slight preload during stud installation. Studs DO NOT need to be super-tight. Finger-tight is fine. However, being able to slightly preload (by a mere 8-10 ft-lb) insures that the stud is fully engaged in case any slight imperfections exist in the block's threaded holes.

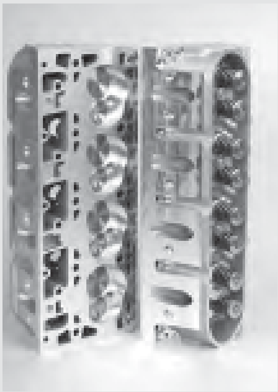
167. If using head studs, apply thread sealer to the lower threads and install finger-tight, followed by a slight preloading of perhaps 8–10 ft-lb, but no more.

163. A gentle tap will easily dislodge the lifters from the buckets.

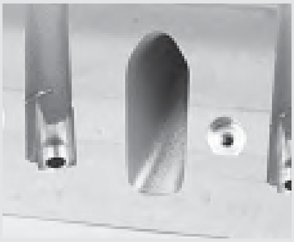


166. OE cylinder head bolts. LS1 and LS6 engines feature three different length head bolts (100mm, 155mm and 45mm), while LS2 and LS7 engines use only the 11mm x 11.25 x 100mm and 8mm x 1.25 x 45mm bolts. The OE tightening values for the LS2 bolts are 22 ft-lb plus 76 degrees plus an additional 34 degrees for the 11mm bolts; and 22 ft-lb for the 8mm bolts.

168. The inboard 8mm pinch studs are also installed finger-tight (lube lower threads with a bit of moly). You can apply a slight preload, using a hex wrench, of about 5ft-lb (60 in-lb).

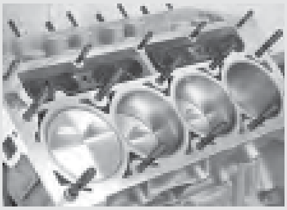


169. I installed Trick Flow's TFS-3060T001-C02. These heads maintain the OE combustion chamber volume (65cc), but provide 225cc intake port volume. Valve angle also changes to 13.5 degrees. 2.055" intake valves and 1.575" exhaust valves, both with 8mm stem diameters are included. Seats are ductile iron instead of powdered metal. Valve springs are 1.300" O.D. doubles (instead of the tapered beehive OE style) and will accommodate 0.600" valve lift. The rocker mounting location is 0.100" taller than the OE, so longer pushrods are necessary.

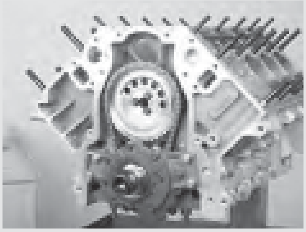


170. The Trick Flow heads retain the LS2 style cathedral intake ports. All intake and exhaust ports are CNC finish-machined for precise uniformity. The Trick Flow intake ports measure 3.250" x 1.070" and featuring 225cc port volume.

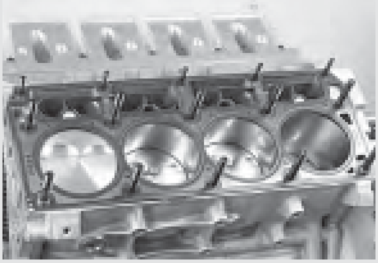
171. The Trick Flow heads feature a slightly more oval shape as opposed to OE style D-shaped exhaust ports. Trick Flow exhaust ports provide 80cc volume. Each exhaust port measures exactly 1.460" x 1.670".



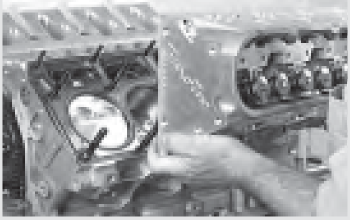
172. Carefully clean the block decks and piston domes in preparation of cylinder head gasket and head installation.



173. Before installing the heads, verify that all rod bolts are tight and that the pistons are oriented properly (dot facing front on OE pistons; valve pocket reliefs at the upper half of the domes, etc.). Verify that all lifters are in place and that all lifter bucket bolts have been tightened.



174. LS2 engines were originally built by GM using multi-layer steel (MLS) head gaskets (earlier LS1 engines featured composite style cylinder head gaskets). Many engine builders prefer MLS for their sealing characteristics. The Victor Reinz MLS gaskets seen here feature a special heat-activated coating that improves combustion, water and oil sealing. Make sure that you install the head gasket in its correct orientation. The front will be marked FRONT, and the small water jacket holes must be located at the rear. DO NOT apply any type of additional coating or adhesive to the head gaskets. Install them dry. Note the gasket is marked "Front" for correct orientation.



175. With the head gaskets in place, carefully position the head. If you have head studs, be careful as the head approaches he deck to avoid nicking the head deck surface with the stud tips. Make sure that the block is secured on the engine stand to avoid block rotation (if the engine stand head is loose, the block could rotate with the added weight of the cylinder head).

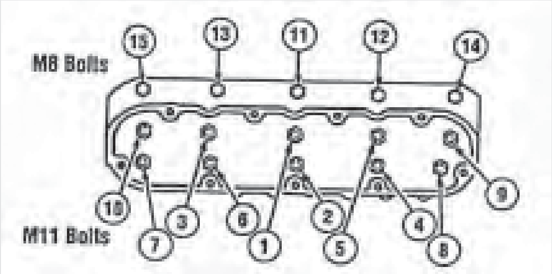
176. If you're using head bolts, the head will register once you align the block deck's dowel sleeves to the head's dowel holes. If you're using studs, the studs immediately aid in positioning the head (using the studs as guides). However, you still need the dowels to accurately register head position.

177. When using aluminum cylinder heads, it's always best to use a hardened washer under the bolt heads and under nuts (when studs are used). This avoids the bolt head or nut from digging into the aluminum. Some makers, such as ARP, will feature washers that have a chamfer on one side of the washer inside diameter. If your washers are chamfered, always place the chamfered side up. This is more critical when using head bolts, since the shank immediately under the bolt head may be slightly oversized, requiring the washer chamfer for clearance.

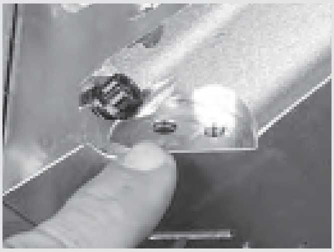
178. Installing a washer onto the inboard head studs can be a challenge due to the recessed location. A pencil magnet makes the job easy. Insert the washer using the pencil magnet, then rotate the magnet to remove it from the washer.

179. Use a quality torque wrench to tighten the cylinder head fasteners, and make sure that it's properly calibrated. I recommend Angle Repair Services in Beckley, WVA (www.anglerepair.com). If using new OE head bolts, initial torque the 11mm bolts to 22 ft-lb, followed by 76 degrees additional rotation, followed by an additional 34 degrees rotation. The 8mm pinch bolts are tightened to 22 ft-lb of torque. If using ARP head studs, tighten the primary 7/16" nuts (ARP features 7/16" threads at the top of their 11mm studs) to a final value of 80 ft-lb (with moly), and tighten the 8mm pinch bolts to 22 ft-lb (with moly). When tightening the primary head stud nuts, don't immediately pull each to 80 ft-lb. Instead, tighten all (in proper sequence) in stages, building up to the final value.

180. A torque wrench socket straight extension (extended perpendicular to the tool's main body) will be needed for most head bolt locations. If you opt to use an *offset* extension, you'll need to calculate the correct torque wrench setting to compensate for the altered leverage. Whenever you extend the length of the torque wrench with an extension (making it longer from handle to tip), the torque setting must be lower than the desired torque value. Where the extension makes the wrench length longer (handle to tip), here's a simple formula: Divide the length of the torque wrench (from center of handle to center of drive head) by the new length (center of handle to center of the extension). Then multiply that result by the desired torque value. Let's say that you want to achieve a value of 60 ft-lb, and your wrench measures 12" long, but you've added a 1" extension. 12 divided by 12 + 1 x 60 = 54.380, so you would adjust the torque wrench to 54 ft-lb.

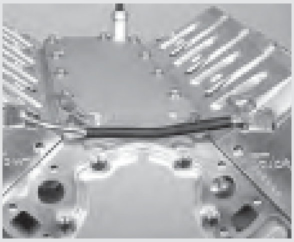


181. In addition to adhering to torque values, always follow the correct tightening pattern (sequence). This is important with any cylinder head, and especially for aluminum heads. The objective is to achieve an even distribution of clamping load across the head. If unevenly tightened, you stand a very good chance of having gasket leakage down the road as a result of head deck warpage.



182. Each end of each cylinder head features a steam hole that ties into the heads' water jackets. In this photo, my finger points to a steam hole. The hole to the right is the threaded mounting hole for a crossover pipe fitting or block-off fitting.

183. The front-mounted crossover pipe connects the two heads together and allows the heads to share a common steam evacuation path to accommodate the OE vehicle system. The tube that enters the steam hole is fitted with a sealing O-ring.



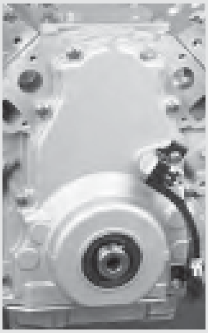
184. Here's a crossover pipe installed at the front of this LS2 engine. Racers or street rodders generally just block these steam holes off or plug the exit pipe with a rubber cap and clamp.

185. Individual block-off fittings are available from GM.

186. Here a block-off is installed on the rear of a cylinder head. The rears are always blocked off.

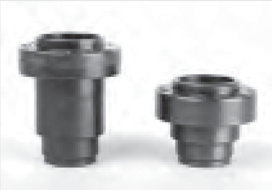
187. In case your block-off fitting is missing its O-ring, GM and aftermarket gasket sets also offers a sealing gasket/plate that sandwiches between the head and block-off.

188. Here's a new front cover (purchased from SDPC). An elastomeric sealing bead is pre-installed. If your cover is a used unit, you can use a metal-cored gasket from your gasket kit that features a sealing bead on both sides.

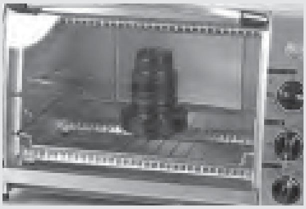


189. The front cover is installed with eight 8mm x 1.25 bolts. Instead of using oh-so-boring OE bolts, I chose ARP polished stainless steel 12-point bolts (P/N 434-1502).

190. Instead of using the one-piece cast OE crank balancer, I upgraded to an ATI setup that features a separate billet CNC-machined mounting hub, a serpentine-belt-ready balancer, all fasteners and an optional AC pulley. Since I didn't care about an AC system, I didn't both with the optional pulley.



191. ATI offers a range of hub lengths and offsets to accommodate all LS-equipped production vehicles (cars and trucks). Check their catalog or website for your application. If you're planning to use your LS engine in a swap (streetrod, etc.), determine where you want your damper fore/aft position and contact ATI for the appropriate length hub adapter.



192. Just like the OE damper, the ATI requires an interference fit onto the crank snout (the ATI hub adapter is keyed as well, for those who wish to install a locating key pin to their crank snout…advisable for hard acceleration hits with nitrous or a blower). Instead of cold-pressing the hub adapter onto the crank snout, ATI advises heating the hub adapter prior to installing in order to slightly expand the hub adapter's bore. A convection oven at 200 degrees F works well.

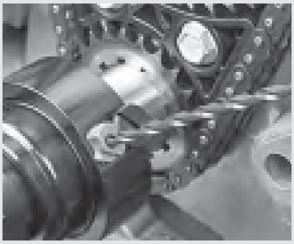
193. With the hub adapter hot and a light smear of moly on the crank snout, push the hub adapter onto the crank snout with a bit of hand force. In order to fully seat the damper hub, install a damper bolt and tighten the bolt to 235 ft-lb. If you plan to use an OE damper bolt for final assembly, use one for seating the damper, and a virgin bolt for final assembly. Since I was using an ARP damper bolt, I snugged that bolt to 235 ft-lb and I was done. The OE damper bolt (according to GM specs) requires a tightening procedure of 110 ft-lb at first, then backing off one full turn, then re-tightening to 35 ft-lb, then tightening an additional 110 degrees. Geez. Just buy an ARP damper bolt. It's stronger and you don't have to go through multiple steps.

194. Once the hub adapter has been installed, install the balancer to the hub adapter using six supplied flat-top 5/16" x 18 x 1" screws. Apply thread locker to the threads and tighten these screws to a value of 16 ft-lb, using a T40 torx bit.

195. The ATI Super Damper features laser etched timing marks and is a precision-machined piece of automotive art. Much more precise and does a better job of reducing crankshaft harmonics as opposed to the OE piece.

196. While LS crankshaft dampers are generally interference-fit with no locating key, you can add a key to insure that the damper won't rotate during engine operation. This is probably only necessary if you plan to hit some heavy inertia loads (nitrous injection, supercharger, etc.). In order to accomplish this, ATI offers a crank damper drilling fixture kit that includes a guide mandrel, a drill, reamer, reamer guide and round key pins.

197. The drilling mandrel features a drill guide that is secured with an adjacent screw head.

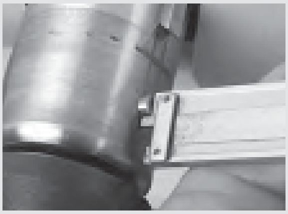


198. This photo shows the drilling fixture mounted to the crank snout for illustration purpose only.

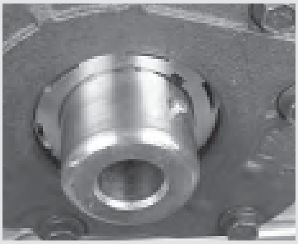
199. If the damper key pin drilling procedure will be done with the crankshaft in the block (obviously not preferred), the front of the engine block must be shielded to prevent particles from contaminating the engine. With the installer mandrel in place and secured with a damper bolt, a 0.1690" hole is drilled into the crank snout, all the way through to the snout centerbore.

200. Next, the hole is reamed to 3/16", using the kit's reamer on an electric drill, in a single pass.

201. The new key pin hole must be in line with the existing crank gear key, to allow installation of the oil pump's keyway, which will pass over this pin and engage on the crank gear's key. This will also make it easier to remove the crank gear at a later date. Here you see marks that were made before drilling to achieve this alignment.

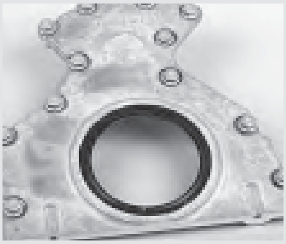


202. One of the kit's 3/16" pins is tapped into the drilled hole and is set at an exposed height of 0.093". Here we check the height with the depth-gauge of a caliper.



203. While you can remove the new key pin and reinstall it after the oil pump is installed, locating the new pin in line with the existing crank gear key allows you to service the oil pump without the need to mess around with the new pin.

204. The rear crankshaft seal is a one-piece round seal that installs into the rear cover. The inside of the seal rides on the crankshaft's rear flange. However, if the seal (already installed in the rear cover) is simply pushed onto the crank, the seal's front lip will fold rearward, resulting in an oil leak. A white nylon installation tool (seen here inserted into a seal) is needed. This holds the seal's inside lips in proper orientation while the seal is slid onto the crank. This white nylon seal installer is usually supplied with a new replacement seal. If you buy a new rear cover with the seal already installed, you may or may not have this nylon tool. If not, they are available at GM parts counters or any auto parts store.



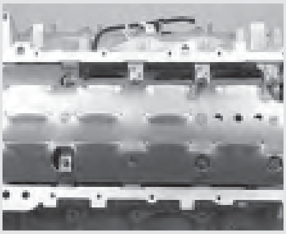
205. Here's a new rear cover with the rear main seal already installed (as purchased from SDPC). The cover secures to the rear of the block with 12 bolts.

206. Here's a rear cover with an aftermarket cover seal (this one from MAHLE, included in their Victor Gaskets engine kit). Instead of two individual O-ring strip seals, this features a metal carrier with both upper and lower seals. This replacement seal for the rear cover is much easier to install compared to the individual seals from GM.

207. Although it may contradict conventional thinking, do not lubricate the rear main seal of the crank flange before installing the rear cover and main seal. The seal should be installed dry to insure proper seal seating. With the rear cover carefully aligned, push the cover to the block, allowing the nylon installer tool to be pushed out as the seal begins to slip over the rear crank flange. Once seated, don't pull the rear cover away from the block, as the seal lip will fold when you push it forward again. If in doubt, or if you see that the seal lip has folded out, remove the rear cover, re-insert the nylon installer tool and try again.

208. Once the rear cover is pushed up against the block, gradually tighten the rear cover bolts. Place a straightedge over the block's pan rail and rear cover bottom to make sure that the cover is straight and relatively flush with the block pan rails.

209. Rear cover installed. Rotate the crankshaft and observe the rear seal and verify that the seal lip has not folded outward.



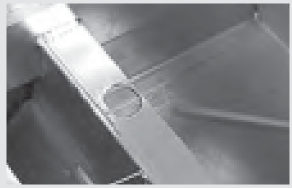
210. Instead of using a plain OE oil pan assembly, I opted for a Moroso setup. Here the Moroso windage tray is installed. This mounts to the main cap fasteners. OE main cap bolts feature extended stud tips to accommodate the windage tray; the ARP main cap studs I used provide enough bare stud to also mount the tray.

211. Moroso's aluminum sheet metal oil pan (P/N 20141) is fabricated of lightweight aluminum (the OE pan is cast alloy) and Tig-welded. This reduces weight and provides a stronger pan construction as well. This model (Moroso offers several for the LS) features –10 AN tubes and fittings for easy connection to a remote-mounted oil filter.

212. This front view shows the windage tray mounted to main cap studs (over top of the nuts that secure the main caps, with tray secured by additional 10mm x 1.25 nuts and loc washers). Note: the OE main cap bolts feature smaller 8mm stud tips for windage tray mounting. Since the tray mounting holes were initially drilled to accommodate the OE studs, I enlarged the holes to fit over the larger ARP 10mm studs.

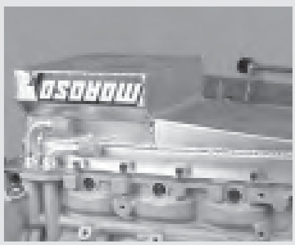
213. The oil pickup tube mounts to the oil pump with a single-bolt tab. A 6mm x 1.0 bolt secures the mounting tab to the pump body (tightened to 106 in-lb). An O-ring must be placed on the pickup tube tip. The O-ring engages into the oil pump inlet counterbore. If reusing an original pickup, be sure to install a new O-ring. A new O-ring was included in my Victor Reinz engine gasket kit and with my Moroso pump.

214. Once the windage tray is installed, check oil dipstick fit. It may be necessary to notch the tray for dipstick clearance. Mark the area to be notched with a marker. Remove the tray, grind a notch, clean the tray and reinstall it. Recheck dipstick clearance.



