THEORY AND DESIGN OF AUTOMOTIVE ENGINES

Syllabus

I Introduction

1 General - Historical development of automobiles, Types of power plant, Principle of engine operation, Classification of engines.

2. Two stroke & four stroke engines; Principles of engine operation (SI & CI), Scavenging - systems, theoretical processes, parameters, relative merits & demerits; Port timing diagrams, port design. Relative merits & demerits compared to petrol & diesel engines, scavenging pumps.

II Engine components –

Classification/types, function, materials, construction details, design and manufacturing processes of the following engine components

3. Cylinders and liners - design, cylinder wear and corrosion, details of water jacket, dry and wet liners, Cylinder head - design;
4. Piston, piston rings, piston pin - design - stress analysis, methods of manufacture, compensation of thermal expansion in pistons, heat treatment, piston ring selection, limits of fit for pins
5. Connecting rod - design, effects of whipping, bearing materials, lubrication
6. Crank shaft - design, firing order, balancing and torsional vibration analysis, vibration dampers, bearings,. Lubrication
7. Flywheel - design; Camshaft - drives of cams, materials, Types (only descriptive)
8. Valve and valve mechanism - design, types of valve operating mechanisms, valve springs, guides, push rods, rocker arms, tappets, valve timing diagrams
9. Crank Case- Design of crank case, oil sumps and cooling features
10. Manifolds-construction and design of inlet and exhaust manifolds.

TEXT BOOKS:

I. High Speed Engines - P .M.Heldt, Oxford & IBH , 1965

2. Auto Design - R.B Gupta, Satya Prakashan, New Delhi 1999

REFERENCE BOOKS:

I.A course in I.c. Engine - Mathur & Sharma, Dhanput Rai & Sons, Delhi, 1994

2.Automobile Engineering VoU & II - Kirpal Singh, Standard publications, New Delhi, 1972

3. Modem Petrol Engine ~ A.W.Judge, B.I. Publications. 1983

4. I.c. Engine - Maleev &Litchy, McGrawHill

5. I.C.Engines - H.B.Keshwani, Standard Pub New Delhi., 1982

6. Fundamentals of I.C.Engines - J.B.Heywood

7. Machine design exercises - S.N.Trikha, Khanna publications, Delhi

8. Automotive mechanics - N.K.Giri, Khanna publications,Delhi

9. Automotive mechanics - William H. Crouse, Tata Mc,Graw Hill Publications Co. New Delhi

10. I.C.Engines and Air Pollution - B.P.Obel'rlntext harper & Roni Pub, New york)

Scheme of Examination (AU511)

Answer any FIVE questions out of EIGHT questions.

Chapter No.	1 &2	3	4	5	6	7	8, 9&10
Question	2	I	I	I	I	I	I

CHAPTER - 1

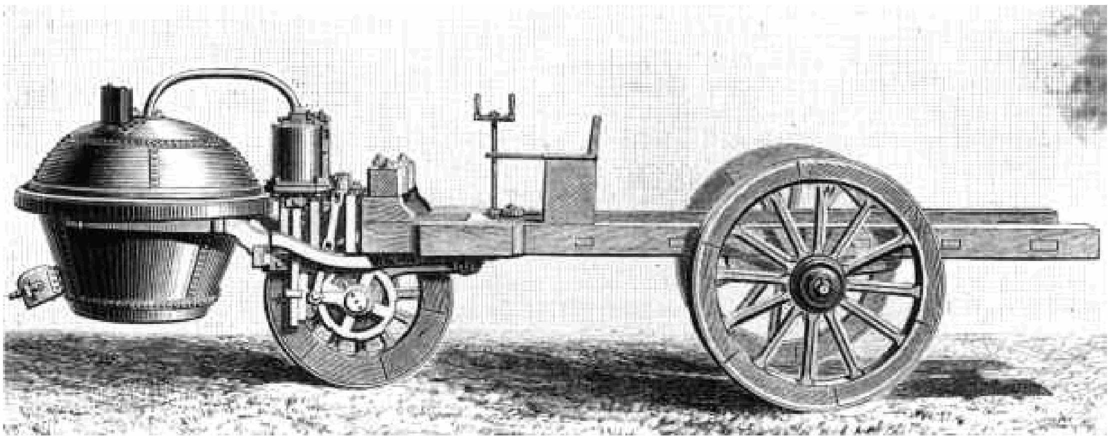
HISTORY

Automobiles through the Years - Since they originated in the late 1800s, automobiles have changed and developed in response to consumer wishes, economic conditions, and advancing technology. The first gas-powered vehicles looked like horse buggies with engines mounted underneath because this was the style to which people were accustomed. By 1910, however, features like the front-mounted engine were already established, giving the automobile a look that was all its own. As public demand for cars increased, the vehicles became more stylized. The classic cars of the 1920s and 1930s epitomize the sleek, individually designed luxury cars called the "classic cars." During the 1940s and 1950s, automobiles generally became larger until the advent of the "compact" car, which immediately became a popular alternative. The gasoline crisis is reflected in the fuel efficient cars made in the 1970s and 1980s. Current designs continue to reflect economy awareness, although many different markets exist.

The history of the automobile actually began about 4,000 years ago when the first wheel was used for transportation in India.

In the early 15th century the Portuguese arrived in China and the interaction of the two cultures led to a variety of new technologies, including the creation of a wheel that turned under its own power.
By the 1600s small steam-powered engine models had been developed, but it was another century before a full-sized engine-powered vehicle was created.

In 1769 French Army officer Captain Nicolas-Joseph Cugnot built what has been called the first automobile. Cugnot's three-wheeled, steam-powered vehicle carried four persons. Designed to move artillery pieces, it had a top speed of a little more than 3.2 km/h (2 mph) and had to stop every 20 minutes to build up a fresh head of steam.



Cugnot Steam Tractor
-the first self-propelled road vehicle, thus, the earliest automobile. Powered by steam, the three-wheeled tractor- invented in 1769 by Nicolas-Joseph Cugnot. designed to carry artillery, but similar vehicles soon found many other uses in industry.

As early as 1801, successful but very heavy steam automobiles were introduced in England. Laws barred them from public roads and forced their owners to run them like trains on private tracks.
In 1802 a steam-powered coach designed by British engineer Richard Trevithick journeyed more than 160 km (100 mi) from Cornwall to London. Steam power caught the attention of other vehicle builders.
In 1804 American inventor Oliver Evans built a steam-powered vehicle in Chicago, Illinois. French engineer Onésiphore Pecqueur built one in 1828.

British inventor Walter Handcock built a series of steam carriages in the mid-1830s that were used for the first omnibus service in London.

By the mid-1800s England had an extensive network of steam coach lines. Horse-drawn stagecoach companies and the new railroad companies pressured the British Parliament to approve heavy tolls on steam-powered road vehicles. The tolls quickly drove the steam coach operators out of business.

During the early 20th century steam cars were popular in the United States. Most famous was the Stanley Steamer, built by American twin brothers Freelan and Francis Stanley. A Stanley Steamer established a world land speed record in 1906 of 205.44 km/h (121.573 mph). Manufacturers produced about 125 models of steam-powered automobiles, including the Stanley, until 1932.

