

Best Automobile Engines and Piston Engines



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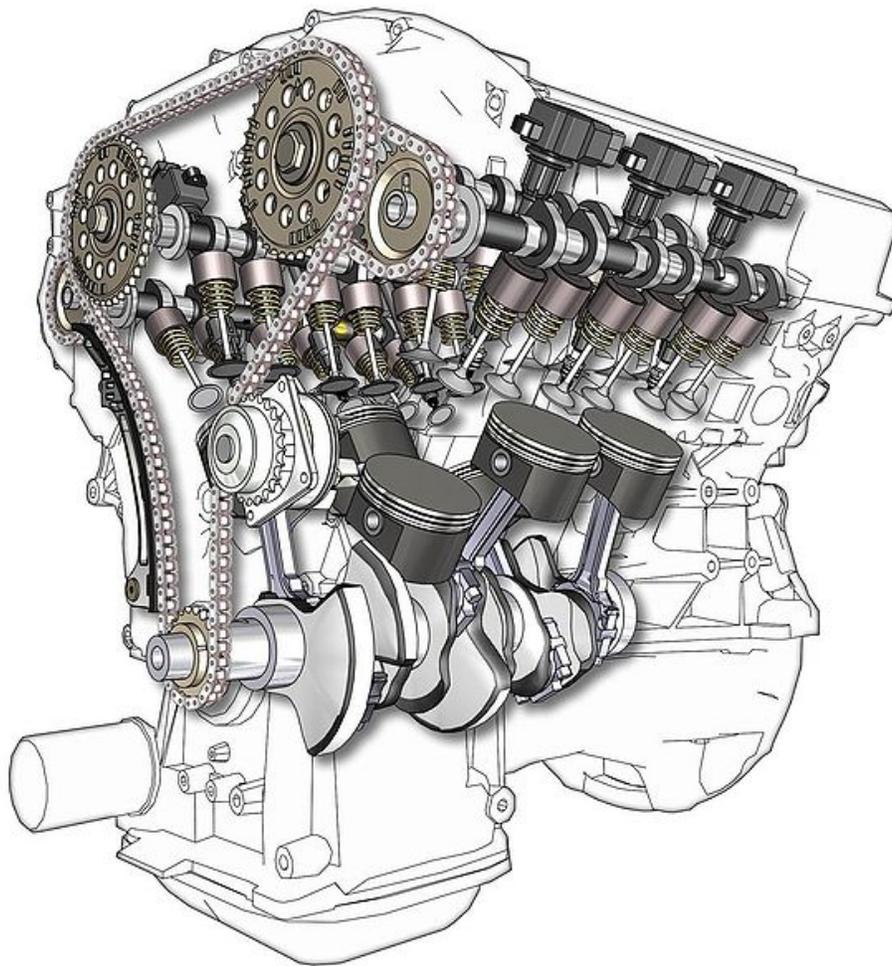
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Chapter- 1

V6 Engine



A V6, 24-valve, DOHC engine

A **V6 engine** is a V engine with six cylinders mounted on the crankcase in two banks of three cylinders, usually set at either a right angle or an acute angle to each other, with all six pistons driving a common crankshaft. It is the second most common engine configuration in modern cars after the inline four.

The V6 is one of the most compact engine configurations, shorter than the straight 4 and in many designs narrower than the V8 engine, and is well suited to the popular transverse engine front-wheel drive layout. It is becoming more common as the space allowed for engines in modern cars is reduced at the same time as power requirements increase, and has largely replaced the inline-6, which is too long to fit in many modern engine compartments. Although it is more complicated and not as smooth as the inline 6, the V6 is more compact, more rigid, and less prone to torsional vibrations in the crankshaft. The V6 engine has become widely adopted for medium-sized cars, often as an optional engine where a straight-4 is standard, or as a base engine where a V8 is a higher-cost performance option.

Recent V6 engines have delivered horsepower and torque output comparable to contemporary V8 engines, while reducing fuel consumption and emissions, such as the Volkswagen Group's G60 3.0 TFSI which is supercharged and directly injected, and Ford Motor Company's turbocharged and directly injected EcoBoost V6, both of which have been compared to Volkswagen's 4.2 V8 engine.

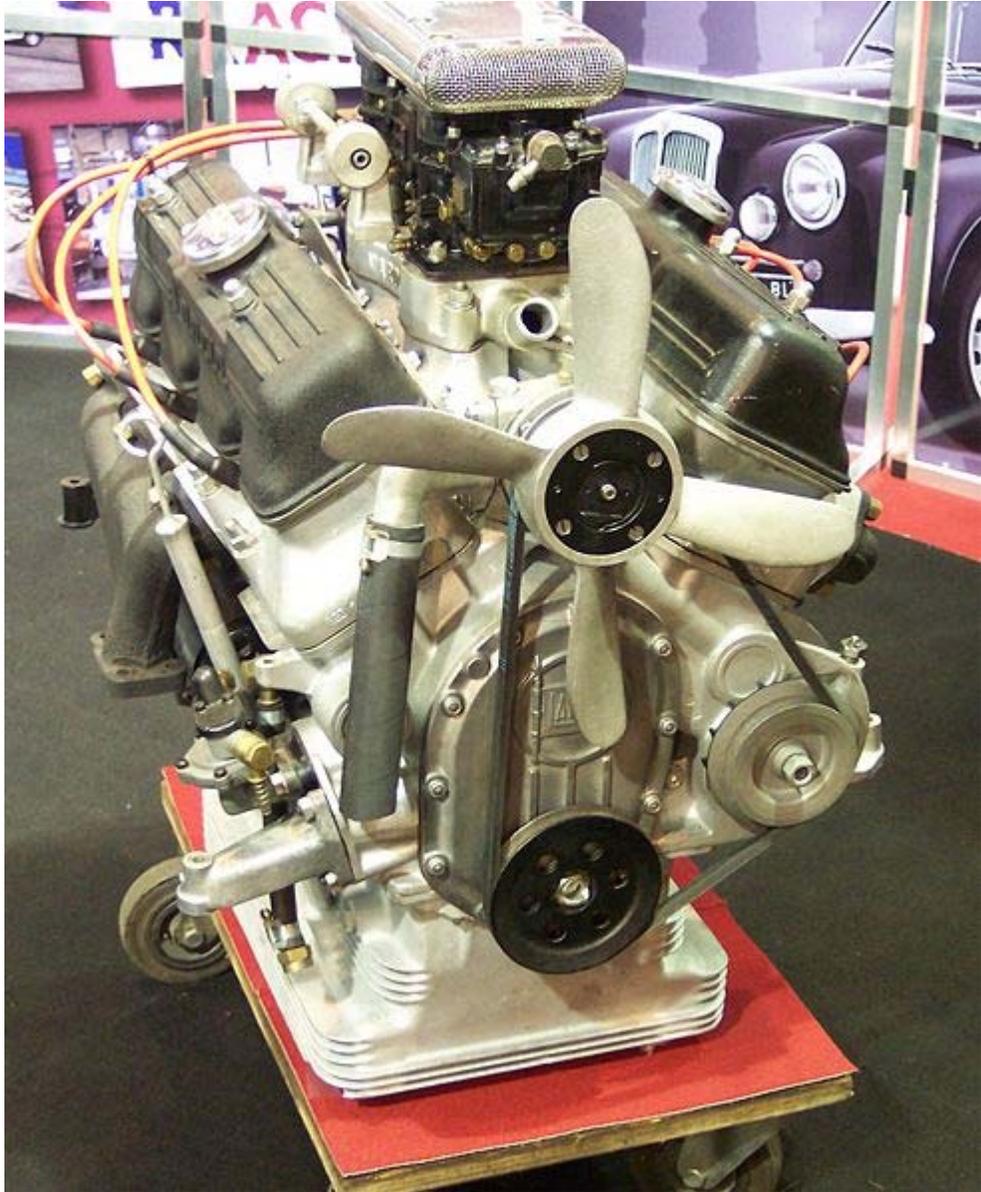
Modern V6 engines commonly range in displacement from 2.5 to 4.3 L (150 to 260 cu in), though larger and smaller examples have been produced.

History

Some of the first V6-cars were built in 1905 by Marmon. Marmon was something of a V-Specialist which began with V2-engines, then built V4's and V6's, later V8's and in the 30's Marmon was one of the few car-makers of the world which ever built a V16 car.

From 1908-1913 the Deutz Gasmotoren Fabrik produced benzene electric trainsets (Hybrid) which used a V6 as generator-engine.

Another V6-car was designed in 1918 by Leo Goosen for Buick Chief Engineer Walter L. Marr. Only one prototype Buick V6 car was built in 1918 and was long used by the Marr family.



Lancia V6

The first series production V6 was introduced by Lancia in 1950 with the Lancia Aurelia. Other manufacturers took note and soon other V6 engines were in use. In 1959, GM introduced a heavy-duty 305 in³ (5 L) 60° V6 for use in their pickup trucks and Suburbans, an engine design that was later enlarged to 478 in³ (7.8 L) for heavy truck and bus use.

1962 saw the introduction of the Buick Special, which offered a 90° V6 with uneven firing intervals that shared some parts commonality with a small Buick V8 of the period. Consequently the Buick Special met consumer resistance due to its excessive vibration. In 1983, Nissan produced Japan's first V6 engine with the VG series.

Balance and smoothness

Due to the odd number of cylinders in each bank, V6 designs are inherently unbalanced, regardless of their V-angle. All straight engines with an odd number of cylinders suffer from primary dynamic imbalance, which causes an end-to-end rocking motion. Each cylinder bank in a V6 has an odd number of pistons, so the V6 also suffers from the same problem unless steps are taken to mitigate it. In the horizontally-opposed flat-6 layout, the rocking motions of the two straight cylinder banks offset each other, while in the inline-6 layout, the two ends of engine are mirror images of each other and compensate every rocking motion. Concentrating on the first order rocking motion, the V6 can be assumed to consist of two separate straight-3 where counterweights on the crankshaft and a counter rotating balancer shaft compensate the first order rocking motion. At mating, the angle between the banks and the angle between the crankshafts can be varied so that the balancer shafts cancel each other 90° V6 (larger counter weights) and the even firing 60° V6 with 60° flying arms (smaller counter weights. The second order rocking motion can be balanced by a single co-rotating balancer shaft.).

This is almost the same technique which balances an even firing 90° crossplane V8 in primary and secondary order. A 90° V8 is in primary balance because each 4-cylinder bank is in primary balance, and the secondary of the two banks can be made to cancel each other using a crossplane. However, there is no equivalent of the crossplane crankshaft for the V6, so that the vibrations from the two banks cannot be made to completely cancel each other. This makes designing a smooth V6 engine a much more complicated problem than the straight-6, flat-6, and V8 layouts. Although the use of offset crankpins, counterweights, and flying arms has reduced the problem to a minor second-order vibration in modern designs, all V6s can benefit from the addition of auxiliary balance shafts to make them completely smooth.

When Lancia pioneered the V6 in 1950, they used a 60° angle between the cylinder banks and a six-throw crankshaft to achieve equally spaced firing intervals of 120°. This still has some balance and secondary vibration problems. When Buick designed a 90° V6 based on their 90° V8, they initially used a simpler three-throw crankshaft laid out in the same manner as the V8 with pairs of connecting rods sharing the same crankpin, which resulted in firing intervals alternating between 90° and 150°. This produced a rough-running design which was unacceptable to many customers. Later, Buick and other manufacturers refined the design by using a *split-pin* crankshaft which achieved a regular 120° firing interval by staggering adjacent crankpins by 15° in opposite directions to eliminate the uneven firing and make the engine reasonably smooth. Some manufacturers such as Buick in later versions of their V6 and Mercedes Benz have taken the 90° design a step further by adding a balancing shaft to offset the primary vibrations and produce an almost fully balanced engine.

Some designers have reverted to a 60° angle between cylinder banks, which produces a more compact engine, but have used three-throw crankshafts with *flying arms* between the crankpins of each throw to achieve even 120° angles between firing intervals. This has the additional advantage that the flying arms can be weighted for balancing purposes.

This still leaves an unbalanced primary couple, which is offset by counterweights on the crankshaft and flywheel to leave a small secondary couple, which can be absorbed by carefully designed engine mounts.

Six-cylinder designs are also more suitable for larger displacement engines than four-cylinder ones because power strokes of pistons overlap. In a four-cylinder engine, only one piston is on a power stroke at any given time. Each piston comes to a complete stop and reverses direction before the next one starts its power stroke, which results in a gap between power strokes and noticeable vibrations. In a six-cylinder engine (other than odd-firing V6s), the next piston starts its power stroke 60° before the previous one finishes, which results in smoother delivery of power to the flywheel. In addition, because inertial forces are proportional to piston displacement, high-speed six-cylinder engines will suffer less stress and vibration per piston than an equal displacement engine with fewer cylinders.

Comparing engines on the dynamometer, a typical even-fire V6 shows instantaneous torque peaks of 150% above mean torque and valleys of 125% below mean torque, with a small amount of negative torque (engine torque reversals) between power strokes. On the other hand, a typical four-cylinder engine shows peaks of nearly 300% above mean torque and valleys of 200% below mean torque, with 100% negative torque being delivered between strokes. In contrast, a V8 engine shows peaks of less than 100% above and valleys of less than 100% below mean torque, and torque never goes negative. The even-fire V6 thus ranks between the four and the V8, but closer to the V8, in smoothness of power delivery. An odd-fire V6, on the other hand, shows highly irregular torque variations of 200% above and 175% below mean torque, which is significantly worse than an even-fire V6, and in addition the power delivery shows large harmonic vibrations that have been known to destroy the dynamometer.

V angles

60 degrees



Nissan VG30E engine

The most efficient cylinder bank angle for a V6 is 60 degrees, minimizing size and vibration. While 60° V6 engines are not as well balanced as inline-6 and flat-6 engines, modern techniques for designing and mounting engines have largely disguised their vibrations. Unlike most other angles, 60 degree V6 engines can be made acceptably smooth without the need for balance shafts. When Lancia pioneered the 60° V6 in 1950, a 6-throw crankshaft was used to give equal firing intervals of 120°. However, more modern designs often use a 3-throw crankshaft with what are termed *flying arms* between the crankpins, which not only give the required 120° separation but also can be used for balancing purposes. Combined with a pair of heavy counterweights on the crankshaft ends, these can eliminate all but a modest secondary imbalance which can easily be damped out by the engine mounts.

This configuration is a good fit in cars which are too big to be powered by four-cylinder engines, but for which compactness and low cost are important. The most common 60° V6s were built by General Motors (the heavy duty commercial models, as well as a

design used in many GM front wheel drive cars) and Ford European subsidiaries (Essex V6, Cologne V6 and the more recent Duratec V6). Other 60° V6 engines are the Chrysler 3.3 V6 engine, the Nissan VQ engine, the Alfa Romeo V6 engine, and later versions of the Mercedes-Benz V6 engine.

90 degrees

90° V6 engines are also produced, usually so they can use the same production-line tooling set up to produce V8 engines (which normally have a 90° V angle). Although it is relatively easy to derive a 90° V6 from an existing V8 design by simply cutting two cylinders off the engine, this tends to make it wider and more vibration-prone than a 60° V6. The design was first used by Buick when it introduced its 198 CID *Fireball V6* as the standard engine in the 1962 Special. Other examples include the Maserati V6 used in the Citroën SM, the PRV V6, Chevrolet's 4.3 L *Vortec 4300* and Chrysler's 3.9 L (238 in³) *Magnum V6* and 3.7 L (226 in³) *PowerTech V6*. The Buick V6 was notable because it introduced the concept of uneven firing, as a result of using the 90° V8 cylinder angle without adjusting the crankshaft design for the V6 configuration. Rather than firing every 120° of crankshaft rotation, the cylinders would fire alternately at 90° and 150°, resulting in strong harmonic vibrations at certain engine speeds. These engines were often referred to by mechanics as "shakers", due to the tendency of the engine to bounce around at idle speed.

More modern 90° V6 engine designs avoid these vibration problems by using crankshafts with offset split crankpins to make the firing intervals even, and often add balancing shafts to eliminate the other vibration problems. Examples include the later versions of the Buick V6, and earlier versions of the Mercedes-Benz V6. The Mercedes V6, although designed to be built on the same assembly lines as the V8, used split crankpins, a counter-rotating balancing shaft, and careful acoustic design to make it almost as smooth as the inline-6 it replaced. However, in later versions Mercedes changed to a 60° angle, making the engine more compact and allowing elimination of the balancing shaft. Despite the difference in V angles, the Mercedes 60° V6s were built on the same assembly lines as 90° V8s.

120 degrees

120° might be described as the *natural* angle for a V6 since the cylinders fire every 120° of crankshaft rotation. Unlike the 60° or 90° configuration, it allows pairs of pistons to share crank pins in a three-throw crankshaft without requiring flying arms or split crankpins to be even-firing. However, unlike the crossplane crankshaft V8, there is no way to arrange a V6 so that unbalanced forces from the two cylinder banks will completely cancel each other. As a result, the 120° V6 acts like two straight-3s running on the same crankshaft and, like the straight-3, suffers from a primary dynamic imbalance which requires a balance shaft to offset.

The 120° layout also produces an engine which is too wide for most automobile engine compartments, so it is more often used in racing cars where the car is designed around the

engine rather than vice-versa, and vibration is not as important. By comparison, the 180° flat-6 *boxer* engine is only moderately wider than the 120° V6, and unlike the V6 is a fully-balanced configuration with no vibration problems, so it is more commonly used in aircraft and in sports/luxury cars where space is not a constraint and smoothness is important.

Spanish truck manufacturer Pegaso built the first production 120° V6 for the Z-207 mid size truck in 1955. The engine, a 7.5 litre alloy Diesel designed under the direction of engineer Wifredo Ricart uses a single balance shaft rotating at the speed of the crankshaft

Ferrari introduced a very successful 120° V6 racing engine in 1961. The Ferrari Dino 156 engine was shorter and lighter than the 65° Ferrari V6 engines that preceded it, and the simplicity and low center of gravity of the engine was an advantage in racing. It won a large number of Formula One races between 1961 and 1964. However, Enzo Ferrari had a personal dislike of the 120° V6 layout, preferring a 65° angle, and after that time it was replaced by other engines.

Bombardier designed 120° V220/V300T V6 engines for use in light aircraft. The ignition sequence was symmetrical, with each cylinder firing 120° after the previous cylinder resulting in smooth power delivery. A balance shaft on the bottom of the engine offset the primary dynamic imbalance. The straight, pin-type crankshaft journals in the 120° V-6 layout allowed a shorter and stiffer crankshaft than competing flat-6 engines, while water cooling resulted in better temperature control than air cooling. These engines could run on automotive gasoline rather than avgas. However, the design was shelved in 2006 and there are no plans for production.

Other angles

Narrower angle V6 engines are very compact but can suffer from severe vibration problems unless very carefully designed. Notable V6 bank angles include:

- The 10.6° and 15° Volkswagen VR6, which is such a narrow angle it can use a single cylinder head and double overhead camshafts for both cylinder banks. With seven main bearings, it is more like a staggered-bank in-line six rather than a normal V6, but is only slightly longer and wider than a straight-4.
- The 45° Electro-Motive 6 cylinder version of their model 567 Diesel locomotive engine. This angle is optimum for the more common 16 cylinder version.
- The 54° GM/Opel V6, designed to be narrower than normal for use in small front-wheel drive cars.
- The 65° Ferrari Dino V6, allowing larger carburetors (for potentially higher power in race tuning) than a 60° angle, while suffering a slight increase in vibrations.
- The 75° Isuzu Rodeo and Isuzu Trooper V6 of 3.2 and 3.5 L in both SOHC and DOHC versions.
- The 80° Honda RA168-E Formula One engine in the McLaren MP4/4.

Odd and even firing

Many older V6 engines were based on V8 engine designs, in which a pair of cylinders was cut off the front of V8 without altering the V angle or using a more sophisticated crankshaft to even out the firing interval. Most V8 engines share a common crankpin between opposite cylinders in each bank, and a 90° V8 crankshaft has just four pins shared by eight cylinders, with two pistons per crankpin, allowing a cylinder to fire every 90° to achieve smooth operation.

Early 90° V6 engines derived from V8 engines had three shared crankpins arranged at 120° from each other, similar to an inline 3-cylinder. Since the cylinder banks were arranged at 90° to each other, this resulted in a firing pattern with groups of two cylinders separated by 90° of rotation, and groups separated by 150° of rotation, causing a notorious *odd-firing* behavior, with cylinders firing at alternating 90° and 150° intervals. The uneven firing intervals resulting in rough-running engines with unpleasant harmonic vibrations at certain engine speeds.

An example is the Buick 231 odd-fire, which has a firing order 1-6-5-4-3-2. As the crankshaft is rotated through the 720° required for all cylinders to fire, the following events occur on 30° boundaries:

Angle	0°	90°	180°	270°	360°	450°	540°	630°
Odd firing	1	6	5		4	3		2
Even firing	1	4	5		6	3	2	

More modern 90° V6 engines avoid this problem by using split crankpins, with adjacent crankpins offset by 15° in opposite directions to achieve an even 120° ignition pattern. Such a 'split' crankpin is weaker than a straight one, but modern metallurgical techniques can produce a crankshaft that is adequately strong.

In 1977, Buick introduced the new "split-pin crankshaft" in the 231. Using a crankpin that is 'split' and offset by 30° of rotation resulted in smooth, even firing every 120°. However, in 1978 Chevrolet introduced a 90° 200/229 V6, which had a compromise 'semi-even firing' design using a crankpin that was offset by only 18°. This resulted in cylinders firing at 108° and 132°, which had the advantage of reducing vibrations to a more acceptable level and did not require strengthening the crankshaft. In 1985, Chevrolet's 4.3 (later the Vortec 4300) changed it to a true even-firing V6 with a 30° offset, requiring larger crank journals to make them adequately strong.

In 1986, the similarly-designed 90° PRV engine adopted the same 30° crankshaft offset design to even out its firing. In 1988, Buick introduced a V6 engine that not only had split crankpins, but had a counter-rotating balancing shaft between the cylinder banks to

eliminate almost all primary and secondary vibrations, resulting in a very smooth-running engine.