215. I needed to cut a relief hole in the oil pan's sump bridge for dipstick clearance. I applied a piece of bodyshop masking tape to the bridge and installed the pan temporarily. I then inserted my dipstick and wiggled it around a bit. With the pan removed, I could see the area of required relief. After the cut, I cleaned the pan and final-installed.

216. Before installing the oil pan, install the front engine cover (the cover may also be installed after the pan is mounted). I prefer to have both front and rear covers in place so that I can check squareness of the cover bottoms to the block pan rails.

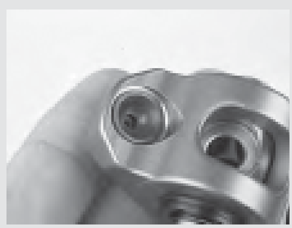


217. Rotate the engine upside down for easy oil pan installation.

218. The oil pan gasket (from my Victor Reinz kit) is a metal core with a formed in place elastomeric sealing bead on both sides. No is prep needed.

219. The Victor oil pan gasket features all sealing beads required, so even though you may be tempted to dab some RTV, don't…there's no need to add any additional sealant.

220. The LS oil pan installs using eleven 8mm pan rail and front cover bolt locations and three rear cover 6mm x 1.0 x 20mm locations. I used 8mm x 1.25 x 20mm socket head cap screws for my pan rail and front cover holes, with the exception of the rearward left side, just above the –10 AN oil tubes. Because of the close location of an oil tube, there wasn't room to wiggle a bolt into place, so for that location, I installed an 8mm x 1.25 stud. The stud needs to protrude no more than 0.750" from the block's pan rail surface. I secured the pan at the stud with an 8mm x 1.25 nut and lock washer. Tighten all 8mm bolts to 18 ft-lb and the three rear 6mm bolts to 106 in-lb).



221. Now we can move on up to installing the valvetrain. The Harland Sharp aluminum roller rockers I chose for Project LS2 feature hardened pushrod cups. Notice the oil feed hole in the cup.

222. Each rocker features an individual mounting pedestal that rests onto the cylinder head (designed for the Trick Flow cylinder heads; this eliminates the need for the OE one-piece pedestal mount bar).

223. Each pair of the Harland Sharp rockers is bridged together by a common pivot shaft in order to insure rocker alignment. This is referred to a shaft-mount.

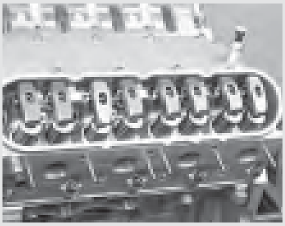
224. This underside view shows the hardened pushrod cups and the shaft bridge. Notice the ball pivot at the shaft pivot location. With bearings at both the rocker pivot and at the valve tips, these are true full-roller rockers. The reduced friction (as compared to the OE style) helps to minimize heat and friction, which theoretically enhances engine power output.

225. Apply thread-sealing compound to the pedestal bolt threads. Since the intake rocker bolts are slightly exposed to the intake ports (the tapped hole partially enters the port), a thread sealer is a good idea to prevent vacuum leaks. I applied Hylomar sealing paste.

226. An 8mm hex wrench is required to install the Harland Sharp socket head cap screws. This bolt passes through the center hole of the pivot ball and the pedestal mount and screws directly into the cylinder head. Remember to install the pushrods prior to mounting the rocker arms. It's best to rotate the crank to place the camshaft lobes on or near the base circle for each rocker location. This will avoid fighting valve spring force as you install the tighten each rocker arm bolt. Be sure to oil the pushrods before installing. Also, douse each rocker arm (pushrod cups and all bearings) with oil before installation. Place a dab of moly assembly lube on each valve stem tip.

227. During test fitting, rotate the crank and inspect the path of the rocker's roller tip to the valve tip. The roller bearing should be reasonably centered (L-R) on the valve tip, and during rocker operation, the bearing should sweep through the center of the valve tip.

228. The Harland Sharp 8mm rocker bolts are tightened to 22 ft-lb (the same spec used for OE rocker arm bolts).



229. This view shows the LH bank of rockers fully installed. In addition to providing a higher level of performance, they sure do look cool.

230. While stock LS pushrod length is 7.400", whenever you change to an aftermarket camshaft, lifters, cylinder heads, rockers, etc., always measure for pushrod length. Variables that can alter necessary pushrod length include cam base circle, lifter length and cylinder head height. Once the cylinder heads have been installed (with gaskets), choose one cylinder location as your reference. Rotate the camshaft to place the intake lobe at its base circle (the lowest section of the lobe, opposite its peak). Using a checking pushrod (an adjustable mock pushrod), install the checking pushrod and its rocker arm. Adjust the pushrod until the rocker achieves zero valve lash. Carefully remove the pushrod and measure its overall length. Perform the same task at the exhaust lobe. Take these measurements a couple of times to make sure that your measurements are correct. The LS pushrods feature ball ends at each end, so they're easy to measure using a long caliper. Custom length pushrods are available, either from a speed parts retailer or direct from the pushrod manufacturer.

231. In the Project LS2 build, the required pushrod length was 7.500", 0.100" longer than stock. These Trick Flow pushrods are laser etched with length and wall thickness. The pushrods I used feature a hefty 0.080" wall thickness and hardened tips.

232. An old-school method to check piston-to-valve clearance, is to wipe the piston dome clean and dry and apply a lump of modeling clay to the potential valve contact areas. After the heads and valvetrain have been installed, rotate the crankshaft two full revolutions. Then remove the cylinder head to examine the crushed areas of the clay. Here you can see trace impressions of the intake and exhaust valves.

233. Using a razor blade, carefully cut a cross section from each valve's pocket area. This provides a clear view of how far the valve is getting to the piston.

234. Minimum valve-to-piston clearance should be at least about 0.100" for a street application (race engines often run tighter to squeeze every bit of power). This provides adequate clearance even when things heat up and slightly expand. In this test-fit inspection, I found more clearance than was necessary, but since I was building this for the street, I let it go. This engine still produced 625.4 hp.

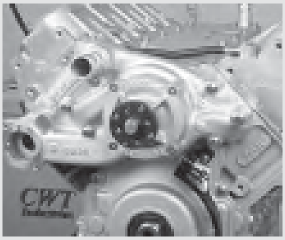
235. Edelbrock makes a great aluminum water pump for the LS engine, featuring better bearings and seals. It bolts right up with no mods.

236. When pre-fitting the water pump, the upper left timing cover bolt head might initially seem to pose a interference problem at the rear of the pump, but the Edelbrock water pump that I chose had already been spotfaced for bolt clearance.

237. Water pump mounting gaskets (provided in the Victor Reinz set) are aluminum with elastomeric seals, and are reusable (providing you don't damage them).

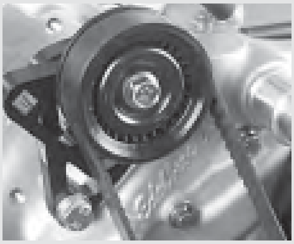
238. Here's the upper left timing cover bolt location that I mentioned earlier. Edelbrock already spotfaced the rear of the water pump to clear this bolt head.

239. This overhead view shows the belt lineup from the damper to the water pump pulley. The Edelbrock water pump pulley has plenty of extra frontal real estate to accommodate additional belts if needed (for accessories).

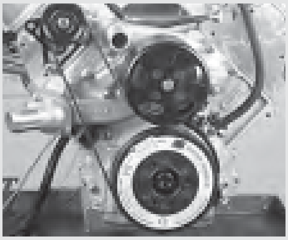


240. Fit and alignment of the Edelbrock water pump was superb. And it looks a bunch nicer than the OE pump (Edelbrock also offers this pump fully polished, by the way). The six 8mm water pump mounting bolts are tightened to 18 ft-lb.

241. The Comp Cams tensioner/idler pulley offers a decent range of adjustment for belt tension and secures very nicely when the set bolt is tightened. The tensioner/pulley includes a pair of aluminum spacers, if needed for belt alignment. If you use the spacers you need a pair of 10mm x 1.5 x 55-60mm bolts to mount the unit to your cylinder head. If you don't need the spacers, use 10mm x 1.5 x 40mm bolts.



242. The Comp Cams tensioner/pulley features a handy square drive in the outer ear to accommodate a ratchet. Loosen the adjuster bolt, pull back on the ratchet to achieve required belt tension and tighten the set bolt.

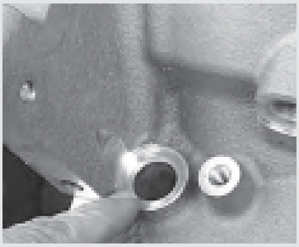


243. On Project LS2, I only planned to run the water pump for the engine's dyno session, so the belt setup was very simple. With my ATI damper, Edelbrock water pump pulley and Comp Cams tensioner/idler, I chose a 43.5" serpentine belt (Goodyear Poly V Gatorback 4060435). Obviously, you'll need a longer belt if you plan to run other accessories such as power steering, alternator or AC).

244. The knock sensor includes a captive 8mm x 1.25 mounting bolt.

245. The knock sensor bolt threads into a blind boss on the lower left side of the block. This will sense cylinder detonation and will signal the ECU to retard timing.

246. The crankshaft position sensor features its own mounting bracket tab and sealing O-ring. Be sure to lube the O-ring before installing.



247. The location of the crankshaft position sensor is towards the rear of the block's right side. This aligns with the crankshaft's reluctor wheel (tone wheel).

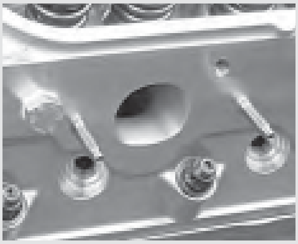
248. Install the crankshaft position sensor with the mounting bracket aimed forward to align with the threaded mounting hole in the block.

249. The crankshaft position sensor is secured with an 8mm x 1.25 bolt. Use a short bolt, about 10-15mm long, since this blind hole is only about 19mm deep at the most.

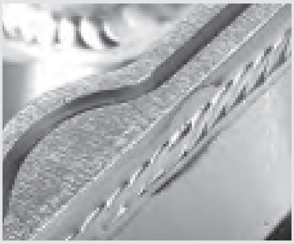
250. Coolant temperature sensor (left) and oil pressure sensor.

251. The coolant temperature sensor mounts to the left cylinder head, in the threaded port immediately forward of the No. 1 cylinder exhaust port. The threads are straight, not tapered, size 12mm x 1.5. Be sure to apply thread sealant before installing (a new sensor will likely feature pre-coated threads).

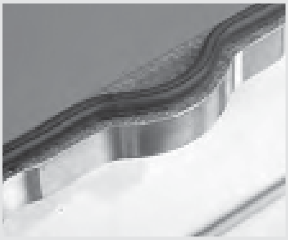
252. In order to plug the same threaded coolant hole on the right-side cylinder head, you can either use a 12mm x 1.5 straight-thread plug from an old OE head, or you can use a 12mm x 1.5 bolt. Install a sealing washer (copper or aluminum crush washer, or an O-ringed Stat-O-Seal) and thread sealant. Unfortunately, you can't buy an OE plug as an individual part (only available with a new GM cylinder head).



253. This photo shows the plugged water port on the right side cylinder head, immediately behind the No. 8 cylinder exhaust port. This isn't a hillbilly fix…it works just fine.



254. The Moroso valve covers I chose feature CNC machined sealing grooves.

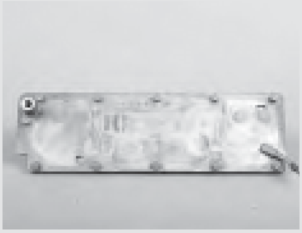


255. Elastomeric sealing gaskets are provided with the covers. The seals feature a barbed installation extension that pushes and locks into the machined groove. It'll stay with the cover, which is handy for those who plan to regularly check their valvetrain.

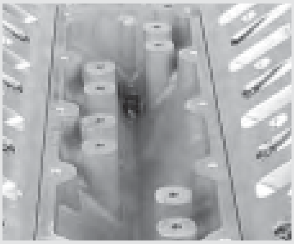
256. Mounting the valve covers to the heads requires the OE-style mounting bolts that feature rubber top grommet seals. These bolts also feature a stopper (above the bolt threads), to prevent over-tightening.

257. The mounting bolts drop into the cover's tubes, and the bottom lip of the bolts' grommets secure the grommet inside the cover tubes.

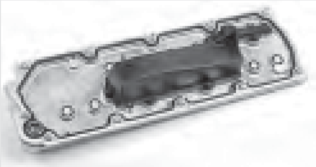
258. Valve cover bolt access is recessed in the bolt tubes. Each valve cover is secured with four bolts.



259. The OE top valley cover is a cast aluminum cover that bolts down to the top of the block between the heads. An oil pressure port is at the left rear of the cover and a PCV nipple is at the right front.

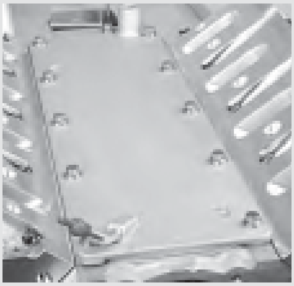


260. The LS2 block features eight oil towers sometimes used for the cylinder-on-demand system that knocks out select cylinders at low-load conditions for better fuel economy. Since, we're building a street thumper here, that's the last thing we need.



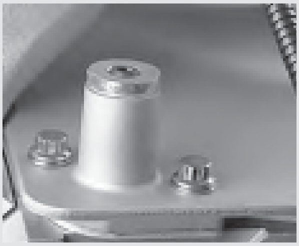
261. If you want to block off and seal those oil towers in the block valley, buy top cover GM P/N 12570471, included in Scoggin Dickey's block completion kit P/N KITLS2CK-1. This features O-ring seals that take care of this.

262. The GM top cover features O-rings for sealing the oil towers and a sealing bead around the perimeter.

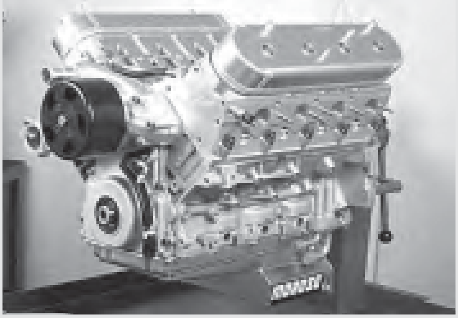


263. The valley cover secures to the block with eleven 8mm bolts. I used ARP stainless steel 12-point bolts and stainless washers.

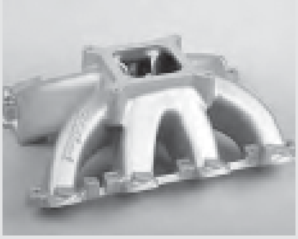
264. The right front of the valley cover features a PCV system connection tube.



265. If you don't plan to use a GM wiring harness and gauges, you can install a 16mm straight-thread plug (available at a GM dealer P/N 11588949 one of the block water jacket screw-in plugs that features a female hex). You can drill and tap the plug (drill into the center of the female hex hole) to 1/8" NPT. The 1/8" NPT hole will then accept a common oil pressure sender connection. Shown here is a 16mm straight thread plug, already drilled and tapped at the center to 1/8" NPT and installed on the valley cover oil pedestal. I temporarily installed a 1/8" NPT plug just to seal the hole during transport of the engine to the dyno shop.



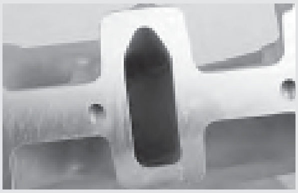
266. My finished long-block LS2, ready for induction, sensors and coils.



267. If you decide to run a carburetor instead of the OE multi-port fuel injection, a single-plane intake manifold. such as the Edelbrock Super Victor Jr. P/N 28097, is the way to go. It is capable of handling over 600 hp and an operating range of 3500 to 8000 rpm. Edelbrock also offers this manifold with or without injector bungs (if you wanna add nitrous). I used the Victor Jr.

268. The Edelbrock Victor Jr. manifold features an open plenum with dividers for great flow and even distribution.

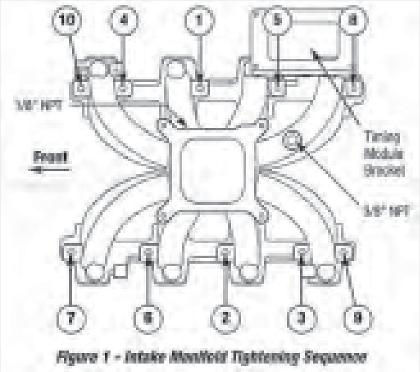
269. Notice the bosses at the ends of the intake runners. These may be drilled and tapped for nitrous injection is you so desire.



270. The Victor Jr. intake ports are cathedral shaped in LS2 fashion. Surprisingly, they port-matched to my Trick Flow heads so well that I didn't feel the need to perform any grinding to achieve port matching.

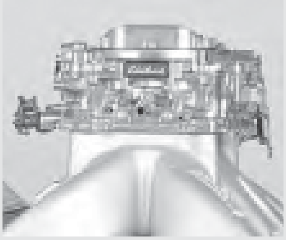
271. Because of the particular valley cover I chose, the Edelbrock Victor Jr. intake manifold contacted the edge of the valley cover, preventing manifold seating.

272. To easily remedy the situation, I simply marked the interference areas on the valley cover, removed the cover and machined relief chamfers on the cover's outer edges. This was easier and quicker than grinding material from the underside of the manifold runners.



273. When installing any aluminum component, tightening sequence is important. Here's Edelbrock's tightening sequence for their manifold. All mounting bolts were snugged to 11 ft-lb.

274. With the valley cover edges chamfered, the manifold fit perfectly.



275. I chose the Edelbrock 800cfm Performer carb for my particular build (P/N 1412). This carb provided surprisingly crisp throttle response. With the LS platform, it's easy to switch back and forth between EFI or carburetion.

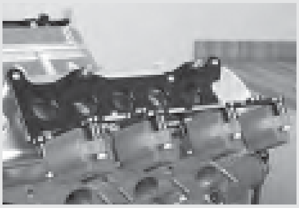
276. MSD (and others) offers LS coil packs for both 24-tooth and 58-tooth reluctor wheel applications. Normally an LS2 would use a 58-tooth wheel, but since I installed a 24-tooth wheel, I went with MSD's P/N 8245 coils.
The MSD coils deliver up to three times the spark energy of stock coils, as well as delivering multiple sparks. Maximum voltage is 44,000 volts. Primary resistance is a mere 0.570 ohms.

277. One downfall (aside from appearance) of the stock coil pack mounting is that the coils deny access to the valve cover bolts. Moroso offers this really nice hinged coil pack mounting bracket assembly to address the issue.

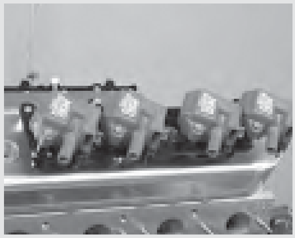
278. The black-anodized billet aluminum baseplate bolts to the valve cover. Access holes in the baseplate provide easy valve cover service. The top plate (to which the coils mount) hinges on the baseplate. Fixed hinge pins allow easy removal of all four coil packs as an assembly.