Internal-Combustion Engine

Development of lighter steam cars during the 19th century coincided with major developments in engines that ran on gasoline or other fuels. Because the newer engines burned fuel in cylinders inside the engine, they were called internal-combustion engines.

In 1860 French inventor Jean-Joseph-Étienne Lenoir patented a one-cylinder engine that used kerosene for fuel. Two years later, a vehicle powered by Lenoir's engine reached a top speed of about 6.4 km/h (about 4 mph).

In 1864 Austrian inventor Siegfried Marcus built and drove a carriage propelled by a two-cylinder gasoline engine.

American George Brayton patented an internal-combustion engine that was displayed at the 1876 Centennial Exhibition in Philadelphia, Pennsylvania.

In 1876 German engineer Nikolaus August Otto built a four-stroke gas engine, the most direct ancestor to today's automobile engines. In a four-stroke engine the pistons move down to draw fuel vapor into the cylinder during stroke one; in stroke two, the pistons move up to compress the vapor; in stroke three the vapor explodes and the hot gases push the pistons down the cylinders; and in stroke four the pistons move up to push exhaust gases out of the cylinders. Engines with two or more cylinders are designed so combustion occurs in one cylinder after the other instead of in all at once. Two-stroke engines accomplish the same steps, but less efficiently and with more exhaust emissions.

Automobile manufacturing began in earnest in Europe by the late 1880s.

German engineer Gottlieb Daimler and German inventor Wilhelm Maybach mounted a gasoline-powered engine onto a bicycle, creating a motorcycle, in 1885.

In 1887 they manufactured their first car, which included a steering tiller and a four-speed gearbox. Another German engineer, Karl Benz, produced his first gasoline car in 1886.

Early Car
The first practical car, built by German engineer Karl Benz in 1885, initiated the era of automobile manufacturing. Benz made improvements to the internal combustion engine and invented the differential drive and other automotive components. The company Benz founded grew into one of the largest automobile manufacturers in Germany.

In 1890 Daimler and Maybach started a successful car manufacturing company, The Daimler Motor Company, which eventually merged with Benz's manufacturing firm in 1926 to create Daimler-Benz. The joint company makes cars today under the Mercedes-Benz nameplate.

In France, a company called Panhard-Levassor began making cars in 1894 using Daimler's patents. Instead of installing the engine under the seats, as other car designers had done, the company introduced the design of a front-mounted engine under the hood. Panhard-Levassor also introduced, a clutch and gears, and separate construction of the chassis, or underlying structure of the car, and the car body. The company's first model was a gasoline-powered buggy steered by a tiller.

French bicycle manufacturer Armand Peugeot saw the Panhard-Levassor car and designed an automobile using a similar Daimler engine. In 1891 this first Peugeot automobile paced a 1,046-km (650-mi) professional bicycle race between Paris and Brest.

Other French automobile manufacturers opened shop in the late 1800s, including Renault.

In Italy, Fiat (Fabbrica Italiana Automobili di Torino) began building cars in 1899.

American automobile builders were not far behind. Brothers Charles Edgar Duryea and James Frank Duryea built several gas-powered vehicles between 1893 and 1895. The first Duryea, a one-cylinder, four-horsepower model, looked much like a Panhard-Levassor model.

Horseless Carriage
The original horseless carriage was introduced in 1893 by brothers Charles and Frank Duryea. It was America's first internal-combustion motor car, and it was followed by Henry Ford's first experimental car that same year.

In 1893 American industrialist Henry Ford built an internal-combustion engine from plans he saw in a magazine. In 1896 he used an engine to power a vehicle mounted on bicycle wheels and steered by a tiller.

Early Electric Cars

For a few decades in the 1800s, electric engines enjoyed great popularity because they were quiet and ran at slow speeds that were less likely to scare horses and people. By 1899 an electric car designed and driven by Belgian inventor Camille Jenatzy set a record of 105.8810 km/h (65.79 mph). Early electric cars featured a large bank of storage batteries under the hood. Heavy cables connected the batteries to a motor between the front and rear axles. Most electric cars had top speeds of 48 km/h (30 mph), but could go only 80 km (50 mi) before their batteries needed recharging. Electric automobiles were manufactured in quantity in the United States until 1930.

Automobiles in the 20th century

For many years after the introduction of automobiles, three kinds of power sources were in common use: steam engines, gasoline engines, and electric motors.
In 1900 more than 2,300 automobiles were registered in New York City; Boston, Massachusetts; and Chicago, Illinois. Of these, 1,170 were steam cars, 800 were electric cars, and only 400 were gasoline cars. Gasoline-powered engines eventually became the nearly universal choice for automobiles because they allowed longer trips and faster speeds than engines powered by steam or electricity.

Improvements in the operating and riding qualities of gasoline automobiles developed quickly after 1900. The 1902 Locomobile was the first American car with a four-cylinder, water-cooled, front-mounted gasoline engine, very similar in design to most cars today. Built-in baggage compartments appeared in 1906, along with weather resistant tops and side curtains. An electric self-starter was introduced in 1911 to replace the hand crank used to start the engine turning. Electric headlights were introduced at about the same time.

Most automobiles at the turn of the 20th century appeared more or less like horseless carriages. In 1906 gasoline-powered cars were produced that had a style all their own. In these new models, a hood covered the front-mounted engine. Two kerosene or acetylene lamps mounted to the front served as headlights. Cars had fenders that covered the wheels and step-up platforms called running boards, which helped passengers, get in and out of the vehicle. The passenger compartment was behind the engine. Although drivers of horse-drawn vehicles usually sat on the right, automotive steering wheels were on the left in the United States.

In 1903 Henry Ford incorporated the Ford Motor Company, which introduced its first automobile, the Model A, in that same year. It closely resembled the 1903 Cadillac, which was hardly surprising since Ford had designed cars the previous year for the Cadillac Motor Car Company. Ford's company rolled out new car models each year, and each model was named with a letter of the alphabet. By 1907, when models R and S appeared, Ford's share of the domestic automobile market had soared to 35 percent.

Ford Model T
A Ford Model T rolls off the assembly line. Between 1908 and 1927, Ford built 15 million Model Ts.

Ford's famous Model T debuted in 1908 but was called a 1909 Ford. Ford built 17,771 Model T's and offered nine body styles. Popularly known as the Tin Lizzy, the Model T became one of the biggest-selling automobiles of all time. Ford sold more than 15 million before stopping production of the model in 1927. The company's innovative assembly-line method of building the cars was widely adopted in the automobile industry.

Silver Ghost
One of the highest-rated early luxury automobiles, the 1909 Rolls-Royce Silver Ghost's features included a quiet 6-cylinder engine, leather interior, folding windscreens and hood, and an aluminum body. Generally driven only by chauffeurs, the emphasis of the luxury car was on comfort and style rather than speed.

By 1920 more than 8 million Americans owned cars. Major reasons for the surge in automobile ownership were Ford's Model T, the assembly-line method of building it, and the affordability of cars for the ordinary wage earner.

Improvements in engine-powered cars during the 1920s contributed to their popularity: synchromesh transmissions for easier gear shifting; four-wheel hydraulic brake systems; improved carburetors; shatterproof glass; balloon tires; heaters; and mechanically operated windshield wipers.