Racing use



Mercedes-Benz V6 DTM engine

The V6 engine was introduced into racing by Lancia in the early '50s. After good results with privately entered Aurelia saloons Lancia set a works competition department in 1951. Four B20 Coupes were entered in the '51 Mille Miglia and the one driven by Giovanni Bracco and Umberto Maglioli caused quite a stir by finishing second overall after the 4.1-litre Ferrari driven by Villoresi and Cassani, a car which had three times more power than the Lancia. After that encouraging start Lancia decided to carry on with the endurance racing program, first with specially prepared Aurelias (called *Da Corsa*) and then with specially built prototypes. A D24 with a 3,102 cc (189 cu in) V6 making 230 PS (170 kW) won the 1953 Carrera Panamericana with Juan Manuel Fangio at the wheel.

After that came the Ferrari Dino V6. Alfredo Ferrari (nicknamed Dino), son of Enzo Ferrari, suggested to him the development of a 1.5 L DOHC V6 engine for Formula Two at the end of 1955. The Dino V6 underwent several evolutions, including an increased

engine displacement to 2,417 cc (147 cu in), for use in the Ferrari 246 Formula One car in 1958.

The use of a wide 120° bank angle is appealing for racing engine designers as it permits a low center of gravity. This design is even considered superior to the flat-6 in that it leaves more space under the engine for exhaust pipes; thus the crankshaft can be placed lower in the car. The Ferrari 156 built for new Formula One 1.5 L regulations used a Dino V6 engine with this configuration.

The Dino V6 engine saw a new evolution in 1966 when it was adapted to road use and produced by a Ferrari-Fiat joint-venture for the Fiat Dino and Dino 206 GT (this car was made by Ferrari but sold under the brand Dino). This new version was redesigned by Aurelio Lampredi initially as a 65° 2.0 L (~122 cu in) V6 with an aluminum block but was replaced in 1969 by a 2.4 L (~146 cu in) cast-iron block version (the Dino car was renamed the 246GT).

The Fiat Dino and Dino 246GT were phased out in 1974, but 500 engines among the last built were delivered to Lancia, who was like Ferrari already under the control of Fiat. Lancia used them for the Lancia Stratos which would become one of the most successful rally cars of the decade.



Alfa Romeo V6

The Alfa Romeo V6 was designed in the 1970s by Giuseppe Busso, the first car to use them being the Alfa Romeo 6. The over-square V6, with aluminium alloy block and heads, has seen continuous use in road vehicles, from the Alfetta GTV6 onwards. A notable use of the *Bussone Sei* (Busso's big Six) V6 was the Alfa Romeo 155 V6 TI. Turbocharged, it had a peak power of 490 PS (360 kW; 480 hp) at 11,900 rpm. The 164 introduced a 3.0 L (~183 cu in) V6, a 2.0 V6 turbocharged in 1991 and in 1992, a 3.0 L DOHC 24 valve version. The Alfa 156 introduced a 2.5 L DOHC 24 valve version in 1997. The engine capacity was later increased to 3.2 L (~195 cu in), where it found application in the 156 GTA, 147 GTA, 166, GT, GTV and Spider 916. Production was discontinued in 2005.

Another influential V6 design was the Renault-Gordini CH1 V6, designed by François Castaing and Jean-Pierre Boudy, and introduced in 1973 in the Alpine-Renault A440. The CH1 was a 90° cast iron block V6, similar to the mass produced PRV engine in those two respects but otherwise dissimilar. It has been suggested that marketing purposes made the Renault-Gordini V6 adopt those characteristics of the PRV in the hope of associating the two in the public's mind.

Despite such considerations, this engine won the European 2 L prototype championship in 1974 and several European Formula Two titles. This engine was further developed in a turbocharged 2 L version that competed in Sports car and finally won the 24 Hours of Le Mans in 1978 with a Renault-Alpine A 442 chassis.

The capacity of this engine was reduced to 1.5 L to power the Formula One Renault RS01. Despite frequent breakdowns that resulted in the nickname of the 'Little Yellow Teapot', the 1.5 L finally saw good results in 1979.

Ferrari followed Renault in the turbo revolution by introducing a turbocharged derivative of the Dino design (a 1.5 L 120° V6) with the Ferrari 126. However, the 120° design was not considered optimum for the wing cars of the era and later engines used V angles of 90° or less.

Both Renault and Ferrari failed in their attempt to win the Drivers' Championship with V6 Turbo engines. The first turbocharged engine to win the championship was the Straight-4 BMW.

They were followed by a new generation of Formula One engines, the most successful of these being the TAG V6 (designed by Porsche) and the Honda V6. This new generation of engines were characterized by odd V angles (around 80°). The choice of these angles was mainly driven by aerodynamic consideration. Despite their unbalanced designs these engines were both quickly reliable and competitive; this is generally viewed as a consequence of the quick progress of CAD techniques in that era.

In 1989 Shelby tried to bring back the Can-Am series, using the Chrysler 3.3 L (201 in³) V6 (not yet offered to the general public) as the powerplant in a special racing

configuration making 255 hp (190 kW). This was the same year that the Viper concept was showed to the public.

Originally the plan was to produce two versions of this race car, a 255 hp (190 kW) version and a 500 hp (370 kW) model, the 255 hp (190 kW) version being the entry circuit. The cars were designed to be a cheap way for more people to enter auto racing. Since all the cars were identical, the winners were to be the people with the best talent, not the team with the biggest pockets. The engines had Shelby seals on them and could only be repaired by Shelby's shop, ensuring that all the engines are mechanically identical.

Only 100 of these 3.3s were ever built. Of these 100, 76 were put into Shelby Can-Am cars (the only 76 that were ever sold). No significant amount of spare parts were produced, and the unsold engines were used for parts/spares. The Shelby specific parts, such as the upper intake manifold, were never made available to the general public. According to a small article in the USA Today (in 1989), these cars were making 250 hp (190 kW) (stock versions introduced in 1990 produced 150 hp) and hitting 160 mph (260 km/h) on the track. The engine itself was not that far from a standard-production 3.3. The Shelby engine is only making about 50 hp (37 kW) more than the newest 3.3 factory engines from Chrysler. The Can-Am engine has a special Shelby Dodge upper intake manifold, a special Shelby Dodge throttle body, and a special version of the Mopar 3.3 PCM (which had this engine redlining at 6800 rpm).

Nissan also has a quite successful history of using V6's for racing in both IMSA and the JGTC. Development of their V6s for sports cars began in the early 1980s with the VG engine initially used in the Z31 300ZX. The engine began life as a SOHC, turbocharged 3.0L power plant with electronic fuel injection, delivering 230 PS (169 kW). The VG30ET was later revised into the VG30DETT for the Z32 300ZX in 1989. The VG30DETT sported both an additional turbocharger and an extra pair of camshafts, making the engine a genuine DOHC twin-turbo V6 producing 300 PS (221 kW). Nissan used both of these engines in its IMSA racing program through out the 1980s and 1990s each producing well over 800 hp (600 kW). In the Japan Grand Touring Car Championship, or JGTC, Nissan opted for a turbocharged version of its VQ30 making upwards of 500 hp (370 kW) to compete in the GT500 class.

Motorcycle use

Laverda showed a 996 cc V6 engined motorcycle at the 1977 Milan show. The motorcycle was raced in the 1978 Bol d'Or.

Marine use



Yamaha OX66 engine, as used in their outboard motor range

Chapter- 2

Straight-Six Engine



A BMW M20B25 engine with the cylinder head removed, showing the pistons in the six cylinders of the engine

The **straight-six engine** or **inline-six engine** (often abbreviated **I6**, **L6** or **R6**) is a six cylinder internal combustion engine with all six cylinders mounted in a straight line along the crankcase. The single bank of cylinders may be oriented in either a vertical or an inclined plane with all the pistons driving a common crankshaft; in vehicles where this engine is installed inclined versus vertical, it is sometimes called a **slant-six engine**. The straight-six layout is the simplest engine layout that possesses both primary and secondary mechanical engine balance, resulting in relatively low manufacturing cost combined with much less vibration than engines with fewer cylinders.

Displacement range

Usually, the straight-six design is used for engine displacements ranging from approximately 2 to 5 litres (120 to 310 cu in) in automobiles. It is also sometimes used for smaller engines but these, although very smooth running, tend to be rather expensive to manufacture in terms of power-to-cost ratio. Since the length of an engine is roughly proportionate to the number of cylinders in one bank (plus the width of one connecting rod in a "V" engine), they are inevitably physically longer than alternative layouts such as L4, V6, or V8.

The smallest production straight-six was found in the Benelli 750 Sei motorcycle, displacing 747.7 cc (45.63 cu in) (0.7477 L). Honda and Mike Hailwood raced in the 1960s with the RC166 250 cc (15 cu in) (0.25 L) six cylinder, 24-valve motorcycle engine. Though pre-World War II engines could be quite large by modern standards — such as the Rolls Royce Silver Ghost's 7.4 L engine and the 824 cuin (13.5 L) of the 1910s Peerless, Pierce, and Fageol, the largest modern passenger-car straight-sixes are the 4.2 L powerplants found in several Jaguars and AMCs, the 4.3 L Hemi Six, the 4.0 TVR Speed Six, the 4.0 Ford Barra, the 4.1 Chevrolet 250, the 4.2 Chevrolet Vortec 4200, 4.9 Ford, 4.8 Chevrolet, and the 5.0L of Hudson H-145 (produced until 1957). As of 2009, the Cummins B Series engine used in Dodge Ram pickup trucks displaced up to 6.7 L

The Gipsy Six and Gipsy Queen, made by the de Havilland Engine Company from 1935 until 1950, were inverted straight-six engines displacing 560.6 cubic inches (9.187 L). They were used in a variety of aircraft including the de Havilland Dragon Rapide and the Cierva W.9 experimental helicopter.

Because it is a fully balanced configuration, the straight-six can be scaled up to very large sizes for heavy truck, industrial and marine use, such as the 16 L (980 cu in) Volvo diesel engine and the 15 L Cummins ISX used in heavy vehicles. The largest are used to power ships, and use fuel oil. The straight-six can also be viewed as a scalable modular component of larger motors which stack several straight-sixes together, e.g. flat- or V-12s, W-18s etc.

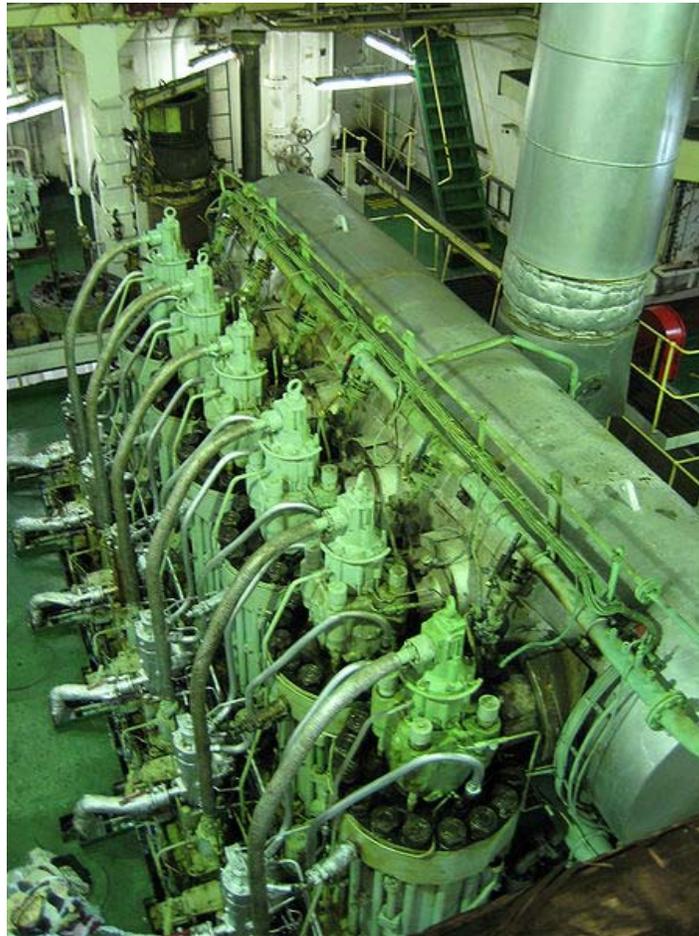
Modern trends

Historically, straight-six engines were introduced much earlier than V6 engines. While the first straight-six was manufactured in 1903 by Spyker, it was 1950 before a production V6 was introduced. V6s (unlike crossplane V8 engines) had intrinsic vibration problems that were difficult to eliminate without modern computer aided design techniques. The length of the straight-six was not a major concern in the older front-engine/rear-wheel drive vehicles, but the modern move to the more space-efficient front-engine/front-wheel drive and transverse engine (left-to-right versus front-to-back) configurations in smaller cars made the length of the V6 (one half the length of an L6 with the same bore size, plus the width of one rod) a major advantage. As a result, in

recent decades automobile manufacturers have replaced most of their straight-six engines (and many of their V8s) with V6 engines; Mercedes-Benz now uses V6 engines despite most of their lineup retaining the front-engine/rear-wheel layout.

Exceptions to the shift to V6 engines include BMW, which specializes in high-performance straight-sixes used in a lineup of front-engine/rear-wheel drive vehicles, Volvo, which designed a compact straight-six engine/transmission package to fit transversely in its larger cars, and the Australian Ford Falcon, which still uses a straight-six configuration. Straight-sixes also continue to be commonly used in medium to large trucks, and sport utility vehicles, where engine length is less of a concern. In 2002, General Motors introduced the Vortec 4200 as part of the modular straight-four, straight-five and straight-six GM Atlas engine line.

Balance and smoothness



An MAN B&W 6S60MC inline six cylinder low-speed diesel engine. This example is used on a 70,000 t (deadweight) bulk carrier, and produces 9,014.8 kW (12,089.0 hp) at 90.3 rpm (1.5 Hz)(703,130 ftlbs torque).

An inline six engine is in perfect primary and secondary mechanical balance, which can be achieved without using a balance shaft. The engine is in primary balance because the front and rear trio of cylinders are mirror images, and the pistons move in pairs. That is, piston #1 balances #6, #2 balances #5, and #3 balances #4, largely eliminating the polar rocking motion that would otherwise result. Secondary imbalance is avoided because an inline six cylinder crankshaft has six crank throws arranged in three planes offset at 120°. The result is that differences in piston speed at any given point in rotation are effectively canceled.

An inline four cylinder or V6 engine without a balance shaft will experience secondary dynamic imbalance, resulting in engine vibration. As a general rule, the forces arising from any dynamic imbalance increase as the square of the engine speed — that is, if the speed doubles, vibration will increase by a factor of four. In contrast, inline six engines have no primary or secondary imbalances, and with carefully designed crankshaft vibration dampers to absorb torsional vibration, will run more smoothly at the same crankshaft speed (rpm). This characteristic has made the inline six popular in some European sports-luxury cars, where smooth high-speed performance and good fuel economy are desirable. As engine reciprocating forces increase with the cube of piston mass, inline six is a preferred configuration for large truck engines.

Crankshaft design

Crankshafts on six cylinder engines generally have either four or seven main bearings. Larger engines and diesels tend to use the latter because of high loadings and to avoid crankshaft flex. Because of the six cylinder engine's smooth characteristic, there is a tendency for a driver to load the engine at low engine speeds. This can produce crankshaft flex in four main bearing designs where the crank spans the distance of two cylinders between main bearings. This distance is longer than the distance between two adjacent main bearings on a V6 with four mains, because the V6 has cylinder bores on opposite banks which overlap significantly; the overlap may be as high as 100%, minus the width of one connecting rod (1.00" or so). In addition, modern high-compression engines subject the crankshaft to greater bending loads from higher peak gas pressures, requiring the crankthrows to have greater support from adjacent bearings, so it is now customary to design straight-sixes with seven main bearings.

Many of the more sporty high-performance engines use the four bearing design because of better torsional stiffness (e.g., BMW small straight 6's, Ford's Zephyr 6). The accumulated length of main bearing journals gives a relatively torsionally flexible crankshaft. The four main bearing design has only six crank throws and four main journals, so is much stiffer in the torsional domain. At high engine speeds, the lack of torsional stiffness can make the seven main bearing design susceptible to torsional flex and potential breakage. Note that a V12 engine can be made with the same number of crank throws as the seven main bearing straight-six, although each throw must be wide enough to accept the connecting rods of both opposing cylinders requiring either that each rod be far narrower, or that the crankshaft length be extended. Another factor affecting large straight-six engines is the front mounted timing chain which connects any

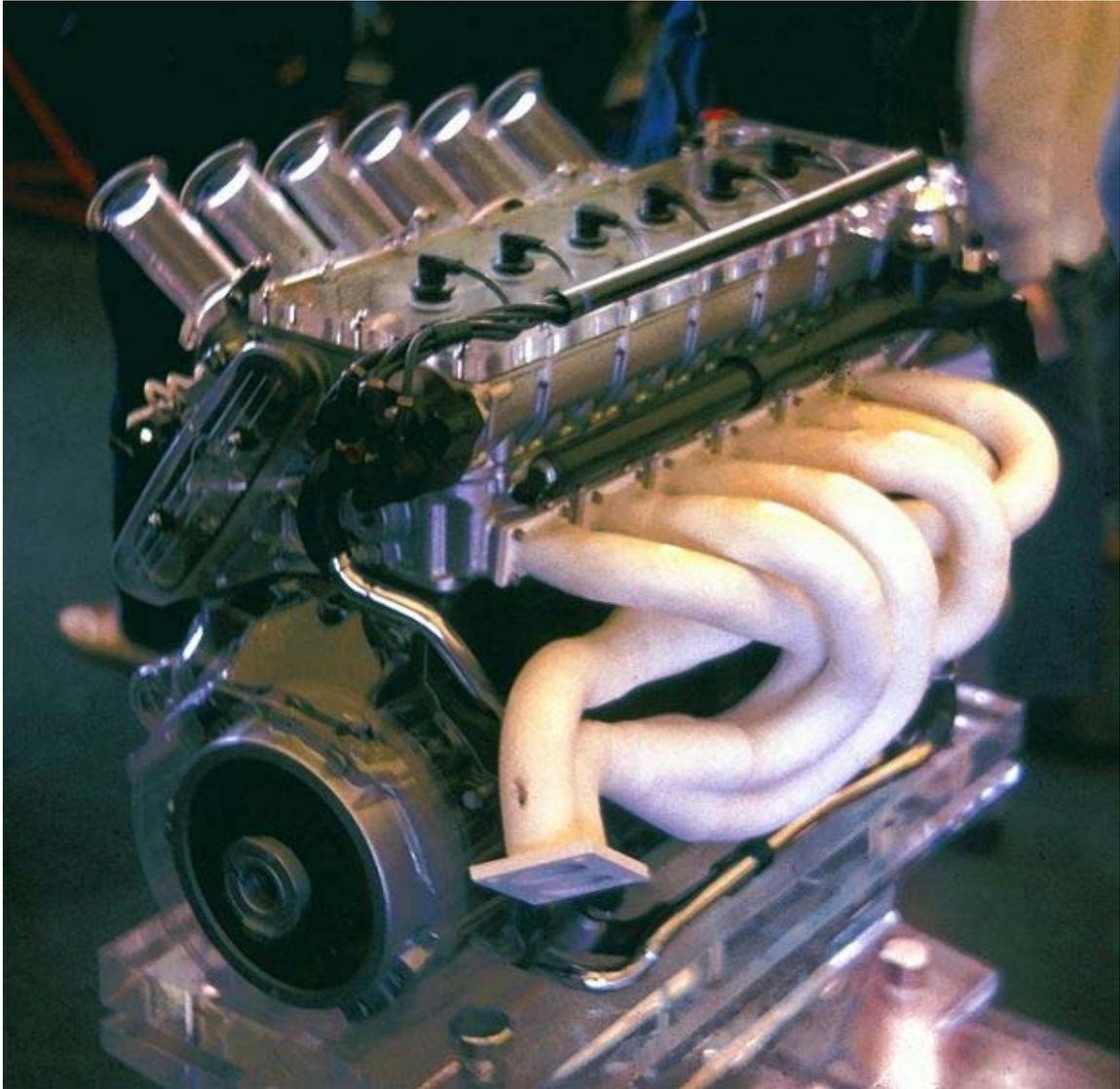
camshafts to the crankshaft. The camshafts are also quite long and subject to torsional flex as they in turn operate valves alternately near the front of the engine and near the rear. At high engine speeds, camshafts can flex torsionally in addition to the crankshaft, contributing to valve timing for the rear most cylinders becoming inaccurate and erratic, losing power, and in extreme cases resulting in mechanical interference between valve and piston — with catastrophic results. Some designers have experimented with installing the timing chain/gears in the middle of the engine (between cylinders 3 and 4) or adding a second timing chain at the rear of the engine. Either method can solve the problem at the cost of additional complexity.

Another factor affecting the ability of the large six cylinder engines to achieve high speed is the simple geometric reality of a relatively long stroke (undersquare) design. A straight-six is a long engine, and the designer is usually encouraged to make it as short as possible, while height is not usually a problem. Hence, the tendency to use a longer stroke and smaller bore than in a V engine to achieve a given capacity. By contrast, a long-stroke V engine tends to become too wide, which encourages increasing the bore rather than the stroke to increase displacement. The typically longer stroke of the straight-six increases crank throw and piston speed, and so tends to reduce the rpm rating of the engine.

History

The first inline six was produced by Spyker in 1903. By 1909, there were some eighty manufacturers using it, 62 in Britain alone, including Darracq, Delaunay-Bellville, Vertex, MMC, White and Poppe, Mutel, and Ford.

Continental Europe



BMW M1 engine

After becoming famous in the last year of World War I through their production of the liquid-cooled BMW IIIa aviation engine of straight-six layout, BMW introduced its first straight 6-cylinder automotive engine in 1933. It developed straight-six engines for the post-World War II era by adding two cylinders to its M10 four-cylinder design. In 1968, it introduced a M30 straight-six design with the same 30° slant, overhead camshaft layout, and 100 mm bore spacing as the four. It originally intended to follow up with a V8 engine line in the early 1970s, but when the 1973 oil crisis hit, BMW canceled its V8 plans and concentrated on refining and enlarging its straight-six lineup. These included a smaller straight-six in 2.0 and 2.3 L (120 and 140 cu in) displacements (the BMW M20), versions of the larger BMW M30 up to 3.8 L (230 cu in) (the S38B38); and beginning in 1983, a series of M21 straight-six diesel engines. In 1986, BMW introduced the M70

V12 which was essentially two 2.5 L (150 cu in) straight-sixes on the same crankshaft. In the mid-90's, they produced a series of straight-6's based on the M50 architecture, the ultimate of which was the 330-360 hp S54, used up to 2008. BMW offered a straight-six for their following line up BMW 1 Series, BMW 3 Series, BMW 5 Series, BMW 6 Series, BMW 7 Series (Euro models), BMW X3, BMW X5, BMW X6, the retired Z3 and current BMW Z4.