279. Here the top hinged plate is engaged to the baseplate's hinge pins.

280. This close up shows the hinge pin engagement. Simply slide the top hinge plate forward to disengage and remove the entire row of coil packs.



281. Here the coil packs are installed to the top plate and hinged away from the base plate.



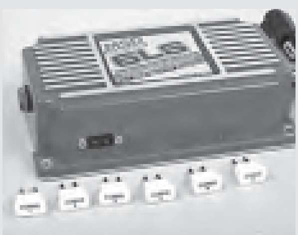
282. Here the top plate is hinged upwards and secured to the baseplate with two nuts.

283. With plug wires disconnected, the entire row of four coil packs (along with their hinge plate) is easily removed. No need to fiddle with each coil pack.

284. Even if you elect to run a carburetor, you still need the coil packs, and you'll need a timing controller to fire the coils (unless you decide to run a distributor, which we'll discuss shortly).

285. Whether you run injected or carb'd, you need a coil wiring harness. These are available from any GM parts dealer.

286. If you do run a carburetor with coil packs, MSD offers a very slick timing control module and wiring harness. Plug this into the injector harnesses and a couple of sensors and you're ready to tune.



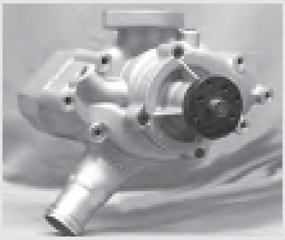
287. The MSD timing controller includes six preprogrammed timing curves. Just plug and play.

288. Each timing curve plug-in module is labeled. MSD's instructions provide the details of each module's characteristics. However, you can create your own custom curves by using the software CD provided in the kit. It's not complicated at all. Plug a laptop or desktop PC into the timing control unit and map your own timing curve. We did this during my LS2's dyno session, and it was easier than I thought it would be.

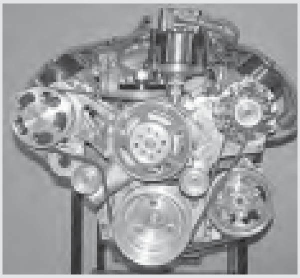
289. Yes, it is possible to run an LS engine not only with a carburetor, but with a distributor (completely eliminating the individual coil packs and timing controller). In fact, this setup was mandated by a Camping World oval track racing series. However, it's expensive. First you need the GM distributor adapter (shown here). This replaces the OE timing cover and accepts a Ford small-block distributor. Since the LS-style camshaft has no drive gear to run a distributor, the adapter kit includes a stubby gear drive that bolts onto the nose of the LS camshaft. Wegner Racing makes this adapter for GM.

290. Here's a sample adapter housing, camshaft gear drive and distributor. Courtesy Wegner.

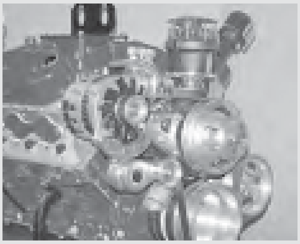
291. This distributor is earmarked for a Ford, but features the convenience of a GM type HEI integrated coil. Yes, it works with the LS, as the adapter kit's cam drive gear and adapter housing distributor depth was designed with the Ford unit in mind.



292. If you plan to run a distributor, you'll discover very quickly that the distributor adapter housing won't clear the OE style water pump, so you'll need to buy a dedicated Stewart water pump designed specifically for this application.

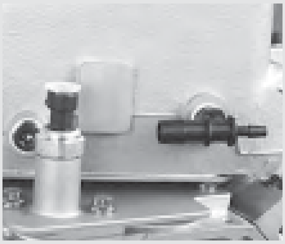


293. You'll also need a completely new pulley setup to align with the new location of the water pump pulley. (Courtesy Wegner).



294. In order to run an LS engine with a distributor, plan on spending somewhere between $1,000 to $2,000, depending on the pulleys and the distributor of choice. If you wanna go for it, be my guest. But it's a whole lot cheaper (and easier) to run a carb with the coil packs and the MSD timing controller.

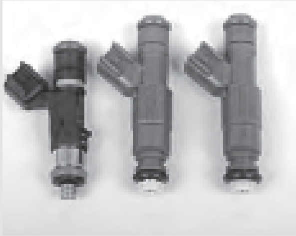
295. There are a number of multi-port electronic fuel injection systems currently available for the LS platform (Edelbrock, FAST, etc.). As an example, here's a injection manifold from Professional Products (their Power Plus Typhoon model P/N 52063). It's a cast aluminum manifold that accepts a 90mm throttle body. Blank bosses are provided if you elect to install nitrous injection.



296. The rear of the injection manifold clears the oil pressure tower with ease. A vacuum port at the rear accepts a MAP sensor.

297. There are many choices with regard to fuel injection plumbing. An example is Professional Products' billet aluminum fuel rail kit.

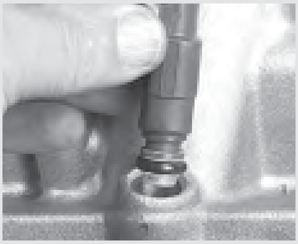
298. The injectors I picked for our injected version of Project LS2 are Bosch P/N 0280 156 127. These are the taller LS1 style, measuring about 2.917" tall.



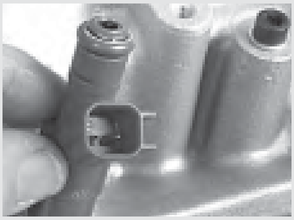
299. This photo illustrates relative height differences. At the far left is an LS2 injector at 2.575" tall and two LS1-style injectors at 2.917" tall. O-ring diameters vary as well, depending on the intended manifold fit.

300. If you want to run the taller LS1-style injectors with an LS2-style manifold, you need an adapter kit. Katech's adapter kit is shown here. The fuel rail bracket spacers are 0.500" tall. The bolts are 6mm x 1.0 x 30mm and the O-rings provide the increased outer diameter of the LS2 requirement (to fit the LS2 manifold ports) at about 0.586" O.D.

301. An intake manifold that is designed for LS2 injectors features a larger diameter injector port as compared to an LS1 manifold, so if you plan to run LS1 style injectors in an LS2 manifold, you need the larger-diameter 0.586" O-rings.



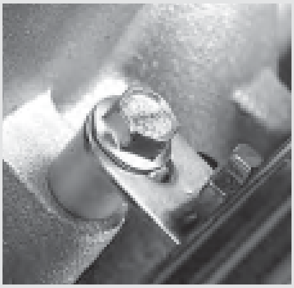
302. Be sure to lubricate the injector O-rings (top and bottom) with lithium lube before installing, to prevent O-ring damage.



303. Once seated, gently rotate the injector to verify proper O-ring seating.

304. All eight injectors installed in the manifold and ready for fuel rails. Be sure to rotate the injectors to orient the connectors outboard to provide wiring harness access.

305. If you're running the taller injectors, the 0.500" tall spacers from the Katech adapter kit are placed between the fuel rail brackets and the manifold. Note that the long slot side of the fuel rail brackets must be placed at the manifold bosses.



306. Closeup of a fuel rail bracket with 30mm bolt and 0.500" spacer.

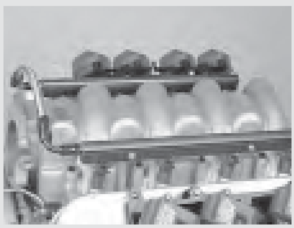
307. The front of each aluminum fuel rail accepts a 3/8" NPT to –6 AN male/male fitting. This allows connection of the –6 crossover hose that plumbs the two fuel rails together. Note the injector connector aiming outboard for wiring harness connection.

308. Whenever working with –AN hose ends, always use an aluminum –AN wrench to prevent burring/marring the aluminum surface. It's best to buy a set of aluminum –AN wrenches that cover –6, -8, –10 and -12 (most common sizes that you're likely to deal with). Manufacturers include Fragola, Earls, Russell, XRP, and Aeroquip.

309. The front ends of the fuel rails are plumbed together using –6 AN 90-degree hose ends and –6 reinforced high pressure hose (stainless braided high pressure hose seen here).

310. The rear end of the right side fuel rail is plugged with an open 3/8" NPT fitting. You can either install a 1/8" NPT plug or you can use the 1/8" NPT center hole to accept a fuel pressure gauge.

311. The rear of the left side fuel rail is plumbed with a 3/8" NPT to –6 male/male 90-degree fitting to accept the –6 fuel inlet hose.



312. Once both fuel rails are installed, and before fully tightening the fuel rail mounting brackets, rotate each injector to verify seating, then carefully tighten the mounting bracket bolts.

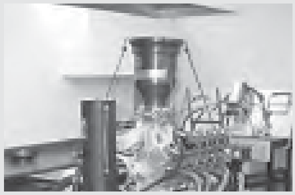
313. The fuel inlet hose features a 90-degree –6 male to locking-flare fitting. This allows connection to an OE type fuel line.

314. At this point, the engine can be easily converted from EFI to carburetor by simply switching intake manifolds.

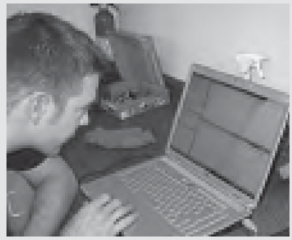
315. The Edelbrock LS EFI system is another example of a complete and ready to install EFI performance upgrade for the LS platform. Complete with controller, making it easy to install in a vehicle that was not originally equipped with an ECU.

316. Here's Project LS2 at Gressman Powersports (Fremont, OH), being set up on their Superflow engine dynamometer.

317. The cooling tower (black vertical tube in foreground) pressure-routes water through the engine's cooling passages, so no finned radiator is needed for dyno operation.

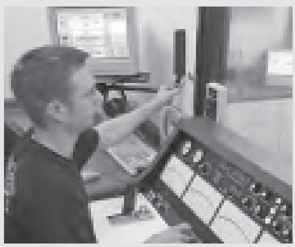


318. A huge air inlet ducts air to the air inlet stack that's fastened to the carb. With ignition connected and water temperature, oil pressure, ambient air temperature, fuel pressure, exhaust gas temperature and barometric pressure monitored, she's ready to fire.

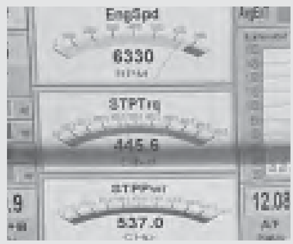


319. Here Scott Gressman plays with the MSD software (with laptop USB-connected to the MSD timing controller), plotting the initial timing curve.

320. Since we were connected to the MSD timing control module and using their software, Scott was able to quickly alter timing curves between runs.

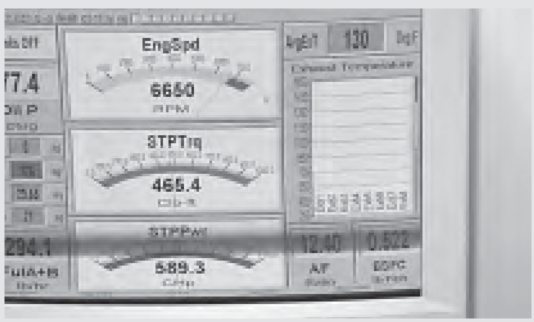


321. Scott controls engine operation at his dyno control center.



322. Our very first run recorded a bit over 537 hp and 446 ft-lb at 6330 rpm.

323. The second run (seen on this screen) revealed in excess of 560 hp.



324. After playing with timing through several more runs, our final pulls netted consistent 625.4 hp and 534 ft-lb. Unfortunately, it's darned near impossible to capture a monitor screen with a digital camera at exactly the moment you want, so the screen here shows 589 hp at 6650 rpm. Throttle response was quick. And we achieved a legitimate and officially recorded 625.4 hp on mere 92 octane pump gas and no nitrous or forced induction. See the complete chart on page 129.

Chapter 10

Camshafts

The cam on the left is a standard firing order big-block Chevy. The cam on the right is a 4/7 swap cam. Notice that the second and fourth lobes from the rear on the 4/7 are opposed vs. the standard cam. This is an easy way to identify a 4/7 swap cam. Courtesy Comp Cams.

All LS engines (Gen III and Gen IV) feature a different firing order as compared to previous-generation Chevy engines. The earlier Chevy small block and big block engines featured a camshaft designed with a firing order of 1-8-4-3-6-5-7-2. As a performance upgrade, all LS engines feature a camshaft with a firing order of 1-8-7-2-6-5-4-3.

Instead of simply accepting this as face value, we need to understand the reasons for the "different" LS firing order. In racing applications, some engine builders, instead of using the standard early-generation firing order for the earlier small-block and big-block Chevy engines, have routinely turned to "special firing order" (SFO) camshafts by swapping cylinders 4/7 and/or 2/3. Today, the LS engines take advantage of this move as a standard design feature for the entire series of LS engines. Basically, the GM engineers decided to move to the new firing order based on what has been developed over the years by race engine builders. What was once considered as a "special" firing order camshaft by racers is now the standard in the LS production engine.

I wanted to point this out, along with the accompanying explanation of camshaft firing order cylinder swaps so that you can better understand why the LS engine uses a different firing order than earlier small-block and big-block Chevy engines.

In this chapter I'll discuss the unique LS camshaft firing order design, and offer camshaft specs and recommendations offered by both GM Performance and a variety of performance aftermarket camshaft manufacturers.

In certain racing applications, a special firing-order camshaft (SFO) has been used for years as a tuning aid, allowing the competition engine builder to further address combustion heat and crankshaft disturbance (harmonic) issues. In essence, the goal in changing firing order is to create a smoother running engine and more even fuel distribution, with enhanced crankshaft and main bearing durability. In the process, horsepower gains may be achieved as well (no guarantees here, but in most cases, a slight power increase does result).

When designing the LS engine, GM engineers decided to move to this previously-special-order-only firing order camshaft in order to optimize performance.

Experimenting with special firing orders (based on camshaft design) isn't limited to the advanced race engine builder. GM adopted a special firing order in their LS engine series (Gen III & IV), which feature a 4/7 and 2/3 swap for the same reasons…to smooth out the harmonics in the pursuit of greater engine durability and to potentially generate more power.

Shown here are three Erson big-block Chevy cams (from left to right): a standard firing order, a 4/7 swap and an LS firing order cam.

What Benefit Does This New Firing Order Provide?—The primary reason to address (and alter) cylinder firing order is to achieve a smoother-running engine (resulting in a smoother, more lineal acceleration ramp), with less harmonic effect and deflection on the crankshaft and the main bearings. Which engines can benefit from this? In theory, virtually all. Typically, the engines that can realize the greatest benefit include those powerplants that are intended to run at or near peak rpm levels for long periods of time, such as oval track, road race and marine engine applications, as well as engines that are called upon to produce maximum power in a very short period of time (drag race). In a V8 configuration, a 4/7 swap theoretically reduces crankshaft torsional vibration for smoother dampening and (potentially) more power.

By swapping firing order positions, one of the primary goals is to reduce crankshaft harmonic effects caused by two adjacent cylinders firing in succession (let's call these "companion" cylinders). By strategically relocating these companions, it's possible for the engine to idle and run smoother, and to reduce isolated hot spots (cylinder-to-adjacent-cylinder walls), and to even out fuel distribution, primarily in applications that feature a single plane intake manifold, and even more noticeably in tunnel-ram intake manifold applications.

As noted earlier, the "traditional" firing order for Chevy small- and big-blocks in automotive applications has commonly been 1-8-4-3-6-5-7-2. Each cylinder has a "companion" in the firing order. This companion cylinder will reach TDC at the same time as its counterpart, one on the power stroke and one on the exhaust stroke. These cylinders (paired as 1 & 6, 2 & 3, 4 & 7 and 5 & 8) can be interchanged in the firing order without altering the crankshaft. While some builders report seeing no power improvement, other builders claim to have achieved power gains by switching cylinders 4 & 7 (to create a new firing order of 1-8-7-3-6-5-4-2). This can enhance fuel distribution, especially in open plenum type intake manifolds, and reportedly can result in an added 5 to 10 horsepower.

According to engine builders at Reher-Morrison, Pro Stock drag engines typically take advantage of a 4/7 swap. By swapping #4 and #7 cylinders in the firing order, this eliminates the fuel distribution and heat problems caused by cylinders #5 and #7 firing in succession. With the revised firing order, the two end cylinders don't have to fight for fuel from the manifold plenum. The result, in many cases, is a measurable power increase (typically 8–10 hp, according to R-M) and a smoother, cooler running engine.

However, achieving this special firing order requires a specially designed camshaft (not achieved by simply switching plug wires). The camshaft lobes must be repositioned to accomplish this power stroke/exhaust switch. Years ago, this required making a special firing order camshaft from scratch, which was time-consuming (and naturally more expensive).

By taking advantage of today's CAD programs and CNC machining, however, special cams can be designed and fabricated in much shorter timeframes (also helping to reduce cost).

Cam Manufacturer Comments

We spoke with a few cam makers to obtain their views on this subject.

Erson Cams—Steve Tanzi at Erson Cams noted that a firing order change accomplishes that task of alleviating the problem of cylinders 5 and 7 firing next to each other (in a Chevy V8). However, Steve noted that this moves the problem to the cylinders 2 and 4 area (no matter what the firing order, you'll always have a pair firing in succession, either in adjacent cylinders or cylinders that share the same rod pin). However, the front of the block will generally cool more efficiently, so the "problem" isn't much of an issue.

Over the years, GM performed quite a bit of research in this area, beginning back in the days of the early Oldsmobile and Cadillac engines, and most recently the LS engine family. All along, the goal was the same…to smooth out engine pulsations and to create a smoother accelerating engine.

Smoothness of operation was always the target. If additional power resulted in the process, so much the better.

"The greatest benefits," said Tanzi, "are seen in oval track and road racing, because those engines run for longer periods of time. In a quarter-mile situation, you have only a few seconds to determine any gains. But, when a builder is trying to find any repeatable gains (even 1 or 2 hp), it's worth experimenting with firing order changes. It's common practice for many Top Fuel, Pro Stock and Comp Eliminator builders to take advantage of firing order modifications. Keep in mind though, that depending on the sanctioning body rules, firing order deviations may not be allowed, such as in IMCA Modifieds."

Crane Cams—Crane Cams' Chase Knight notes that Crane offers SFO cams at no extra charge. Order time for a custom SFO was about four days.

Applications included small-block and big-block Chevy, 429-460 Ford, Chrysler LA small block, Chrysler B blocks and Chrysler 426 Hemi.

Chase noted that "Regardless of what approach you take, you'll always have two cylinders firing next to each other (or two opposing cylinders that share he same rod pin). But, by swapping certain cylinder firing orders, you can more evenly distribute combustion pressures and resulting crankshaft loads to either generate more power, or to extend crankshaft, main bearing and crankshaft seal life, or both power and durability. There are so many variables, depending on factors such as intake manifold design, engine speed, type of use, etc., that the benefits are sometimes difficult to quantify. There are cases where no power improvement is evident on the dyno, yet on-track power is improved."

