

Corvette Engine Comparison				
Corvette model	Base		Z06	
Engine	2004 LS1	2005 LS2	2004 LS6	2005 LS7
Displacement	5.7 L	6.0 L	5.7 L	7.0 L
Power	350 hp (261 kW) at 5200 rpm	400 hp (298 kW) at 6000 rpm	405 hp (302 kW) at 6000 rpm	500 hp (373 kW) at 6200 rpm
Torque	375 lb-ft (508 N-m) at 4000 rpm	400 lb-ft (542 N-m) at 4400 rpm	400 lb-ft (542 N-m) at 4800 rpm	475 lb-ft (644 N-m) at 4800 rpm

quirements. Housed in the manifold are 90-mm (3.54-in), single-bore throttle bodies and higher-capacity, 5-g/s (0.18-oz/s) fuel injectors.

The aluminum cylinder heads are CNC-ported on state-of-the-art five-axis milling machines to meet airflow demands that are 25% greater than LS2's. The engine has straight intake runners and very large (by production-vehicle standards) ports to speed airflow. The combustion chambers are fed by large—56-mm (2.2-in)—titanium intake valves that each have a mass 21 g (0.7 oz) less than the stainless-steel valves used in the LS2 despite having 22% more area. The sodium-filled exhaust valves are 41.0 vs. 39.4 mm (1.61 vs. 1.55 in) in the LS2. The valve seats are Siamesed to accommodate the large valve face diameters,

and experience with the C5R results in valve angles of 12° vs. 15° (for the LS2) for enhanced airflow.

Unique hydraulic rollers actuate the larger valves, and based on C5R racing experience, the LS7's cam has a new profile to provide 0.066 in (1.7 mm) more lift—0.591 vs. 0.525 in (15.0 vs. 13.3 mm)—on both the intake and exhaust valve. Higher-performance (1.8:1 vs 1.7:1) roller rocker arms, which are offset on the intake side, and raised valve spring seats accommodate the high valve lift and large ports.

On the exhaust side, hydroformed steel exhaust headers are unique to the LS7. Individual header tubes meet at a special quad-outlet collector flange at the header outlet where they smoothly attach to the "wide-mouth" catalytic converter for reduced back pressure. Four rectangu-



The LS7's aluminum flat-top pistons are connected to a forged-steel crankshaft with titanium connecting rods.

lar sections of the flange smooth the exhaust flow out of the engine.

LS7s will be hand-assembled at GM's new Performance Build Center in Wixom, MI, using procedures—such as deck-plate boring and honing of the cylinders and crank line-boring of the block with the deck plates and side bolts installed—normally associated with race-engine building. The engines are pushed through about 15 subassembly stations. Team members are engine-build specialists selected from GM's experimental engine lab, and they complete about 30 LS7 engines per day.

Kevin Jost

BMW builds better inline six

"Efficient dynamics" is the declared goal of the **BMW** Group's drivetrain development division. "This resolves the apparent conflict between reducing consumption and emissions on the one hand and enhancing performance and agility on the other," commented Professor Burkhard Göschel.

With that goal in mind, BMW undertook development of a new 3.0-L inline-six gasoline engine, the R6, that is said to be the most comprehensive engine project since the introduction of its first automobile. Rather than upgrade its existing I6 to state-of-the-art technical specifications, which would have resulted in an engine 14 kg (31 lb) heavier, BMW engineers decided to develop an entirely new engine, leaving only the inline arrangement of six cylinders unchanged.

The high-tech power unit has a composite magnesium/aluminum crankcase, BMW's Valvetronic infinitely variable valve

timing that eliminates the throttle butterflies, and a number of other innovations such as the world premiere of the electric water pump. The R6 is said to distinctly surpass the final version of its predecessor in every aspect. BMW's medium-term corporate plans reveal that around half of all new BMW cars will be powered by the engine.