Phaeton
Cars of the 1920s exhibited design refinements such as balloon tires, pressed-steel wheels, and four-wheel brakes. Although assembly lines (which originated with Henry Ford in 1908) continued to bring the price of automobiles down, many cars in this time were one-of-a-kind vintage models, made to individual specifications. The 1929 Graham Paige DC Phaeton shown here featured an 8-cylinder engine and an aluminum body.

From 1930 to 1937, automobile engines and bodies became large and luxurious. Many 12- and 16-cylinder cars were built. Independent front suspension, which made the big cars more comfortable, appeared in 1933. Also introduced during the 1930s were stronger, more reliable braking systems, and higher-compression engines, which developed more horsepower. Mercedes introduced the world's first diesel car in 1936.

Automobiles on both sides of the Atlantic were styled with gracious proportions, long hoods, and pontoon-shaped fenders. Creative artistry merged with industrial design to produce appealing, aerodynamic automobiles.

De Luxe Sedan
The roomy interior and rear-hinged back door of this 1937 Pontiac De Luxe sedan represent a move toward a car more suited to the needs of families. With these consumers in mind, cars were designed to be convenient, reliable, and relatively inexpensive. Vehicles in the 1930s were generally less boxy and more streamlined than their predecessors.

Some of the first vehicles to fully incorporate the fender into the bodywork came along just after World War II, but the majority of designs still had separate fenders with pontoon shapes holding headlight assemblies. Three companies, Ford, Nash, and Hudson Motor Car Company, offered postwar designs that merged fenders into the bodywork. The 1949 Ford was a landmark in this respect, and its new styling was so well accepted the car continued in production virtually unchanged for three years, selling more than 3 million. During the 1940s, sealed-beam headlights, tubeless tires, and the automatic transmission were introduced.

Two schools of styling emerged in the 1950s, one on each side of the Atlantic. The Europeans continued to produce small, light cars weighing less than 1,300 kg (2,800 lb). European sports cars of that era featured hand-fashioned aluminum bodies over a steel chassis and framework.

Studebaker
This 1940 Studebaker Champion two-door sedan was designed by Raymond Loewy and built by Studebaker craftsmen. Features emerging in the 1940s include automatic transmission, sealed-beam headlights, and tubeless tires.

In America, automobile designers borrowed features for their cars that were normally found on aircraft and ships, including tailfins and portholes. Automobiles were produced that had more space, more power, and smoother riding capability. Introduction of power steering and power brakes made bigger cars easier to handle. The Buick Motor Car Company, Olds Motor Vehicle Company (Oldsmobile), Cadillac Automobile Company, and Ford all built enormous cars, some weighing as much as 2,495 kg (5,500 lb). The first import by German manufacturer Volkswagen AG, advertised as the Beetle, arrived in the United States in 1949. Only two were sold that year, but American consumers soon began buying the Beetle and other small imports by the thousands.

VW Beetle
The Volkswagen Beetle dominated the market for several years, during which few modifications were made on the original design. Volkswagen's name means "car for the people," and the car served at least two important consumer needs. The rear-mounted engine and small, rounded, buglike shape of the European car represented an appealing combination of look and economy that remained popular for more than four decades.

That prompted a downsizing of some American-made vehicles. The first American car called a compact was the Nash Rambler. Introduced in 1950, it did not attract buyers on a large scale until 1958. More compacts, smaller in overall size than a standard car but with virtually the same interior body dimensions, emerged from the factories of many major manufacturers. The first Japanese imports, 16 compact trucks, arrived in the United States in 1956.

In the 1950s new automotive features were introduced, including air conditioning and electrically operated car windows and seat adjusters. Manufacturers changed from the 6-volt to the 12-volt ignition system, which gave better engine performance and more reliable operation of the growing number of electrical accessories.

By 1960 sales of foreign and domestic compacts accounted for about one-third of all passenger cars sold in the United States. American cars were built smaller, but with increased engine size and horsepower. Heating and ventilating systems became standard equipment on even the least expensive models. Automatic transmissions, power brakes, and power steering became widespread. Styling sometimes prevailed over practicality—some cars were built in which the engines had to be lifted to allow simple service operations, like changing the spark plugs. Back seats were designed with no legroom.

Gullwing
Powerful high-performance cars such as this 1957 Mercedes-Benz 300SL were built on compact and stylized lines. Also called the Gullwing because its doors open upward into the shape of a gull's wings, the 300SL was capable of 230 kmh (144 mph), its on-road performance matching its racing capacity.

El Dorado
This 1957 Cadillac El Dorado convertible epitomizes the large cars of the "American Dream" era. Tail fins are an example of a trend in car design. Although the feature did little for the performance of the vehicle, consumers loved the look, and demanded fins of increasing size until the 1960s.

Mustang
More than 100,000 Ford Mustangs sold during first four months the model was on the market in 1964, making it Ford's best early sales success since the introduction of the Model T. A vehicle from the "muscle car" category, the Mustang's popular characteristics included a small, fast design, excellent handling, a powerful engine, and a distinctive look.

In the 1970s American manufacturers continued to offer smaller, lighter models in addition to the bigger sedans that led their product lines, but Japanese and European compacts continued to sell well. Catalytic converters were introduced to help reduce exhaust emissions.

Digital speedometers and electronic prompts to service parts of the vehicle appeared in the 1980s. Japanese manufacturers opened plants in the United States. At the same time, sporty cars and family minivans surged in popularity.

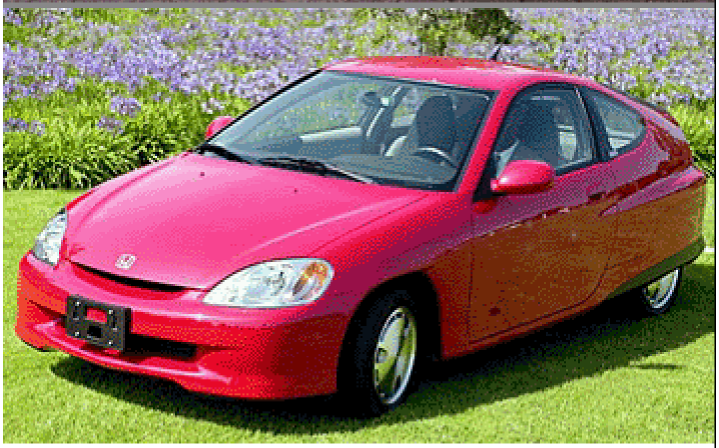
Advances in automobile technology in the 1980s included better engine control and the use of innovative types of fuel. In 1981 Bayerische Motoren Werke AG (BMW) introduced an on-board computer to monitor engine performance. A solar-powered vehicle, SunRaycer, traveled 3,000 km (1,864 mi) in Australia in six days.

MR-2 Turbo
Modern cars like the Japanese 1992 MR-2 Turbo T-bar Toyota are generally light, aerodynamically shaped, and compact. Japanese imports changed the automobile industry significantly. The generally reliable, inexpensive cars increased competition between manufacturers dramatically, to the benefit of consumers.

New technologies

Gas-Electric Hybrids

The Toyota Prius,
a four-seat hybrid electric vehicle (HEV), was the first HEV to be marketed when Toyota introduced it in Japan in 1997.