Comp Cams—Following are comments provided by Billy Godbold of Comp Cams. This is very insightful info, so I urge you to read this. I've provided this information in a question and answer format.

Q: A typical camshaft firing order swap of 4/7 seems to be fairly common today. Why is this firing order beneficial?

A: *There are three basic issues that engine builders or developers try to address with firing order as follows:*

Hot Spots in the Head and Block: *With a common pin V8 crankshaft, it is impossible to eliminate having adjacent cylinders fire subsequent to one another in the sequence. While this is unavoidable on a four-throw crank, you do have some choice as to which pair(s) fire together. The 4&7 firing order moves that hot spot from the 5&7 cylinders up to the 4&2 cylinders. Clearly, the front pair is easier to keep cool with a front mounted water pump than the back pair.*

Note that both the 4/7 swap cam (center) and the LS cam (right) both feature the second and fourth lobes from the front in an opposed position as compared to the stock firing order cam.

Main Bearing Issues: *Most engine builders see better bearing life and less indications of scuffing when going to the 4&7 swap. The LS firing order (the 4&7 swap plus an additional 2&3 swap) may be even better for bearing life. Again, firing pairs is what we are trying to change. Here I think the focus is on pairs that fire on the same pin, thereby focusing the force on the adjacent crank main bearings. Moving this to the back of the engine seems to be a good idea because, even with a crank dampener, the drive train is much better at dampening these forces than a small mass on the end of the crank. When we consider the power that can be gained with lighter weight, lower viscosity oils, bearing life becomes not only a durability, but also a power concern.*

Fuel Distribution: *Changing the firing order is one of the best ways to change the cylinder to cylinder fuel and air distribution in the engine. Just like throws on the crank and cylinders next to each other in the block or head, we have to deal with ports next to each other and across from each other asking the manifold for air right after one another. This creates a very dynamic system in the manifold plenum where pressure waves of air (and also fuel in a wet manifold) are moving from front to back and side to side. Changing the firing order definitely changes how the ports interact. Depending on the configuration, this can be the main plus or minus for an engine builder when they consider changing firing order.*

This view of the rear of the cams shows the same lobe orientation of the rear lobes on the stock cam (left) and the 4/7 cam (center), but the second and fourth lobes from the rear of the LS cam (right) are opposed as compared to the stock and 4/7 cams. These tips help to easily identify a 4/7 swap and an LS firing order camshaft.

Q: In what type of motorsports application is a firing order swap most helpful? (drag racing, oval track, road race, etc.)

A: *We have certainly seen the types of benefits engine builders look for with firing order swaps being beneficial across the board. You see them more in drag racing and road racing than in oval track, but that is likely a function of the sanctioning body rules. Certainly, OEM's competing in NASCAR try various firing orders before submitting a new engine to NASCAR because they know it will be tied down if it is accepted.*

Q: It's commonly said that a firing order swap (4/7 or the LS swap of 4/7 and 2/3) results in reduced crankshaft and main bearing deflection. Is this true?

A: *It simply has to do with neighboring cylinders firing subsequent and the subsequent force pulses due to the firing sequence.*

Q: As far as we are aware, SFO cams for small- and big-block Chevy include the 4/7 swap and the LS firing order. Are there any different firing order swaps that are applicable to other make of engines?

A: *On any even-fire, common-pin, 90-degree V8 application, a cam can be made to swap any of the cylinders that are four apart in the firing order. What may be the third most common order is called a "Bank-Bank" where you fire all the cylinders on one side and then the other. Simply swapping 2&3 (w/o 4&7) will give 1-8-4-2-6-5-7-3 with the each bank's cylinders firing all four before jumping to the other side. Some engine builders believe this helps traction limited and/or restricted applications. It may be that a particularly clever NASCAR engine builder used something like this at Daytona one year and this led to NASCAR not allowing ANY firing order changes…*

Firing Order (Small- and Big-Block Chevy)

Standard Firing Order:	1-8-4-3-6-5-7-2
4/7 Swap Firing Order:	1-8-7-3-6-5-4-2
OE LS Firing Order	1-8-7-2-6-5-4-3

Q: Are there any concerns or issues with regard to valve operation with the use of a special firing order camshaft?

A: *We have not measured a change in valve duration that we can trace to a firing order change.*

Q: How does an SFO cam benefit engine horsepower and/or torque?

A: *The power and torque changes vary depending on the intake manifold, fuel delivery exhaust system along with a host of other considerations. Improvements of 1–3% are actually quite common (much to my personal surprise). If you see changes greater than 3%, I would imagine you have either created or eliminated a major distribution problem that could have been addressed in another way (likely in the manifold).*

Q: Is it correct to assume that all SFO cams require the use of steel billet stock?

A: *Actually Comp Cams does have cast iron flat-tappet cores to make flat tappet 4&7 swap camshafts for small- and big-block Chevys. Also, most cam companies have two firing orders available for small-block Fords due to the factory 302 versus the later 351W (50.0 HO) firing order. That 351 firing order is basically Ford's version of the Caddy/LS1 4&7 & 2&3 GM firing order. There are also billet steel cores on the shelf for the common two Chevy and Ford firing orders readily available from Comp Cams. Most of the other firing orders require a very expensive custom core.*

GM LS Series Camshafts

2002–2004 LS6 Cam 12565308: Valve Spring 12586484, 204/218 dur @0.050", max lift 0.550/0.550 w/1.7 rockers, LSA 117.5 deg.

2001 LS6 Cam 12560950: Valve Spring 12586484, 207/217 dur @0.050", max lift 0.525/0.525 w/1.7 rockers, LSA 116

ASA Race Cam 12480110: Valve Spring 12586484, 226/236 dur @0.050" max lift 0.525/0.525 w/1.7 rockers, LSA 110

Hot Cam Kit 12480033: Includes springs 12565117 & retainers, 219/228 dur @0.050", max lift 0.525/0.525 w/1.7 rockers, LSA 112

GM OEM Camshaft Specificaitons

LS2

Intake Lift @Valve	Intake Duration @0.004	Intake Duration @0.050	Int Open @0.004	Intake Close @0.004	Intake Open @0.050	Intake Close @0.050
0.525	270	204	9 deg BTDC	81 deg ABDC	18 deg ATDC	42 deg ABDC
Exhaust Lift @Valve	Exhaust Duration @0.004	Exhaust Duration @0.050	Exhaust Open @0.004	Exhaust Close @0.004	Exhaust Open @0.050	Exhaust Close @0.050
0.525	275	211	65 deg BBDC	30 deg ATDC	37 deg BBDC	6 deg BTDC

LS3

Intake Lift @Valve	Intake Duration @0.004	Intake Duration @0.050	Intake Open @0.004	Intake Close @0.005	Intake Open @0.050	Intake Close @0.050
0.551	267	204	7 deg BTDC	80 deg ABDC	19 deg ATDC	43 deg ABDC
Exhaust Lift @VALVE	Exhaust Duration @0.004	Exhaust Duration @0.050	Exhaust Open @0.004	Exhaust Close @0.004	Exhaust Open @0.050	Exhaust Close @0.050
0.525	275	211	66 deg BBDC	29 deg ATDC	38 deg BBDC	7 deg BTDC

LS7 Camshaft (1.8:1 Rocker Ratio)

Intake Lift @Valve:	0.591"
Exhaust Lift @Valve:	0.591"
Intake Duration @0.050":	211 deg
Exhaust Duration @ 0.050":	230 deg
Lobe Separation Angle:	120 deg

LS9 Camshaft (1.7:1 Rocker Ratio)

Intake Lift @Valve:	0.562"
Exhaust Lift @Valve:	0.558"
Intake Duration @0.050":	211 deg
Exhaust Duration @ 0.050":	230 deg
Lobe Separation Angle:	122.5 deg

LS Hot Cam 88958733: Includes hot cam kit springs & retainers, 219/228 dur @0.050", max lift 0.525/0.525 w/1.7 rockers, LSA 112

Showroom Stock Cam 88958606: 239/251 dur @0.050", max lift 0.570/0.570 w/1.7 rockers, LSA 106.5. **Note:** For SS racing. Requires hollow stem intake valves 12565311, hollow stem exhaust valves 12565312, valve springs 12586484 and aftermarket notched pistons, or machine stock pistons.

LS7 Cam 12571251: Stock, will not work on LS1/LS6. 211/230 dur @0.050", max lift 0.558/0.558 w/1.7 rockers. Max lift .591/.591 w/ 1.8 rockers. LSA 121)

2001–2004 LS1 Cam 12561721: Stock cam for 2001–2004 LS1. 196/201 dur @0.050", max lift 0.467/0.479 w/1.7 rockers, LSA 116

LS Stage 2 Cam 88958722: 227/239 dur @0.050", max lift 0.551/0.551 w/1.7 rockers, max lift 0.583/0.583 w/1.8 rockers, LSA 108

LS Stage 3 Cam 88958723: 233/276 dur @0.050", max lift 0.595/0.595 w/1.7 rockers, max lift 0.630/0.630 w/1.8 rockers

Camshaft Installation Kit 12499228: For LS1, LS6, LS2 engines. To ease camshaft swaps. Includes all necessary gaskets and balancer bolt

LSX Camshaft 19166972: LSX454 camshaft is a high-lift hydraulic roller designed for the LSX454 crate engine. Maximizes potential of big-displacement engines at higher rpm. With 1.7:1 rocker arm ratio, maximum lift is 0.612/0.612". With 1.8:1 rockers, maximum lift is 0.648/0.648". Duration is 236/246 int/exh. Lobe separation angle is 110 degrees. Three-bolt design. Good mid-range and top end.

Comp Cams

Comp Cams has such an incredibly wide range of engine components for the LS series that it would be a real task to attempt to list everything here. Comp offers roller camshafts in their Thumpr, XFI, XFI rpm, XFI rpm Hi-Lift, XFI XE-R and LSR series, each with a range of profiles. As an example, here are a few part numbers in their broad Thumpr line:

54-600-11.1: Thumpr 275THR7 high performance street/stock, choppy, thumping. Stock converter okay, best w/2000+ converter & gears)

54-601-11: Mutha Thumpr 283THR7 High performance street/strip, rough idle. Need 9:1 CR, 2500+ stall, bigger intake, gears, headers.

54-602-11: Big Mutha Thumpr 291THR7 street/strip, very rough idle. Need 9.5:1 CR, 2800+ stall, intake, gears, headers.

Lunati

Street/Strip Hydraulic Roller Cam 55001LUN: Excellent idle. Increased low- and mid-range torque and horsepower over stock cam. Duration 270/279; @ 0.050" 212/216; gross valve lift 0.471/0.507"; LSA 116/112; rpm range 1500–4500.

Street/Strip Hyd. Roller Cam 55002LUN: Good idle. Excellent low-end torque and mid-range horsepower. Duration 270/279, @ 0.050" 212/221, gross valve lift 0.510/0.510", LSA 116/112, rpm range 1800–4800.

Street/Strip Hyd. Roller Cam 55003LUN: Fair idle. Good high-performance cam with lots of mid-range torque and upper-end horsepower. Duration 282/287; @ 0.050" 218/221; gross valve lift 0.526/0.534"; rpm range 2000–5000.

Street/Strip Hyd. Roller Cam 55004LUN: Fair idle. Good all-out street performance or mild race cam. Valvetrain modifications necessary (valve springs). Duration 283/283; @ 0.050" 221/221; gross valve lift 0.558/0.558"; LSA 114/110, rpm range 2500–6000.

Street/Strip Hyd. Roller Cam 55005LUN: Choppy idle. Good Pro Street or mild race cam. Valvetrain modifications necessary (valve springs). Duration 287/298; @ 0.050" 222/230; gross valve lift 0.534/0.544"; LSA 114/110; rpm range 2500–6000.

Street/Strip Hyd. Roller Cam 55006LUN: Rough idle. Good all-out street performance and mid-level race cam. Engine and computer modifications required. Duration 283/293; @ 0.050" 224/224; gross valve lift 0.560/0.560"; LSA 112/108; rpm range 2500–6000.

Street/Strip Hyd. Roller Cam P/N 55007LUN: Rough idle. Good Pro Street or road race cam. Engine and computer modifications necessary. Duration 298/286; @ 0.050" 230/237; gross valve lift 0.544/0.543"; LSA 112/108; rpm range 2800–6000.

Street/Strip Hyd. Roller Cam P/N 55008LUN: Rough idle. Good drag race or road race cam only. Major engine and computer modifications necessary. Duration 298/301; @ 0.050" 237/242; gross valve lift 0.595/0.595"; LSA 112/108; rpm range, 3000–6500.

Street/Strip Hyd. Roller Cam 55009LUN: Rough idle. Excellent all-out performance cam for large cubic inch engines. Major engine and computer modifications necessary. Duration 300/300; @ 0.050" 242/242; gross valve lift 0.595/0.595"; LSA 112/108; rpm range 3500–6500.

Voodoo Hyd. Roller Cam 60510: Excellent increase in torque and mid-range power. Great LS6 replacement performance camshaft. Works well with 5.3–5.7L engines. Duration 262/268; @ 0.050" 212/218; gross valve lift 0.531/0.531"; LSA 113/109; rpm range 1400–6200.

Voodoo Hyd. Roller Cam 60513: Excellent increase in torque and mid-range power. Has exceptionally wide power band with very crisp throttle response. A good all-around street performance cam. Duration 267/273; @ 0.050" 217/223; gross valve lift 0.549/0.549"; LSA 113/109; rpm range 1800–6400.

Voodoo Hyd. Roller Cam 60511: Great street performance choice. Very strong hp increase above 3500 rpm with proper computer tuning. Very drivable with excellent street manners. Works well with 5.3–6.0L engines. Duration 272/278; @ 0.050" 222/228; gross valve lift 0.567/0.567"; LSA 113/109; rpm range 2000–6600.

Voodoo Hyd. Roller Cam 60512: Serious street/strip cam for 5.7-6.0L engines. Requires computer modifications. Needs upgraded intake manifold, exhaust and aftermarket fully adjustable rocker arms to maximize performance. Duration 282/288; @ 0.050" 232/238; gross valve lift 0.599/0.601"; LSA 113/109; rpm range 2400–7000.

Voodoo Hyd. Roller Cam 60514: Hot street performance camshaft. Works well with 5.7–6.0L engines. Duration 277/283; @ 0.050" 227/233; gross valve lift 0.584/0.584"; LSA 113/109; rpm range 2200–6800.

Voodoo Hyd. Roller Cam 60515: Duration 287/293; @ 0.050" 237/243; gross valve lift 0.600/0.600"; LSA 113/109; rpm range 2600–7200.

Crower Cams (LS1/LS6/LS2)

Stage 1 00571: Works well with stock or slightly modified engines. Duration 258/262; @ 0.050" 208/216; gross lift 0.514/0.514"; lobe center 114 deg; rpm range 1000–5500.

Stage 2 00572: Modified computer, exhaust and high flow intake recommended. Duration 272/280; @ 0.050" 217/226; gross lift 0.553/0.575"; lobe center 114 deg; rpm range 1500–5800.

Stage 3 00573: Mid- to top-end power in highly modified engines. Duration 285/289; @ 0.050" 226/232; gross lift 0.566/0.566"; lobe center 114 deg; rpm range 2000–6000.

Crane Cams (LS1/LS6/LS2)

P/N 1449545, grind HR-200/2951-25-15 1A: Big torque for trucks. Use with stock or mild engine modifications. Smooth idle. Duration @ 0.050" 200/208; gross lift 0.502/0.502"; LSA 115 deg; rpm range idle–4500.

P/N 1449571, grind HR-210/3121-25-12 2A: Performance cam for cars or trucks. Stock or mils engine modifications. Good idle, slight chop. Good cam for supercharger w/PowerMax tuner. Must use 144832-16 valve springs. Duration @ 0.050" 210/218; gross lift 0.531/0.531"; LSA 112 deg; rpm range 1000–6000.

P/N 1449561, grind HR-216/3241-25-15: Performance cam for cars and trucks. Stock or mild engine modifications. Good idle, slight chop. Good cam for supercharger with PowerMax tuner. Duration @ 0.050" 216/224; gross lift 0.551/0.551";LSA 115 deg; rpm range 1500–6000.

P/N 1449581, grind HR-220/3241-12: Performance cam for cars. Stock or with mild engine modifications. Good idle, slight chop. Must use valve springs 144832-16. Duration @ 0.050" 220/220; gross lift 0.551/0.551"; LSA 112 deg; rpm range 3000–6500.

P/N 1449591, grind HR-224/3241-14: Performance cam for cars. Stock or with mild engine modifications. Good idle, slight chop. Must use valve springs 144832-16. Duration @ 0.050" 224/224; gross lift 0.551/0.551"; LSA 114 deg; rpm range, 3500–6500.

P/N 1449601, grind HR-228/353-25-12: Performance cam for cars and trucks. Stock or with mild engine modifications. Rough idle, slight chop. Must use 144832-16 valve springs. Duration @ 0.050" 228/232; gross lift 0.600/0.600"; LSA 112 deg; rpm range 3500–6500.

P/N 1449611, grind HR-236/353-25-12: Performance cam for cars. Stock or with mild engine modifications. Rough idle, slight chop. Must use 144832-16 valve springs. Duration @ 0.050" 236/240; gross lift 0.600/0.600"; LSA 112 deg; rpm range 4000–7000.

As far as recommending a specific cam profile for a given engine, there are simply too many variables (engine displacement, type of intake system, cylinder head choice, compression ratio, vehicle weight, type of transmission, final drive gear ratio, intended use, etc.) to make any specific recommendations here. It's always best to discuss the details of your needs with your camshaft supplier. If we were to make any broad suggestions, it's usually best to stick with a slightly lower lobe separation angle for an engine that will be coupled to a manual transmission as opposed to an automatic transmission. For example, an LSA of 112 degrees might be better for a given engine when mated to a manual transmission, and an LSA of 114 degrees with the same engine equipped with an automatic transmission would likely make sense. As far as duration is concerned, generally the bigger the displacement, the more duration you can likely use. But again, there are too many variables based on each individual build for me to make any qualitative recommendations here.

SWAPPING CAMS

If you decide to perform a camshaft change in an already-built LS engine, here's the procedure.

When performing a cam change, naturally the lifters need to be pulled out of the way of the camshaft in order to remove the existing cam and to install the replacement cam. Since lifter access is hidden by the cylinder heads, don't fret. There's no need to yank the heads off or to remove the intake manifold to perform a cam swap.

Remember those plastic lifter buckets that guide the lifters? If the lifters are pushed upwards, they'll lodge into the buckets and will be held up and out of the way.

Here's the procedure:

1. Remove the valve covers.
2. Remove all of the rockers, but leave the pushrods in place.
3. Remove the serpentine belt and the water pump.
4. Remove the crankshaft balancer (damper). You'll need a puller for this, since it's interference-fit onto the crank snout. If you're dealing with an aftermarket balancer such as an ATI, remove the balancer from its hub (via six flat-top torx screws), the use a puller to remove the damper hub from the crank snout.
5. Remove the front engine cover (timing cover).