Peak output of the R6 surpasses its predecessor by 20 kW (27 bhp) with 190 kW (258 bhp) at 6650 rpm. Maximum torque of 300 N-m (221 lb-ft) is available between 2500 and 4000 rpm. The company says the basic unit has the highest specific power output per liter and the highest power/mass ratio in its class at 63 kW/L (84 hp/L) and 1.18 kW/kg (0.717 hp/lb), respectively. At just 161 kg (355 lb), the R6 is 7% lighter than its predecessor, making it the world's lightest six-cylinder engine, says BMW. Power output is up by 12%, with fuel consumption

down by 12%—and the lowest specific fuel consumption in its class.

For the first time in modern engine construction, BMW uses magnesium for the engine's crankcase, with the material also employed for the new bedplate and cylinder-head cover. The 7%, or 10-kg (22-lb), reduction in engine mass resulting from use of magnesium and from other lightweight engine components such as exhaust manifolds and camshafts is said to contribute substantially to increased agility and dynamics of future BMW automobiles.

The composite magnesium/aluminum crankcase weighs just 57% of a comparable grey-cast iron block, and has a 24% advantage compared to aluminum. Being the largest single engine component, it makes a significant contribution to reducing total mass.

However, use of magnesium does pose some interesting technical challeng-

es. A crankcase made exclusively of magnesium or a conventional magnesium alloy is inadequate for high-performance production engines; it has insufficient stability and the surface structure of magnesium is unsuitable for the cylinder liners. So the inner part of the R6 crankcase features an aluminum insert that incorporates the cylinder liners and coolant ducts. The insert provides the required stability under the high thermal and mechanical strains of the engine. The cylinder head is mounted directly onto the insert, the lower section of the latter serving as the upper section of the crankshaft mounting. BMW overcame the problem of the chemical incompatibility of magnesium and water by not allowing the coolant to come in contact with the magnesium crankcase shell because it flows exclusively inside the aluminum insert.

The magnesium jacket accommodates the oil ducts, gear casing, as well as most mounts and brackets for ancillary components. The integration of supports and brackets increases stiffness of the ancillary component connection, enhancing the acoustics of the crankcase/ancillary component package. The R6 engine continues BMW's tradition of chain drive of the valves. The company prefers the method because they say it contributes greatly to accurate and durable functioning of the engine and reduced maintenance—and cost—for the vehicle owner. During engine assembly, the chain drive is placed into a chamber at the front of the engine and fixed into place without gear casing bolts and time-consuming sealing of the cylinder head and crankcase.

Since the magnesium bedplate functions as a load-bearing engine component of the R6's central frame structure, it also employs composite construction. The crankcase is mounted on the bedplate from above, together with the upper section of the crankshaft bearing. The lower counterpart of the crankshaft bearing is integrated into the bedplate. The crankshaft runs on sintered steel inserts surrounded by magnesium. After the bedplate and crankcase are bolted together, a sealing compound is injected under high pressure between the two components. Due to similar coefficients of expansion, aluminum bolts are used for fixing parts to magnesium components, adding to the reduction in engine mass.

After the aluminum-magnesium



BMW calls its new R6 3.0-L inline six the most comprehensive engine project since the introduction of its first automobile.

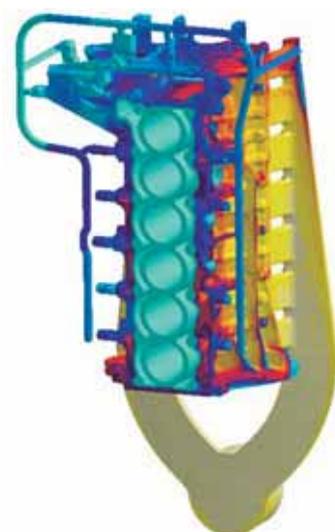
crankcase, the new lightweight camshafts are the largest single contributors to the R6's low mass. Hydroforming reduces the mass of each of the two finished camshafts by 25%, or 600 g (21.1 oz). The primary camshaft component, a steel tube, is pulled through the high-strength steel cam rings. The assembly is placed in

a die and the tube is subjected to internal water pressure of 4000 bar (58 ksi) to achieve the desired wave shape and pressed against the cams from the inside. Finally, the cams are polished down to a 39- μ m finish.

New connecting rods also contribute to mass savings. When viewed from the side, their upper eye is tapered to save a few grams each, which might not seem like a lot but is significant considering the high speed at which the connecting rods



The R6 crankcase features a magnesium shell around an aluminum insert (image) that incorporates the cylinder liners and coolant ducts.