The Honda Insight,
a two-seat HEV, followed in 1999 when it was sold in both Japan and the United States. The Prius had its U.S. debut in 2000.

Gas-Electric Hybrids The Toyota Prius, a four-seat hybrid electric vehicle (HEV), was the first HEV to be marketed when Toyota introduced it in Japan in 1997. The Honda Insight, a two-seat HEV, followed in 1999 when it was sold in both Japan and the United States. The Prius had its U.S. debut in 2000.

Pollution-control laws adopted at the beginning of the 1990s in some of the United States and in Europe called for automobiles that produced better gas mileage with lower emissions. In 1996 General Motors became the first to begin selling an all-electric car, the EV1, to California buyers. The all-electric cars introduced so far have been limited by low range, long recharges, and weak consumer interest.

Engines that run on hydrogen have been tested. Hydrogen combustion produces only a trace of harmful emissions, no carbon dioxide, and a water-vapor by-product. However, technical problems related to the gas's density and flammability remains to be solved.

Diesel engines burn fuel more efficiently, and produce fewer pollutants, but they are noisy. Popular in trucks and heavy vehicles, diesel engines are only a small portion of the automobile market. A redesigned, quieter diesel engine introduced by Volkswagen in 1996 may pave the way for more diesels, and less pollution, in passenger cars.

While some developers searched for additional alternatives, others investigated ways to combine electricity with liquid fuels to produce low-emissions power systems. Two automobiles with such hybrid engines, the Toyota Prius and the Honda Insight, became available in the late 1990s. Prius hit automobile showrooms in Japan in 1997, selling 30,000 models in its first two years of production. The Prius became available for sale in North America in 2000. The Honda Insight debuted in North America in late 1999. Both vehicles, known as hybrid electric vehicles (HEVs), promised to double the fuel efficiency of conventional gasoline-powered cars while significantly reducing toxic emissions.

Computer control of automobile systems increased dramatically during the 1990s. The central processing unit (CPU) in modern engines manages overall engine performance. Microprocessors regulating other systems share data with the CPU. Computers manage fuel and air mixture ratios, ignition timing, and exhaust-emission levels. They adjust the antilock braking and traction control systems. In many models, computers also control the air conditioning and heating, the sound system, and the information displayed in the vehicle's dashboard.

Expanded use of computer technology, development of stronger and lighter materials, and research on pollution control will produce better, "smarter" automobiles.

In the 1980s the notion that a car would "talk" to its driver was science fiction; by the 1990s it had become reality.

Onboard navigation was one of the new automotive technologies in the 1990s. By using the satellite-aided global positioning system (GPS), a computer in the automobile can pinpoint the vehicle's location within a few meters. The onboard navigation system uses an electronic compass, digitized maps, and a display screen showing where the vehicle is relative to the destination the driver wants to reach. After being told the destination, the computer locates it and directs the driver to it, offering alternative routes if needed.

Some cars now come equipped with GPS locator beacons, enabling a GPS system operator to locate the vehicle, map its location, and if necessary, direct repair or emergency workers to the scene. Cars equipped with computers and cellular telephones can link to the Internet to obtain constantly updated traffic reports, weather information, route directions, and other data. Future built-in computer systems may be used to automatically obtain business information over the Internet and manage personal affairs while the vehicle's owner is driving.

During the 1980s and 1990s, manufacturers trimmed 450 kg (1,000 lb) from the weight of the typical car by making cars smaller. Less weight, coupled with more efficient engines, doubled the gas mileage obtained by the average new car between 1974 and 1995. Further reductions in vehicle size are not practical, so the emphasis has shifted to using lighter materials, such as plastics, aluminum alloys, and carbon composites, in the engine and the rest of the vehicle.

Looking ahead, engineers are devising ways to reduce driver errors and poor driving habits. Systems already exist in some locales to prevent intoxicated drivers from starting their vehicles. The technology may be expanded to new vehicles. Anti-collision systems with sensors and warning signals are being developed. In some, the car's brakes automatically slow the vehicle if it is following another vehicle too closely. New infrared sensors or radar systems may warn drivers when another vehicle is in their "blind spot."

Catalytic converters work only when they are warm, so most of the pollution they emit occurs in the first few minutes of operation. Engineers are working on ways to keep the converters warm for longer periods between drives, or heat the converters more rapidly.

Types of power plant

An engine is a device which transforms one form of energy into another form. However, while transforming energy from one form to another, the efficiency of conversion plays an important role. Normally, most of the engines convert thermal energy into mechanical work and therefore they are called 'heat engines'.

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes this thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine.

Heat engines can be broadly classified into two categories:

(i) Internal Combustion Engines (IC Engines) (ii) External Combustion Engines (EC Engines)

Table 1.1 Classification of heat engines

Classification	*Name of Engines*	*Reciprocating or Rotary*	*Maximum size in kW*	*Principal Use*
(a) Internal combustion engines	1. Gasoline or petrol engine (SI)	Reciprocating	4000	Road vehicles, small, industrial, small marine, (propulsion of ships), small aircrafts
	2. Gas engine (SI)	Reciprocating	4000	Industrial, electric power
	3. Diesel engine (CI)	Reciprocating	40,000	Road vehicles, industrial, locomotives electric power, marine
	4. Wankel engine (SI, CI)	Rotary	400	Road vehicles, small aircrafts
	5. Open cycle gas turbine	Rotary	15,000	Electric power, aircraft
	6. Jet engine	Rotary	8000	Aircraft
	7. Rocket	No mechanism	Very big	Missiles, space travel
(b) External combustion engines	1. Steam engine	Reciprocating	4000	Locomotives, ships
	2. Steam turbine	Rotary	5,00,000	Electric power, large marine
	3. Stirling or hot air engine	Reciprocating	800	Experimental, power in space, vehicles
	4. Closed cycle gas turbine	Rotary	80,000	Electric power, marine

SI = spark ignition CI = compression ignition

Engines whether Internal Combustion or External Combustion are of two types, viz.,

(i) Rotary engines (ii) Reciprocating engines

Of the various types of heat engines, the most widely used ones are the reciprocating internal combustion engine, the gas turbine and the steam turbine. The steam engine is rarely used nowadays. The reciprocating internal combustion engine enjoys some advantages over the steam turbine due to the absence of heat exchangers in the passage of the working fluid (boilers and condensers in steam turbine plant). This results in a considerable mechanical simplicity and improved power plant efficiency of the internal combustion engine.