In order to remove the timing chain and cam gear, you'll first need to remove the oil pump, which also means that you'll need to remove the oil pump pickup.

6. Remove the oil pan.
7. Remove the oil pump pickup (be careful not to lose the O-ring where the pickup seats into the oil pump). Once the pickup is out of the way, remove the oil pump from the front of the block and slide it off of the crank snout.
8. Temporarily install a crankshaft balancer bolt into the crank snout, and rotate the crankshaft and camshaft a full 360 degrees (roll the crank twice). This will cause the camshaft to push all of the lifters up. Since there's no rocker arm pressure holding the pushrods and lifters back, the lifters will engage into their lifter buckets.
9. Remove the three bolts that secure the camshaft gear to the camshaft.
10. Remove the cam gear and timing chain (pull and wiggle the gear from the cam nose). There's no need to remove the crankshaft gear.
11. By hand, roll the camshaft a few times again, just to make sure that all of the lifters are up inside their buckets. In order to insure that none of the lifters can accidentally drop down, carefully insert a 22" long or longer 1/4"-diameter metal rod into each of the lifter galley oil channels (insert the rods from the front of the block, in the upper passages to the right and left of the cam until the rods seat against the rear of the block). With these rods in place, this will block the lifters from dropping.
12. Next, remove the camshaft retainer plate (this secures the cam from moving out of the block). The retainer plate is secured with four bolts.
13. Now you're ready to remove the camshaft. Be careful! The camshaft must travel through its bores without nicking or scratching the cam bearings. If you dig into a cam bearing, you'll end up with an oil pressure drop that can prove catastrophic. Whenever removing or installing any in-the-block camshaft, first install a camshaft installer tool to the camshaft nose. This will provide you with a handle, and much-needed leverage in order to properly support the camshaft and keep it level and straight.

Note: Commonly available camshaft installer tools will not feature the proper nose adapter to fit an LS camshaft. Make sure that you buy a camshaft tool that is designed to fit onto an LS camshaft! If you don't have this tool, you can make one fairly easily. Insert three 8mm x 1.25 bolts into the cam nose (the bolts should be at least about 4", or about 100mm long). Then grab a piece of metal or PVC pipe that will fit over one or two of these bolts. Run the pipe all the way over the bolts to the cam nose. Then tightly secure the pipe to the exposed bolts with a worm-drive hose clamp. It may sound and look hokey, but it works just fine. Using the pipe as a handle, carefully draw the camshaft out of the block…slowly, supporting the cam as it leaves the block. If you feel any resistance, stop…then gently alter the angle until it moves out smoothly. Don't rush this. Each time one of the camshaft's journals rests on the front cam bearing bore, you can take a rest and then continue. The important thing is to keep the cam straight so that it moves through the cam bores smoothly without hanging up. *Do not allow the lobes to scrape the cam bearings!*

Once the cam is removed, set it aside and label it with a tag, just to insure that you don't mix it up with the new cam.

14. Carefully clean the replacement camshaft to remove any dust or contaminants that may be present as a result of shipping and handling. Make sure that all journals and all lobes are perfectly clean.
15. Lube the new cam's journals, using either clean engine oil, a camshaft assembly lube. Don't use anti-seize. Lube the cam lobes with a high pressure camshaft assembly lube. (I personally like Royal Purple Max Tuff assembly lube.) Since this is a roller cam, you could probably get away with simply using engine oil, but if the engine is going to sit around for a while before being fired, a sticky lube (such as camshaft assembly lube) is preferred. If your new cam included camshaft lube, use it.

16. Using the same procedure (and installation tool), carefully install the camshaft into its bore, until the cam nose is about flush with the block face. Install the camshaft retainer plate (apply a thread locking compound to the plate's bolt threads) and tighten the four retainer plate bolts to a value of 18 ft-lb. Now that the camshaft is in place, you can remove those temporary 1/4" rods from the block's galleys.

17. Rotate the crankshaft until the zero mark on the crank gear is at 12 o'clock. Rotate the camshaft to place the dowel pin at about the 3 o'clock position. Install the cam gear and timing chain, aligning the cam gear's timing mark with the crank gear's zero mark (the mark on the cam gear should be at 6 o'clock).

18. Secure the camshaft gear to the camshaft nose. Remember to clean and dry the three camshaft gear bolts and to apply a thread-locking compound to the clean threads before installing the bolts. Slowly and alternately tighten the three camshaft gear bolts to a final value of 26 ft-lb. Make sure that all three bolts have been fully tightened!

19. Using your finger, push each pushrod down against the lifters to dislodge them from the buckets. Some will pop down noticeably (in locations where the lifters are on or near their base circles) and others won't move much at all (if on or near the lobe peaks). Don't worry about it at this point.

20. Continue assembly in the reverse order from the disassembly procedure.

Once you install the rocker arms, rotate the crank and cam a full 360 degrees again, verifying that all lifters are down and making full contact with the cam lobes.

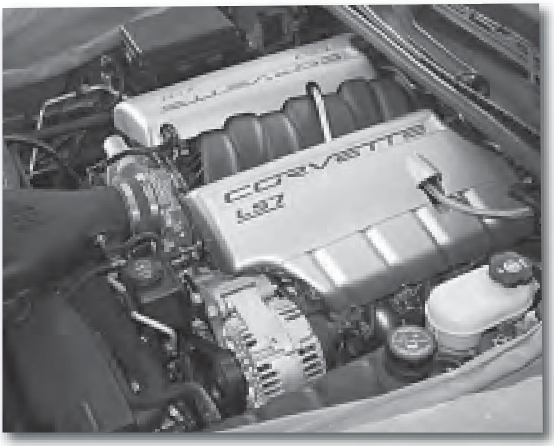
If you're concerned about "breaking in" the new camshaft, don't be. Cam break-in is really only a concern with regard to flat tappet cams, where the lifters faces must be able to rotate as they ride against the cam lobes during engine operation. Roller-tipped lifters do just that…they roll on the lobes, so unless you have a faulty roller, there's really no great "break-in" issue. Lube it, install it and run it.

Note: When installing the water pump, initially tighten the six mounting bolts to a value of 11 ft-lb, followed by a final tightening at 22 ft-lb. This two-step tightening helps to insure even clamping load against the block for a leakproof seal. While the water pump gaskets are designed to be somewhat reusable, they're cheap, so it's best to use new gaskets. I've run LS engines, disassembled and reassembled using the same water pump gaskets 4–6 times with no problems, but considering the small cost, just buy fresh ones.

When performing a camshaft installation for the first time during a fresh build, follow the same installation procedures listed here. Of course, if you're performing assembly on a bare block, it's best to install the camshaft even before you install the crankshaft. In this way, you can rotate the block upside down, which allows you to reach into the cam bore areas with one hand while guiding the cam with the other. Either way, extreme care must be taken to avoid damaging the cam bearings.

Chapter 11

EFI System Upgrade



Although this chapter details an intake manifold swap on a Z06 Corvette equipped with the LS7 engine, the procedures are similar for other LS models.

Upgrading to an aftermarket fuel injection (multiple port) intake manifold can provide not only enhanced appearance (a nice side benefit), but more importantly, improved performance. It's all about airflow and the control of incoming air that feeds the combustion chambers. A proven upgrade is FAST's LSX series of manifolds, the installation of which we'll detail here. Two versions are offered, including the LSXr (with versions for both cathedral port and rectangular port heads) and the LSXrt, designed specifically for GM 4.8, 5.3, 5.7 and 6.0L heads with cathedral ports. The RSXrt is much taller and should only be considered for applications where hood clearance isn't a concern. Both models feature longer runner and less restrictive runner design, far surpassing the OE manifolds in terms of power potential.

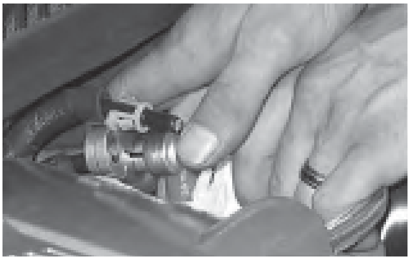
During testing, the LSX line of manifolds has shown slight horsepower gains on an otherwise stock engine, and up to 25 horsepower or more on highly modified engines (bigger bores, longer strokes, cams, heads, etc.).

One very cool design feature of these intake manifolds is the ability to disassemble the manifold and remove individual runners if any tuning modification is desired. These intakes are made of an advanced polymer, which is lighter, stronger and provides less heat soak than aluminum manifolds. The RSX series features a 102mm air inlet port, but can be used with 90, 92 or 102mm throttle bodies (same bolt pattern). Basically, you can start with the intake manifold, and as time goes on, you can always upgrade to the 102mm throttle body when it suits your fancy.

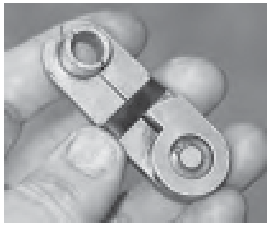
Throttle Body Increase

When it comes to throttle body diameter, many folks misunderstand the effect of the inlet diameter. Throttle diameter has nothing to do with torque curves (making power at low end, mid-range or top end). Rather, the throttle body inlet (diameter) provides a path, and a designed restriction. The goal is to produce less restriction so that enough incoming air is available based on the engine's fuel/air needs at any given moment. As but one example, FAST's 102mm Big Mouth throttle body allows maximum air-feed availability when building the engine for additional power gains.

According to the FAST engineers, the 102mm throttle body produces a gain of up to five horsepower over a 92mm throttle body. Throttle response is improved as well. Features of FAST's Big Mouth include not only better airflow, but a beefed-up dual spring mechanism and linkage for more durable throttle control, a thicker throttle blade and shaft (which reduces the chance of deflection, especially in boosted applications), and an offset blade pivot for quicker throttle response and smoother operation. The air passage



After relieving fuel pressure at the fuel rail's Schrader valve, place a rag under the fuel line connection and use the fuel line quick-disconnect tool to separate the flexible fuel hose from the vehicle's main fuel feed tube.



You'll need the specialty tool to separate the fuel line connection.

Here the 3/8" I.D. fuel hose has been disconnected from the fuel tube.

also features a convoluted shape designed to eliminate airflow turbulence (especially beneficial at part-throttle operation). Be aware that the Big Mouth 102mm throttle bodies are only available in cable-operated versions, so if you have a fly-by-wire throttle system, you'll either need to switch over to cable or live with your stock throttle body.

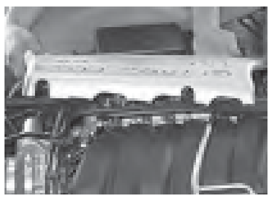
Adding high-flow billet aluminum fuel rails is another consideration. The larger inside diameter of these rails (as compared to stock rail tubes) serves to dampen injector pulses while providing more fuel volume, which helps to insure that the injectors won't run dry (more fuel volume available at the injectors).

FAST LSXR Installation

To illustrate how you can upgrade your multi-port fuel injection system, we've chosen to install a FAST LSXR manifold (P/N 146302) FAST (www.fuelairspark.com) on a Z06 Corvette equipped with the LS7 engine. The installation was performed by Xtreme Performance in North Ridgeville, Ohio (www.Xtremeperformance.info). I'd like to thank owner Steve Ali and master tech Brian for the opportunity to visit their shop during this procedure.

Disassembly/Removal of the Stock Intake Manifold

Allow the engine to cool. Disconnect the negative (–) battery cable and remove the plastic coil covers. These simply pop off, but be careful not to pull on one end only—use both hands. Relieve fuel pressure by depressing the Schrader valve on the end of the fuel rail. Lay a towel in position to catch and reduce fuel spill.



Simply wiggle and pull to remove the plastic coil pack covers.

With covers removed, the fuel rail assembly is fully exposed.

Clean off any excess dirt and debris around the intake manifold that could become dislodged and fall into the engine during manifold removal.

Disconnect the fuel line from the fuel rail by using a quick-connect separator tool (J37088-A). Place shop towels around the connection to catch additional fuel. Use the proper disconnect tool! If you try to remove the connector with a screwdriver or other common tool, you'll break the fitting.

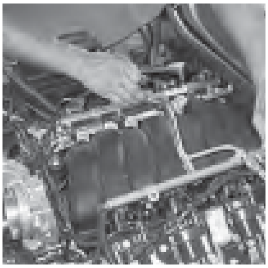
Disconnect the mass air flow sensor (MAF), located between the air filter and throttle body. Remove the remaining air filter assembly. Disconnect any PCV hoses or vacuum lines on the intake manifold, including the brake booster vacuum hose. Note the position of each line/hose for reinstallation. Disconnect the Idle Air Control (IAC) and the throttle position sensor (TPS) from the throttle body. Disconnect the Intake Air Temperature sensor (IAT) from the intake, between the filter and throttle body.

Unplug all eight fuel injector harness clips. Remove the four fuel rail mounting bolts and remove the stock fuel rail and injectors as an assembly.

Loosen all ten intake manifold bolts (these require

Remove the air filter intake assembly. Be sure to unplug the MAF connector.

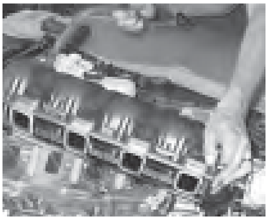
Remove the fuel rail mounting bolts. Access is a bit tight at the rear.



With the fuel injector harnesses disconnected from all eight injectors, remove the OE fuel rail assembly, gently wiggling and pulling to remove the fuel injectors from their intake manifold ports.

Note that the injectors are secured to the OE fuel rail with metal clips. Set the fuel rail aside until you're ready to install the fuel rail assembly.

Using an 8mm wrench, remove all intake manifold mounting bolts.



With all intake manifold bolts removed, and verifying that the rear vacuum hose connections have been disconnected (and the MAP sensor disconnected, if your application features a rear-mounted MAP), carefully remove the intake manifold. Make sure that no debris falls into the exposed cylinder head intake ports.

an 8mm socket wrench). The five rearmost bolts cannot be removed fully in F-body Camaros and Firebirds until the manifold can be partially lifted out of the way. In order to temporarily hold these bolts up, cut a slit in a piece of rubber hose that is 1" long with a 1/4" I.D., lengthwise, and slip the hose over the exposed bolt shank.

Before removing the intake manifold, you must disconnect the manifold absolute pressure (MAP) sensor connector, a small vacuum line on the right (passenger) side, and the brake boost vacuum hose on the rear of the intake manifold. On the Camaro and Firebird, there is also a tall oil pressure sensor that is trapped between the manifold and brake hose. Carefully lift the manifold and move it forward until you can reach behind the manifold and disconnect these connections. Clean any remaining debris that might fall into the engine. Carefully remove the intake manifold.

Cover the open cylinder head intake ports with a clean, lint-free rag, or tape the intake ports using duct tape, to prevent anything from falling into the ports while the ports remain exposed.

Remove the injector clips from the OE fuel rail by gently prying with a screwdriver.

At a safe location (workbench, etc.), remove the injectors from the OE fuel rail. The rail is likely full of fuel, so keep away from any open flames or sparks. Wear rubber gloves, safety glasses, and use a towel to catch any spilled fuel.

Required Modifications

There are a couple of tasks required before installing the new manifold.

Note: Do not reuse the OE top valley plate bolts. You must use the button-head bolts (supplied in the kit), which must be tightened to 18 ft-lbs. The height of the original hex bolt heads will interfere with the FAST manifold and could result in manifold damage. Remove the original hex-head bolts one at a time and finger-install the supplied button-head bolts. Once all button heads are in place, tighten to 18 ft-lbs using a crisscross tightening pattern to evenly distribute the clamping force.

The rear coolant vent line on 1997–2000 Corvette and 1998–2000 Camaro/Firebird (located in the valley) must be replaced to clear the FAST manifold. Replace with GM P/N 12568478 front crossover and two P/N 12563325 plugs. Tighten the vent pipe bolts to 106 in-lbs.

Remove the plastic clips from the knock sensor wire harness (unwrap the tape to access the clips) and discard these clips.

Due to the wide range of LSX R applications, the selected MAP sensor location requires drilling. The

FAST manifold features two (one front and one rear) locations which are currently plugged. Drill the location best suited for your MAP sensor installation.

Remove the upper shell from the FAST manifold. The manifold features five upper shell hold-down bolts (two in the front, near the throttle body location and three in the rear). The screws that secure the upper and lower halves feature nuts that are seated in hexagonal holes. After removing each screw, be sure to capture each nut to prevent losing the nuts.

For EGR use, you must open the hole in the manifold beneath the front MAP sensor location. Use a large diameter drill and a Dremel-type tool to remove the front MAP sensor location and open up the 30mm (1.181") hole. Be careful not to damage the upper diameter where the O-ring seals. If your engine uses an EGR, you must use the rear MAP sensor location for the MAP sensor.

Decide which MAP sensor location will work best for your application. It will need to be drilled all the way through to allow the MAP sensor to read manifold vacuum. Note that the rear MAP sensor location is located in the lower shell. Be careful to prevent debris from entering the manifold. Our application required mounting the MAP sensor in the front location (since this was the location of the MAP sensor on the original intake manifold). In the Corvette Z06 application, the front MAP sensor port was drilled open using a 15/32" drill. Before drilling, remove the upper manifold shell to prevent debris from being trapped.

There are two different MAP sensors that may be used. If your MAP sensor is the grommet style, use a 3/8" drill to drill through the front MAP port location. If your MAP sensor is the O-ring style, you must drill out the front MAP sensor location with a 15/32" drill.

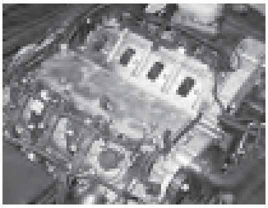
A MAP sensor hold-down insert and bolt has been added to the LSX R to help hold the MAP sensor in position. The MAP sensor bolt must not be tightened beyond 19 in-lb when mounting the sensor to the manifold.

Note: If you plan to run a nitrous injection system, the manifold's nitrous bosses may be drilled and tapped to 1/8" NPT maximum (do not tap larger then 1/8" NPT!).

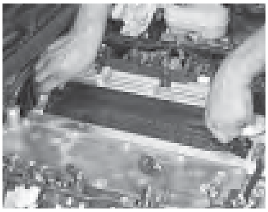
Installation Prep

Remove all drill shavings from the MAP sensor and EGR locations.

When reattaching the upper shell to the lower manifold, insert the nuts from underneath, using a skinny deepwell socket or a screwdriver to push the



With the manifold removed, check for any debris lying on the top cover area.



Mask the intake ports at this point to prevent anything from falling into the ports. Here Brian applies duct tape.

The FAST intake manifold is packaged well for shipping protection.

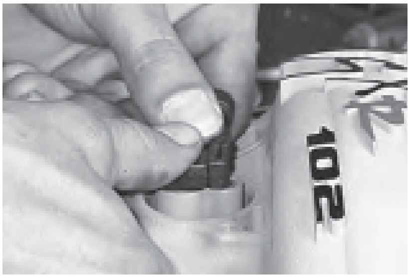
The FAST LSX R manifold that we're installing in this example features a 102mm throttle body port. The precision molded composite manifold is designed as a 2-piece assembly.