Mercedes-Benz has used straight-six engines in its cars for around 100 years, starting in the first decade of the 20th century with a monstrous 10 L (610 cu in) engine producing 75 hp (56 kW), and producing in parallel through the World War I years the majority of German aviation engines of straight-six layout, culminating in the Mercedes D.III engine series of 1916-18 for the *Luftstreitkräfte*. Before and after the merger of Daimler and Benz in 1926, the combined company produced a variety of powerful straight-six engines, culminating in a 7 L (430 cu in) supercharged unit producing up to 300 hp (224 kW). Mercedes-Benz began the post-war era by producing straight-fours, but resumed making straight-sixes in 1951 with the M130, which were the beginning of the modern era of MB straight-sixes. Following that introduction, the company produced two lines of petrol (gasoline) straight-sixes at any one time, a small six and a larger six, in addition to its straight-fours, straight-fives, and later V8s and V12s. Although the company has used diesel engines in its cars since 1934, it introduced its first straight-six OM603 a 3.0 L (180 cu in) diesel in 1985. In 1996, the company replaced its petrol straight-sixes with a series of 90° M112 V6s, although it continued to produce diesel straight-sixes.

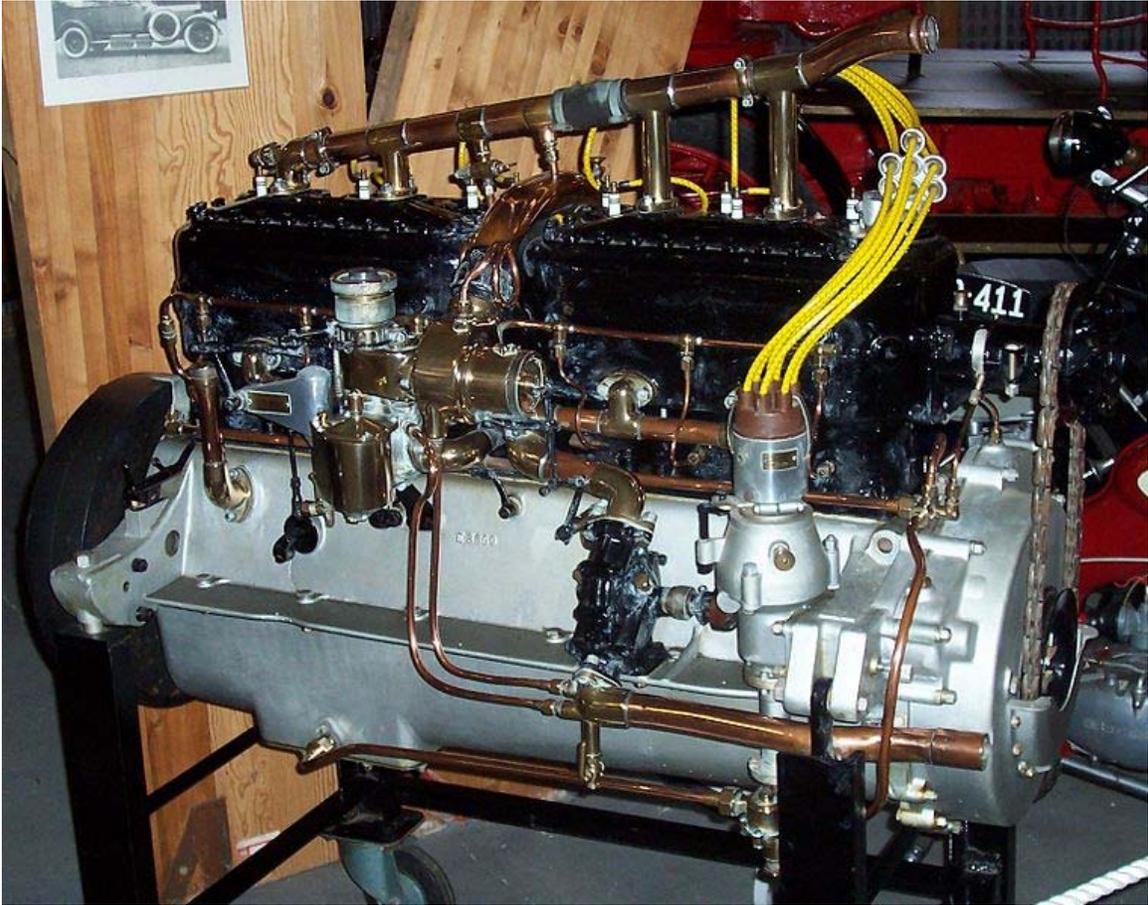
Volvo produced straight-sixes, the Volvo B30 engine (1969–1975), also the B6304 and the B6254 engines during late 1990s. As Volvo developed front-wheel drive models, they mounted their inline-six engine transversely by using a short transaxle package, and relocated engine-driven accessories. The 3.2 L (200 cu in) straight-six introduced in 2006 was only slightly longer than its straight-five, achieved by moving the camshaft drive to the back of the engine and sharing the same gear train with ancillaries mounted in otherwise unused space over top of the transmission. It was short for a straight-six and also very narrow. Volvo claims a transversely mounted inline engine leaves more crush space to protect against frontal impacts than a (shorter) transverse V6 or a longitudinally mounted inline-six.

Opel has also used a straight-six engine since 1930s until the early 1990s, ranging between 2.5 and 4.0 L (150 and 240 cu in). They powered Opel's top of the line models, including the Admiral, Kapitän, Monza, Senator, Omega, and Commodore.

In 1959, Saab had an experimental car with two transverse straight-three engines bolted together—the Saab Monster.

Alfa Romeo used straight-six engine in G1 and G2 models (1921–1923), RL model (1922–1927) and between 1925–1954 in Alfa Romeo 6C series road and racing cars, the 1500 version had one of the smallest straight-six engines (1,487 cc (90.7 cu in)). The last Alfa Romeo model using straight-six was Alfa Romeo 2600 (1961–1969).

United Kingdom



Rolls-Royce 40/50hp Silver Ghost 7,400cc side valve six cylinder engine



Jaguar XJ6 engine

The straight-six was the archetypal British engine for sports and luxury cars for many years. Rolls-Royce used straight-six engines until changes in their design made the shorter V8 engine layout more suitable. Jaguar and other manufacturers built straight-six engines from 1935 until the 1990s.

The most prominent of these was the Jaguar XK6 engine, which reportedly was developed during long nights during World War II when Jaguar founder William Lyons and his staff were on fire watch duty in the Jaguar factory in Coventry, and had nothing better to do than design a new engine. The result was displayed in the Jaguar XK120 at the London Motor Show in 1948. The 3.4 L (210 cu in) twin overhead camshaft XK6 engine engine was highly advanced compared to previous British engines. The Jaguar XK120 and the XK-powered Jaguar C-Type and Jaguar D-type, went on to score victories in races and rallies in the UK, Europe and North America. They dominated the 24 Hours of Le Mans during the 1950s, where Jaguar C-Types won in 1951 and 1953, and the D-Types had three more wins in 1955, 1956 and 1957. Subsequently, fitted to Lister Cars Lister-Jaguar, the D-type engine contributed to their success in international sportscar-racing in the late-1950s. The engine design, enlarged to 3.8 L (230 cu in), reached its apogee in the Jaguar E-type introduced in 1961, which was capable of 150 mph (240 km/h). In 1964, the XK engine was again enlarged to 4.2 L (260 cu in), which was considered the most powerful and refined of the series. The last XK-engined

Jaguar went out of production in 1986, but some XK engined cars such as the Daimler DS420 limousine were still available into 1990s. A variant of the 4.2 L engine powered some Scorpion light tanks. The XK6 engine was followed by the AJ6 and AJ16 engines. After Jaguar was acquired by Ford, these engines were replaced with the Ford Duratec-derived Jaguar AJ-V6 engine.

Aston Martin used a straight-six for many years, as did Austin-Healey in their Austin-Healey 3000. The latter used an engine originally built for the Austin Motor Company A105 saloon. Jensen also used Austin straight-six engines in their post WW-2 cars until 1962, re-engineering the Austin Sheerline's 4 L DS range to increase the power output. MG also used a straight-six in some pre-war cars (examples: MG K-type and MG N-type) and more recently in the MGC.

Bristol produced a straight-six until 1961, based on a BMW design, that was also used by many small automakers. Prior to World War II, Riley built a number of models fitted with straight-six engines, including the Kestrel 12/6 saloon and the MPH roadster.

The compact Triumph straight-six powered their high-end saloon and sports cars from the mid-1950s to the mid-1970s. It was available in 1.6 L (98 cu in), 2.0 L (120 cu in), and 2.5 L (150 cu in) capacities. Triumph claimed that their TR5 model was the first car in the UK to come with fuel injection as standard; the TR5 has a 2.5 L Triumph straight-six. Other Triumph vehicles that use the Triumph straight-six are:

- GT6 1966-73
- Vitesse 1962–71
- The 2000 Range 1963-77
- TR6 1969-76

The Austin 1800 range was expanded in 1972 when a 2.2 L six cylinder version of the BMC E-Series engine was installed transversely. The Austin and Morris models were called 2200 and the Wolseley version was called the Wolseley Six. Although this motor was originally designed by BMC in the sixties it was British Leyland who completed the planned upgrade to the 1800 range when they fitted this motor. This motor then went on to be used in the same configuration on the Leyland Princess which superseded the 1800 in 1975. This motor was designed to be as short as possible so the six cylinder would fit transversely, no water bores were between cylinders and the cylinders were too close together to allow boring; the only way to gain extra capacity was by lengthening the stroke.

The Rover SD1 saloon used a Triumph designed straight-six of 2.3 and 2.6 L (140 and 160 cu in) capacities as its base and mid-range engines.

British sports car company TVR designed its own straight-six, known as the Speed Six, which was also used in the Sagaris, with its capacity of 4 L (240 cu in). At 405 hp, it is the most powerful naturally-aspirated straight-6 ever fitted to a regular production car,

though some turbocharged engines are considerably more powerful (notably, the Toyota 2JZGTE and Nissan RB26DETT).

The Rover Company used straight-sixes in many of its saloon cars. A family of straight-4 and straight-6 engines with an unusual 'Inlet-Over-Exhaust' layout were developed. Introduced in the 1930s, these engines were used with great success in Rover's post war cars (the 'P3', 'P4' and 'P5' models). The sixes were available in a variety of capacities- 2.1 L (130 cu in), 2.2 L (130 cu in), 2.3 L (140 cu in), 2.6 L (160 cu in) and 3.0 L (180 cu in). In 1968, Rover began offering the 2.6 L engine as an option in long-wheelbase variants of its Land Rover 4x4. The engine remained available in the Land Rover until 1980, long after production of the other versions of the Rover IOE straight-six had stopped.

Ford UK produced a straight-six engine for the Zephyr and Zodiac range of passenger cars from the Mk1 of 1951 (2262 cc) through the Mk2 (2,553 cc (155.8 cu in)) and Mk3 until 1966. The straight-six was a four main bearing 12 overhead valve design with a short stroke. Rated output grew from just 65 hp (48 kW) in the Mk1 to 110 hp (82 kW) in the Mk3 Zodiac.

United States



1954 Hudson Wasp I6



Modified Chrysler slant-6



Carbureted 1977 AMC 258 cu in (4.2 L)



The 5 millionth Jeep 4.0 L produced in Kenosha, Wisconsin on 2001-06-15

Engines of this type were popular before World War II in mid-range cars. Most manufacturers started building straight-six engines when cars grew too large for the inline-four engine.

After World War II, larger cars required larger engines, and buyers of larger cars tended to prefer V8s; performance sixes such as the Hudson Hornet 308 cu in (5.0 L) engine were exceptions to the rule, and were not often top sellers although it became one of the hottest cars on the road and dominated stock car racing (NASCAR) in the early Fifties.

After Chevrolet introduced its V8 in 1955, the straight-six became almost exclusively a base engine model pitched to economy-minded customers. Trucks (both light and heavy

duty) also incorporated the straight-six until the mid-1950s, and they are still used in light trucks available today. The new wave of compact cars that started in the late 1950s provided a suitable home for straight-six designs.

The Chrysler Slant-6 engines used in the Plymouth Valiant and Dodge Dart A-body models of the 1960s and 1970s featured a 30° inclined design to achieve a lower overall height. Originally designed to be built of aluminum, but after encountering problems in manufacturing the engines in aluminum, they were built in cast iron without changing the design to compensate for the stronger metal. Although it only had four crankshaft main bearings instead of the seven used by its competitors, they were the same size as those on the 426 cu in (7.0 L) Hemi V8. The Slant-6 achieved some success in racing when engineers utilized the slant of the engine for very long intake ports to boost horsepower by tuning the intake system. After 30 years of production, it was discontinued in favor of V6 engines because it was too long to mount transversely in front wheel drive cars.

Kaiser Jeep introduced the Tornado straight-6 for 1963. It was the first U.S. designed mass produced overhead cam (OHC) automobile engine. It was robust and built for heavy-duty performance, as well as featuring the lowest specific fuel consumption of all production gasoline engines in the market at the time. However, it was complex (by 1960s standards) for civilian vehicles in the U.S., but continued to be installed in military Jeeps and was also produced through 1982 by IKA in Argentina.

A "modern era" straight-six engine family was introduced by American Motors (AMC) in 1964. These lighter in weight engines were used in a variety of AMC passenger and Jeep utility vehicles. American Motors also sold their straight-sixes to International Harvester for powering International's "Light Line" of trucks: Scouts, pickups, and Travelalls. These engines were also assembled and marketed internationally. Some markets (such as Vehiculos Automotores Mexicanos [VAM] in Mexico) built their own specialized versions. This engine is considered to be one of the best ever made and it received modifications and upgrades as engine control technology improved. This engine was produced continuously for 42 years (even after Chrysler's buyout of AMC in 1987) all the way through 2006. It featured a durable design with a cast iron block and cylinder head, hydraulic lifters (with non-adjustable rockers), and seven main bearings. Since AMC cars were designed to take the weight of an optional V8, AMC was able to make their straight-sixes much stronger and heavier than they needed to be. As a result, the engine blocks were so sturdy that some were used in race cars in the Indianapolis 500. In the 1978 race, an AMC 199 cu in (3.3 L) engine built by Navarro produced 875 hp (652 kW) at 8500 rpm with 80 in (2,000 mm) of manifold pressure.

Ford and General Motors straight-sixes of the 1960s and 1970s were generally nondescript, except for the unusual (for the United States) OHC Pontiac six of the late-1960s. Although it was one of the few American straight-sixes of its era to be advertised as exceeding 200 hp (150 kW), it wooed few performance buyers away from V8s during the muscle car era, and was eventually discontinued in favor of a less costly but less powerful pushrod design.

American automakers found it more profitable to sell slow-speed straight-sixes as "economy" engines, and V8s as "performance" engines regardless of their horsepower potential, since big, unsophisticated, overhead valve engines were relatively cheap to manufacture, and fuel economy was not a concern prior to the 1973 oil crisis.

The trend after the fuel crises in the 1970s was towards smaller cars with better fuel economy. Despite this, straight-six engines became rare in American cars, although they continued to be used in trucks and vans. The decline of the straight-six was in response to the more compact size of the V6 layout. The straight-six required a longer engine compartment that was more appropriate to a larger car. The shorter V6 could be used in a shorter engine compartment and therefore fit better in a more compact car. It was also relatively easy to cut two cylinders off a V8 design to produce a V6 that could be manufactured on the same assembly line as the V8, which was convenient for American manufacturers.

Jeeps were an exception to the trend to V6s, and began offering AMC's 258 cu in (4.2 L), known as "High Torque," straight-sixes as a common engine option in 1972. These engines continued to receive upgrades that were advanced for their time, including the fuel-injected high-performance 4.0 L (240 cu in) version for the 1987 model year. The five millionth 4.0 L was produced in Kenosha, Wisconsin by Chrysler on 15 June 2001, autographed by the assembly workers, and donated to the Rambler Legacy Gallery. Usage of the AMC 4.0 declined in Jeep vehicles after the Jeep Cherokee (in North America) was replaced by the Liberty in 2002, which featured Chrysler's 3.7 L (230 cu in) V6 instead. It declined further after the 2005 introduction of the third generation Jeep Grand Cherokee, which also used the 3.7 L (230 cu in) V6. The last application of the 4.0 was in the 2006 Jeep Wrangler; for 2007, the engine was replaced with a 3.8 L (230 cu in) V6.

Ford used a straight-six in baseline Mustangs and in its other models for many decades. They were also found in F-series pickups, E-series vans, and Broncos (most notably the venerable Ford 300 inline six) until 1997 when they were replaced with a V6.

In 1989, Chrysler introduced the 5.9 L (360 cu in) Cummins B Series engine as an option on its pickup trucks. Displacing nearly 1 L per cylinder, this straight-six turbocharged diesel engine was an attractive alternative to the big gasoline V8s normally used on full-sized pickups, because of its better fuel economy and nearly twice as much low-speed torque. The usual marketing cachet of competing V8s from GM and Ford was offset by the "real" truck origin of the Cummins engine because earlier GM diesel V8s derived from gasoline engines had reliability problems.

In 2001, General Motors introduced a new family of straight engines, the *Atlas*, for use in the Chevrolet TrailBlazer/GMC Envoy. The straight-six was chosen for development because of the desirable operating characteristics of its self-balanced design.

Asia



Nissan S20 engine

Japanese automakers have used the straight-six since the 1960s in a wide range of vehicles. More recently though, Nissan (the 1984 300ZX switched to V6) and Toyota have changed to V6s, saying the straight-sixes were too long and expensive to manufacture for the engine compartments in their newer vehicles. The Nissan Skyline GT-R also used this layout and so had a long hood.

Toyota started with their F-series engine, and later the M, FZ, G, and JZ engines, and Nissan started with their H-series, and later the L (up until 1984) of the early Nissan Z-cars, also known as Fairlady Zs, as well as the RB series engines (in the R31-R34 Skyline). Honda built the Honda CBX1000 motorcycle from 1978-1981. In the 1990s, Toyota offered straight-sixes in all their lines: the G in the Altezza (and others); the M and its part-replacement, the JZ, in the Toyota Supra (and others); and the F and its replacement, the FZ, in the Land Cruiser. In the first decade of the 21st century, Toyota still offers the FZ-series, G-series, and the JZ-series engines.

Suzuki introduced the Verona a mid-sized front wheel drive car in 2004 with a straight-six and discontinued it 4 years later.

In Korea, GM Daewoo's FWD Magnus (sold abroad as the Chevrolet Evanda, Chevrolet Epica, Holden Epica or Suzuki Verona) comes with a Daewoo-designed straight-six. The

Daewoo engine is one of the few straight-sixes designed to be installed transversely in front-wheel drive cars, and it is an extremely short engine in its configuration.

Australia

Historically, all major manufacturers in Australia used straight-six engines.

BMC developed a straight-six engine based on the B-series engine in the late 1950s. It appeared in the Austin Freeway and Wolseley 24/80. Although successful in Australia, and tried successfully in the prototype MGC, the cost of retooling meant that the engine remained indigenous to Australia. In 1971, Leyland Australia replaced the Austin 1800 with the Austin X6 range, marketed as the Austin Tasman and Austin Kimberley . This car was based on the 1800's platform but had different front and rear styling and a new interior. It introduced a 2.2 L six cylinder version of the E-series engine four years ahead of the UK market. It has the distinction of being the first car with a transverse front-wheel-drive straight six. The car was supposed to offer more competition to the Australian big six market but it achieved less sales than the superseded four cylinder 1800. The E series six cylinder in 2.6 L form (achieved using a longer stroke) went on to be used in the Leyland P76 and the Marina.



Chrysler Hemi-6 Engine, unique to Chrysler Australia

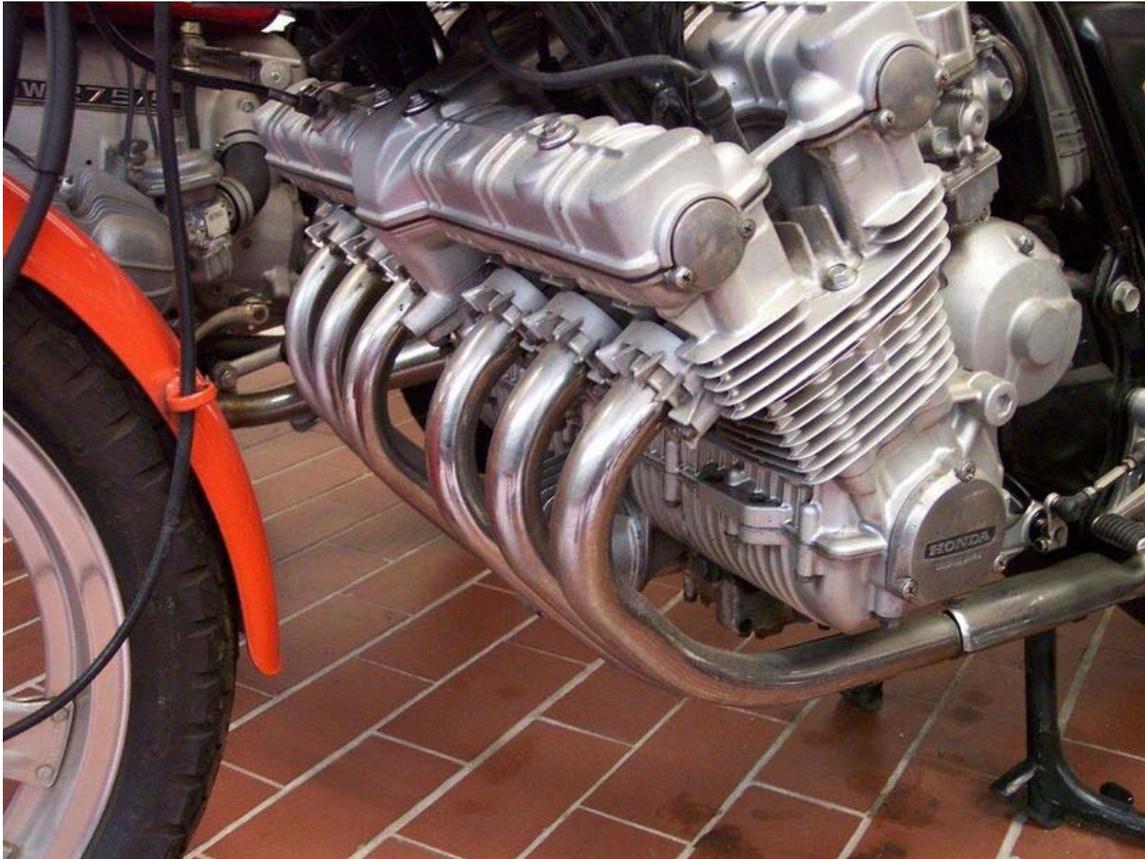
Chrysler had built the Slant 6 in Australia, and the unique to Australia Chrysler Hemi-6 Engine. These engines, made in 215 cu in (3.52 L), 245 cu in (4.01 L), and 265 cu in (4.34 L) capacity, were used in the Chrysler Valiant and the Valiant Charger producing up to 320 horsepower (239 kW). Chrysler no longer owns any factories in Australia.