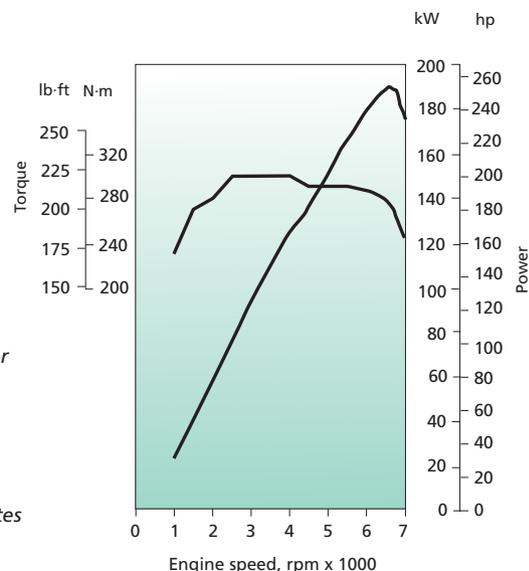
The R6 gets BMW's second-generation Valvetronic for higher engine speeds. The innovation adjusts valve opening times and valve timing infinitely according to accelerator pedal position and eliminates the need for throttle butterflies

reciprocate. The lower area of the connecting rod eye is wider so the gudgeon pin can transfer the high forces of the crankshaft via the connecting rod.

Second-generation Valvetronic makes its first appearance on the R6, following implementation of the first generation on BMW four-, eight-, and twelve-cylinder power units. The innovation adjusts valve opening times and valve timing infinitely according to accelerator pedal position. This technology eliminates the need for throttle butterflies and very accurately

regulates charge-changing processes, achieving better fuel economy and improved engine response. The hike in rated R6 engine speed and maximum engine speed to 7000 rpm necessitated the system's redesign, specifically for enhanced stiffness. The system now achieves valve actuation acceleration ratings equal to those of bucket tappet valvetrains. It also incorporates more aluminum components, contributing to mass reduction.

BMW believes Valvetronic will be distinctly more successful than lean direct-



Peak output of the R6 surpasses its predecessor by 20 kW (27 bhp), with 190 kW (258 bhp) at 6650 rpm. Maximum torque of 300 N-m (221 lb-ft) is available between 2500 and 4000 rpm.

injection concepts. Employing it on the six-cylinder, the most widely sold BMW power unit, means there will be a quantum leap for this technology's market penetration and the overall fleets' reduction in fuel consumption, regardless of region. In contrast, the full fuel-consumption potential of lean DI systems, for example, can only be exploited in markets with adequate sulfur-free fuel, which is not available in some countries. On average and under all operating conditions, Valvetronic achieves a drop in fuel consumption of 10% in the composite EU cycle.

The cooling system's electric water pump, another R6-first innovation, operates according to the engine's actual cooling requirements, regardless of engine speed. Its use results in a significant reduction in consumption. While a conventional water pump consumes up to 2 kW, the new electric unit needs just 200 W.

For a conventional water pump, cooling capacity is designed to cope with a maximum engine load at low engine speeds and is, therefore, too great for many operating conditions, especially at high engine speeds. It also operates continually via a belt drive, with excessive losses due to friction. Pump flow rate is dependent on engine speed and not on the engine's actual cooling requirements.

During warmup of the engine, its least efficient phase, the electric water pump requires little power. And the residual

R6 Engine Specifications

Configuration	Inline six
Maximum output	190 kW (258 bhp) at 6650 rpm
Maximum torque	300 N-m (221 lb-ft) at 2500-4000 rpm
Combustion	Naturally aspirated, Lambda=1.0, Valvetronic valve control
Capacity	2977 cm ³
Compression ratio	10.7:1
Bore x stroke	85 x 88 mm (3.35 x 3.46 in)
Crankcase material	Magnesium with aluminum insert, Alusil-type liners
Distance between cylinders	91 mm (3.58 in)
Conrods	Cracked, trapezoidal
Camshafts	Two, chain-driven, hydroformed, in seven bearings
Camshaft adjustment	Infinitely variable phase adjustment of intake and exhaust (bi-VANOS and Valvetronic)
Valve drive	Roller rocker arms, hydraulic valve play compensation
Valves	Four per cylinder
Intake system	Three-stage resonance
Engine mass (BMW standard)	161 kg (355 lb)
Engine management	Digital engine control with integrated Valvetronic valve management (MSV70)
Fuel	87-98 RON (rated output with RON 98 fuel)
Cooling	Electric pump, map-controlled coolant temperature

heat in the coolant can be used to heat the car's interior with the electric pump even when the engine is not running.