The FAST manifold is a bit taller than the stock unit, requiring either the use of injector spacers along with the stock fuel rail assembly, or the use of FAST's billet fuel rails.

The underside of the FAST manifold features a network of strengthening ribs, the result of extensive research and development.

The FAST manifold features two choices for MAP sensor location. The front location, seen here, is on top, behind the throttle body port.

The rear MAP sensor location is at the rear-right area of the manifold. Depending on your application (the stock location of your MAP sensor), you'll need to drill the sensor mounting hole.



Gently push the MAP sensor probe into the drilled hole (make sure that the sensor's silicone seal is not damaged). Secure the MAP sensor using the screw provided in the FAST kit. Tighten gently. Do not tighten to more than 19 in-lbs.

Before drilling for the MAP sensor, disassemble the upper and lower manifold sections to prevent plastic debris from being trapped. Using a hex wrench, remove the socket head cap screws that secure the two halves together. The nuts are located inside hexagonal passages in the lower section.

Here the upper shell has been removed from the lower manifold runner body.

Using a 15/32" drill, fully drill through the MAP sensor port location.

This inside view shows the hole that Brian drilled. Dress the hole edges to remove any burrs.

nut up and to hold it level as you engage the screw threads.

Apply medium-strength thread-locking compound to the upper shell bolt threads and reinstall the intake manifold's upper shell to the intake manifold and tighten the upper shell bolts to a value of 70-89 in-lbs.

Flip the intake manifold upside down. Note the three circles molded into the base for rubber bumper installation. Because the bumpers are self-adhesive style, it's important to clean the manifold's bumper locations with a cleaner such as isopropyl alcohol and allow the solvent to dry. Next, install the three rubber bumpers.

Verify that the throttle body seal is in position. With the throttle body in position, install the four throttle body-to-manifold bolts, using the bolts supplied in the kit. For FAST cable-driven throttle body applications, use the four 6mm x 22mm; or for electronic throttle body applications, use the four 6mm x 40mm bolts. Tighten all four bolts to 70-89 in-lbs (tighten evenly in a crisscross pattern to avoid warping the mounting base).

Installation of the New Intake Manifold

Uncover the cylinder head intake ports (remove tape or rags) and take the time to clean the deck surfaces with denatured alcohol or a brake cleaning solvent. Make sure that the deck surfaces are clean and dry.

Place the manifold in the valley, but do not move fully rearward yet. Attach the brake booster hose, and install and connect the MAP sensor (if your MAP sensor is rear-mounted). Access at the rear is very tight, so take your time. Be sure to route the brake booster vacuum hose properly before connecting.

Reassemble the upper shell to the lower manifold. Insert the nuts into the hexagonal passages. Hold the nut steady until the bolt threads engage.

Apply medium-strength thread locker to all manifold bolt threads. Loosely install the rear bolts to the manifold, using the split rubber sleeves (if applicable).

Gently move the manifold into its final position, but *do not* slide the manifold, to avoid seal damage or seal dislodging. Pick the manifold up and carefully place it into its final position. Once in the correct position, the bolt bosses will find the counterbores in the cylinder head intake decks. The FAST intake features a locating dowel on each side to provide proper location. Make sure these dowels align with their holes in the heads.

Reconnect the coolant crossover line hose. Tighten the crossover pipe bolts to 70–89 in-lbs.

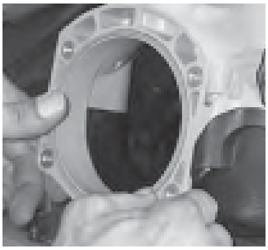
With medium thread locker on all ten intake bolts, hand-start all ten bolts (don't forget to install the fuel rail stop brackets, if required).

Using two passes in the proper sequence, tighten the ten intake manifold-to-head bolts to 45 in-lbs, with the second and final pass at 70–89 in-lbs. *Do not* overtighten!

Remove the fuel injectors' lower O-rings and replace with new O-rings (supplied in the kit). Lubricate the O-rings with a white lithium grease or clean engine oil to ease installation.

Select your fuel rail option. When planning to install previously used fuel injectors, inspect all O-rings for damage. GM recommends installing new O-rings, but if your O-rings are not damaged, they should be OK to re-use. Lubricate all O-rings with clean engine oil, including upper and lower injector O-rings and injector spacer cup O-rings. When installing injector to the fuel rails, insert using a slight wiggling action. Do not force the injectors, since O-ring damage may occur.

The underside of the manifold requires the installation of three rubber bump-stops. These are self-adhesive. Here Brian's middle finger points to the center bumper.

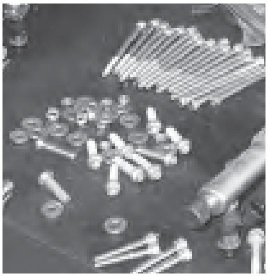


Install a new elastomer sealing ring (supplied in the kit) to the manifold. Do not apply any adhesives. These seals feature a self-gripping design.

Once all intake seals have been installed, apply a light coat of petroleum jelly lubricant to the seal faces. This aids in seating and can prolong the life of the seals with regard to future service.

The throttle body port features an O-ring groove for installation of the sealing ring. Note the threaded brass inserts for throttle body mounting.

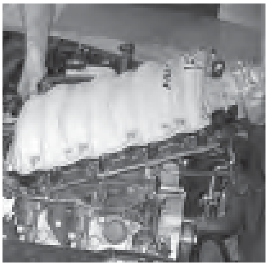
Install new intake port seals to the manifold (also supplied in the FAST kit).



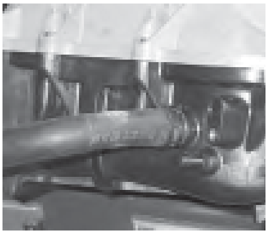
The FAST installation kit includes all necessary threaded hardware that replaces the original manifold and fuel rail bolts.

When installing the throttle body, tighten all four socket head cap screws in a crisscross manner to evenly distribute clamping force.

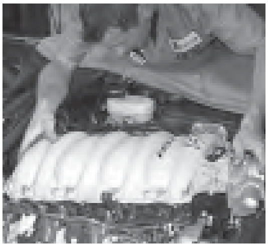
Before installing the new manifold, the engine's top cover hex-head bolts must be replaced with FAST's button-head bolts to provide clearance under the manifold. These are tightened to a value of 18 ft-lbs.



Carefully lower the intake manifold but do not fully position yet.



Attach the rear brake vacuum hose (and MAP sensor connection, if your MAP sensor is located at the rear).



Lift (do not slide) the manifold into final position. The underside of the manifold features a pair of dowels that will locate the manifold to the heads.

Apply a medium-strength thread-locking compound to all of the newly supplied manifold mounting socket head cap screw threads and install finger-tight.

Manifold-to-Head Tightening Sequence

Note: LH is driver side; RH is passenger side

1. 3rd from front, RH side
2. 3rd from front, LH side
3. 4th from front, LH side
4. 2nd from front, RH side
5. 4th from front, RH side
6. 2nd from front, LH side
7. Front, LH side
8. Rear, RH side
9. Rear, LH side
10. Front, RH side

Install the injectors (as a fuel-rail-group) to the intake manifold. Carefully start all injectors into their pockets, the firmly seat one side at a time. Do not reuse the OE fuel rail hold-down bolts. Instead, use the four 6mm x 12mm button-head bolts (supplied in the kit). Add medium strength thread locker to the bolt threads before installation. Tighten these bolts to 70-89 in-lbs.

Install the intake port seals to the manifold runners. You can re-use the OE LS1/LS6/LS2 port seals, or use the FAST #146203-8 intake port seals. Failure to install seals will result in massive vacuum leaks, rough idle and a dangerously lean running condition. Once all seals have been installed to the manifold, lightly lube each seal with a light lubricant such as KY jelly. This will help to extend seal serviceability in the future.

Throttle Body Options

You have several choices with regard to the throttle body:

1. FAST 92mm throttle body (OE cable drive only)
P/N 54092 or P/N 54095 (w/TPS)
(Note: FAST also offers IAC sensors if needed, P/N 307059)
2. FAST 102mm throttle body (OE cable drive only)
P/N 54102 or 54103 (w/TPS)
3. Reuse the OE electronic throttle body if applicable (90mm LS2)
4. Reuse the OE electronic throttle body, 1997-2004 Corvette (Note: this throttle body requires the use of the FAST P/N 146029-KIT 75mm to 102mm adapter plate)

Note: The FAST 92mm and 102mm cable throttle bodies will not work on the LS2/LS3/LS7, or any engine with electronic throttle control. Removal of the electronic throttle body will disable the engine via the ECU.

Fuel Rail Options

1. FAST billet fuel rail kit for LS1/LS6 fuel injectors P/N 146032-KIT* (includes FAST billet fuel rails, mounting brackets and –AN fittings)
*1998-2002 LS1 F-body fuel line conversion kit P/N 54028-KIT can be used in conjunction with P/N 146033-KIT for bolt-on installation.
2. FAST OE-type fuel rail kit for LS1/LS6 fuel injectors P/N 146021-KIT* (includes OE-style LS2 fuel rail, bolts and spacers)
*P/N 146021-KIT cannot be used on 1997–1998 Corvettes that feature a return-style fuel system.
3. FAST billet fuel rail for LS2 style injectors, P/N 146033-KIT (includes FAST billet fuel rails, mounting brackets and –AN fittings)
4. Reuse OE LS2 fuel rail and injectors (no extra parts required)

Note: If you elect to use the FAST aluminum fuel rails, note that each end of these rails features a female threaded hole. This thread size is 3/4" x 16 (commonly known as –8 AN straight thread). On our Corvette example, Brian, Xtreme Performance's head tech, installed the supplied adapters (–8 straight to –8 AN male) to the front of each rail, then plumbed the front of the right and left fuel rails using 45-degree –8 hose ends and a length of –8 braided hose, routing the hose under the throttle body. The rear of the right rail was plugged using a –8 AN straight thread (3/4"x16) O-ring sealed plug (Fragola P/N 481408).

For fuel feed (OE fuel line to the rear of the left side rail), Brian used a Fragola adapter, P/N 491989 that features a quick-connect female at one end (to snap onto the original fuel line) and a –6 male fitting at the opposite end. At the rear of the left side rail, Brian installed a 90-degree fitting (-8 straight to –6 male), and plumbed from the rail to the adapter with a length of –6 braided hose. The 90-degree fitting at the rear of the rail features the required 3/4"x16 male thread to engage to the rail (O-ring sealed), and a male –6 nipple to allow connection with a –6 hose end. Clearance between the left fuel rail and the firewall on the Corvette was tight, so a fitting with a very short 90-degree fitting was required. There simply was no room to use a straight adapter mated with a 90-degree hose end.

Note: Whenever installing any –AN straight thread fitting, this requires an O-ring to create the seal. Unlike NPT threads that require thread sealant dope, straight –AN threads are sealed only with an O-ring. Do not apply any type of thread sealant to a straight-thread fitting.

Reconnect the PCV hose—Reconnect all eight fuel injector wire connectors. Finally, reconnect MAP (front mount) MAF, IAC, TPS, brake booster hose, etc.

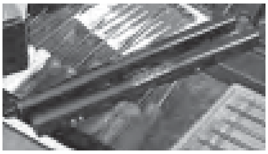
Tighten the manifold mounting screws in the proper sequence initially to 45 in-lbs, then to a final value of 70–89 in-lbs. It's important to follow the tightening sequence to obtain even load distribution.

Reconnect coolant crossovers and all vacuum lines. Reconnect the MAP sensor harness.

If you plan to use new billet fuel rails, remove the injectors from the stock fuel rail. Remove the retaining slip that secures the injector.

Remove the injectors from the OE fuel rail. Perform this task over a safe area, as fuel will likely run out of the rail.

Inspect the fuel injector's O-rings (upper and lower). It's always a good idea to replace all O-rings whenever servicing injectors.



The FAST billet aluminum fuel rails are precision-machined and anodized red. Definitely a cool dress-up in addition to providing fit and function.

If using the front MAP sensor location, push-in the MAP sensor, secure with the hold-down bracket and bolt, and reconnect the MAP sensor wiring connector.

If using the original style fuel line connections, add a few drops of clean engine oil to the male end of the fuel line and connect the fuel line to the fuel rail.

Reconnect the battery and check for fuel leaks before starting the engine by cycling the key a few times to build fuel pressure in the system. Seriously, take your time when checking for fuel leaks. Make absolutely certain that no leaks exist before attempting to start the engine.

Once all checks have been completed (everything reconnected and you've checked for leaks), have a rag, a fire extinguisher handy, and be prepared to quickly disconnect the battery. After the engine has started, immediately recheck for any fuel leaks.

FAST Fuel Injectors

Plenty of injector brands are available, but since we're featuring a FAST intake, we'll quickly discuss their injectors as well. State of the art magnetics improve injector opening times in order to yield faster throttle response. Precision-ground pintle and valve spray angle both help to produce and deliver superior fuel atomization. Redesigned valve body resists clogging and improves hot starting. High-impedance injector models are available up to 60 lb/hr for trouble-free OEM computer or FAST XFI compatibility. Low-impedance injectors are available up to 60 lb/hr for maximum performance with aftermarket EFI systems, including FAST XFI. All of FAST's injectors are flow-rated at 43.5 psi.

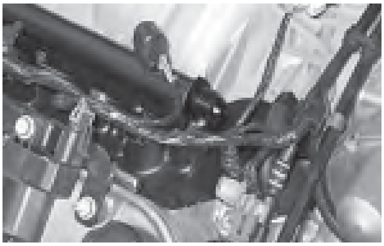
The ends of the billet rails feature female threads to accept adapter fittings. These threads are –8 AN straight port threads that measure 3/4" diameter with a 16-thread pitch. These are straight threads, and require straight-thread fittings. Do not attempt to use NPT threaded plugs or adapters!

Straight-thread –AN fittings must always be sealed with an O-ring. Here an O-ring is installed to a –8 straight thread fitting. Do not apply any type of chemical or tape thread sealant to straight threads.

The FAST fuel rail kit includes four adapters, including two –6 male to –8 AN straight male and two –8 male to –8 AN straight male. Shown here is a –6 (left) and a –8. The –6 angle-seat accepts a –6 hose end and the –8 accepts a –8 hose end. In the installation depicted here, Brian opted to use the –8 adapters at the front of each rail to plumb the left-to-right rail crossover feed. The rear of the right side rail was plugged using a –8 AN straight-thread plug. Fuel inlet at the rear of the left rail was handled using a –6 adapter.

This underside view of a FAST billet fuel rail shows one of the angled ports for fuel injector connection.

Lubricate the injector O-rings with clean gas or lithium lube and gently wiggle and push to seat the injector into the fuel rail port. Be careful to avoid damaging the upper O-ring. Once installed to the rail, gently rotate the injector to verify smooth rotation.



With four injectors installed to their fuel rail, gently insert all four injectors into the intake manifold injector ports using a gentle pushing motion on the rail. Be sure that all injector connectors face outward for easy harness connection.

How to Choose Injector Size

Determine your target peak horsepower (the maximum horsepower that you realistically expect to produce). Multiply the target peak horsepower by a factor, based on the type of induction. The factors are:

Normally aspirated: 0.5
Supercharged: 0.6
Turbocharged: 0.625

After multiplying the peak horsepower number times the induction factor, divide that result by the number of cylinders. Finally, divide that result by 0.9 (for 90% duty cycle). The equation is:

Injector size = [(target peak hp x induction factor) ÷ no. of cylinders] ÷ 0.9

Example: Let's say that your peak anticipated horsepower is 520 hp, and you plan to run a V8 engine, normally aspirated.

Injector size = [(520 x 0.5) ÷ 8] ÷ 0.9
Injector size = (260 ÷ 8) ÷ 0.9
Injector size = 32.5 lb/hr

If your math results in a number that is not available, the general rule is to move up to the next largest size. For example, if your math tells you that you need a 38 lb/hr injector, but your injector supplier only offers a jump from 36 lb/hr to 42 lb/hr, the best choice is to move up to the 42 lb/hr injector.

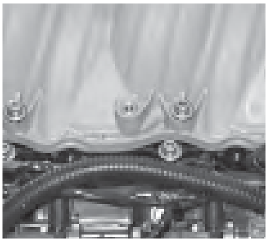
The issue of injector selection can get pretty hairy if you're not an injection tuner specialist, but this at least gives you a starting point. For example, if you're planning to make around 500–600 hp, LS2 OE 30-lb injectors are probably a bit on the light side, so 39-lb-rated injectors would be a better choice. Of course, if you're a tuner and know what you're doing, you can always manipulate injectors via programming to achieve various output pressure rates.

The subject of fuel injector selection can be quite daunting to engine builders who are not seasoned "tuners" of electronically-controlled fuel injected engines.

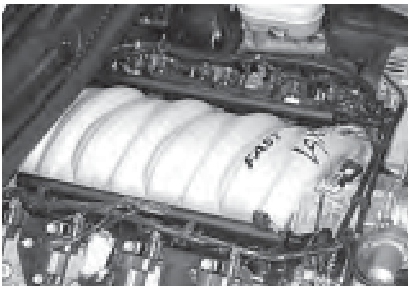
Note: While physically interchangeable, LS1 and LS2 intake manifolds differ in terms of fuel injector bore size (the hole into which the injector seats). LS1 style intake manifolds feature an injector bore diameter of 13.9mm, while the LS2 manifold features a larger 14.7mm bore size.

One thing to remember: just because the injector physically fits the application, that doesn't mean that it will perform properly. Injectors must be selected based not only on the injector's own pressure rating, but in conjunction with the system flow pressure, which takes into account the fuel pump, the intake manifold volume, etc.

The FAST fuel rail kit includes steel mounting brackets that secure the fuel rails to the intake manifold. A screw passes through the rail's horizontal mounting hole and threads into the small threaded hole in the bracket. The larger hole provides a bolt-down to the manifold.



The intake's upper shell features two threaded brass inserts for fuel rail mounting.



Here both fuel rails and injectors are mounted. Once the rails are secured, connect the injector harness connectors.

LS TORQUE VALUES

Main Cap Bolt Torque Values

Inner main cap bolts:	15 ft-lb (1st pass), 80 deg (final)
Outer main cap stud nuts:	15 ft-lb (1st pass), 53 deg (final)
Main cap side bolts:	18 ft-lb

If using aftermarket main cap studs:

ARP inboard primary main cap nuts:	50 ft-lb
ARP outboard primary main cap nuts:	60 ft-lb
ARP 8mm main cap side bolts:	20 ft-lb

Note: When using aftermarket main studs, always follow the stud maker's tightening specifications for their studs and nuts.