Holden up until 1986 built their own straight-sixes, adapted from a Chevrolet design. A 132.5 cu in (2.171 L) unit (known as the *grey* motor) was used until 1963, with a minor increase in displacement in 1960 to 138 cu in (2.26 L) when it was replaced by a newer Chevrolet based design (known as the *red* engine) which was offered in different capacities. Holden engine sizes included the 138 cu in (2.26 L), 149 cu in (2.44 L), 179 cu in (2.93 L) (1964–1966), 161 cu in (2.64 L), 173 cu in (2.83 L) (1971–1984), 186 cu in (3.05 L) (1968–1971), and 202 cu in (3.31 L) (1971–1986, the largest and most popular of the series). This motor was firstly replaced by an imported RB20/30 Nissan straight-six, offered in 2.0 L (120 cu in) (in New Zealand) and 3.0 L (180 cu in) forms, until Holden's Buick designed 3.8 L (230 cu in) V6 replaced it outright in 1988. Holden now make and use the new global HFV6 in their local and export passenger cars.

Ford Australia has been producing straight-sixes since 1960, and is the only manufacturer in Australia to still build straight-sixes. Ford has built 144 cu in (2.36 L), 170 cu in (2.8 L), 188 cu in (3.08 L), 200 cu in (3.3 L), 221 cu in (3.62 L), 240 cu in (3.9 L), and 250 cu in (4.1 L) engines, with the 240 being called the 3.9 L (240 cu in), or 4.0 L (240 cu in) and the 200 being called the 3.3 L (200 cu in). They have been used since 1960 in the Falcon, 1972-1981 in the Cortina, and from 2004, in the Ford Territory. The current straight-six engines in the Falcon and Territory are called the Barra and have a 4.0 L (240 cu in) displacement.

The high-performance division of Ford Australia, Ford Performance Vehicles, produce vehicles equipped with the 4.0 L (240 cu in) 24-valve dual overhead camshaft (DOHC) turbocharged straight-six with variable cam timing, which produces 416 hp (310 kW) at 5,250 rpm (87.5 Hz) and 565 N·m (417 lb·ft) at 1,950 rpm (32.5 Hz) — the highest level of torque in any Australian production car to date.

Motorcycle use



Honda CBX1000 engine

Honda raced a number of straight-six engines in the Honda RC series of motorcycles, starting with the 249 cc (0.249 L) 3RC164 in 1964, with a bore of 39 mm, and a stroke of 34.8 mm. This became the RC165 in 1965. For 1966, bore and stroke became 41 mm and 31 mm in the RC166, continuing with the RC167 in 1967. Also in 1967, Honda raced the straight-six 297 cc (18.1 cu in) RC174 in the 350 class, with bore and stroke of 41 mm and 37.5 mm.

For road use, Honda introduced the Honda CBX1000 in 1978. Kawasaki introduced the 1,300 cc (79 cu in) KZ1300 in 1979. Benelli introduced the 750 Sei in 1976, which was later enlarged to 900 cc (55 cu in) to become the 900 Sei.

BMW has developed a straight six engine for motorcycle use, debuting in a concept bike in 2009, which will feature on the K1600GT and K1600GTL motorcycles in 2011. The 1,649 cc (100.6 cu in) engine is mounted transversely across the chassis.

Straight-six diesel engines

The straight-six in diesel engine form with a much larger displacement is commonly used for industrial applications. These include various types of heavy equipment, power generation, as well as transit buses or coaches. Virtually every medium-duty to large over-the-road truck employs an inline-six diesel engine. Its virtues are superior low-end torque, very long service life, smooth operation and dependability. On-highway vehicle operators look for straight-six diesels, which are smooth-operating and quiet. Likewise, off-highway applications such as tractors, marine engines, and electric generators need a motor that is rugged and powerful. In these applications, compactness is not as big a factor as in passenger cars, reliability and maintainability are much more important concerns.

As with everyday passenger vehicles, the smooth running characteristics of the straight-six engine are what make it desirable for industrial use. The straight-six is a simple engine that is in both primary and secondary balance. This means it can be scaled up to very large sizes without causing excessive vibration. Most of the engine components and accessories can be located along both sides, rather than on top of or underneath the cylinder banks, means that access and maintenance is easier than on a V engine in a truck or industrial configuration. In addition, a straight-six engine is mechanically simpler than a V6 or V8 since it has only one cylinder head and in the overhead camshaft configuration has only half as many camshafts.

Notable versions include Toyota's normally-aspirated 2H and 12HT turbo from the 1980s, and the similar 1HZ 4 or 4.2 L. The 5.9 and 6.7 L straight-six Cummins found in the Dodge Ram and the DT series Navistar DT Engine of inline 6-cylinder medium-duty diesels by International Truck and Engine Corporation, are widely praised for use in the North American truck market. Caterpillar makes also engines in same displacement range for automotive, industrial and marine applications.

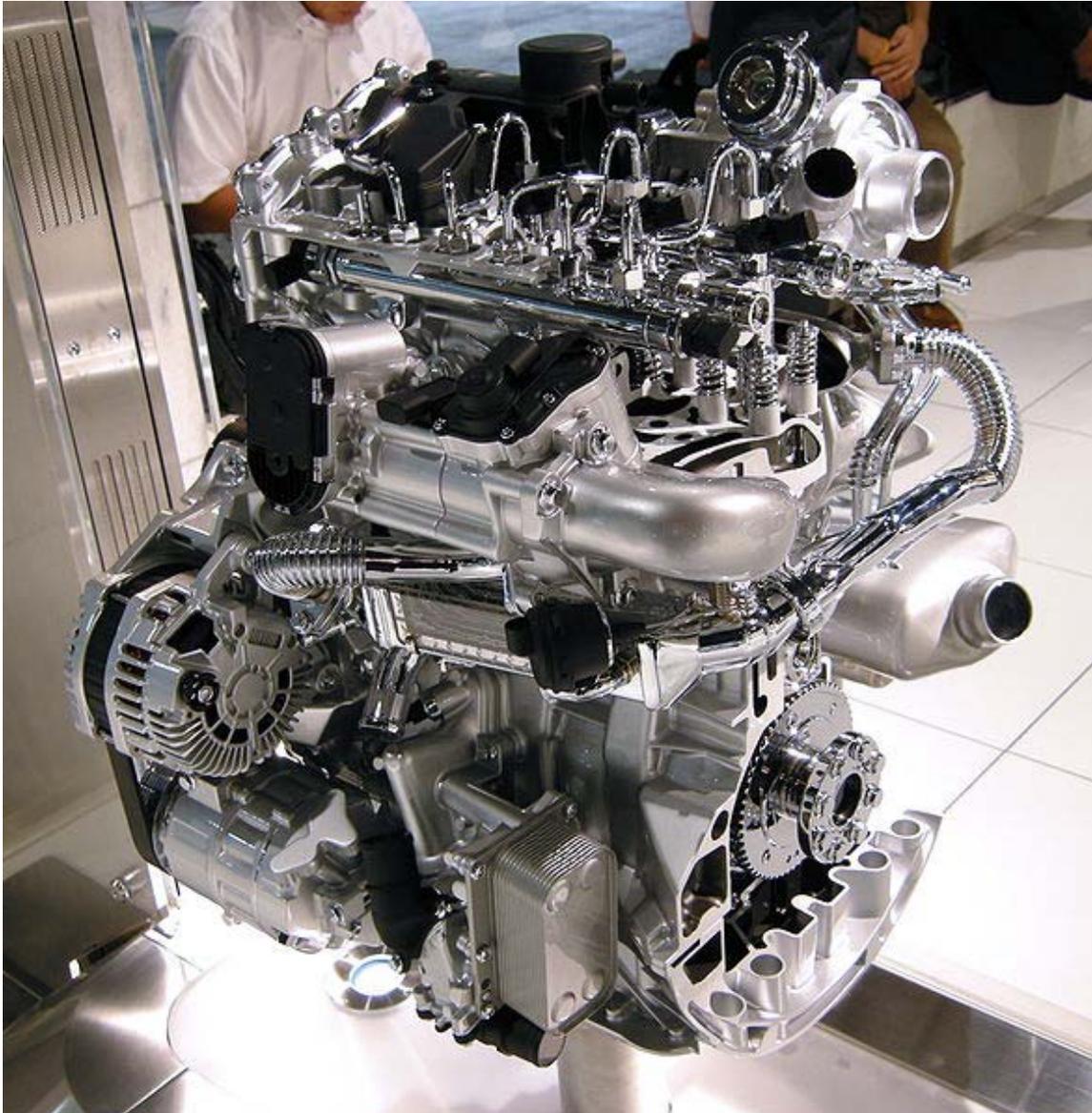
Diesel straight-sixes are also found in passenger cars, most notably those made by BMW. The twin-turbo M57 produces up to 272 bhp (203 kW; 276 PS) from its 3 L capacity, and it has won International Engine of the Year awards. Mercedes-Benz debuted the OM603 3.0 L (180 cu in) diesel in 1985. Nissan produced a range of straight-six diesels to be used in their vehicles. Some examples would be the Nissan RD engine, or the Nissan TD engine, which have similar characteristics to the RB engines. However, the RD engine was designed to be quiet, efficient and smooth, so it could be fitted to a range of Nissan luxury vehicles, such as the Nissan Laurel, and power output suffered as a result of these requirements.

Chapter- 3

Inline-Four Engine



Ford inline-four engine with cylinder head removed



A cutaway photograph of Nissan M9R 2.0L Straight-4 DOHC Common rail Diesel Engine installed

The **inline-four engine** or **straight-four engine** is an internal combustion engine with all four cylinders mounted in a straight line, or plane along the crankcase. The single bank of cylinders may be oriented in either a vertical or an inclined plane with all the pistons driving a common crankshaft. Where it is inclined, it is sometimes called a **slant-four**. In a specification chart or when an abbreviation is used, an inline-four engine is listed either as **I4** or **L4** (for *longitudinal*, to avoid confusion between the digit 1 and the letter I).

The inline-four layout is in perfect primary balance and confers a degree of mechanical simplicity which makes it popular for economy cars. However, despite its simplicity, it suffers from a secondary imbalance which causes minor vibrations in smaller engines.

These vibrations become worse as engine size and power increase, so the more powerful engines used in larger cars generally are more complex designs with more than four cylinders.

The inline-four is the most common engine configuration in modern cars, while the V6 is the second most popular. Today most manufacturers of four cylinder engines for automobiles produce the inline-four layout, with Subaru's flat-four being a notable exception. In the late 2000s, with auto manufacturers making efforts to increase fuel efficiency and reduce emissions, due to the high price of oil and the economic recession, the proportion of new vehicles with four cylinder engines (largely of the inline-four type) has risen from 30 percent to 47 percent between 2005 and 2008, particularly in mid-size vehicles where a decreasing number of buyers have chosen the V6 performance option.

Displacement

This inline engine configuration is the most common in cars with a displacement up to 2.4 L. The usual "practical" limit of the displacement of inline-four engines in a car is around 2.7 L. However, Porsche used a 3.0 L four in its 944 S2 and 968 sports cars, and Rolls Royce produced several inline-four engines of 2,838 cc with basic cylinder dimensions of 3.5 in (89 mm) diameter and 4.5 in (110 mm) stroke (Rolls Royce B40);

Classic and Antique vehicles tended to have larger displacements to develop horsepower and torque. The Model A Ford was built with a 3.3 L inline-four engine.

Inline-four diesel engines, which are lower revving than gasoline engines, often exceed 3.0 L. Mitsubishi still employs a 3.2 L inline-four turbodiesel in its Pajero (called the Shogun or Montero in certain markets), and Tata Motors employs a 3.0 L inline-four diesel in its Spacio and Sumo Victa.

The Toyota B engine series of diesel engines varies in displacement from 3.0- 4.1 L. The largest engine in that series was used in the Mega Cruiser.

One of the strongest Powerboat-4-cylinders is the Volvo Penta D4-300 turbodiesel. This is a 3.7L-inline-4 with 300hp and 516ft-lbf(700Nm).

One of the strongest truck/tractor/railcar-4-cylinders is the MAN D0834 turbodiesel. This is a 4.6L-inline-4 with 220hp and 627ft-lbf(850Nm).

The Isuzu Forward is a medium-duty truck which is available with a 5.2 L inline-four engine that delivers 210hp and 470 ft-lbf (637Nm).

The Hino Ranger is a medium-duty truck which is available with a 5.1 L inline-four engine that delivers 175hp (129kW) and 465ft-lbf(631Nm). The earlier Hino Ranger even had a 5.3 L inline-four engine.

The Kubota M135X is a tractor with a 6.1 L inline-four. This turbo-diesel engine has a bore of 118 mm and a relative long stroke of 140 mm.

Larger inline-four engines are used in industrial applications, such as in small trucks and tractors, are often found with displacements up to about 4.6 L. Diesel engines for stationary, marine and locomotive use (which run at low speeds) are made in much larger sizes.

One of the largest inline-four engines is the MAN B&W 4K90 marine engine. This two stroke turbo-diesel has a giant displacement of 6,489 L. This results from a massive 0.9 meter bore and 2.5 meter stroke. The 4k90 engine develops 18,280 kW or 24,861 hp at 94 rpm and weighs 787 tons.

Displacement can also be very small, as found in kei cars sold in Japan, such as the Subaru EN series; engines that started out at 550 cc and are currently at 660 cc, with variable valve timing, DOHC and superchargers resulting in engines that produce 65 PS (48 kW; 64 bhp).

Balance and smoothness



Computer generated image showing the major internal moving parts of an inline-four engine with belt-driven double overhead camshafts and 4 valves per cylinder.

The inline-four engine is much smoother than one, two, and three cylinder engines, and this has resulted in it becoming the engine of choice for most economy cars, although it can be found in some sports cars as well. However, the inline-four is not a fully balanced configuration.

An even-firing inline-four engine is in primary balance because the pistons are moving in pairs, and one pair of pistons is always moving up at the same time as the other pair is moving down. However, piston acceleration and deceleration are greater in the top half of the crankshaft rotation than in the bottom half, because the connecting rods are not infinitely long, resulting in a non sinusoidal motion. As a result, two pistons are always accelerating faster in one direction, while the other two are accelerating more slowly in the other direction, which leads to a secondary dynamic imbalance that causes an up-and-down vibration at twice crankshaft speed. This imbalance is tolerable in a small, low-displacement, low-power configuration, but the vibrations get worse with increasing size and power.

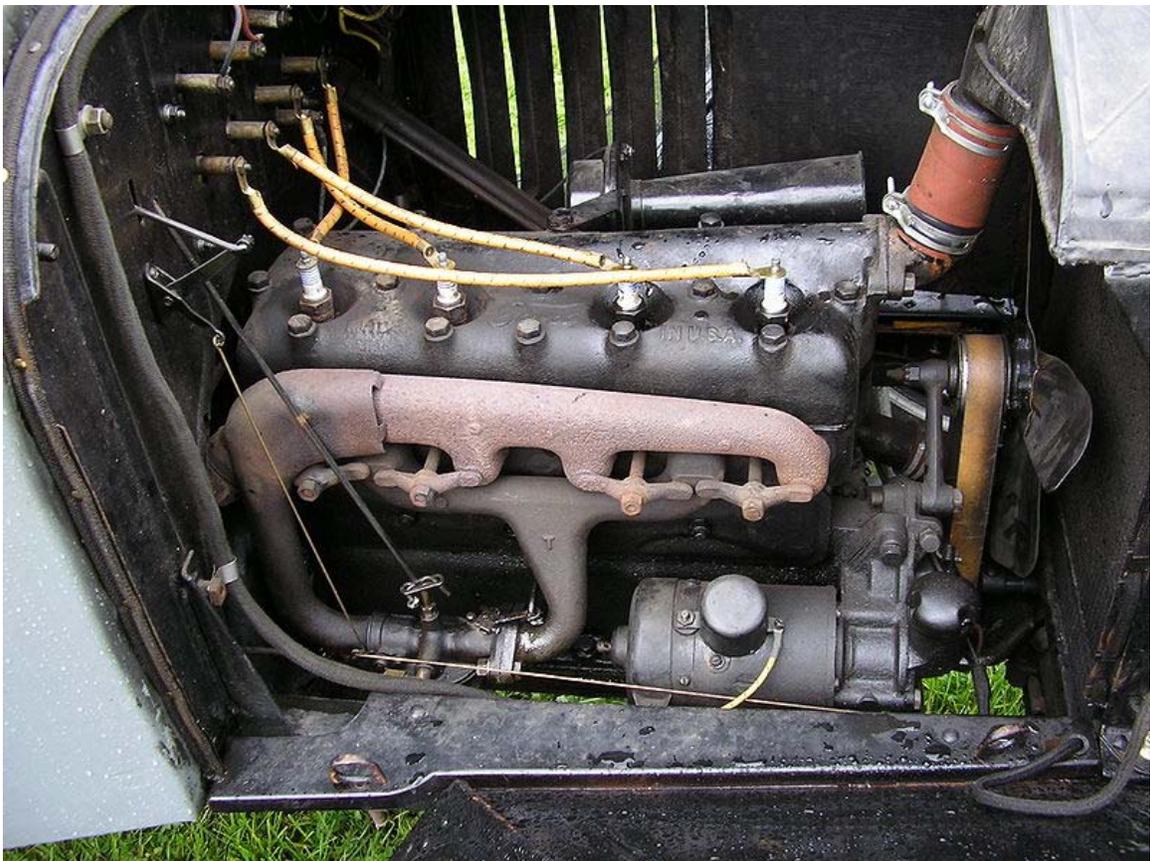
The reason for the piston's higher speed during the 180° rotation from mid-stroke through top-dead-centre, and back to mid-stroke, is that the minor contribution to the piston's up/down movement from the connecting rod's change of angle here has the same direction as the major contribution to the piston's up/down movement from the up/down movement of the crank pin. By contrast, during the 180° rotation from mid-stroke through bottom-dead-centre and back to mid-stroke, the minor contribution to the piston's up/down movement from the connecting rod's change of angle has the opposite direction of the major contribution to the piston's up/down movement from the up/down movement of the crank pin.

Most inline-four engines below 2.0 L in displacement rely on the damping effect of their engine mounts to reduce the vibrations to acceptable levels. Above 2.0 L, most modern inline-four engines now use balance shafts to eliminate the second-order harmonic vibrations. In a system invented by Dr. Frederick W. Lanchester in 1911, and popularised by Mitsubishi Motors in the 1970s, an inline-four engine uses two balance shafts, rotating in opposite directions at twice the crankshaft's speed, to offset the differences in piston speed. However, in the past, there were numerous examples of larger inline-fours without balance shafts, such as the Citroën DS 23 2,347 cc engine that was a derivative of the Traction Avant engine, the 1948 Austin 2,660 cc engine used in the Austin-Healey 100 and Austin Atlantic, the 3.3 L flathead engine used in the Ford Model A (1927), and the 2.5 L GM Iron Duke engine used in a number of American cars and trucks. Soviet/Russian GAZ Volga cars and UAZ SUVs, vans and light trucks used aluminium big-bore inline-four engines (2.5 or later 2.9 L) with no balance shafts from the 1950s-1990s. These engines were generally the result of a long incremental evolution process and their power was kept low compared to their capacity. However, the forces increase with the square of the engine speed — that is, doubling the speed makes the vibration four times worse — so modern high-speed inline-fours have more need to use balance shafts to offset the vibrations.

Four cylinder engines also have a smoothness problem in that the power strokes of the pistons do not overlap. With four cylinders and four strokes to complete in the four-stroke cycle, each piston must complete its power stroke and come to a complete stop before the next piston can start a new power stroke, resulting in a pause between each power stroke and a pulsating delivery of power. In engines with more cylinders, the power strokes overlap, which gives them a smoother delivery of power and less vibration than a four can achieve. As a result, six- and eight- cylinder engines are generally used in more luxurious and expensive cars.

Automobile use

Notable production inline-four engines



Ford Model T engine



1970 Alfa Romeo 1750 GTV engine

The smallest automobile production inline-four engine powered the 1962-1970 Mazda P360 Carol kei car. Displacing just 358 cc, the Mazda *DA* was a conventional but tiny pushrod engine. Honda produced, from 1963–1967, a 356 cc (21.7 cu in) inline-four engine for the T360 truck. Inline-four motorcycle engines are built down to 250 cc, e.g. in the Honda CBR250.

Most inline-four engines, however, have been over 700 cc (43 cu in) displacement. A practical upper limit could be placed in the 2.5 L range for contemporary production cars. Larger engines (up to 6.1 L) have been seen in tractors (Kubota M135X) and medium duty truck use (Isuzu Forward, Hino Ranger), especially using diesel fuel (one of the strongest is the MAN D0834 engine with 220hp and 627ft·lbf(850Nm)). The use of balance shafts allowed Porsche to use a 3.0 L (2990 cc) inline-four engine on road cars first in the 944 S2, but the largest modern non-diesel was the plain 3,188 cc (194.5 cu in) *I95* in the 1961 Pontiac Tempest.

Currently, one of the largest straight-4 engines in production is General Motors' Vortec 2900 installed in the GMC Canyon and Chevrolet Colorado small pickup trucks. It shares the same 95.5 mm bore and 102 mm (4.0 in) stroke as the larger inline-five Vortec 3700. The latest version of the Vortec 2900, the LLV, displaces 2.9 L (2921 cc, 178 in³) and produces 185 hp (138 kW) at 5600 rpm and 195 ft·lbf (263 N·m) at 2800 rpm. Engine

redline is 6300 rpm. Another example of a large inline-four engine is the Russian 2.89 L UMZ 421 series UMZ engine.