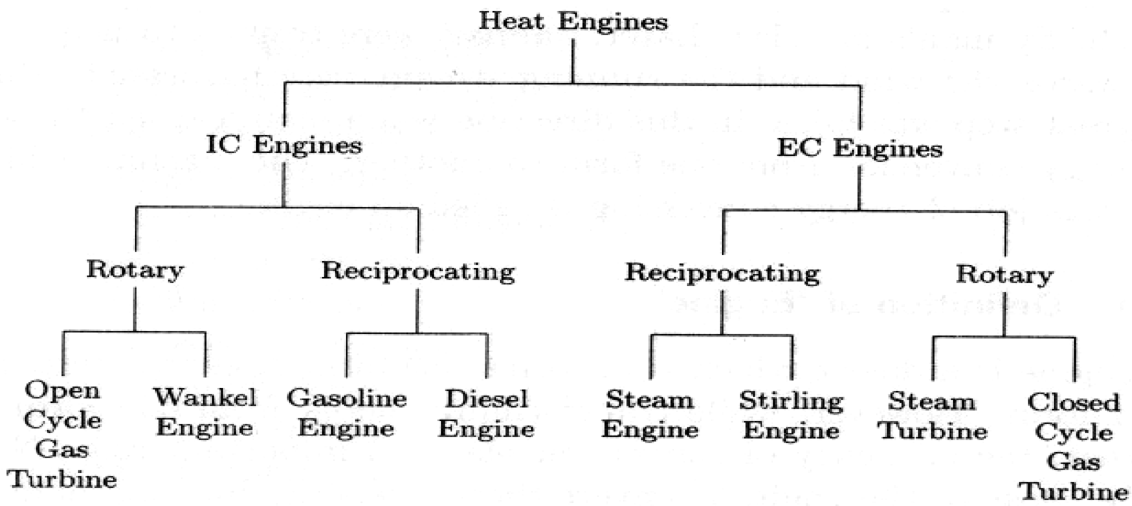


Fig.1.1
Classification of heat engines

Another advantage of the reciprocating internal combustion engine over the other two types is that all its components work at an average temperature which is much below the maximum temperature of the working fluid in the cycle. This is because the high temperature of the working fluid in the cycle persists only for a very small fraction of the cycle time. Therefore, very high working fluid temperatures can be employed resulting in higher thermal efficiency.

Further, in internal combustion engines, higher thermal efficiency can be obtained with moderate maximum working pressure of the fluid in the cycle, and therefore, the weight of power ratio is less than that of the steam turbine plant. Also, it has been possible to develop reciprocating internal combustion engines of very small power output (power output of even a fraction of a kilowatt) with reasonable thermal efficiency and cost.

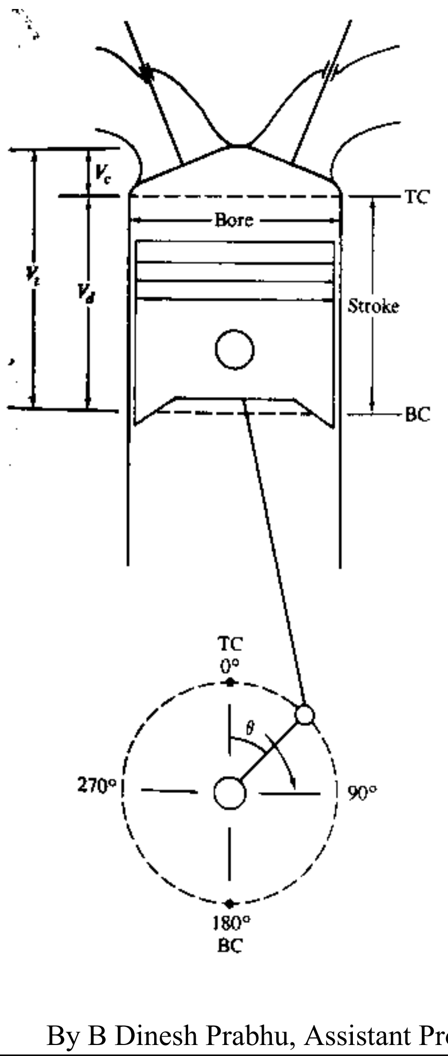
The main disadvantage of this type of engine is the problem of vibration caused by the reciprocating components. Also, it is not possible to use a variety of fuels in these engines. Only liquid or gaseous fuels of given specification can be efficiently used. These fuels are relatively more expensive.

Considering all the above factors the reciprocating internal combustion engines have been found suitable for use in automobiles, motor-cycles and scooters, power boats, ships, slow speed aircraft, locomotives and power units of relatively small output.

External Combustion and Internal Combustion Engines

External combustion engines are those in which combustion takes place outside the engine whereas in internal combustion engines combustion takes place within the engine. For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine. In case of gasoline or diesel engines, the products of combustion generated by the combustion of fuel and air within the cylinder form the working fluid.

Principle of engine operation (4 stroke & 2 stroke operating cycles)



In reciprocating engines, the piston moves back and forth in a cylinder and transmits power through a connecting rod and crank mechanism to the drive shaft as shown in Fig1.2. The steady rotation of the crank produces a cyclical piston motion. The piston comes to rest at the top center (TC) crank position and bottom-center (BC) [These crank positions are also referred to as top-dead-center (TDC) and bottom-dead-center (BDC)] crank position when the cylinder volume is a minimum or maximum, respectively. The minimum cylinder volume is called the clearance volume.

The volume swept out by the piston, the difference between the maximum or total volume V_t and the clearance volume, is called the displaced or swept volume V_d. The ratio of maximum volume to minimum volume is the compression ratio r_c. Typical values of r_c are 8 to 12 for SI engines and 12 to 24 for CI engines.

Fig 1.2
Basic geometry of the reciprocating internal combustion engine.
V_c, V_d, and V_t, indicate clearance, displaced, and total cylinder volumes.