Cylinder Head Bolt Tightening

11mm x 20.0 x 155.5mm bolts:	22 ft-lb, plus 76 deg
11mm x 20.0 x 101.0 mm bolts:	22 ft-lb, plus 76 deg, plus 34 deg
8mm x 1.25 x 46mm bolts:	22 ft-lb

Note: Original equipment cylinder head bolts are torque-to-yield-type and should not be reused. If planning to use OE cylinder head bolts during a build, always use new bolts.

ARP Cylinder Head Studs

ARP cylinder head stud 7/16" nuts:	80 ft-lb w/ARP moly (in 3 steps)
ARP 8mm upper studs:	22 ft-lb w/ARP moly

Connecting Rod Bolts

OE rod bolts (First Design):	15 ft-lb (1st pass), plus 65 deg (2nd pass)
OE rod bolts (Second Design):	15 ft-lb (1st pass), plus 75 deg (2nd pass)

Note: When using aftermarket rod bolts, follow the bolt manufacturer's tightening specifications, which might include torque, torque-plus-angle, or bolt stretch specs.

Intake Manifold

OE Plastic Injection Manifold:	44 in-lb (1st pass), 89 in-lb (2nd pass)
Aftermarket aluminum four-barrel carb intake manifold:	44 in-lb

Exhaust Manifold/Header to Heads

Exhaust manifold bolts first pass:	11 ft-lb
Exhaust manifold bolts final pass:	18 ft-lb
Exhaust manifold heat shield bolts:	80 in-lb

Miscellaneous OE Torque Specs

Camshaft retainer plate bolts:	18 ft-lb
Camshaft gear bolts:	26 ft-lb
OE timing chain damper bolts:	18 ft-lb
Oil pump mounting bolts:	18 ft-lb
Oil pump cover bolts:	106 in-lb
Oil pump relief valve plug:	106 in-lb
Oil pump screen nuts:	18 ft-lb
Oil pump to screen bolt:	106 in-lb
Oil pan bolts 8mm (pan to block and pan to front cover):	18 ft-lb
Oil pan bolts 6mm (pan to rear cover):	106 in-lb
Oil filter fitting:	40 ft-lb
Oil level indicator tube bolt:	18 ft-lb
Oil level sensor:	115 in-lb
Oil pan baffle bolts:	106 in-lb
Oil pan closeout cover bolts:	106 in-lb
Oil pan cover bolts:	106 in-lb
Oil pan drain plug:	18 ft-lb
Oil pressure sensor:	15 ft-lb
Oil filter:	22 ft-lb
Knock sensors:	15 ft-lb
Front cover bolts:	18 ft-lb
Rear cover bolts:	18 ft-lb
Block valley cover bolts:	18 ft-lb
Water pump bolt:	11 ft-lb (1st pass), 22 ft-lb (2nd pass)
Water pump cover bolts:	11 ft-lb
Lifter bucket 6mm bolts:	125 in-lb
Flywheel bolts:	15 ft-lb (1st pass), 37 ft-lb (2nd pass), 74 ft-lb (final)
Spark plugs:	15 ft-lb (new), 11 ft-lb (used)
Throttle body bolts:	106 in-lb
Transmission housing (bellhousing) bolts:	37 ft-lb
Valve lifter guide tray bolts:	106 in-lb
Rocker arm bolts:	22 ft-lb
Rocker arm cover bolts:	106 in-lb
Water inlet housing bolts:	11 ft-lb
Crankshaft balancer bolt initial seating:	24 ft-lb
Crankshaft balancer bolt (using new bolt):	37 ft-lb plus 140 deg
Crankshaft oil deflector nuts:	18 ft-lb
Crankshaft position sensor bolt:	18 ft-lb
Coolant temperature sensor:	15 ft-lb

Cylinder head coolant plug:	15 ft-lb	Alternator rear bracket to block bolt:	18 ft-lb
Cylinder head core hole plug:	15 ft-lb	Alternator rear bracket to alternator bolt:	18 ft-lb
Block coolant drain plugs:	44 ft-lb	Ground strap bolt at rear of cylinder head:	37 ft-lb
Coolant air bleed pipe bolts:	106 in-lb	Ignition coil to bracket bolts:	106 in-lb
Engine mount heat shield nuts:	89 in-lb	Ignition coil bracket to valve cover bolts:	106 in-lb
Engine mount through bolts:	70 ft-lb	Drive belt idler pulley bolt:	37 ft-lb
Engine mount through bolt nuts:	59 ft-lb	Drive belt tensioner bolts:	37 ft-lb
Engine mount to engine block bolts:	37 ft-lb	Air injection reaction pipe to exhaust manifold bolts:	15 ft-lb
Engine service lift bracket 10mm bolts:	37 ft-lb	A/C compressor bolts:	37 ft-lb
Engine service lift bracket 8mm bolt:	18 ft-lb	A/C compressor bracket bolts:	37 ft-lb
EGR valve bolts first pass:	89 in-lb	A/C idler pulley bolt:	37 ft-lb
EGR valve bolts final pass:	22 ft-lb	A/C tensioner bolt:	18 ft-lb
EGR valve pipe to cylinder head bolts:	37 ft-lb	Accelerator control cable bracket bolts:	89 in-lb
EGR valve pipe to exhaust manifold bolts:	22 ft-lb		
EGR valve pipe to intake manifold bolts:	89 in-lb		
Fuel injection rail bolts:	89 in-lb		
Alternator bracket bolts:	37 ft-lb		

OE BLOCK FASTENER SIZES

Note: OE LS engine fasteners are metric

Cylinder head bolts (OE):	11mm x 1.5 x 100mm
Cylinder head pinch bolts:	8mm x 1.25 x 45mm
Main cap primary bolts (inner):	10mm x 2.0 x 100mm
Main cap bolts with stud tips (outer):	10mm x 2.0 x 85mm
Main cap side bolts:	8mm x 1.25 x 25mm
Timing cover bolts:	8mm 1.25 x 30mm
Rear cover bolts:	8mm x 1.25 x 25mm
Lifter tray retaining bolts:	6mm x 1.0 x 20mm (shouldered)
Camshaft plate screws:	8mm x 1.25 x 25-30mm
Valley cover plate bolts:	8mm x 1.25 x 30mm
Timing chain dampener bolts:	8mm x 1.25 x 35mm
#12561663 straight-thread block L-side water plug:	30mm x 1.25 x 10mm
#11588949 straight-thread plugs:	16mm x 1.5 x 10mm
#9427693 front oil expansion plug:	16mm dia.
Connecting rod bolts:	9mm x 1.0 x 43mm
Crankshaft snout damper bolt:	16mm x 2.0 x 105mm

GM LS PART NUMBERS

LS Blocks and Block Components

LS1/LS6 12561166: Aluminum, 9.240" deck height, 3.890" bore, iron caps

LS2 12568950: Aluminum, 9.240" deck height, 4.000" bore, iron caps

LS3 12584727: Aluminum, 9.240" deck height, 4.065" bore, iron caps

LS7 19213580: Aluminum, 9.240" deck height, 4.125" bore, powdered metal caps

C5R 12480030: Aluminum, 9.240" deck height, 4.117–4.160" bore, 8620 steel caps

LQ9 12572808: Iron block, 9.240" deck height, 4.000" bore, iron caps

LSX 19213964: Iron block, 9.260" deck height, 3.890" bore, 1045 steel caps

LSX 19244059: Iron block, tall deck 9.720"deck height, 3.890" bore, 1045 steel caps

LS1/LS6 front timing cover 12561243: No cam sensor

LS2/LS3 front timing cover 12600325: With cam sensor

L92 front timing cover 12616491: With cam sensor

LS7/LS9 front timing cover 12598292: Required for 2-stage oil pump clearance. Cam sensor included.

LS front distributor drive cover 88958679: For converting to carb and distributor. Fits all LS engines except LS7/LS9. Accepts small-block Ford-style distributor and mechanical fuel pump. Special water pump, accessory drive and damper required.

Front cover gasket 12574294: All LS engines

Front crank seal 12585673: All LS models

Front cover bolt 11515758: Eight required. All LS engines.

Rear cover 12615666: All OE LS blocks

Rear crank seal 89060436: All LS models

Main bearing 88894271: All LS models except LS7/LS9. For positions 1,2,4,5. Four required.

Main thrust bearing 89017572: All LS models except LS7/LS9. For position 3.

Main bearing 89017877: For LS7/LS9, positions 1,2,4,5. Four required.

Main thrust bearing 89017808: For LS7/LS9 No. 3 thrust position.

LS7 oil hose adapters 25534412: Kit adapts the LS7 oil pan to aftermarket-style –AN hose ends for aftermarket dry-sump oil tanks.

LS2 timing chain dampener 12588670: Will not fit LS1/LS6 blocks

LS7 timing chain dampener 12581276: 1.1mm thinner than P/N 12588670

Camshaft sprocket 12586481: Fits all LS cams with 3-bolt design. 4X camshaft gear.

Camshaft sprocket 1X 12576407: Fits all LS cams with 3-bolt design. 1X camshaft gear.

VVT camshaft sprocket 12585994: Combination camshaft sprocket and VVT activator. Production on 2007–2008. Cadillac Escalade L92 engine. Single-bolt design. 4X camshaft gear.

Crankshaft sprocket 12556582: Fits all except LS7/LS9. For standard single-stage oil pumps. Works with cam sprockets 12576407 or 12586481.

Crankshaft sprocket 12581278: For use with 2-stage LS7/LS9 oil pump only. Works with cam sprockets 12576407 or 12586481.

Timing chain 12586482: Fits all 1997–2009 LS engines

Timing chain tensioner 12585997: For L92 and LS3. Includes retainer and bolts.

Camshaft sprocket bolt 12556127: For use with 3-bolt (non-VVT) cams. For LS1, LS6, LS2, LS9 and early LS7.

Camshaft sprocket bolt 12561283: For 2008-2009 LS3 and LS7. For use with single-bolt cams and non-VVT timing covers.

Camshaft sprocket bolt 12588151: Combination bolt and valve for VVT engines and for L92. Use with VVT camshaft sprocket 12585994.

GM Flywheels, Flexplates and Clutches
Flywheel 12598613: LS9 only. 9-bolt

Flywheel 12571611: LS2, LS3, LS7 models

Flywheel w/pressure plate 12581650: For LS1 Camaro

Clutch disc/pressure plate 24248985: For LS2, LS3, LS7 Corvette

Flywheel/clutch/pressure plate 12570806: For LS2 GTO

Dual mass clutch/pressure plate 24237568: LS9 ZR1

Flywheel 12598613: For LS9 ZR1

Flexplate 12606620: For LS 6-bolt crank

Flywheel bolt 11569956: For LS1/LS6, LS2, LS3/LS7, L92 models

Flywheel dowel 11505820: All LS models

Flexplate bolt 11569956: LS1, LS6, LS2 models, six required.

GMPP LSX Pistons
GM Performance Parts upgrade pistons. Lightweight forged 4032 aluminum. Anti-friction skirt coating. Forced pin oiling. Pistons include wrist pins and rings.

LSX376 Piston 19166957: Flat top, no valve notches, 4.065" bore. For use with stock connecting rods only. Weight-matched to stock LS3 piston weight.

LSX376 Piston 19244016: The 14cc dish lowers compression to approx. 9:1 with most standard LS cylinder heads. Optimized for supercharged or turbocharged applications, 4.065" bore. Use with stock-type connecting rods only.

LSX454 Piston 19166958: Dished with valve reliefs, 4.185" bore. Must be used with LSX connecting rods. Features 0.866" wrist pin.

GM LS Crankshafts
LS1/LS6 89017522: Used on 1997–2004. Standard 3.622" stroke. Nodular cast. With 24X reluctor wheel installed. Balanced for stock 3.898" bore.

LS2/LS3 12588612: Nodular cast 3.622" stroke with 58X reluctor wheel installed. Used on 2006–2007 Corvette. Balanced for 4.000" bore.

LS7/LS9 12611649: Forged steel 4.000" stroke, with 58X reluctor wheel installed. Rebalancing required if stock LS7 rods and pistons are not used. **Note:** Machine 0.866" from snout length for use in wet-sump applications.

Rear Crank Seal 89060436: For all LS engines.

Roller Pilot Bearing 12557583: For high-performance manual transmission applications. Fits all LS cranks.

Reluctor Wheel 24X 12559353: 24-tooth crankshaft position sensor timing wheel for 1997–2005 engines.

Reluctor Wheel 58X 12586768: 58-tooth crankshaft position sensor timing wheel for 2006 and newer.

GMPP LSX Crankshafts
Note: LSX components are GMPP's performance upgrade items, not originally used in production vehicle engines.

LSX Crankshaft 19170388: 3.622" stroke, 4340 forged steel. Includes 58X reluctor wheel. Reluctor wheel can be swapped to 24X for use with LS1/LS6/LS2 controller. 8-bolt flexplate/flywheel required. Balancing required. Generous fillets. Requires use of chamfered rods.

LSX Crankshaft 119244018: 4.125" stroke, 4340 forged steel. Includes 58X reluctor wheel. Reluctor wheel can be swapped to 24X for use with LS1/LS6/LS2 controller. 8-bolt flexplate/flywheel required. Balancing required. Generous fillets. Requires use of chamfered rods.

GM LS Connecting Rods
LS1/LS6 Rod 12568734: Press-fit for all 1997–2004 LS1/LS6

LS2/LS3 Rod 12617570: Bronze bushing. For all 2005–2007 LS2 and 2008–2009 LS3.

LS6 Rod Bolts 11610158: Recommended for performance Gen III engines. Greater strength than pre-2000 rod bolts. One bolt per package.

LS7 Rod 12586258: Titanium rod used in 2006–2009 LS7 crate engines.

LS7 Rod Bolts 11609825: Required for LS7 builds. Sold individually.

LS1/LS6/LS2/LS3 Rod Bearing 89017573: One upper and lower per rod. For all LS engines except LS7 and LS9.

LS7/LS9 Rod Bearing 89017811: One upper and lower per rod.

GMPP LSX Connecting Rods
GMPP performance upgrade rods not used in production engines. All LSX rods are made from 4340 forged steel and feature I-beam design, chamfered big ends, 2.100" big end journals, 0.866" bushed small ends, 7/16" 12-point 8740 rod bolts and doweled caps and are weight-matched in sets of eight. Cannot be used with production pistons. Require LSX or aftermarket pistons.

LSX Rod Kit 19166964: 6.000"
LSX Rod Kit 19166965: 6.098"
LSX Rod Kit 19166966: 6.125"

GM CRATE ENGINES

P/N	Model	Liter	CID	HP	TQ	Bore	Stroke
19165628	LS327/327	5.3	327	327	347	3.780	3.622
17801267	LS1	5.7	346	350	365	3.898	3.622
17801266	LS6	5.7	346	405	395	3.898	3.622
19165484	LS2	6.0	364	400	400	4.000	3.622
12611022	L99	6.2	376	430	424	4.065	3.622
19171224	LS376/480	6.2	376	485	475	4.065	3.622
19171225	LS376/515	6.2	376	515	469	4.065	3.622
19201992	LS3	6.2	376	430	424	4.065	3.622
19211978	LSA	6.2	376	556	551	4.065	3.622
19201990	LS9	6.2	376	638	604	4.065	3.622
19171821	CT525	6.2	376	525	471	4.065	3.622
19165058	LS7	7.0	427	505	470	4.125	4.000

PROJECT LS2 PART NUMBERS

This is a comprehensive listing of every part used in the stroked 625.4 hp build that I have documented in this book as the sample build. If you want to duplicate the engine I built, this list of components provides everything required.

Part	**Manufacturer**	**P/N**
Block (6.0L LS2 alum.)	GM (SDPC)*	12568950
Block completion kit	GM (SDPC)	KITLS2CK-1
Rear engine cover	GM (SDPC)	12615666
Camshaft retainer plate	GM (SDPC)	12589016
Crankshaft (forged 4.000")	Lunati	J0711ER
Crankshaft 24-tooth		
reluctor wheel (1997–2005)	GM	12559353
58-tooth (2006 & newer)	GM	12586768
Rods (H-beam 6.125")	Lunati	6125H3
Camshaft (hyd. roller)	Crane	144HR00162
Lifters	Crane	144536-16
Pushrods (5/16"x 7.500")	Trick Flow	TFS-21407500
Rocker arms (1.7:1 rollers)	Harland Sharp	SLS17
Cylinder heads	Trick Flow	TFS-3060T001-C02
Damper/crank pulley	ATI Super Damper kit	917286
LS crank pin drill fixture	ATI	918993
Oil pump	Melling	10296
Timing chain setup	SDPC	SD7245
Oil dipstick tube	GM	1257-0787
Oil dipstick	GM	12570788
Oil pump pickup	Moroso	24050
Oil pan windage tray	Moroso	22941
Oil pan	Moroso	20141
Main cap stud kit	ARP	234-5608
Cyl. head stud kit	ARP	234-4317
Front cover fasteners	ARP	434-1502
Rear cover fasteners	ARP	434-1504
Valley cover fasteners	ARP	434-8002
Camshaft retainer plate bolts	ARP	134-1002
Cam sprocket bolts	ARP	134-1003
Carburetor studs	ARP	400-2401
Water pump bolts	ARP	434-3202
Exhaust header studs	ARP	434-1301
Crank snout/damper bolt	ARP	234-2503
Main bearings	MAHLE Clevite	MS2199HK
Rod bearings	MAHLE Clevite	CB663HNK
Pistons (forged side-relief)	JE	243016
Piston rings	JE	J60008-4000-5
Oil ring support rails	JE	RA4000-183
Wrist pin wire locks	JE	927-073-MW
Wrist pins	JE	927-2250-15-51C

Part	Manufacturer	P/N
Water pump	Edelbrock	8896
Water pump pulley	Edelbrock	8898
Cylinder head gaskets	MAHLE Victor	54332
Engine gasket set	MAHLE Victor	CS5975
Spark plugs	NGK	4177
Carburetor intake manifold	Edelbrock Victor Jr.	28097
Carburetor	Edelbrock Performer 800cfm	1412
LS Coil pack kit	MSD	82458
Timing control module (module for 24-tooth reluctor)	MSD	6010
Timing control harness	MSD	60101
Valve covers	Moroso	68355
Coil pack hinge brackets	Moroso	72396
Spark plug wires	Moroso Ultra 40	73436
Belt Tensioner	Comp Cams	54021
Oil pressure sensor	GM	12616646
Water temp sensor	GM	15326388
Crankshaft position sensor	GM	12560228
Knock sensor	Standard Motor Products	KS211
Valve cover bolts and grommets	GM	12577215
Cyl head coolant crossover tube	GM	1260-2548
Cyl head rear steam covers	GM	12602540
Water plug for RH cyl head		

12mmx1.5x15-20 mm bolt with Teflon and crush washer. This plug is not available separately from GM; only with new cyl head.

*SDPC is Scoggin-Dickey Parts Center

Note: All of the parts listed above can be found at retailers such as SDPC, Pace Performance, Summit Racing and Jegs.