In the early 20th century, bigger engines existed, both in road cars and sports cars. Due to the absence of displacement limit regulations, manufacturers took increasing liberties with engine size. In order to achieve power over 100 hp (75 kW), most engine builders simply increased displacement, which could sometimes achieve over 10.0 L. One of the biggest inline-fours of its time was De Dietrich 17,000 cc engine. Its cubic capacity is over twice the size of the Cadillac's 500 CID 8.2 L V8 engine, which was considered the largest engine of its type in the 1970s. These engines ran at very low rpm, often less than 1,500 rpm maximum, and had a specific output of about 10 hp/L. The US tractor industry both farm and industrial relied on large four cylinder power units until the early 1960s, when six cylinder designs came into favor. International Harvester built a large 5.7 litre (350 CID) four cylinder for their WD-9 series tractors.

Other technologically or historically notable engines using this configuration include:

- Alfa Romeo Twin Cam engine - one of the first mass produced twin cam engines produced from 1954. Also first engine in production car with variable valve timing.
- BMC A-Series engine - the first engine to be used in a transverse drive train powering the front wheels of a mass-produced automobile (Mini).
- Chevrolet Cosworth Twin-Cam Vega - 2.0 L all aluminum (block & head), DOHC, 16 valves, electronic fuel injection, stainless steel header.
- Dodge A853 - intercooled turbo engine from the SRT-4, set the land speed record for 4 cylinder production cars at the Bonneville Salt Flats.
- Ford Model T engine - one of the most-widely produced engines in the world.
- Ford Model A engine - the follow-up design to the Model T.
- GM Quad-4 engine - twin-cam Oldsmobile engine offered in GM small, sporty cars.
- Honda ED engine - first use of Honda's CVCC technology.
- Honda F20C engine - its 240 horsepower (180 kW) from 2.0 L was the highest specific output of its time, particularly noteworthy in that it achieved this without forced induction.
- Mitsubishi Sirius engine - includes the 4G63, which has the highest specific output of a turbocharged production engine in the world with the Lancer Evolution FQ-400 available in the United Kingdom (202.9 hp/L)
- GM Iron Duke engine - A versatile 151 CID 2.5 L 95 horsepower (71 kW) engine used in many GM cars in longitudinal configuration powering rear wheels or a transverse configuration powering front wheels or rear wheels. "Super Duty" racing versions of the Iron Duke were developed by Pontiac Racing.
- Triumph Slant-4 engine - the first mass-produced multi-valve engine for Triumph and an early turbo engine for Saab.
- Willys L-134 engine - nicknamed the Go Devil engine. Powered the World War II Jeep and post-war models. Notably undersquare, with 3.125 in (79.4 mm) bore and 4.375 in (111.1 mm) stroke.

In the late 2000s, with auto manufacturers making efforts to increase fuel efficiency and reduce emissions, due to the high price of oil and the economic recession, the proportion of new vehicles with inline-four engines have increased considerable at the expense of V6 and V8 engines. This is particularly evident in mid-size vehicles where a decreasing number of buyers have chosen the V6 performance options, and in fact the 2010 Hyundai Sonata no longer has a V6 option, instead offering a 2.0T (2.0L turbocharged and directly-injected) inline-four as the upgrade engine. The Volkswagen Group in particular has made widespread use of its 2.0 TFSI inline-four, which also features turbocharging and direct injection, as a performance option for its Volkswagen Golf (Golf GTI) and as the base engine for its Audi A4 (in the latter capacity where it provides superior torque to contemporaries with V6 engines, namely Audi's own 3.2 FSI V6). A tuned version of the Volkswagen 2.0 TFSI engine powers the Audi TTS

Racing use

1913 saw a Peugeot driven by Jules Goux winning the Indianapolis 500. This car was powered by an inline-four engine designed by Ernest Henry. This design was very influential for racing engines as it featured for the first time dual overhead camshafts (DOHC) and four valves per cylinder, a layout that would become the standard until today for racing inline-four engines.

This Peugeot was sold to the American driver "Wild Bob" Burman who broke the engine in 1915. As Peugeot couldn't deliver a new engine during World War I, Burman asked Harry Arminius Miller to build a new engine. With John Edward and Fred Offenhauser, Miller created a Peugeot-inspired inline-four engine. This was the first version of the engine that would dominate the Indianapolis 500 until 1976 under the brand Miller and later Offenhauser. The Offenhausers won five straight victories at Indianapolis from 1971 to 1976, and it was not until 1981 that they were eliminated as competitors by engines such as the Cosworth V8 engine.

Many cars produced for the pre-WWII voiturette Grand Prix motor racing category used inline-four engine designs. 1.5 L supercharged engines found their way into cars such as the Maserati 4CL and various English Racing Automobiles (ERA) models. These were resurrected after the war, and formed the foundation of what was later to become Formula One, although the straight-eight supercharged Alfettas would dominate the early years of F1.

Another engine that played an important role in racing history is the inline-four Ferrari engine designed by Aurelio Lampredi. This engine was originally designed as a 2 L Formula 2 engine for the Ferrari 500, but evolved to 2.5 L to compete in Formula One in the Ferrari 625. For sports car racing, capacity was increased up to 3.4 L for the Ferrari 860 Monza.

Yet another very successful engine was the Coventry Climax inline-four originally designed by Walter Hassan as a 1.5 L Formula 2 engine. Enlarged to 2.0 L for Formula

One in 1958, it evolved into the large 2495 cc FPF that won the Formula One championship in Cooper's chassis in 1959 and 1960.

Motorcycle use



Honda CB750 engine

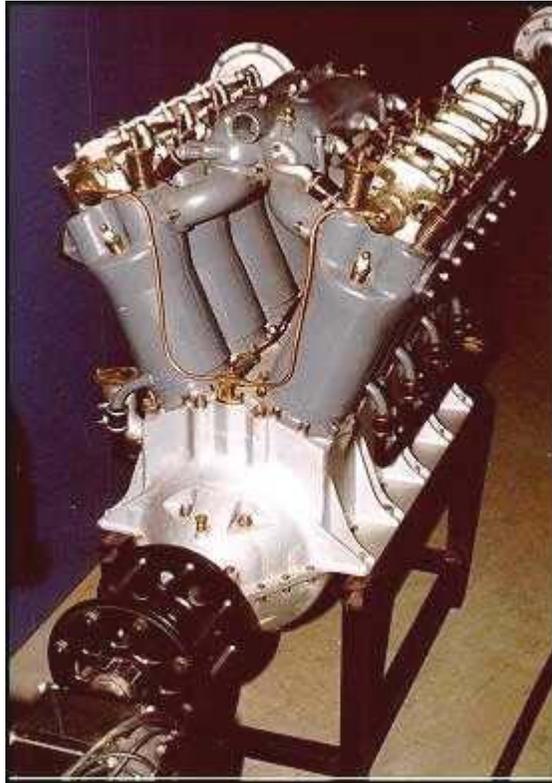
For racing, Honda built inline-four engines as small as a 125 cc for the Honda 125/4. This engine was replaced by a 125 cc straight-five engine. The largest proprietary inline-four engine in a commercially-produced motorcycle is the 1402 cc engine in the Suzuki GSX1400.

Modern inline-four motorcycle engines first gained their popularity with Honda's SOHC CB750 in the 1970s. Since then, the inline-four has become one of the most common engine configurations in street bikes. Outside of the cruiser category, the inline-four is simply the most common configuration because of its relatively high performance-to-cost ratio. All of the Japanese motorcycle manufacturers offer motorcycles with inline-four engines, as does MV Agusta and BMW who employ both longitudinal and transverse-mounted engines. Even the modern Triumph company has offered inline-four-powered motorcycles, though they were discontinued in favour of a triple.

The 2009 Yamaha R1 has an interesting inline-four engine that does not fire at even intervals of 180° . Instead, it uses a crossplane crankshaft that prevents the pistons from simultaneously reaching top dead centre. This results in increased torque at lower engine speeds.

Chapter- 4

V8 Engine



The Liberty V8 aircraft engine clearly shows the configuration, although modern automotive versions use a 90 degree block angle.



Bare block of an American Motors V8 engine showing the four cylinders on each side of the V configuration

A **V8 engine** is a V engine with eight cylinders mounted on the crankcase in two banks of four cylinders, in most cases set at a right angle to each other but sometimes at a narrower angle, with all eight pistons driving a common crankshaft.

In its simplest form, it is basically two straight-4 engines sharing a common crankshaft. However, this simple configuration, with a single-plane crankshaft, has the same secondary dynamic imbalance problems as two straight-4s, resulting in vibrations in large engine displacements. As a result, since the 1920s most V8s have used the somewhat more complex crossplane crankshaft with heavy counterweights to eliminate the vibrations. This results in an engine which is smoother than a V6, while being considerably less expensive than a V12 engine. Racing V8s continue to use the single plane crankshaft because it allows faster acceleration and more efficient exhaust system designs.

Applications



Assembled overhead valve engine with heads and complete valve train but without manifolds, rocker covers, timing chain cover or oil pan



Assembled and installed with all components as seen in a rear-wheel drive vehicle

The V8 with a crossplane crankshaft is a common configuration for large automobile engines. V8 engines are rarely less than 3.0 L (183 cu in) in displacement and in automobile use have exceeded 8.2 L (500 cu in) in production vehicles. Industrial and marine V8 engines can be much larger.

V8s are generally only standard on more powerful muscle cars, pony cars, sports cars, luxury cars, pickup trucks, and SUVs. However they are often options in vehicles which have a V6 or straight-6 as standard engine. In some cases, V6 engines were derived from V8 designs by removing two cylinders maintaining the V-angle so they can be built on the same assembly lines as the V8s and installed in the same engine compartments with few modifications. Some of these employed offset crankpins driving connecting rod pairs, enabling a regular firing sequence.

The traditional 90° big-bore V8 engine is generally too wide and too long to fit easily in vehicles with a transverse engine front-wheel drive layout, so its applications are limited to rear-wheel drive sports cars, muscle cars, pony cars, luxury cars and light trucks. The shorter and occasionally narrower V6 engine is easier to fit in small engine compartments, but a few compact V8 engines are used in transverse FWD and transverse AWD engine configurations in larger cars, such as Cadillacs and Volvos. These engines

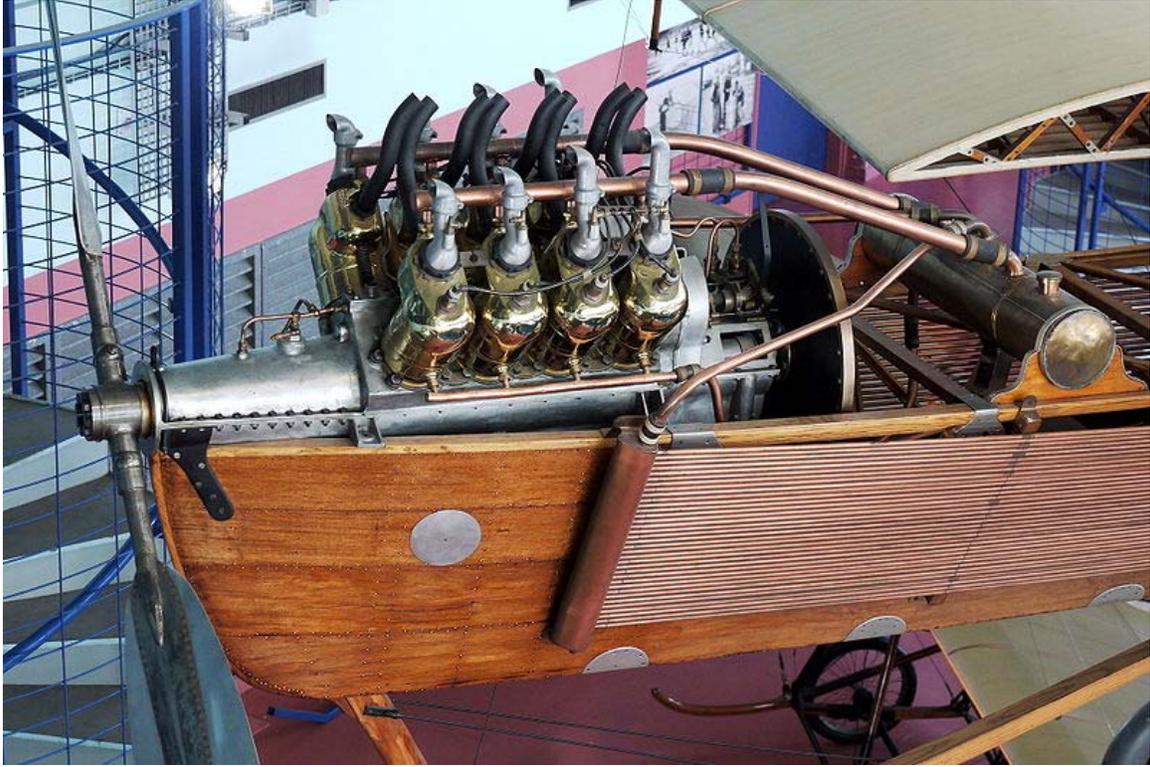
often have tighter cylinder bore spacings, narrower cylinder bank angles, and other modifications to reduce their space requirements.

V8s are common in purpose-designed engines for racing cars. They usually have flat-plane crankshafts, since a crossplane crankshaft results in uneven firing into the exhaust manifolds which interferes with engine tuning, and the crossplane's heavy crankshaft counterweights prevent the engine from accelerating rapidly. They are a common engine configuration in the highest echelons of motorsport, especially in the USA where it is required in IRL, ChampCar and NASCAR. V8 engines are also used in Australian motorsport, most notably in the V8 Supercars. Formula One began the 2006 season using naturally aspirated 2.4 L (~146 cu in) V8 engines, which replaced the 3.0 L (~183 cu in) V10 in a move to reduce costs and power.

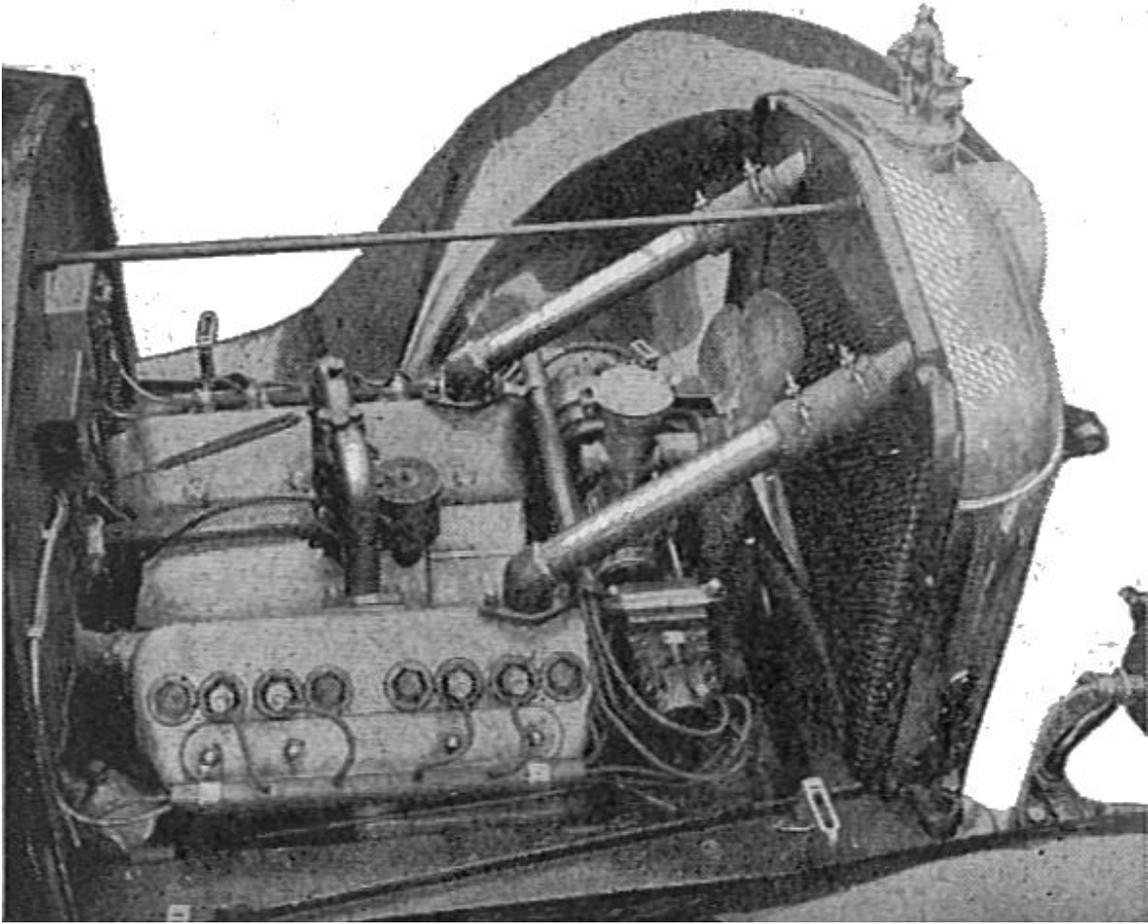
Heavy trucks and railroad locomotives tend to use the straight-6 configuration since it is simpler and easier to maintain, and because the straight-6 is an inherently balanced layout which can be scaled up to any size necessary. Large V8s are found in the larger truck and industrial equipment lines, however.

Although it was the early choice for aircraft engines, the V8 engine is seldomly used in modern aircraft engine as the typically heavy crankshaft counterweights are a liability. Modern light planes commonly use the flat-8 configuration instead as it is lighter and easier to air cool, in addition it can be manufactured in modular designs sharing components with flat-4 and flat-6 engines.

History



1909 Antoinette VII aircraft with Antoinette V8 engine



V8 Vulcan engine, circa 1919

In 1902, Léon Levavasseur took out a patent on a light but quite powerful gasoline injected V8 engine. He called it the 'Antoinette' after the young daughter of his financial backer. From 1904 he installed this engine in a number of competition speedboats and early aircraft. The aviation pioneer Alberto Santos-Dumont saw one of these boats in Côte d'Azur and decided to try it on his 14-bis aircraft. Its early 24 hp (18 kW) at 1400 rpm version with only 55 kg (120 lb) of weight was interesting, but proved to be underpowered. Santos-Dumont ordered a larger and more powerful version from Levavasseur. He changed its dimensions from the original 80 mm stroke and 80 mm bore to 105 mm stroke and 110 mm bore, obtaining 50 hp (37 kW) with 86 kg (190 lb) of weight, including cooling water. Its power-to-weight ratio was not surpassed for 25 years. Levavasseur eventually produced its own line of V-8 equipped aircraft, named Antoinette I to VIII. One of these aircraft, piloted by Hubert Latham, tried but failed to cross the English Channel in 1909 due to the engine's gasoline injection. However, in 1910, the same plane with the same engine and the same pilot was first in the world to reach an altitude of 3600 feet. Voisin constructed pusher biplanes with Antoinette engines, also, notably the one first flown successfully by Henry Farman in 1908.

The V8 engine configuration became popular in France from 1904 onward, and was used in a number of aircraft engines introduced by Renault, and Buchet among others. Some of these engines found their way into automobiles in small quantities. In 1905, Darracq built a special car to beat the world speed record. They came up with two racing car engines built on a common crankcase and camshaft. The result was monstrous engine with a displacement of 1551 in³ (25422 cc), good for 200 bhp (150 kW). Victor Hemery fixed that record on 30 December 1905 with a speed of 109.65 mph (176.46 km/h). This car still exists.

Rolls Royce built a 3,535 cc (216 cu in) V8 car from 1905 to 1906, but only 3 copies were made and Rolls Royce reverted to a straight-6 design. De Dion-Bouton introduced a 7,773 cc (474 cu in) automobile V8 in 1910 and displayed it in New York in 1912. It was produced only in small quantities, but inspired a number of American manufacturers to follow suit.

The first mass-production automobile V8 was introduced in the United States in 1914 by Cadillac, a division of General Motors which sold 13,000 of the 5,429 cc (331 cu in) L-head engines in its first year of production. Cadillac has been primarily a V8 company ever since. Oldsmobile, another division of General Motors, introduced its own 4 L (~244 cu in) V8 engine in 1916. Chevrolet introduced a 288 cu in (4.7 L) V8 engine in 1917, but after merging with General Motors in 1918, discontinued the V8 to concentrate on economy cars.

V angles

The most prevalent V angle for a V8 is 90°. This configuration features a wide, low engine with optimal firing and vibration characteristics. Many V6 and V10 engine configurations are derived from production V8 designs, they often use the 90° angle; however, balance shafts are incorporated to reduce vibration or more complex cranks to even the firing cycle. V8s can use different angles. One notable example is the Ford/Yamaha V8 used in the Ford Taurus *SHO*. It was based on Ford's Duratec V6 and shares that engine's 60° vee angle. A similar Yamaha-built engine is used by Volvo Cars as of 2005. These engines were designed for transverse front wheel drive installation and are narrower than usual for efficient use of space. Because they are not at the ideal 90° angle for a V8, they require a counter-rotating balance shaft and offset split crankpins for complete smoothness. In 2010, GM will introduce a 4.5 L Duramax diesel V8 with a 72° angle in which they state, "Considering manufacturing tolerances, a 72 V-8 engine can actually deliver better balance than a 90 engine." 72° V8's have been used in modern racing.

The Rover Meteorite V8 engine was derived from the Rover Meteor tank engine (hence derived from the Merlin aero engine), so shared the Meteor's 60° vee angle. In years past, Electro-Motive produced an 8-cylinder version of their model 567 Diesel locomotive engine, with a 45 degree cylinder angle. The 1932 Miller four-wheel drive race cars also featured a 45° V8.

An extremely narrow-angle V8 was introduced by Lancia in 1922, which had an angle between cylinder banks of only 14°. This created an engine that was shorter than a straight-6, but much narrower than a conventional V8. It was based on a Lancia V4 engine design that was almost completely "square" in the length and width of its layout. Because of their compact design and overhead camshafts, these engines were lighter and more powerful than comparable engines of the time. Although Lancia stopped making the V8 design around World War II, the basic concept is used today in the Volkswagen VR6 engine.