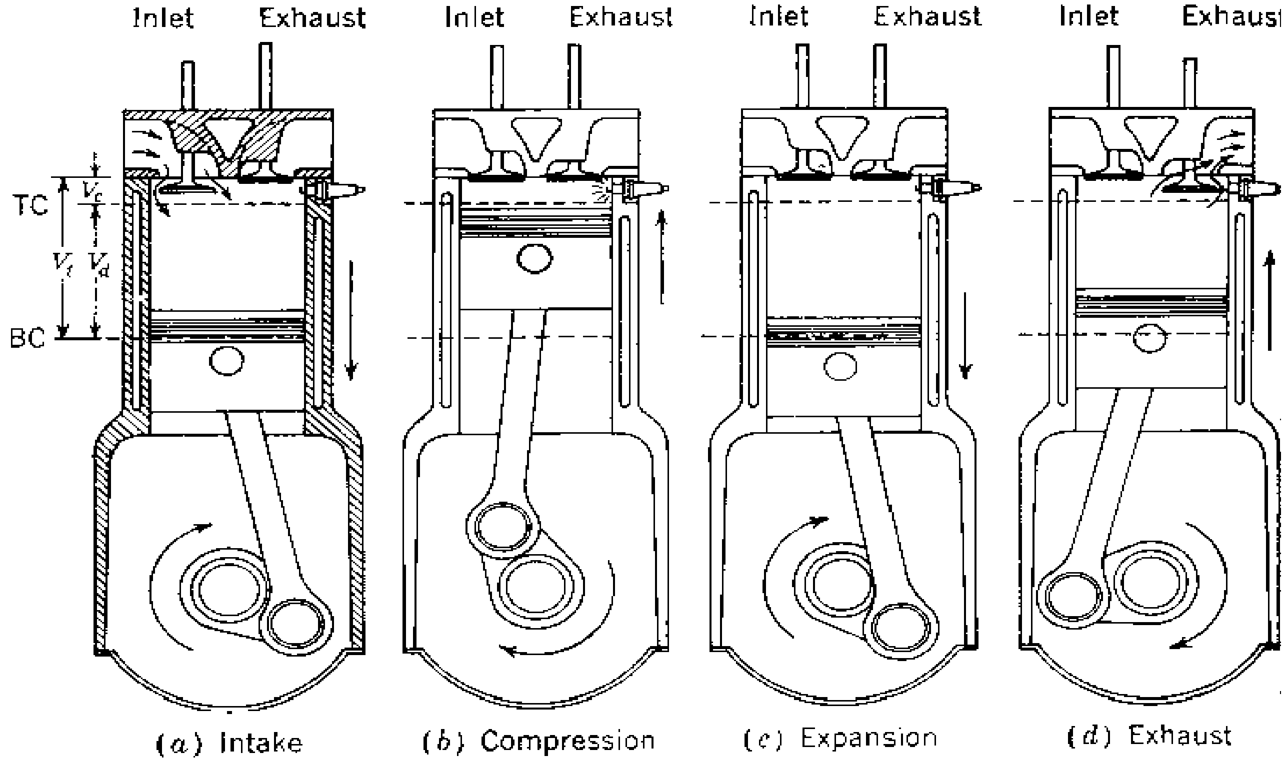


Fig.1.3 :-The four-stroke operating cycle.

The majority of reciprocating engines operate on what is known as the *four-stroke cycle.* Each cylinder requires four strokes of its piston-two revolutions of the crankshaft-to complete the sequence of events which produces one power stroke. Both SI and CI engines use this cycle which comprises

1. ***An intake stroke,*** which starts with the piston at TC and ends with the piston at BC, which draws fresh mixture into the cylinder. To increase the mass inducted, the inlet valve opens shortly before the stroke starts and closes after it ends.

2. ***A compression stroke,*** when both valves are closed and the mixture inside the cylinder is compressed to a small fraction of its initial volume. Toward the end of the compression stroke, combustion is initiated and the cylinder pressure rises more rapidly.

3. ***A power stroke,*** or expansion stroke, which starts with the piston at TC and ends at BC as the high-temperature, high-pressure, gases push the piston down and force the crank to rotate. About five times as much work is done on the piston during the power stroke as the piston had to do during compression. As the piston approaches BC the exhaust valve opens to initiate the exhaust process and drop the cylinder pressure to close to the exhaust pressure.

4 ***An exhaust stroke,*** where the remaining burned gases exit the cylinder: first, because the cylinder pressure may be substantially higher than the exhaust pressure; then as they are swept out by the piston as it moves toward TC. As the piston approaches TC the inlet valve opens. Just after TC the exhaust valve closes and the cycle starts again.

Though often called the Otto cycle after its inventor, Nicolaus Otto, who built the first engine operating on these principles in 1876, the more descriptive four-stroke nomenclature is preferred.

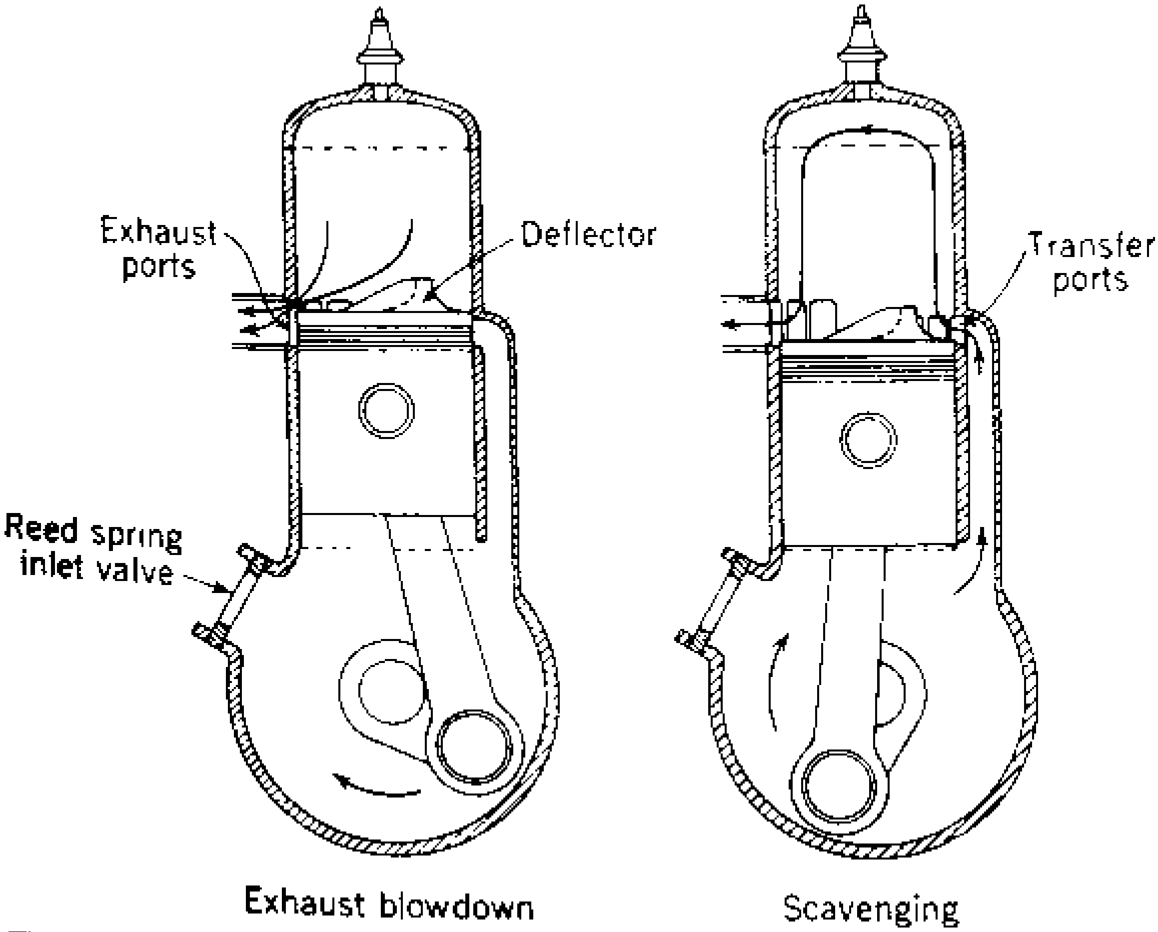
The four-stroke cycle requires, for each engine cylinder, two crankshaft revolutions for each power stroke.

To obtain a higher power output from a given engine size, and a simpler valve design, the *two-stroke* cycle was developed. The two-stroke cycle is applicable to both SI and CI engines.

Figure 1.4 shows one of the simplest types of two-stroke engine designs. Ports in the cylinder liner opened and closed by the piston motion, control the exhaust and inlet flows while the piston is close to BC. The two strokes are:

A compression stroke, which starts by closing the inlet and exhaust ports, and then compresses the cylinder contents and draws fresh charge into the crankcase. As the piston approaches TC, combustion is initiated.