The use of the electric water pump, which operates without a belt, meant that all ancillary components of the R6 could be driven by one belt. The result is reduced engine length and lighter weight since accessory parts such as the belt, belt pulley, and tightener are eliminated.

As with the electric water pump, the engine's capacity-controlled oil pump supplies the specific quantity of oil for given engine operating conditions and consumes up to 2 kW less than conventional oil pumps.

The R6's three-stage air intake system, a development of the previous dual configuration, allows for higher torque at lower engine speeds. The third resonance pipe, which is actuated via resonance valves, effectively increases the engine speed range downward.

BMW engineers threw all their know-how into the exhaust manifold, with a resulting mass reduction of 0.8 kg (1.8 lb). The differing thermal expansion coefficients of aluminum (cylinder head) and steel (exhaust manifold) necessitated new solutions in this particular area. So its lightweight, deep-draw flange is reduced from 12 to 2 mm (0.47 to 0.08 in) and a

graphite ring is used on each cylinder to achieve significantly improved tightness to the engine's header. The thin-walled ceramic catalysts are smaller and lighter, so they reach operating temperature faster and eliminate the need for secondary air intake.

A new oil/water heat exchanger transfers heat to the engine oil so that it reaches operating temperature much earlier, shortening the uneconomical warmup phase. Conversely, heat is extracted from the oil circuit by the heat exchanger and from the engine via the coolant circuit during periods of greater engine output and oil temperatures.

Kevin Jost

Yamaha engineers Volvo V8

Physics and market forces are pushing most newly developed engines into very similar configurations as designers seek to optimize power and efficiency in engines that appeal to the broadest array of customers. In some cases there are overriding factors that cause manufacturers to forego the efficiency, balance, or packaging benefits of these popular solutions. In **Porsche's** case, for example, the heritage of the traditional horizontally opposed engine configuration outweighs other considerations.

Volvo's most prominent core value is safety, so when market forces dictated that an eight-cylinder engine should be offered in its XC90 mid-size SUV, the company faced a challenge packaging a wider transverse-mounted V8 engine in the space of the inline six-cylinder without compromising crush space in the engine bay.

A normal, balanced 90° V8 simply wouldn't fit with the required crush space, the company concluded. Volvo engineers estimated that to use the **Jaguar** V8 would require the XC90 front end to be extended by 200 mm (8 in). The solution would be to develop a new 60° V8. The company's acquisition by **Ford** helped Volvo engineers make the necessary connections, and Ford Chief Technical Officer Richard Parry-Jones pointed them to **Yamaha**, the company that supplied first a high-performance V6 for the Taurus SHO, and later a 60° V8 that was derived from the original six-



The compact 4.4-L Yamaha-built 60° aluminum V8 measures only 29.7 x 25 in (755 x 635 mm) and has a mass of 419 lb (190 kg), but produces 315 hp (235 kW).

cylinder.

"From the very beginning, we knew that it takes a V8 to go all the way in the premium SUV segment," said Kjell Hvarfvén, XC90 V8 Project Director. "We looked for many years for a V8 that would fit, even before Ford bought us."

Because Yamaha provides the Volvo's 4.4-L, 315-hp (235 kW), 325 lb-ft (440 N·m), 60° V8, using the same bore spacing and stroke as the old 3.4-L Taurus SHO V8, it would be easy to assume that the XC90's engine is simply a larger-displacement version of its predecessor. But that assumption would be wrong.

While some fundamental dimensions



Volvo determined that only a very narrow 60° V8 would fit in the XC90's engine bay while preserving the requisite forward crumple zone.