Crankshaft design

There are two classic types of V8s which differ by crankshaft:

- The **cross-plane** or two-plane crankshaft is the configuration used in most V8 road cars. The first and last of the four crank pins are at 180° with respect to each other as are the second and third, with each pair at 90° to the other, so that viewed from the end the crankshaft forms a cross. The cross-plane can achieve very good balance but requires heavy counterweights on the crankshaft. This makes the cross-plane V8 a slow-revving engine that cannot speed up or slow down very quickly compared to other designs, because of the greater rotating mass. While the firing of the cross-plane V8 is regular overall, the firing of each bank is LRLRLRR. In stock cars with dual exhausts, this results in the typical V8 *burble* sound that many people have come to associate with American V8s, In all-out racing cars it leads to the need to connect exhaust pipes between the two banks to design an optimal exhaust system, resulting in an exhaust system that resembles a *bundle of snakes* as in the Ford GT40. This complex and encumbering exhaust system has been a major problem for single-seater racing car designers, so they tend to use flat-plane crankshafts instead.
- The **flat-plane** or single-plane crankshaft has crank pins at 180°. They are imperfectly balanced and thus produce vibrations unless balance shafts are used, with a counter rotating pair flanking the crankshaft to counter second order vibration transverse to the crankshaft centerline. As it does not require counterweights, the crankshaft has less mass and thus inertia, allowing higher rpm and quicker acceleration. The design was popularized in modern racing with the Coventry Climax 1.5 L (~92 cu in) V8 that evolved from a cross-plane to a flat-plane configuration. Flat-plane V8s on road cars come from Ferrari, (every V8 model they ever made, from the 1973 *308 GT4*, to today's *F430* and *California*), Lotus (the *Esprit V8*), and TVR (the *Speed Eight*). This design is popular in racing engines, the most famous example being the Cosworth DFV.

In 1992, Audi left the German DTM racing series after a controversy around the crankshaft design of their Audi V8 DTM. After using the road car's cross-plane 90° crankshaft for several years, they switched to a flat-plane 180° version which they claimed was made by "twisting" a stock part. The scrutineers decided that this would stretch the rules too far.

The cross-plane design was neither obvious nor simple to design. For this reason, most early V8 engines, including those from De Dion-Bouton, Peerless, and Cadillac, were flat-plane designs. In 1915, the cross-plane design was proposed at an automotive engineering conference in the United States, but it took another eight years to bring it to production. Cadillac and Peerless (who had hired an ex-Cadillac mathematician for the job) applied for a patent on the cross-plane design simultaneously, and the two agreed to share the idea. Cadillac introduced their "Compensated Crankshaft" V8 in 1923, with the "Equipoised Eight" from Peerless appearing in November 1924.

American V8 engines



De Soto Fire Dome V8 engine, at the 1952 LA Auto Show

A full decade after Britain's 1904 Rolls-Royce Legalimit, Cadillac produced the first American V8 engine, the 1914 *L-Head*. It was a complicated hand-built unit with cast iron paired closed-head cylinders bolted to an aluminum crankcase, and it used a flat-plane crankshaft. Peerless followed, introducing a V8 licensed from amusement park manufacturer, Herschell-Spillman, the next year. Chevrolet produced a crude overhead valve V8 in 1917, in which the valve gear was completely exposed. It only lasted through

1918 and Chevrolet would not produce another V8 until the introduction of the small block in 1955.

Cadillac and Peerless were one year apart again (1923 and 1924, respectively) with the introduction of the cross-plane crankshaft. Lincoln also had V8 cars in those years, as did Ferro, Northway (supplier to Cadillac, Cole Indianapolis, and Jackson, Mississippi), Perkins (Detroit), Murray, Vernon, and Yale. Oakland, a division of GM, introduced an 85 hp (63 kW) 250 cu in (4.1 L) V8 with a 180° crankshaft in 1930-1931. In 1932, the Oakland marque was discontinued and the V8 was used in its companion marque, Pontiac, for one year. Pontiac dropped the V8 engine in 1933 and replaced it with its smoother running Silver-Streak straight eight.

Ford was the first company to use V8s *en masse*. Instead of going to an inline six like its competitors when something larger than an inline four was needed, Ford designed a modern V8, the *Flathead* of 1932. This flat head engine powered almost all larger Ford cars through the 1953 production year, and was produced until around 1970 by Ford licensees around the world, with the valve-in-block engine powering mostly commercial vehicles.

After World War II, the strong demand for larger status-symbol cars made the common straight-6 less marketable. Straight-8 engines have problems with crankshaft whip and require a longer engine bay. In the new wider body styles, a V8 would fit in the same space as a straight-6. Manufacturers could simplify production and offer the bigger engines as optional upgrades to base models.

In 1949, General Motors (GM) responded to Ford's V8 success by introducing the *Oldsmobile Rocket* and *Cadillac OHV*. Chrysler introduced their *FirePower* 331 cu in (5.4 L) hemi-head V8 in 1951. That year Studebaker introduced its V8. Buick followed in 1953, while Packard and GM's Chevrolet and Pontiac introduced V8s of their own in 1955. American Motors initially purchased V8 engines from Packard, but developed its own lower-weight, 600 lb (272 kg), design in 1956.



Shelby Mustang GT350 V8 engine

A full history of each manufacturer's engines is outside of the scope, but engine sizes on full-size cars grew throughout the 1950s, 1960s, and into the early to mid-1970s. The increasing size of full-size cars meant smaller models of car were introduced and became more popular, with the result, by the 1960s, Chrysler, Buick, Ford, and Chevrolet had two V8 model ranges.

The larger engines, known as big-block V8s, were used in the full-size cars. Big-blocks generally had displacements in excess of 360 cu in (5.9 L), but in stock form are often not all that efficient. Big-block displacement reached its zenith with the 1970 Cadillac Eldorado's 500 cu in (8.2 L) 500. Once the 1970s oil crisis and pollution regulations hit, big-block V8s did not last too much longer in cars; luxury cars lasted the longest, but by 1977 or so they were gone. In trucks and other larger vehicles, big-block V8s continue to be used today, though some manufacturers have replaced them with small-block-based V10s or more efficient Diesels. Big-block V8s are used in racing and such engines are available from independent engine builders. Some applications produce 2,000 hp (1,491 kW) from volumes exceeding 800 cu in (13.1 L).

Smaller engines, known as small-block V8s, were fitted in the mid-size car ranges and generally displaced between 270 cu in (4.4 L) and 360 cu in (5.9 L), though some grew as large as Ford's 408 cu in (6.7 L) 400 *Cleveland*. There is overlap between big-block and

small-block ranges, and a factory engine between 6.0 and 6.6 L (366 and 403 cu in) could belong to either class. Engines like this (much evolved) are still in production.



A 4.0 L (244 cu in) V8 engine from an Oldsmobile Aurora

During the 1950s, 1960s and, 1970s, every GM division had their own engines, whose merits varied. This enabled each division to have its own unique engine character, but made for much duplication of effort. Most, like the comparatively tiny *Buick 215* and familiar *Chevrolet 350*, were confusingly shared across many divisions. Ford and Chrysler had fewer divisions, and division-specific engines were quickly abandoned in favor of a few shared designs. Today, there are fewer than a dozen different American V8 engines in production.

Lately, Chrysler and GM have designed larger displacement V8s out of existing modern small-block V8s for use in performance vehicles, such as Chrysler's 6.1 L (~372.2 cu in) and 6.4 L (~390.6 cu in) Hemis, and the LS7 7.0 L (~427.2 cu in) version of GM's LS engines.

Today, the major use for big V8s is in racing, where aluminum copies of the venerable Chrysler Hemi still dominate professional drag racing (Top Fuel Dragster and Funny Car).

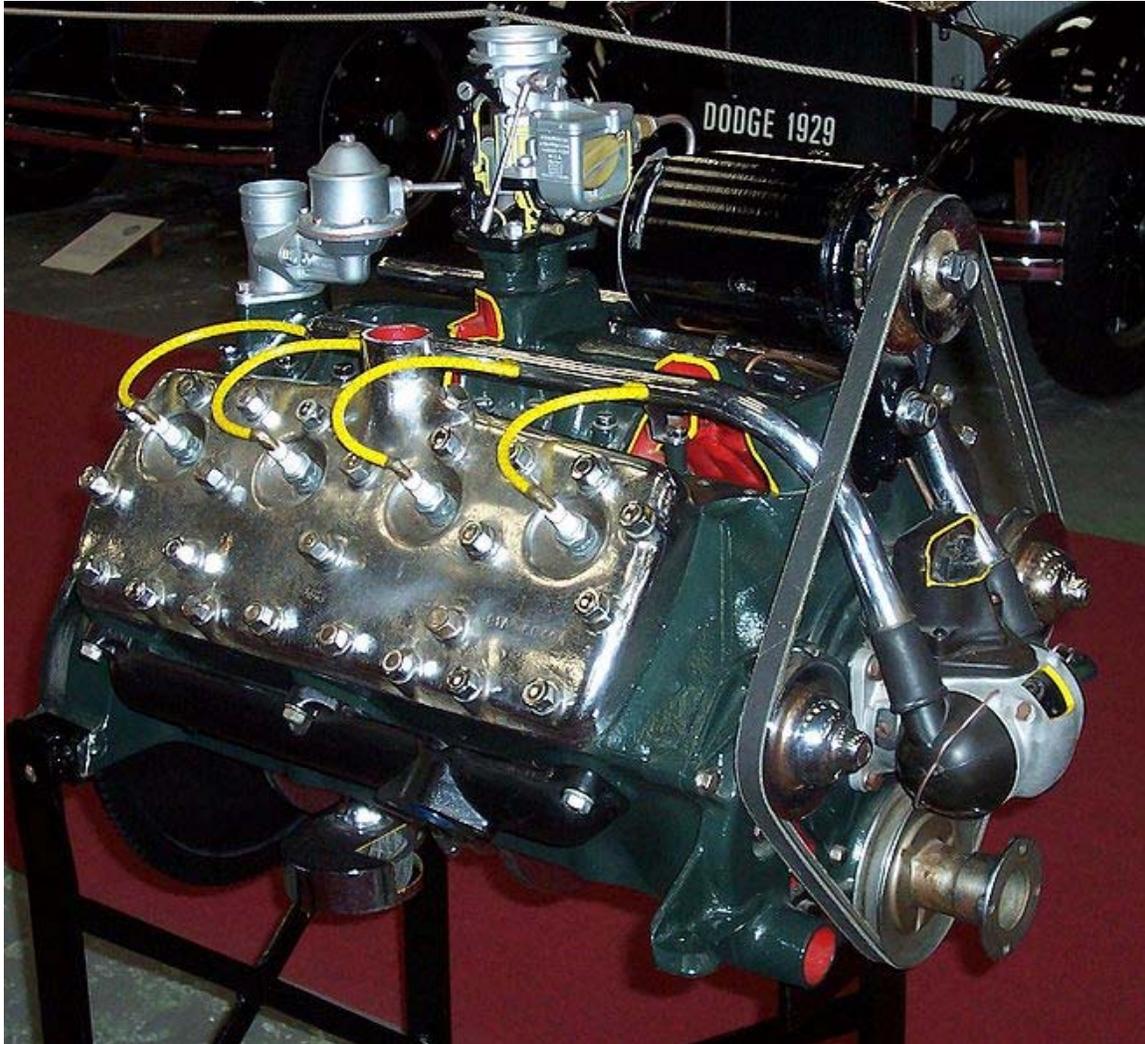
American V8s (by manufacturer and year)



A Supercharged custom V8 engine

- American Motors (AMC)
 - 1956-1966 GEN-1 Nash/Hudson/Rambler V8
 - 1966-1991 GEN-2 AMC and Jeep V8
- Chrysler
 - 1951-1959 FirePower
 - 1951-1958 and 1964-1971 Hemi (Original)
 - 1956-1967 A family
 - 1958-1971 B family

- 1959–1978 RB family
- 1964–2003 LA Family
- 1999–present PowerTech
- 2003–present New Hemi



1930's flathead Ford V8 engine

- Ford
 - 1920–1932 Lincoln Liberty
 - 1932-1953 Flathead V8
 - 1954-1962 Y-block V8
 - 1958-1967 MEL V8
 - 1958-1976 FE V8
 - 1958-1982 Super Duty engine
 - 1962-2001 Windsor V8
 - 1966–present Cosworth DFV
 - 1968-1997 385 V8

- 1970-1982 335/Cleveland V8
- 1991–present Modular V8/Triton V8
- 1996–present Jaguar AJ-V8
- 1996–1999 Yamaha V8
- 2004–present AJD-V8
- 2009–present Lion V8
- 2009–present Boss/Hurricane
- 2011- Ford Coyote

- General Motors
 - 1914-1992 Cadillac V8
 - 1930-1931 Oakland V8
 - 1932 Pontiac V8
 - 1949-1990 Oldsmobile Rocket V8
 - 1954-1970s Pontiac V8
 - 1950s-1970s Buick V8
 - 1954-2002 Chevrolet small-block V8
 - Chevrolet Big-Block engine
 - 1992–present Northstar/Premium
 - 1992-1997 Generation 2 small-block
 - 1997–present Generation 3 small-block
 - 2005–present Generation 4 small-block
 - Duramax Diesel

- Packard
 - 1955–1956

- Studebaker
 - 1951–1964

British V8 engines



1962 Coventry Climax FWMV 1500cc V8 Formula 1 engine in a Lotus 24



BentleyV8 engine

The first British V8 was the 3.5 L Rolls-Royce V-8 (1905) followed shortly by Darracq.

The Rolls-Royce and Bentley V8 still used in modern Bentleys was designed from 1952 and entered production in 1959 in the Rolls Royce Silver Cloud and Bentley S2.

Following then current design practice, it featured overhead valves (OHV), a central camshaft and wedge-shaped combustion chambers. It was designed by the Rolls-Royce and Bentley Motors engineering team, led by Jack Phillips. Some of its features were inspired by the Rolls-Royce Merlin aircraft engine, including the aluminium block with wet liners, gear-driven camshaft, (initially) outboard spark-plugs and porting. Early versions were of 6.25 L (381 cu in) displacement, growing to 6.75 L (412 cu in) in the 1970s. Turbocharging in various Bentley models beginning in the 1980s led to the resurgence of the Bentley marque as the power outputs of the engine were increased in several steps to the current 500 bhp (370 kW) and 1,000 N·m (740 ft·lbf) in the 2007 model-year Bentley Arnage, while meeting all emission standards. The Bentley V8 has

thus increased power and torque by more than 150% in its life. It is the highest torque V8 used in a production car. In 2007, the final components that could be traced back to the 1959 engine were replaced.

In 1936, the Standard Motor Company introduced its 'Flying Twenty V-Eight' model featuring a 2.7 L flathead V8 developing 20 RAC horsepower. It was the flagship model of the company's 'Flying Standard' range but proved unpopular as it offered little performance improvement over the normal 'Flying Twenty' model (which used a straight-6 engine) whilst costing much more to buy and suffering higher fuel consumption. The Twenty V-Eight was on sale only for the 1936 model year and fewer than 400 were sold.

Rover was in need of a new, more powerful engine in the mid 1960s. The managing director of Rover, on a trip to the USA to sell marine engines, saw an example of the GM engine in a Mercury Marine experimental shop and noticed its light weight and small size. The 215 cu in (3,520 cc) GM V8 was only 12 pounds (5.4 kg) heavier and less than 1 inch (2.5 cm) longer than the 2,000 cubic centimetres (120 cu in) Rover straight-4 and sent the GM Oldsmobile/Buick cast-aluminum 215 V8 back to the UK for evaluation. It worked well in the large Rovers, being considerably shorter, lighter, and more powerful than the Rover straight 6, and Rover acquired manufacturing rights to it. The Rover V8 was redesigned to improve the durability and high-RPM performance, leaving few parts interchangeable with the original Buick engine. The engine first appeared in Rover saloons in the late 1960s. GM aided the process by allowing Buick's chief engine designer, who was close to retirement, to assist Rover.

As well as appearing in Rover cars, the engine was also sold to small car builders, and powered various vehicles. Rover V8s feature in some models from Morgan, TVR, Triumph, Marcos, and MG, among others. The Australian firm Repco converted this engine for Formula One by reducing it to 3.0 L (183 cu in) (the stroke was shortened and using con-rods from the 2.5 L/153 cu in Daimler V8) and fitting a single overhead camshaft per bank rather than the shared pushrod arrangement. Repco-powered Brabhams won the F1 championship twice, in 1966 and 1967. Land Rover also used the V8, appearing in the Range Rover in various guises, from 3.5 L (~214 cu in) in the earlier models to the 4.6 L (~281 cu in) used in the 1994-2002 models. The last mass-produced car to use the Rover V8 was in some models of the Land Rover Discovery, up to 2004. Many independent sports cars manufacturers still use it in hand-built applications.

Recently Land Rover (Tata) added the TDV8 to its list of engines. It is a V8 version of the popular TDV6 found in Discovery models. This diesel engine will be found in the 2007 Range Rovers. This 3.6 L (~220 cu in) engine produces 472 ft·lbf (640 N·m) at 2000 rpm.

The Rover Meteorite petrol or diesel V8 was used in trucks and transporters from 1943, and for marine or stationary use.

Triumph used the Triumph Slant-4 engine as a base of a V8 engine. The Triumph V8 was used only in the Triumph Stag.

Edward Turner designed the 2.5 L (~153 cu in) and 4.5 L (~275 cu in) hemi-head Daimler V8 engines announced in 1959. The 2.5 saw service in the Daimler SP250 (1959–1964), and, after the Jaguar takeover, in the "Daimler 2.5 Litre V8"/"Daimler 250" (1962–1969) versions of the Mk2 Jaguar bodyshell. The 4.5 was used in the Daimler Majestic Major, (1959–1968).

The Jaguar company introduced the new AJ26 V8 engine in 1996. It has been developed and updated since, and appears in the S-Type and later vehicles from Jaguar. This V8 was used in some of Ford's Premier Automotive Group Jaguar and Land Rover brands. These included a 4.2 (Jaguar XJ, XK and S-Type), 4.2 supercharged (Jaguar XJR, XKR, S-Type-R, Land Rover Range Rover and Range Rover Sport) and a 4.4 (Range Rover and Range Rover Sport). New V-configuration engines are used since the buy out by the Tata Motor group.

The specialist sports car firm TVR also produced their own V8 engine in 4.2 L (~256 cu in) 350 bhp (261 kW) and 4.5 L (~275 cu in) 440 bhp (328 kW) liter forms for the TVR Cerbera. Designed by Al Melling, the APJ8 engine features a flat-plane crank and 75° Vee.

Aston Martin has used a variety of V8 engines in its cars, starting with the 1969 DBS V8, followed by many models badged V8 Vantage, or Virage, plus Volante convertible versions. After the Vantage was discontinued in 2000, there were no V8 models until the introduction of the Jaguar derived 4.3l V8 in the 2005 V8 Vantage. The V8s used in Aston Martins from 1969-2000 were based on an internal design by Tadek Marek, while the V8 engines used in the 2005–present V8 Vantage are based on the Jaguar AJ26 V8.

Lotus introduced a V8-powered version of the Esprit in 1996. The engine was an in-house 3.5 L (~214 cu in) unit, with twin turbochargers.

Radical Sportscars offer a V8 powered car, the SR8, whose Powertec RPA engine is based upon two Suzuki Hayabusa engines joined to a common crank, utilising the original heads with a purpose designed block.

In 2010, McLaren Automotive developed M838T 3.8-litre V8 twin-turbo engine, used in MP4-12C

Chinese V8 engines

- FAW Hongqi by First Automobile Works
 - CA72
 - CA770
 - HQ430

Czech V8 engines



Tatra T603 engine

Tatra used air-cooled V8 engines. These culminated in the 2.5 L unit used in the Tatra T603 range of cars. The most powerful of these was fitted to the racing variant — known as the B-5. This was a higher compression version of the standard engine which replaced a standard single 2BBL carburettor with two 4BBL downdraft units on a new induction manifold. Tatra later produced another air-cooled engine, used in Tatra 613 and later, in Tatra 700. These engines were well known for their reliability, good fuel consumption, and specific sound.

In the Tatra 603, two engine driven fans help pull cooling air into the engine bay — when the vehicle is in motion the air enters through intakes in the rear wing panels and is exhausted through cut-outs below the bumper and alongside the engine itself. In the Tatra 613, one large ventilator pushes fresh cold air into the engine bay.

Tatra has used V8 air cooled engines in their heavy duty trucks until the present day in their Tatra 815 and other models.

- T77 1934-1938 - 3.0 Litre air cooled V8

- T87 1936-1950 - 3.0 Litre air cooled V8
- T607 Monopost - 2.35 Litre V8
- T603 1956-1975 - 2.5 Litre air cooled V8
- T613 1974-1996 - 3.5 Litre air cooled V8
- T700 1996-1999 - 3.5 or 4.4 Litre air cooled V8
- T815 1983-now - 12.7 Litre air cooled V8

French V8 engines



Prototype V8 engine for the Peugeot 802

The French De Dion-Bouton motorcar firm was first to produce a V8 engine for sale in 1910. Later examples came from Citroën, with the never produced 1934 22CV *Traction Avant*, and Simca. Peugeot's upcoming 608 and its Citroën C6 stablemate may have a new HDi 4.0–5.0 L (240–310 cu in) V8 as well as a possible petrol 3.6 and 4.4 L (220 and 270 cu in) V8. The "PRV" (Peugeot, Renault, Volvo) V6 was actually supposed to be a V8, but two cylinders were "dropped" because of the oil crisis of the 1970s. Gordini also developed a 3 L V8 for the Alpine A310, but a Renault 4-cylinder block was mounted instead because of cost issues.

German V8 engines



BMW S65 4.0L V8 Engine

German V8s (by manufacturer and date)

- Audi
 - 1988–present V8 engine
- BMW
 - OHV V8 1954-1965
 - M60 1992-1995

- M62 1994-2005
 - S62 1998-2003
 - N62 2002–present
 - S65 2007–present
 - M67 1998–present
- Horch
 - 830, 930 1933-1940



Mercedes-Benz M156 AMG 6.3L V8 DOHC Engine

- Mercedes-Benz
 - 1965-1979 M100
 - 1971-1991 M117
 - 1981-1991 M116
 - 1990-1999 M119
 - 1999–present M113
 - 2004–present M155
 - 2006–present M273
 - 2006–present M156
 - OM402 Diesel

- OM422 Diesel
- Porsche
 - Porsche 928 1978–1995
 - Porsche Cayenne 2002–present
 - Porsche Panamera 2009–present
- Stoewer
 - Greif V8 1934-1937

Italian V8 engines

Alfa Romeo

The Alfa Romeo Montreal was powered by a dry sump 2,593 cc (158.2 cu in) 90° quad-cam 16-valve V8 (type 00564) derived from the Tipo 33 race car. Because of the limited space available for the cross-plane crankshaft, the physically small but heavy crank counterweights were made of a sintered tungsten alloy called turconit. The Montreal V8 was rated at 230 horsepower (170 kW) at the flywheel and weighed 162 kg (360 lb). There were also eighteen 33 Stradale cars built with a detuned 1,995 cc 260 hp (190 kW) Tipo 33/2 flat-crank engine. The Montreal cross-crank engine was also used in a very limited production run of 22 Alfetta GTV2.6i. The Alfa Romeo 8C Competizione sports car has a Ferrari-built 4,691 cc (286.3 cu in) 450 PS (330 kW; 440 hp) cross-crank V8.