Fig.1.4 The two-stroke operating cycle.
A crankcase-scavenged engine



A power or expansion stroke, similar to that in the four-stroke cycle until the piston approaches BC, when first the exhaust ports and then the intake ports are uncovered. Most of the burnt gases exit the cylinder in an exhaust blow down process. When the inlet ports are uncovered, the fresh charge which has been compressed in the crankcase flows into the cylinder.
The piston and the ports are generally shaped to deflect the incoming charge from flowing directly into the exhaust ports and to achieve effective scavenging of the residual gases.

Each engine cycle with one power stroke is completed in one crankshaft revolution. However, it is difficult to fill completely the displaced volume with fresh charge, and some of the fresh mixture flows directly out of the cylinder during the scavenging process. The example shown is a *cross-scavenged* design; other approaches use *loop-scavenging* or *uniflow* systems

Engine classifications

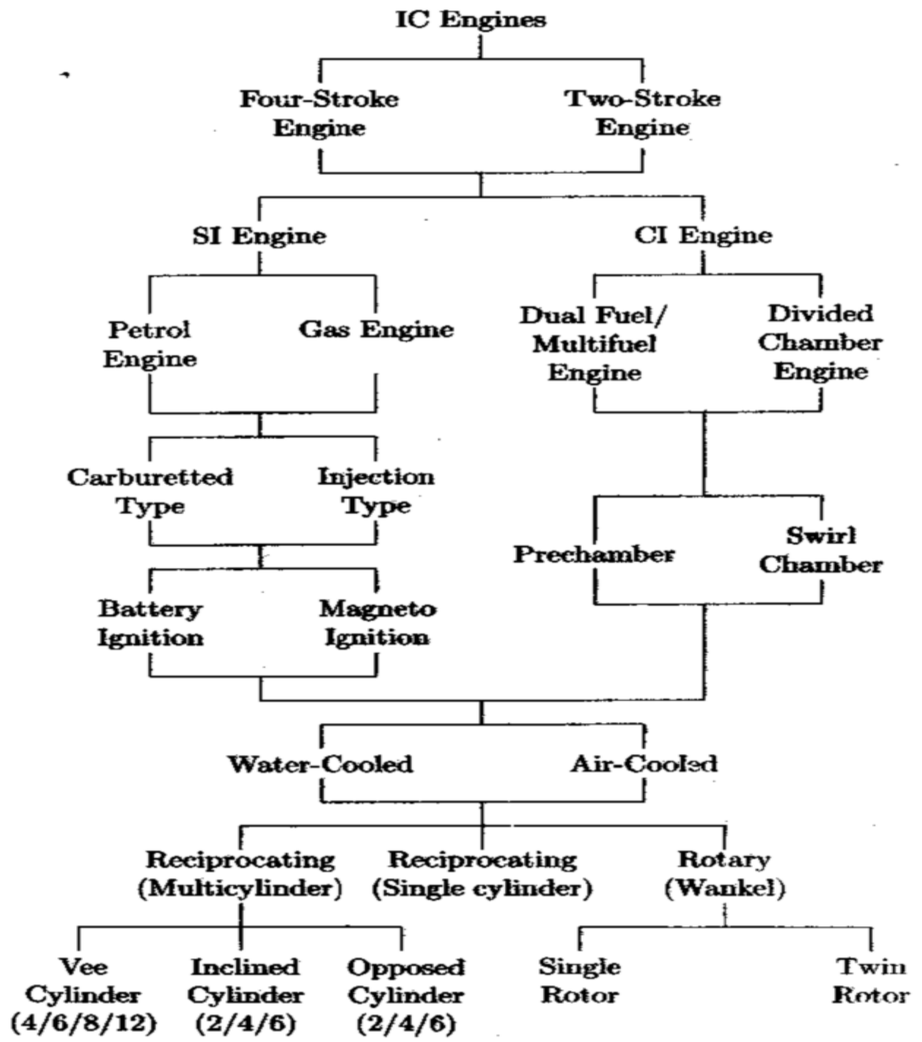


Fig.1.5
IC engine classification

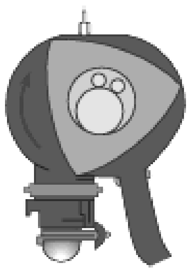
There are many different types of internal combustion engines. They can be classified by:

1. Application.

Automobile, truck, locomotive, light aircraft, marine, portable power system, power generation

2 Basic engine design

Reciprocating engines (in turn subdivided by arrangement of cylinders: e.g., in-line, V, radial, opposed-ref, fig1.6.), rotary engines (Wankel and other geometries)



Wankel rotary engine

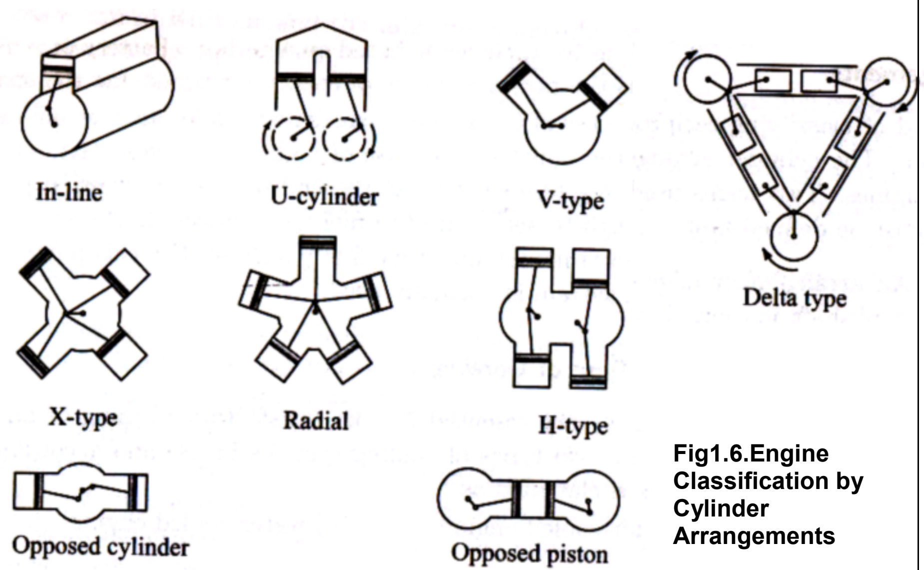


Fig1.6.Engine Classification by Cylinder Arrangements

3. Working cycle.

Four-stroke cycle: naturally aspirated (admitting atmospheric air), supercharged (admitting pre-compressed fresh mixture), and turbocharged (admitting fresh mixture compressed in a compressor driven by an exhaust turbine),

Two-stroke cycle: crankcase scavenged, supercharged, and turbocharged,

Constant volume heat addition cycle engine or Otto cycle engine -SI engine or Gasoline engine,

Constant pressure heat addition cycle engine or Diesel cycle engine-CI engine or Diesel engine.