SOURCE INDEX

Bearings & Gaskets
Cometic Gasket, Inc.
8090 Auburn Rd.
Concord, OH 44077
800-752-9850
cometic.com

Federal Mogul Corp.
26555 Northwestern Hwy.
Southfield, MI 48033
248-354-9282
federal-mogul.com

Fel-Pro
(See Federal Mogul, above)

Mahle Clevite
mahleclevite.com

Camshafts & Valvetrain
Cloyes Gear
6101 Phoenix Ave., Ste. 2
Ft. Smith, AR 72903
248-365-0363
cloyes.com

Comp Cams (RHS)
3406 Democrat Rd.
Memphis, TN 38118
800-999-0853
compcams.com

Crane Cams, Inc.
1640 Mason Ave., Unit 180
Daytona Beach, FL 32117
866-388-5120
cranecams.com

Crower Cams
6180 Business Center Ct.
San Diego, CA 92154
619-661-6477
crower.com

Del West Engineering
28128 W. Livingston Ave.
Valencia, CA 91355
800-990-2779
www.delwestusa.com

Edelbrock Corp.
2700 California St.
Torrance, CA 90503
310-781-2222
edelbrock.com

Electronic Chrome & Grinding
9128 Dice Rd.
Santa Fe Springs, CA 90670
562-946-6671
ecgrinding.com

Elgin Industries
1100 Jansen Farm Dr.
Elgin, IL 60123-2555
847-742-1720
elginind.com

Erson Cams
16 Kit Kat Dr.
Carson City, NV 89706
800-641-7920
pbm-erson.com

Ferrea Racing Components
2600 NW 55th Ct., Ste.234
Ft. Lauderdale, FL 33309
888-733-2505
ferrea.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Harland Sharp
19769 Progress Dr.
Strongsville, OH 44149
440-238-3260
harlandsharp.com

Isky Racing Cams
16020 S. Broadway
Gardena, CA 90248
323-770-0930
iskycams.com

Jesel, Inc.
1985 Cedar Bridge Ave.
Lakewood, NJ 08701
732-901-1800
jeselonline.com

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

KPMI
580 Crespi Dr., Ste. 1
Pacifica, CA 94044-3426
650-359-4704
blackdiamondvalves.com

Lunati
11126 Willow Ridge Dr.
Olive Branch, MS 38654
662-892-1500
lunatipower.com

Manley Performance Products
1960 Swarthmore Ave.
Lakewood, NJ 08701
800-526-1362
manleyperformance.com

Manton Racing Products
558 Birch St. Bldg 4
Lake Elsinore, CA 92530
951-245-6565
mantonpushrods.com

Milodon, Inc.
2250 Agate Ct.
Simi Valley, CA 93065
805-577-5950
milodon.com

Pioneer, Inc.
5184 Pioneer Rd.
Meridian, MS 39301
800-647-6272
pioneerautoinc.com

PRW Industries, Inc.
193 West Orangethorpe Ave.
Placentia, CA 92870
714-792-1000
prw-usa.com

Racing Engine Valves, Inc.
2610 Windsor Ave.
West Palm Beach, FL 33407
800-398-6348
revvalves.com

RPM International, Inc.
16313 Arthur St.
Cerritos, CA 90703
800-981-0776
racingpartsmaximum.com

Scorpion Performance
3000 SW 4th Ave.
Ft. Lauderdale, FL 33315
954-799-3600
scorpionperformance.com

SI Valves
4477 Shopping Ln.
Simi Valley, CA 93063
800-564-8258
sivalves.com

Supertech Performance
3580 Charter Park Dr.
San Jose, CA 95136
408-448-2001
supertechperformance.com

T&D Machine Products
4859 Convair Dr.
Carson City, NV 89706
775-884-2292
tdmach.com

Trend Performance
23444 Schoenherr Rd.
Warren, MI 48089
586-447-0400
trendperform.com

Xceldyne Technologies
37 High Tech Blvd.
Thomasville, NC 27360
888-481-2310
www.xceldyne.com

Zanzi Spa
Corso Vercelli 159
10015 Ivrea (TO), Italy
+39 0125251540
www.zanzi.com

Connecting Rods
Callies Performance Products
P.O. Box 926
Fostoria, OH 44830
419-435-2711
callies.com

Carrillo Industries, Inc.
990 Calle Amanecer
San Clemente, CA 92673
949-498-1800
carrilloind.com

Eagle Specialty Products
8530 Aaron Ln.
Southaven, MS 38671
662-796-7373
eaglerod.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

Lunati
11126 Willow Ridge Dr.
Olive Branch, MS 38654
662-892-1500
lunatipower.com

Oliver Racing Parts
1025 Clancy Ave. NE
Grand Rapids, MI 49503
800-253-8108
oliverconnectingrods.com

Scat Enterprises
1400 Kingsdale Ave.
Redondo Beach, CA 90278
310-370-5501
scatcrankshafts.com

Crankshafts

Bryant Racing
1600 East Winston Rd.
Anaheim, CA 92805
714-535-2695
bryantracing.com

Bullet Racing Cams
8785 Old Craft Rd.
Olive Branch, MS 38654
662-893-5670
bulletcams.com

Callies Performance Products
P.O. Box 926
Fostoria, OH 44830
419-435-2711
callies.com

Crower Cams
6180 Business Center Ct.
San Diego, CA 92154
619-661-6477
crower.com

Eagle Specialty
8530 Aaron Ln.
Southaven, MS 38671
662-796-7373
www.eaglerod.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

K-1 Technologies
889 76th St. Unit 6
Byron Center, MI 49315
616-583-9700
k1technologies.com

King's Crankshafts
4106 Sinclair St.
Denver, NC 28037
704-483-1005
kingscrankshaft.com

KP Crankshafts
3524 Wayland Dr.
Jackson, MI 49202
800-443-0415
kpcrankshafts.com

Lunati
11126 Willow Ridge Dr.
Olive Branch, MS 38654
662-892-1500
lunatipower.com

Mile High Crankshafts
888 South Lipan St.
Denver, CO 80223
303-781-6764
milehighcranks.com

Mittler Brother
Machine & Tool
P.O. Box 110
Foristell, MO 63348
800-467-2464
mittlerbros.com

Oliver Racing Parts
1025 Clancy Ave. NE
Grand Rapids, MI 49503
800-253-8108
oliverconnectingrods.com

Scat Enterprises
1400 Kingsdale Ave.
Redondo Beach, CA 90278
310-370-5501
scatcrankshafts.com

Crankshaft Balancers/Dampers

ATI Performance Products
6747 Whitestone Rd.
Baltimore, MD 21207
877-298-4817
atiracing.com

BHJ Dynamics, Inc.
37530 Enterprise Ct.
Newark, CA 94560
510-797-6780
bhjdynamics.com

CVR
P.O Box 185
Amprior, ON
K7S 3H4, Canada
613-623-8064
cvrproducts.com

Fluidampr
180 Zoar Valley Rd.
Springville, NY 14141
716-592-1000
fluidampr.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

PRW Industries
193 West Orangethorpe Ave.
Placentia, CA 92870
714-792-1000
prw-usa.com

Trick Flow Specialties
1248 Southeast Ave.
Tallmadge, OH 44278
330-630-1555
trickflow.com

Wegner Automotive
Research
N 2258 Hilltop Rd.
Markesan, WI 53946
920-394-3557
wegnerautomotive.com

Cylinder Heads

Airflow Research (AFR)
10490 Llex Ave.
Pacoima, CA 91331
818-890-0616
airflowresearch.com

Dart Machinery
353 Oliver St.
Troy, MI 48084
248-362-1188
dartheads.com

Edelbrock Corp.
2700 California St.
Torrance, CA 90503
310-781-2222
edelbrock.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

Pro-Filer Performance
New Carlisle, OH 45344
937-846-1333
profilerperformance.com

RHS
3406 Democrat Rd.
Memphis, TN 38118
800-999-0853
racingheadservice.com

Trick Flow Specialties
1248 Southeast Ave.
Tallmadge, OH 44278
330-630-1555
trickflow.com

Engine Blocks
Dart Machinery
353 Oliver St.
Troy, MI 48084
248-362-1188
dartheads.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

RHS
3406 Democrat Rd.
Memphis, TN 38118
800-999-0853
racingheadservice.com

World Products
51 Trade Zone Ct.
Ronkonkoma, NY 11779
631-981-1918
worldcastings.com

Exhaust Systems
Borla
701 Arcturus Ave.
Oxnard, CA 93073
877-462-6752
borla.com

Corsa Performance Exhaust
140 Blaze Industrial Parkway
Berea, OH 44017
440-891-0999
corsaperf.com

Edelbrock Corp.
2700 California St.
Torrance, CA 90503
310-781-2222
edelbrock.com

Hedman Heddars
12438 Putnam St.
Whittier, CA 90602
562-921-0404
hedman.com

Hooker/Flowtech
(Div.. of Holley)
704 Highway 25 South
Aberdeen, MS 39730
662-369-6153
holley.com

SLP Performance Parts
1501 Industrial Way North
Toms River, NJ 08755
732-349-2109
slponline.com

Fasteners & Plumbing
A1 Technologies
7022 Alondra Blvd.
Paramount, CA 90723
562-408-1808
a1technologies.com

Aeroquip Performance Products
14615 Lone Oak Rd.
Eden Prairie, MN 55344
888-258-0222
aeroquip.com

ARP, Inc.
1863 Eastman Ave.
Ventura, CA 93003
800-826-3045
arp-bolts.com

Earl's Plumbing
19302 S. Laurel Park Rd.
Rancho Dominguez, CA 90220
310-609-1602
earlsplumbing.com

Earl's Indy
302 Gasoline Alley
Indianapolis, IN 46222
800-331-4639
earlsindy.com

Fragola Performance Systems
888 West Queen St.
Southington, CT 06489
866-337-2739
fragolaperformancesystems.com

Russell Performance
(A Div. of Edelbrock)
2700 California St.
Torrance, CA 90503
310-781-2222
russellperformance.com

XRP, Inc.
5630 Imperial Hwy.
South Gate, CA 90280
562-861-4765
xrp.com

GM Performance Parts Distributors
GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Pace Performance
430 Youngstown-Warren Rd.
Niles, OH 44446
800-748-3791
paceparts.com

Scogging Dickey Performance Parts (SDPC)
P.O. Box 64910
Lubbock, TX 79464
806-798-4108
sdparts.com

Ignitions
ACCEL
10601 Memphis Ave. #12
Cleveland, OH 44144
216-688-8300
mrgasket.com

AEM
2205 W. 126th St., Unit A
Hawthorne, CA 90250
310-484-2322
aempower.com

Mallory Ignition
10601 Memphis Ave. #12
Cleveland, OH 44144
216-688-8300
mrgasket.com

Moroso Performance Products
80 Carter Dr.
Guilford, CT 06437
203-453-6571
moroso.com

MSD Ignition
1490 Henry Brennan Dr.
El Paso, TX 79936-6805
915-857-5200
msdignition.com

Performance Distributors
2699 Barris Dr.
Memphis, TN 38132
901-396-5782
performancedistributors.com

Pertronix
440 East Arrow Hwy.
San Dimas, CA 91773
909-599-5955
pertronix.com

Procomp Electronics
605 S. Milliken Ave., Unit A
Ontario, CA 91761
909-605-1123
procompelectronics.com

Professional Products
12705 S. Van Ness Ave.
Hawthorne, CA 90250
323-779-2020
professional-products.com

Intake Manifolds, Throttle Bodies & Induction
BBK Performance
27440 Bostik Ct.
Temecula, CA 92590
951-296-1771
bbkperformance.com

Edelbrock Corp.
2700 California St.
Torrance, CA 90503
310-781-2222
edelbrock.com

FAST
3406 Democrat Rd.
Memphis, TN 38118
800-999-0853
compcams.com

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

Holley Performance Products
1801 Russellville Rd.
Bowling Green, KY 42102
270-782-2900
holley.com

Precision Metalcraft
138 S. Vinewood St. #A
Escondido, CA 92025
760-741-1539
precision-metalcraft.com

Professional Products
12705 S. Van Ness Ave.
Hawthorne, CA 90250
323-779-2020
professional-products.com

Pro-Filer Performance
P.O. Box 217
New Carlisle, OH 45344
937-846-1333
profilerperformance.com

Weiand
(A Div. of Holley)
1801 Russellville Rd.
Bowling Green, KY 42102
270-782-2900
holley.com

Weinle Motorsports
4817 E. Miami River Rd.
Cleves, OH 45002
513-607-2592
weinlemotorsports.com

Wilson Manifolds
4700 NE 11th Ave.
Ft. Lauderdale, FL 33334
954-771-6216
wilsonmanifolds.com

LS Engine Builders

Birchwood Automotive Group
10205 Wooster Pike Rd.
Creston, OH 44217
330-435-6347
birchwoodautomotive.com
(custom engine prep and assembly, and custom engine installation for street rods and classic/muscle cars)

Fall Automotive Machine
3519 Jackman Rd.
Toledo, OH 43612
419-473-1557
(street and race engines)

Gressman Powersports
904 Lime St.
Fremont, OH 43420
419-355-8980
gressmanpowersports.com
(street and race engines)

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com
(street and race engines)

Lingenfelter Performance Engineering
1557 Winchester Rd.
Decatur, IN 46733
260-724-2552
lingenfelter.com
(street and race engines)

Livernois Motorsports
2500 South Gulley Rd.
Dearborn Heights, MI
313-561-5500
livernoismotorsports.com
(street and race engines)

Shafiroff Racing Engines
35 Davinci Dr.
Bohemia, NY 11716
800-295-7142
shafiroff.com
(racing engines)

Oil Pumps, Pans & Valve Covers

Aviaid Oil Systems
10041 Canoga Ave.
Chatsworth, CA 91311
818-998-8991
aviaid.com

Canton Racing Products
232 Branford Rd.
North Branford, CT 06471
203-481-9460
cantonracingproducts.com

Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

Melling Select Performance
P.O. Box 1188
Jackson, MI 49204
517-787-8172
melling.com

Milodon, Inc.
2250 Agate Ct.
Simi Valley, CA 93065
805-577-5950
milodon.com

Moroso Performance Products
80 Carter Dr.
Guilford, CT 06437
203-453-6571
moroso.com

PRW Industries
193 West Orangethorpe Ave.
Placentia, CA 92870
714-792-1000
prw-usa.com

Pistons

Arias Pistons
13420 S. Normandie Ave.
Gardena, CA 90249
310-532-9737
ariaspistons.com

CP Pistons
1902 McGraw
Irvine, CA 92614
877-874-7866
cppistons.com

Diamond Racing Products
23003 Diamond Dr.
Clinton Twp., MI 48035
877-552-2112
diamondracing.net

GM Performance Parts
6200 Grand Pointe Dr.
Grand Blanc, MI 48439
810-606-3310
gmperformanceparts.com

JE Pistons
15312 Connector Ln.
Huntington Beach, CA 92649
714-898-9763
jepistons.com

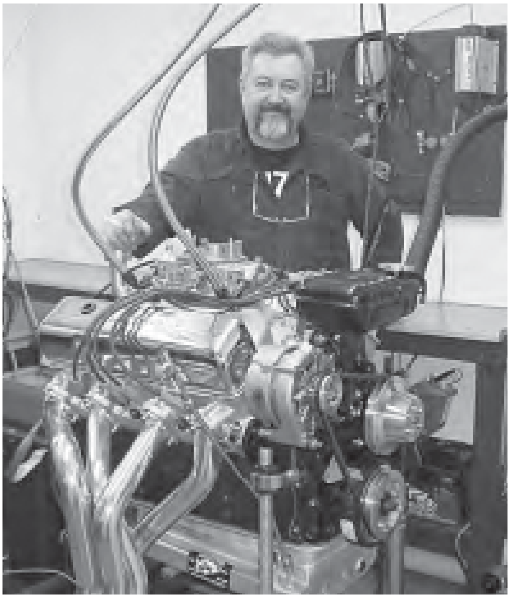
Katech, Inc.
24324 Sorrentino Ct.
Clinton Twp, MI 48035
586-791-4120
katechengines.com

KB Performance Pistons
P.O. Box 2680
Carson City, NV 89702
800-648-7970
kb-silvolite.com

Probe Industries
2555 West 237th St.
Torrance, CA 90505
310-784-2977
probeindustries.com

Ross Racing Pistons
625 S. Douglas St.
El Segundo, CA 90245
310-536-0100
rosspistons.com

ABOUT THE AUTHOR



Mike Mavrigian has written a broad range of automotive technical articles for the past 30 years involving a variety of industry areas, including engine rebuilding, performance and race engine building, tires, wheels, brakes, wheel alignment, suspension, ride control, steering, drivetrain, engine diagnostics, air compressors, pneumatic tools, metallurgical issues relating to engine building/rebuilding, vibrational stress relief and cryogenic treatment of metals, paint and body, climate control, electric winches, trailer towing/hitch systems, SUV upgrades, sport/compact upgrades, race car preparation, street rod construction and automotive-related threaded fasteners/clamping forces.

In addition to his magazine work, Mike has authored consumer-oriented books, including the following HPBooks titles: *Performance Wheels & Tires*, *Brake Systems*, *Rebuilding Gen V/VI Big-Block Chevy Engines*, *How to Rebuild Small-Block Chevy LT-1/LT-4 Engines* and *High-Performance Fasteners & Plumbing,* as well as several other books dealing with general automotive repair. Mike also writes each issue of *Modern Tire Dealer* magazine's popular annual *Performance Handbook* and has authored technical training manuals for McGraw-Hill and a host of automotive parts and tool manufacturing clients.

Mike serves as editor of *Precision Engine* magazine, a technical publication focused on professional performance and racing engines. Mike has authored automotive technical articles for a host of other industry publications, including *Modern Tire Dealer*, *Motor Age*, *Automotive Body Repair News*, *Truck & SUV Performance*, *Aftermarket Business*, *Engine Professional, SEMA News*, *Jobber Retailer* and *Parts Professional* magazines. Consumer magazine work includes *Mopar Action*, *Street Rodder*, and *Sport Compact Car* magazines.

Corporate Project Vehicle Programs—Mike owns and operates Birchwood Automotive Group, based in Creston, Ohio, which prepares specialty vehicles and engines for a range of automotive industry manufacturers and other clients.

Birchwood's client list includes Porsche Cars North America, *Field & Stream* magazine, *Outdoor Life* magazine, Holley Performance Products, BFGoodrich, Michelin and AERA, to name but a few. In addition to executing project vehicle programs for its corporate clients, Birchwood produces street rods, muscle cars, custom cars and sport-compact performance cars for a range of consumer customers.

Motorsports Programs—The Birchwood operation also maintains an 18-person experienced and skilled motorsports team that specializes in endurance road racing programs. The team has competed in over fourteen 24-hour and 12-hour endurance races at tracks including: Nelson Ledges, Mid-Ohio, Watkins Glen, Summit Point Raceway, and Moroso Motorsports Park, where the team garnered a class win during a 1999 24-hour race. In 2005, Mike was contracted by Porsche Cars North America to facilitate Porsche's Speed Record Run event at Talladega Superspeedway, involving the firm's Carrera GT cars, driven by pro driver David Donohue and celebrity Jay Leno.