Ferrari



Ferrari V8, 4,300cc

Arguably, Ferrari had their first contact with V8 power with the "inherited" Lancia D50s in 1955. Ferrari adopted the V8 configuration for themselves for racing in 1962 with the 268 SP. The first V8-powered Ferrari road car was 1974's 308 GT4, with the familiar 308 GTB following closely behind. The company continued to use this *Dino* V8 engine ever since with the 328, 348, and successors. Ferrari's smallest V8 (and indeed, the smallest ever) was the 2.0 L (1990 cc) unit found in the 1975 208 GT4. The company produced a slightly-larger 2.0 L V8 in the 208 GTB and the 2.9 L Ferrari F40 of the 1980s. Five-valve versions of Ferrari's 3.5 L and 3.6 L V8s were found in the Ferrari F355 and Ferrari 360. The old *Dino* V8 was retired for 2004 with the introduction of a 4.3 L V8, based on the originally Ferrari designed Maserati 4.2 V8, in the F430. And F430's successor, 458 Italia, with 4.5 V8.

Fiat

The only Fiat to have a V8 was the Fiat 8V. The engine was a very compact OHV 1996 cc (122 CID) V8 with a 70° V angle and 2 valves per cylinder. The Fiat 8V was designed to participate in the Italian two-litre racing class.

Lamborghini

Lamborghini have always fitted V12s in their top-of-the-line cars, but have built many V8s for their lower models, including the Urraco, Silhouette and Jalpa.

Lancia

Lancia used V8 engines in their top of the range luxury cars in the interwar period. The first V8 engine was available in 1922 in the Trikappa with a 4595 cc (280 CID) making 98 bhp (73 kW). In 1928 they introduced the Dilambda with a 3956 cc (242 CID) V8 developing 100 bhp (75 kW). Later in 1931 the Astura was unveiled with two smaller versions of the existing V8, 2604 cc (159 CID) and 2973 cc (181 CID) with 72 bhp (54 kW) and 82 bhp (61 kW) respectively. All of those engines featured Lancia's trademark narrow angle V (less than 25°). In the 1990s, Lancia Thema had 3 L V8.

Maserati

Maserati have used V8s for many of their models, including the Maserati Bora and the Maserati Khamsin. This engine was initially designed as a racing engine for the Maserati 450S. The company's latest 4.2 V8, found in the Maserati Quattroporte and Maserati Coupé & Spyder was originally designed by Ferrari, and is related to the 4.2l V8 in the F430.

Japanese V8 engines

Japanese manufacturers are traditionally not known for V8 engines in their roadcars. However, they have built a few V8 engines to meet the needs of consumers, as well as for their own racing programs.

Honda

Honda has never built a V8 for passenger vehicles. In the late 1990s, the company resisted considerable pressure from its American dealers for a V8 engine (which would have seen use in top-of-the-line Honda SUVs and Acuras), with American Honda reportedly sending one dealer a shipment of V8 beverages to silence them.

However, Honda has built V8s for racing, most notably for Formula One. Honda is also the sole engine builder for Indy Racing. The Honda Indy V-8 has a 10,300 rpm redline. Also, their affiliate Mugen Motorsports (now known as M-Tec) has built racing V8s that eventually found their way into limited production road cars as well as concept cars. Their MF408S engine, which powers cars in the ALMS, is also found in prototype racers such as the Mooncraft Shiden. It is also known for being the engine in the Honda Legend based Honda Max concept.

Mitsubishi

In 1999, Mitsubishi Motors developed an alloy-headed 4.5 L V8, dubbed the 8A8, with double overhead camshafts and gasoline direct injection (GDI) technology for use in its Proudia and Dignity models. Financial pressures forced the company to discontinue sales of both these vehicles after only fifteen months

Nissan



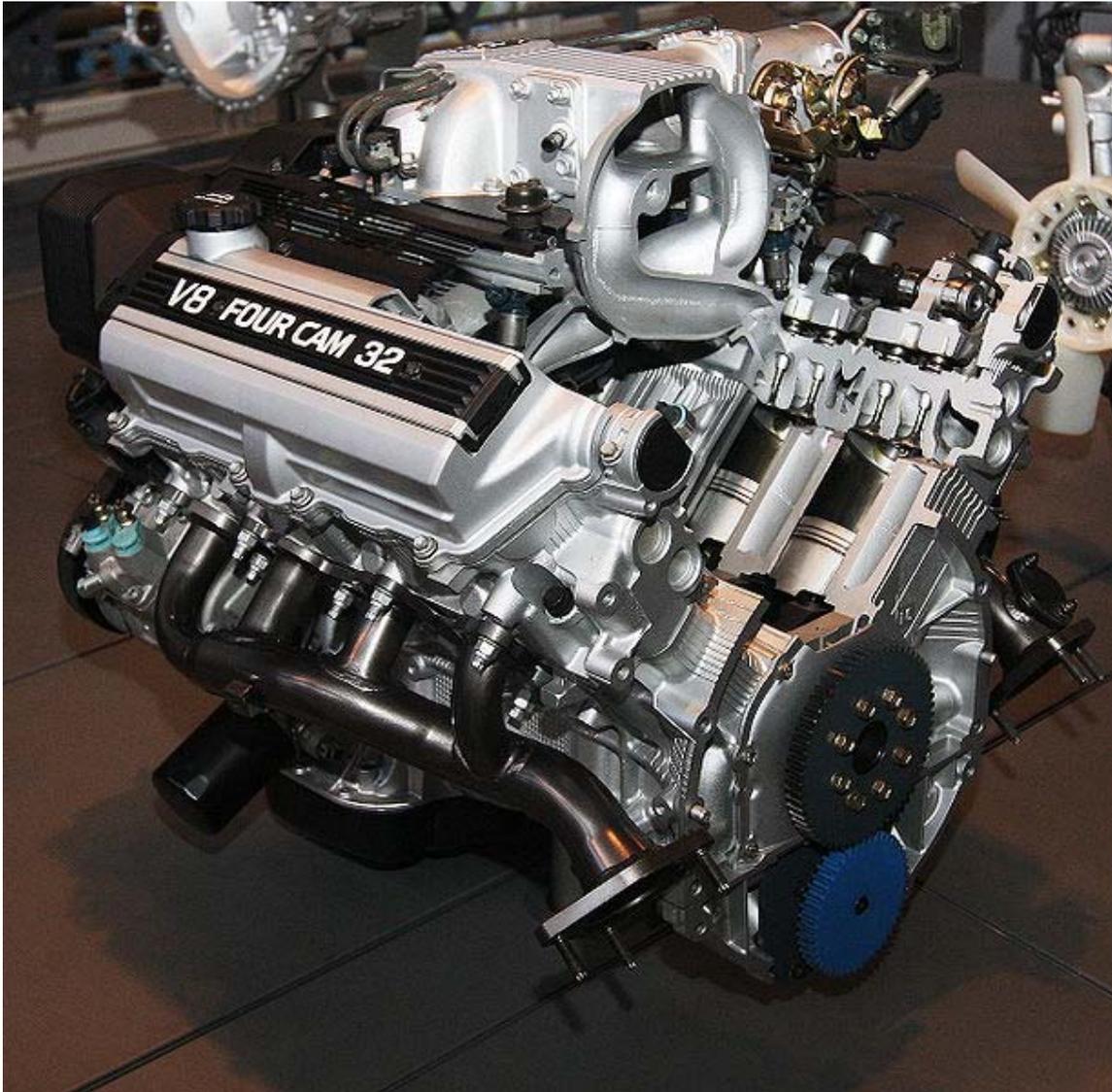
2008 Nissan VK50VE engine. V8 5,026cc

Nissan built its first V8, the Y40, in 1965 for its President limousine. The Y engine has been succeeded by two families of V8, the VH series during the 1980s and 1990s and the new VK series.

- VK engine
- VH engine

- Y engine

Toyota



1989 Toyota 1UZ-FE Type engine. V8 3,968cc.

Toyota's first V8 engine family was the V series used in the Toyota Century luxury car. This engine remained in use in the Century until it was replaced by a V12 in 1997. Other Toyota V8 families are the UZ engines and the new UR engines.

- UR engine
- UZ engine

- V engine

Yamaha



1989 Yamaha OX88 engine

While better known as a manufacturer of motorcycles, Yamaha also makes engines under contract from auto-manufacturers. They currently produce a V8 engine in conjunction with Volvo Cars for vehicles such as the Volvo XC90 and the Volvo S80.

Swedish V8 engines



2005 Volvo (Yamaha) V8 engine for Volvo XC90. V8 4,414cc

The most well-known Swedish V8 engine is probably the Scania AB 14 L (854 cu in) diesel, which was released in 1969 for use in the 140 model heavy trucks. At this point, the 350 hp (261 kW) turbo-charged engine was the most powerful diesel in Europe. Scania has continued using a V8 as its largest displacement engine. Currently a series of 16 L (976 cu in) diesel engines is available in several versions with power ranging between 500 hp (373 kW) — 730 hp (544 kW) in the truck segment and going as high as 900 hp (671 kW) in the marine engines segment. Emission norms range between Euro 3-Euro 5 depending on which market the vehicle is sold to.

Volvo's 1950s concept car Philip also had a gasoline V8 engine. The car never went into production, but the engine evolved into a 120 hp 3.6 L V8 (in many aspects a "double B18" engine) for use in the light trucks Volvo Snabbe and Volvo Trygge from the late 1950s on.

Supercar manufacturer Koenigsegg has developed a 4.7 L (~287 cu in) twin-supercharged V8 loosely based on the Ford Modular engine. This engine is unique in that it is a flexible fuel engine and produces more power while running on biofuel than on regular unleaded.

Russian V8 engines

ZIS, ZIL

For the ZIL-111 (1959), an all-new aluminium 6 L OHV V8 was developed, initially it produced 200 hp (149 kW) at 4200 rpm.

ZIL-114 (1967) was powered by a 6,960 cc (425 cu in) V8 giving 300 hp (224 kW) at 4400 rpm. Its more modern derivative model, the ZIL-41047, is powered by a ZIL-4104 engine, a 7680 cc carburetted V8 giving 315 hp (235 kW) at 4600 rpm.

The ZIL trucks used (and still use) a modification of this engine (cast-iron block, aluminum heads, 6L, 150 hp (112 kW) at 3200 rpm, 6.5:1 compression rate, one 2-bbl carburetor).

GAZ (ZMZ)



GAZ-24-34 Volga with ZMZ-503 V8 engine, 1992-built car.

Several cars produced under the Volga brand name; the GAZ-23 (1962–1970), the GAZ-24-24 V8 (1974–1992), the GAZ-31013 V8 (1982–1996), as well as both generations of the GAZ Chaika limousines (1959–1982 and 1976–1988) were powered by an all-aluminum OHV 5.5L V8. These engines were designated: ZMZ-13 (Chaika GAZ-13, one 4-bbl carburetor), ZMZ-14 (Chaika GAZ-14, two 4-bbl carburetors), ZMZ-2424 (Volga GAZ-24-24), ZMZ-505 (two 4-bbl carburetors) and -503 (one 4-bbl carburetor) (GAZ-24-34, GAZ-31013). Power output varied from 195–220 hp (145–160 kW). A modification of the same engine was also used in the BRDM-2 military armored vehicle, designated ZMZ-41.

The GAZ-53 was powered by a 4254 cc ZMZ-53 engine, which substantially was a modification of the Chayka's engine with one 2-bbl carburetor and decreased displacement and compression rate. More modern version of the GAZ engine for intermediate trucks is designated ZMZ-511.

Spanish V8 engines

Spanish truck and sportscar company Pegaso made around 100 cars in the 1950s and 1960s. There were two types of engines; the Z-102 and the Z-103/4 engines.

The Z-102 first introduced in 1951 engine was an advanced design sporting quadruple camshafts (two per bank) and had 2 valves per cylinder. It was available with 1, 2 or 4 twin Weber carburetors and either normally aspirated or with one or two superchargers. It had three different capacities, 2472 cc (151 CID), 2816 cc (172 CID) and 3178 cc (194 CID) and made between 165 bhp (123 kW) and 360 bhp (270 kW).

The Z-103/4 developed in the mid/late 1950s (the first prototype was made in 1954) was a much simpler design destined to power a new series of luxury and sportscars. It had a single central camshaft and 2 valves per cylinder actuated by pushrods. It had hemispherical combustion chambers (like the Z-102 engine) and twin spark plugs. It was available with three different cubic capacities as well, 3900 cc (238 CID), 4500 cc (275 CID) and 4700 cc (287 CID). The 3.9 L engine had a twin Weber carburetor and the 4.5 and 4.7 L engines 2 quadruple Weber carbs, which gave the later a power output in excess of 300 bhp (220 kW). The very few engines of this type produced were installed in Z-102 cars.

Australian V8 engines

Holden, including its performance vehicle operations Holden Racing Team and Holden Special Vehicles, have been manufacturing V8 performance vehicles since the late 1960s, as has Ford Australia. The performance arm of Ford Australia, Ford Performance Vehicles (FPV), have recently resurged in the market with the new Falcon BA and BF based models, and the brand new FG series.

The Australian V8 is typically an American-manufactured block from either Ford, Chrysler or General Motors yet often uses local heads and auxiliary systems (pistons, exhaust etc.). However, there are a couple of exceptions to this — the Holden V8 engine small block V8, and the British Leyland alloy small-block V8.

The Holden small-block V8 was an all Australian designed and manufactured cast-iron 90° pushrod OHV engine, manufactured in the capacities of 4.2 L (253 CID), 5.0 L (308 CID), later destroked to 304 CID), and 5.7 L (348 CID — never actually built as a 'production' motor). First introduced in 1969, finally ceasing production in 1999, it powered a variety of Holden vehicles including the Kingswood, Monaro, Torana and Commodore, and proved to be a popular and successful powerplant in Australian motorsport (especially Touring cars).

The British Leyland small block V8 was also a pushrod OHV engine, however it was an all alloy block like the British Rover V8 it was based on. The stroke was increased to give it a capacity of 4.4 L (270 cu in). The motor was originally designed and fitted to the Leyland P76 sedan.

Currently, the only V8 produced in Australia is the 5.4l V8 built by FPV (Ford Performance Vehicles) to power the Falcon GT — this motor is a combination of US-sourced and locally manufactured parts. The V8 used in current Holdens is sourced complete from GM in Canada, modified versions of the GM LS-series engine.

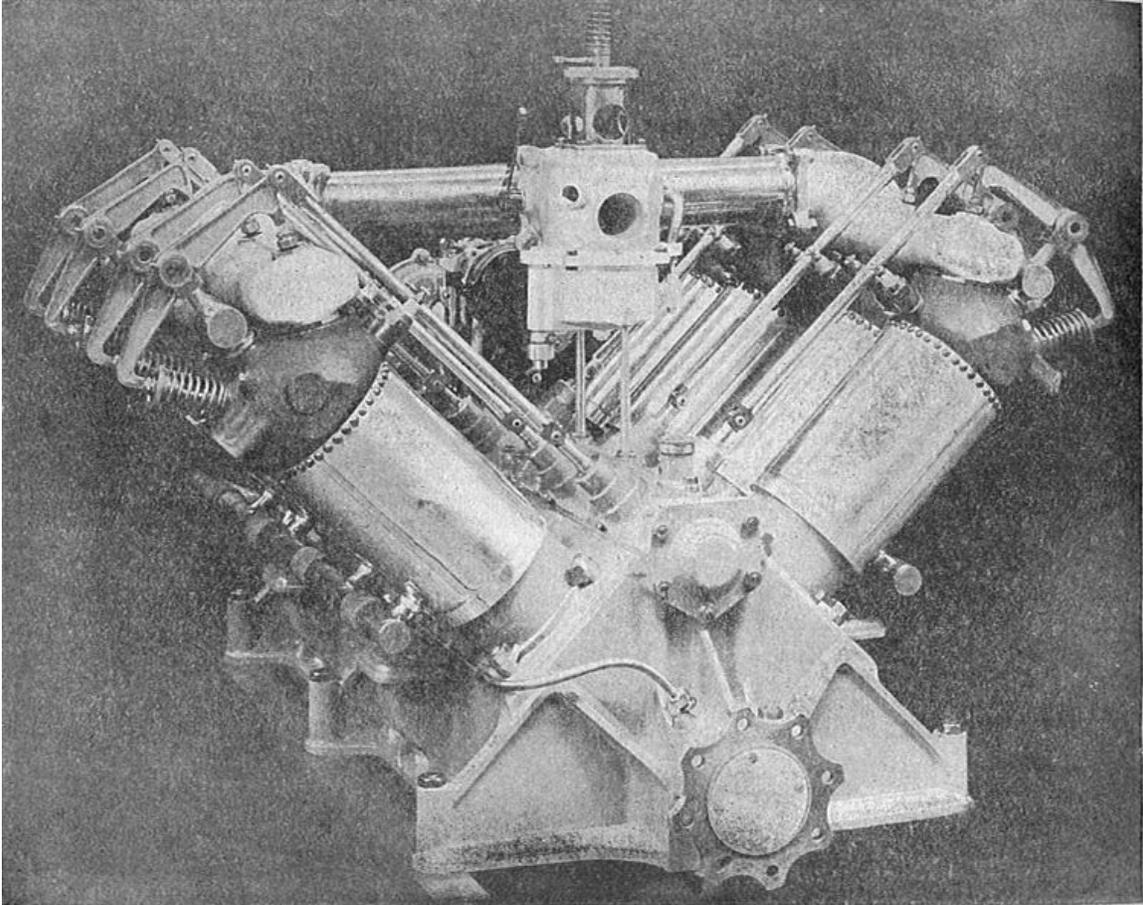
When U.S. production of the Cleveland V8 range ceased in the early seventies, the tooling was moved to Australia where Ford Australia continued to produce a local version of the 351 and a unique-to-Australia 302 Cleveland. The Australian-built motors were also sold to De Tomaso to be used in the Pantera and Longchamps. Australian production ceased in 1982, with the last Cleveland-powered Falcon being the XE range (1400-odd 302s and 409 351s). The location of the Cleveland tooling is unknown although it was possibly broken up.

Korean V8 engines

- Hyundai
 - D8 - 16/18 L-Diesel
 - Omega - 4.5 L (~275 cu in)
 - Tau - 4.6 L (~281 cu in)

Other V8 applications

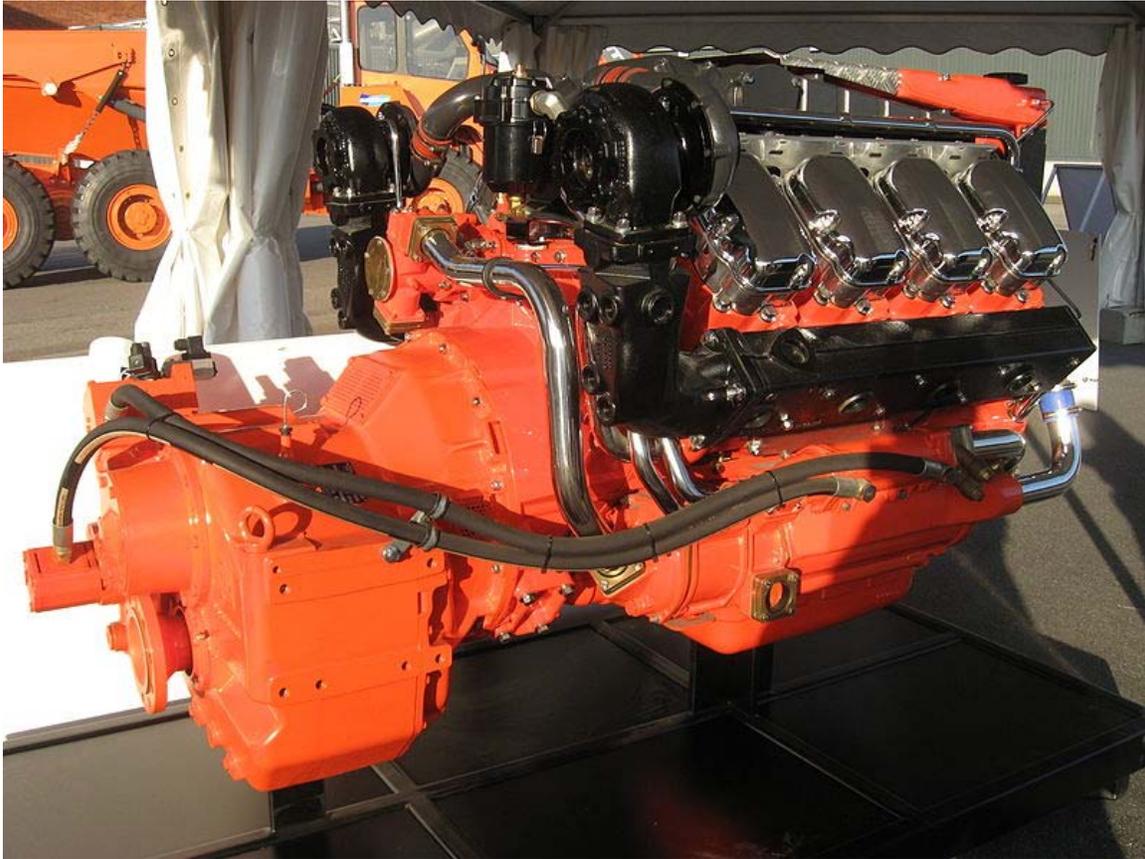
In aviation



1905 Wolseley 120 hp V8 aero engine

- Argus As 10 inverted, air-cooled German V8 engine of World War II.
- Hispano-Suiza 8 of World War I V8.
- Liberty L-8 of World War I, 45° V8 (a prototype for the Liberty L-12).
- Renault of WW1, 240 hp (180 kW) V8
- Trace Engines Turbocharged V8.

Ship's engines

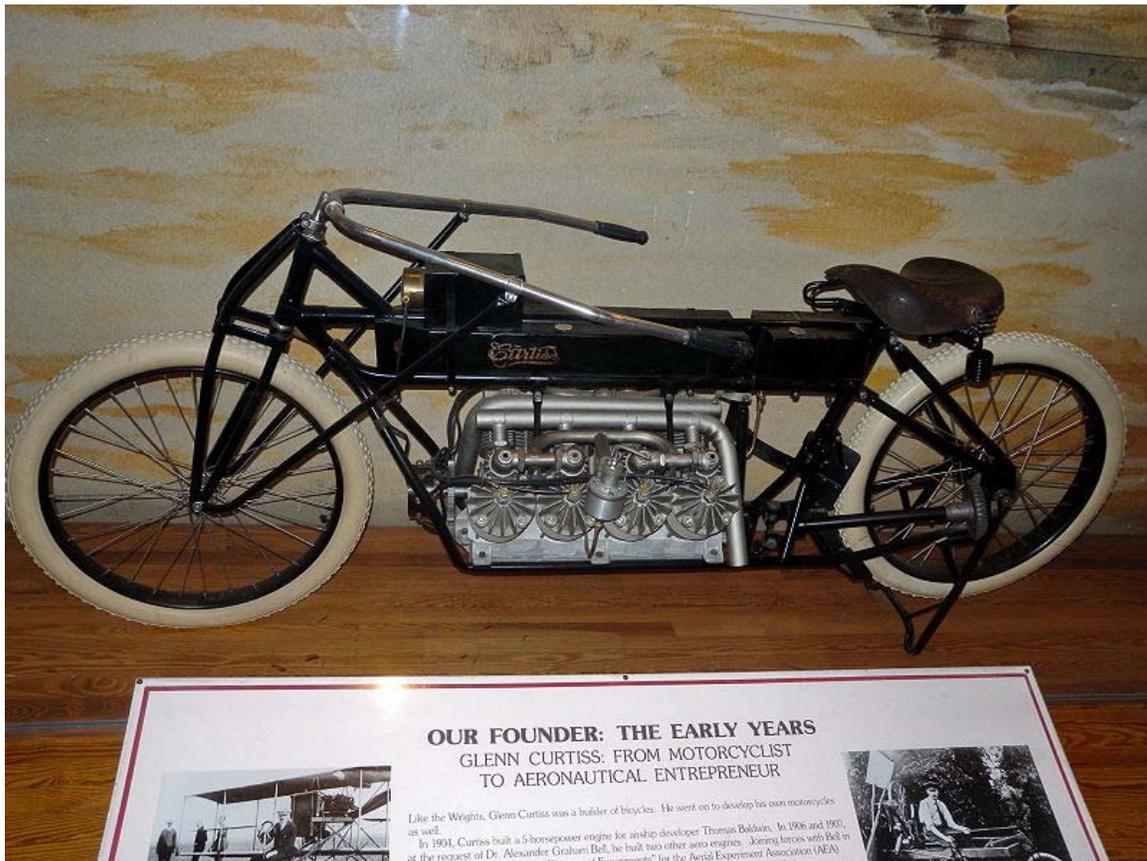


Scania V8, 16 litre marine engine with reverse.

There are numerous marine diesel engines of V8 configuration.

- Brons V8 two-stroke diesel engine.
- Scania
- Yanmar

In motorcycles



V8 Motorcycle of Glenn Curtiss. In 1907, Curtiss set an unofficial world record of 136.36 mph (219.45 km/h) on this 40 hp (30 kW), 4,000 cc V8 powered motorcycle of his own design and construction

Moto Guzzi of Italy built a 148 kg (330 lb) 82 bhp (61 kW) water cooled DOHC V8 4-stroke motorcycle for Grand Prix racing between 1955 and 1957, referred to as the Moto Guzzi Grand Prix 500 cc V8. It was known as the *Otto Cilindri*, and had a very high power output but was not developed to its full potential. Each cylinder had its own carburettor.

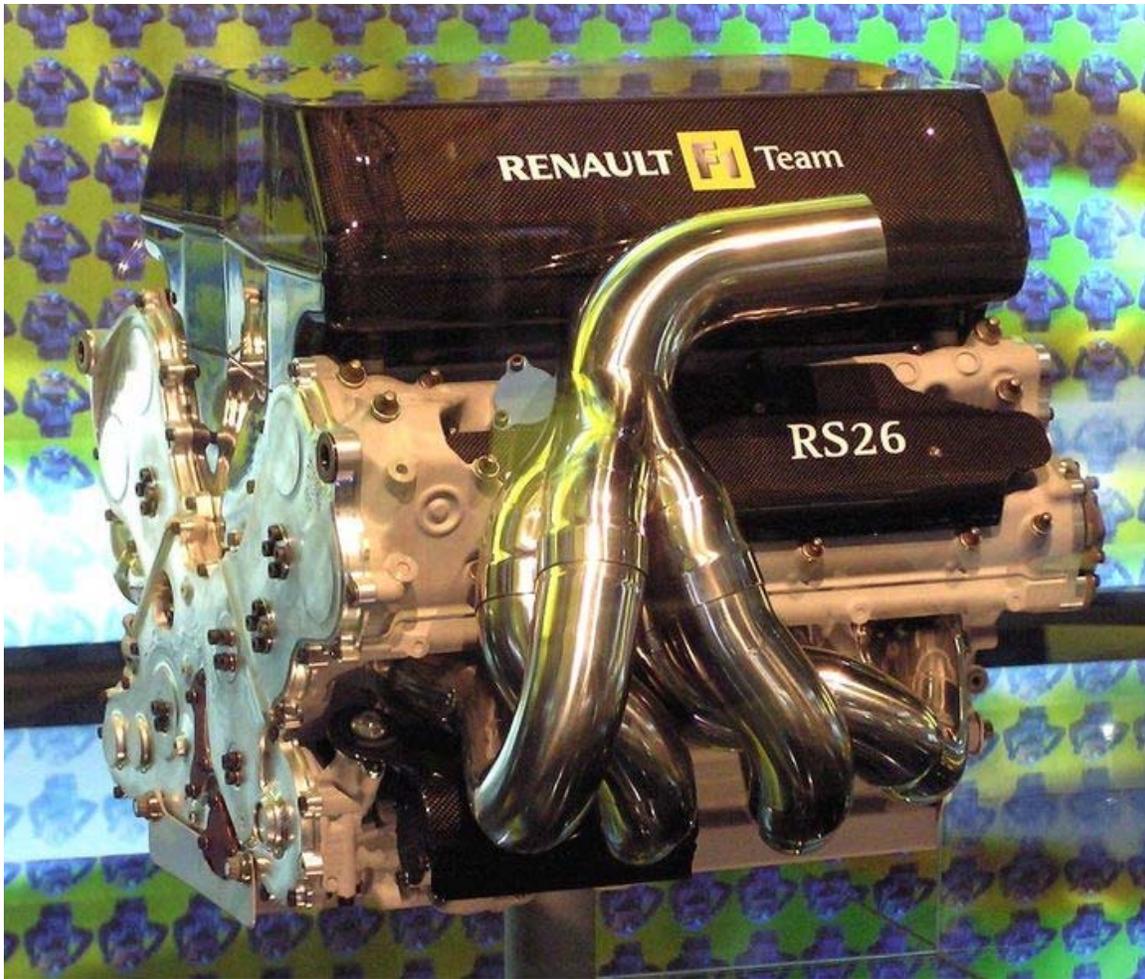
Morbidelli produced an 848 cc V8 in 1994. Earlier, Galbusera had produced a two-stroke V8 in 1938.

Honda released the NR750 in 1992. The bike had a 750 cc V4 with oval pistons, utilising 8 valves per cylinder and 2 conrods per piston; the design allowed the engine to meet FIM racing regulations limiting the number of cylinders to 4, while providing the valve area (and therefore increased efficiency) of a V8.

In motorsport



A 2004 Cosworth Champ Car World Series V-8 engine, capable of generating over 800 horsepower from just 161 cu./in



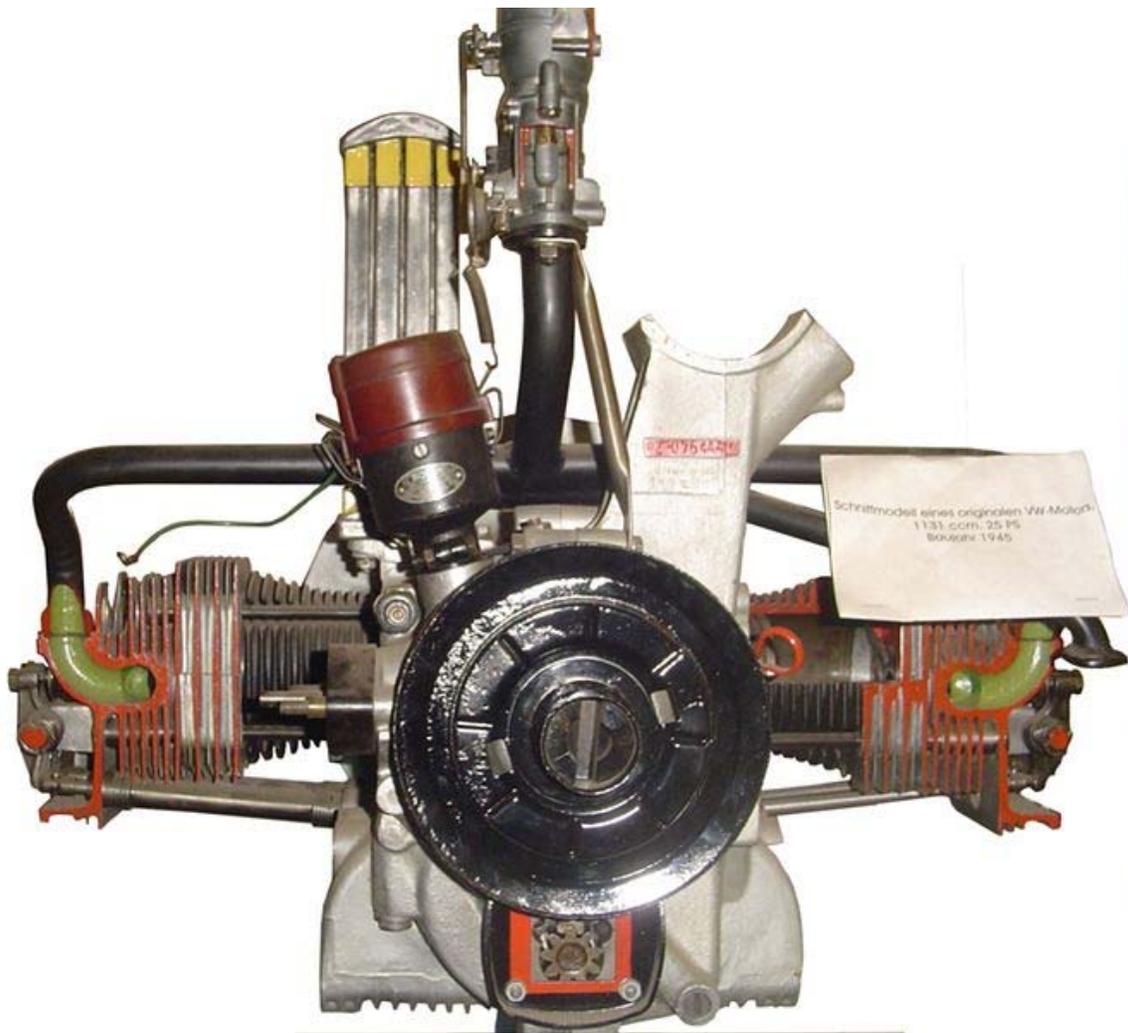
Renault F1 RS26 (2006), 2,398cc V8 engine

Up until recently, Formula One cars used 3 L V10 engines. However, the FIA considered speeds were getting too high to be safe (even with the banning of turbochargers in 1989, which allowed engines to develop 1,300 bhp (970 kW), 1,000 bhp (750 kW) from a naturally-aspirated engine was not impossible by 2005, and with better aerodynamics, cars were shattering straight-line speed records.) So, the permitted engine size was cut to 2.4 L V8 (This reduced average power output of the engines from 900 bhp (670 kW), in the 2005 season, to a 2006 season average of 750 bhp (560 kW) — equivalent to power outputs that were being achieved on 3 L around the 1999/2000 seasons.) This also had the effect of reducing overall costs for the teams, an aim which is currently being vigorously pursued by FIA.

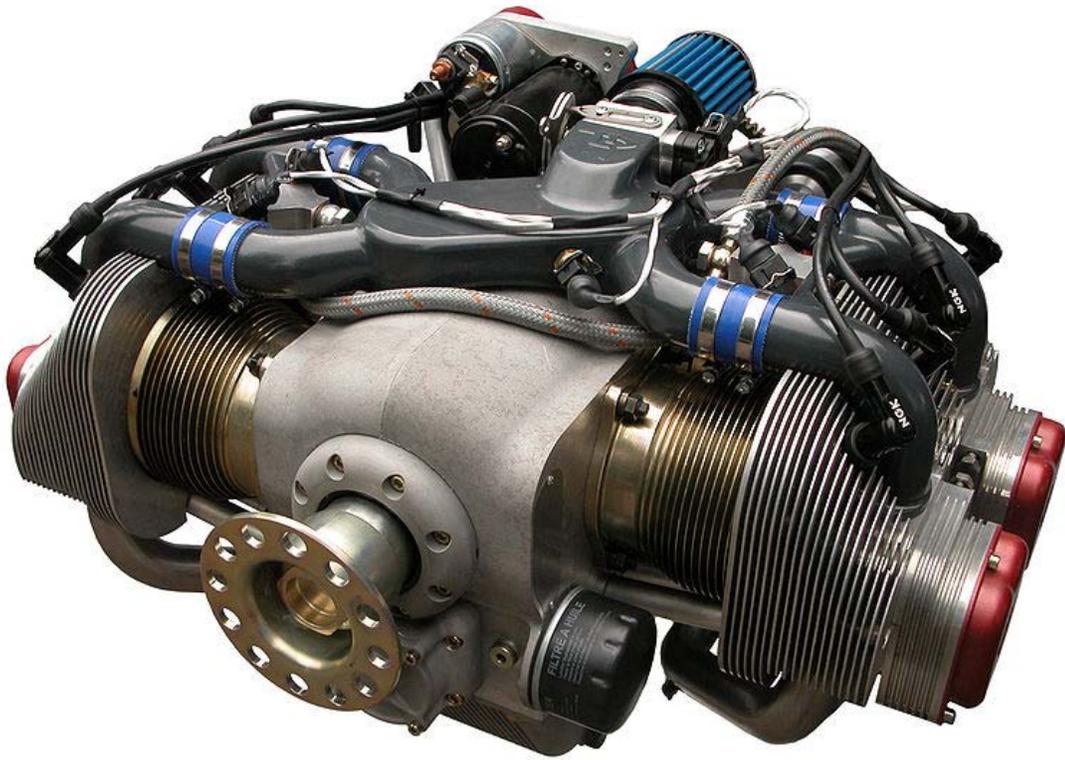
In the 'Top Fuel' class of Drag Racing, V8 engines displacing 8.2 L or 500 in³ produce up to 8,000 horsepower (6,000 kW). Based on the Chrysler Hemi and running on highly explosive Nitro-Methane fuel, these powerful units propel the cars from 0-100 mph in 0.8 seconds or less, and from 0-325 mph (0-523 km/h) in under 4.5 seconds. During the race the crankshaft in the engine will turn over less than 1000 times and may then have to be rebuilt.

Chapter- 5

Flat-Four Engine



VW Beetle engine, one of the most prominent flat fours



Flat-4 aircraft engine

A **flat-4** or **horizontally-opposed-4** is a flat engine with four cylinders arranged horizontally in two banks of two cylinders on each side of a central crankcase. The pistons are usually mounted on the crankshaft such that opposing pistons move back and forth in opposite directions at the same time, somewhat like a boxing competitor punching their gloves together before a fight, which has led to it being referred to as a **boxer** engine.

The configuration results in inherently good balance of the reciprocating parts, a low centre of gravity, and a very short engine length. The layout also lends itself to efficient air cooling. However, it is an expensive design to manufacture, and somewhat too wide for compact automobile engine compartments, which makes it more suitable for cruising motorcycles and aircraft than ordinary passenger cars.

This is no longer a common configuration, but some brands of automobile use such engines and it is a common configuration for smaller aircraft engines such as made by Lycoming or Continental. Although they are somewhat superior to straight-4s in terms of vibrations, they have largely fallen out of favor because they have two cylinder banks thus requiring twice as many camshafts as a straight-4 (if an OHC rather than OHV or F-head configuration is used) while the crankshaft is as complex to manufacture. The low centre of gravity of the engine is an advantage. The shape of the engine suits it better for

mid engine or rear engine designs. With a rear engine layout it allows a low-tail body while in front engine designs the width of the engine interferes with the ability of the front wheels to steer. The latter problem has not stopped Subaru from using it in its all-wheel drive cars, where the difficulty of fitting the short engine between the front wheels ahead of the front axle is compensated for by the ease of locating the transmission and four-wheel drive mechanisms behind it, between the front and rear axles.

The open and exposed design of the engine allows air cooling as well as water cooling, and in air cooled applications fins are often cast into the external cylinder block walls to improve the engine cooling.

Balance and smoothness

Boxer engines are better balanced than other engine types in 4 cylinder configurations. The more common inline-4 configuration suffers from an engine balance problem caused by the fact that the pistons travel faster on the top half of the crankshaft rotation than the bottom half, which causes the engine to vibrate up and down twice per crankshaft revolution. This problem becomes worse with increased engine size and power so inline-4s larger than 2.0 L usually have balance shafts and ones over 3.0 L are seldom used in passenger cars. However, the flat-4 does have a less serious secondary imbalance that causes it to rotate back and forth around a vertical axis twice per crankshaft revolution. This is because the cylinders cannot be directly opposed, but must be offset somewhat so the piston connecting rods can be on separate crank pins, which results in the forces being slightly off-centre. The vibration is usually not serious enough to require balance shafts.

In addition, four-stroke cycle flat-4s have a problem common to all four-cylinder engines: the power strokes do not overlap. With a piston starting its power strokes every 180 degrees of crankshaft rotation, and the crank throws 180 degrees apart, all the pistons must come to complete stop and reverse before the next one can start its power stroke. This results in a gap between power strokes and a pulsating delivery of power to the flywheel. By contrast, in engines with more cylinders the power strokes overlap: the next piston starts its power stroke before the previous one has finished, and the delivery of power is much smoother.

As a result of the relatively high manufacturing costs of the flat-4 compared to the inline-4, most manufacturers now choose the inline-4 engine for economy models and have moved to inline-5 or V6 engines for models requiring more power. These engines also suffer from dynamic imbalance problems, but with modern computer-aided design techniques, the problems can be overcome with a variety of complex crankshaft, balance shaft, and engine mounting designs. Luxury performance car manufacturers prefer to use the inline-6, flat-6, or V8 configurations because these designs are in intrinsic primary and secondary balance and thus are much smoother than the flat-4, particularly at high power outputs.

Automobile use

Tatra introduced an air-cooled flat four engine in the 1926 Tatra 30, followed by the T52 of 1930, T54 of 1931, T57 in 1931, and T75 in 1933, all with air-cooled flat fours of varying displacement. The 1936 T97 model pioneered the rear-engined, air-cooled flat-four, backbone chassis layout, later copied by the Volkswagen KdF-Wagen.

Jowetts before the Second World War were best known for their flat twin engines, but they made a flat four for the Jason and 10 hp models in the 1930s. Post-war Gerald Palmer designed Javelin saloon and Jupiter sports models used a totally different design of flat four. Alec Issigonis originally designed the Morris Minor for a flat four, but cost constraints meant it was never used.



Flat-4 engine in a 1955 Porsche 550 Spyder

Volkswagen used air-cooled flat-4s extensively in their early days, in the VW Beetle and most early VW designs. Porsche also used the VW engine in the early Porsche 356. This engine was replaced by a Porsche designed flat-4 in the late 356s and the 912. The 914 that replaced the 912 was built in partnership with VW using a VW engine.

The Goliath 1100 appeared at the Geneva Motor Show in March 1957, with a water-cooled 1100 cc flat four driving the front wheels. In 1958 the name was changed to the Hansa 1100, and this car was produced through 1961.

VW used a water-cooled flat-4 Wasserboxer in the later third-generation Type 2 until 1991.

Citroën used an air-cooled flat-4 on the Ami Super, GS, GSA and Axel.

Water-cooled Alfa Romeo flat-4 was introduced in 1971 on the Alfa Romeo Alfasud. That engine was later used on the Alfa Romeo Arna, the Alfa Romeo 33, the Alfa Romeo Sprint and the Alfa Romeo 145/146.

Lancia used a water-cooled flat-4 on the Lancia Flavia and high-end Lancia Gamma.

Subaru produces a water-cooled front mounted flat-4 engine marketed as H-4, by which they mean **H**orizontal rather than the H cross-section normally meant by H engine. Subaru has created a number of engines, starting with the EA series introduced in 1966, progressing towards the currently used EJ series, which is wide but very short and light, and is mounted ahead of the front axle with the transmission behind. With this layout, the gearbox can remain very similar in design and weight without the need for a bulky and inefficient transfer case. Although it is more expensive than a straight-4, it allows Subaru to build an all wheel drive vehicle at little extra cost over two wheel drive.

Motorcycle use



Honda GL1000 flat-four engine

- Honda introduced a liquid cooled shaft drive flat-4 on a production motorcycle in 1975 on the Honda GL1000 Gold Wing.
- From 1938 to 1939 Zündapp produced the shaft drive K800 opposed four in Germany.

- In 1955 in Britain Wooler produced a small number of 500cc flat opposed fours with shaft drive.
- The BFG-Citroën of 1982 was powered by a flat-4 1,299cc Citroën automobile engine and shaft drive. About 450 of them were built in 1981 and 1982. One-quarter of them were purchased by the French police.

Aircraft use

Lycoming manufactures a very successful series of flat-4 aircraft engines ranging up to 360 cu in (5.9 L), as used in many smaller Cessna and other general aviation aircraft. Similar engines are produced by Continental Motors, Franklin Engine Company, and others. Retired aircraft engines power many shallow draft boats in the Florida Everglades.

The OS Engines company in Japan has made miniature, air-cooled flat-4 engines in 40 cc and 52 cc sizes for radio-controlled aircraft hobby use, with the 52 cc "FF-320" engine currently in production.