4 Valve or port design and location.

Overhead (or I-head) valves, under head (or L-head) valves, rotary valves, cross-scavenged porting (inlet and exhaust ports on opposite sides of cylinder at one end), loop-scavenged porting (inlet and exhaust ports on same side of cylinder at one end), through- or uni-flow scavenged (inlet and exhaust ports or valves at different ends of cylinder)

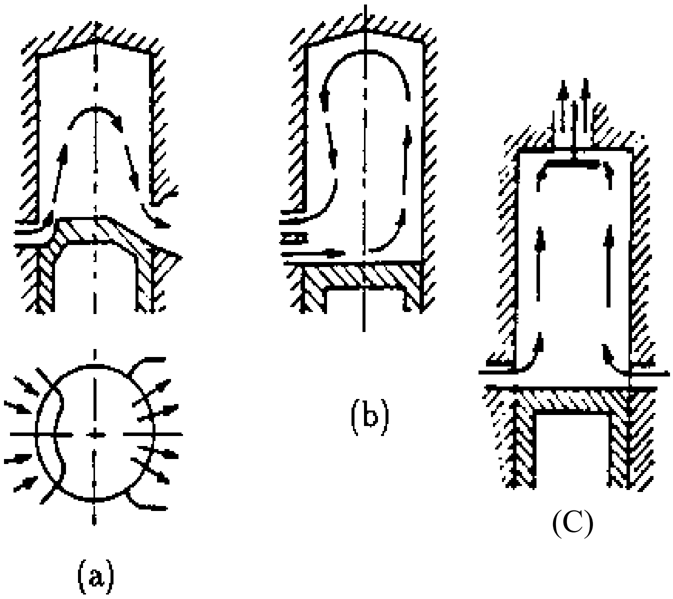
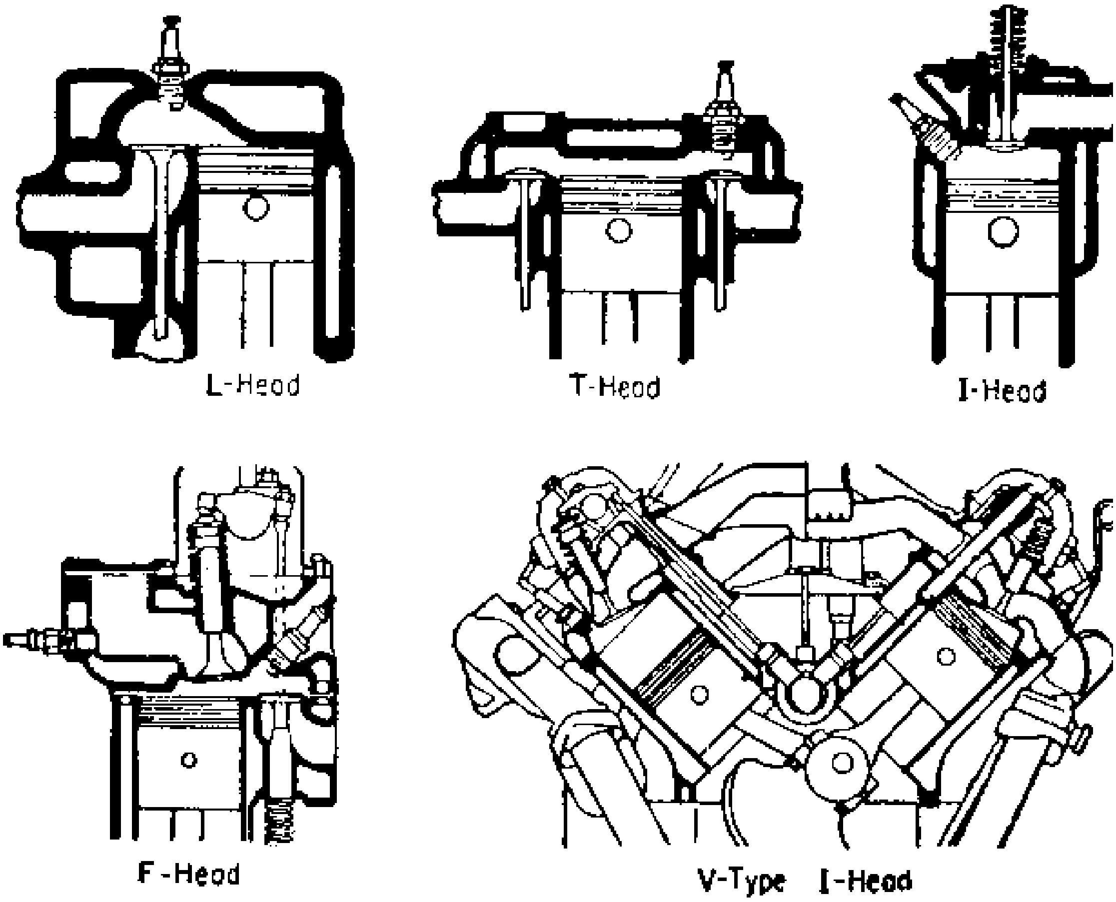


Fig1.7
classification of SI engine
by port/ valve location

(a)Cross, (b) Loop, (c) Uniflow Scavenging



5. Fuel

Gasoline (or petrol), fuel oil (or diesel fuel), natural gas, liquid petroleum gas, alcohols (methanol, ethanol), hydrogen, dual fuel

6. Method of mixture preparation.

Carburetion, fuel injection into the intake ports or intake manifold, fuel injection into the engine cylinder

7. Method of ignition

Spark ignition (in conventional engines where the mixture is uniform and in stratified-charge engines where the mixture is non-uniform), compression ignition (in conventional diesels, as well as ignition in gas engines by pilot injection of fuel oil)

8. Combustion chamber design.

Open chamber (many designs: e.g., disc, wedge, hemisphere, bowl-in-piston), divided chamber (small and large auxiliary chambers; many designs: e.g., swirl chambers, pre-chambers)

9. Method of load control.

Throttling of fuel and air flow together so mixture composition is essentially unchanged, control of fuel flow alone, a combination of these

10. Method of cooling.

Water cooled, air cooled, un-cooled (other than by natural convection and radiation)

. All these distinctions are important and they illustrate the breadth of engine designs available from a fundamental point of view. The method of ignition has been selected as the primary classifying feature. From the method of ignition-spark-ignition or compression-ignition-follow the important characteristics of the fuel used, method of mixture preparation, combustion chamber design, method of load control, details of the combustion process, engine emissions, and operating characteristics. Some of the other classifications are used as subcategories within this basic classification. The engine operating cycle--four-stroke or two-stroke--is next in importance.

Table 1.2

Classification of reciprocating engines by application

Class	Service	Approximate engine power range, kW	Predominant type		
			D or SI	Cycle	Cooling
Road vehicles	Motorcycles, scooters	0.75–70	SI	2, 4	A
	Small passenger cars	15–75	SI	4	A, W
	Large passenger cars	75–200	SI	4	W
	Light commercial	35–150	SI, D	4	W
	Heavy (long-distance) commercial	120–400	D	4	W
Off-road vehicles	Light vehicles (factory, airport, etc.)	1.5–15	SI	2, 4	A, W
	Agricultural	3–150	SI, D	2, 4	A, W
	Earth moving	40–750	D	2, 4	W
	Military	40–2000	D	2, 4	A, W
Railroad	Rail cars	150–400	D	2, 4	W
	Locomotives	400–3000	D	2, 4	W
Marine	Outboard	0.4–75	SI	2	W
	Inboard motorcrafts	4–750	SI, D	4	W
	Light naval craft	30–2200	D	2, 4	W
	Ships	3500–22,000	D	2, 4	W
	Ships' auxiliaries	75–750	D	4	W
Airborne vehicles	Airplanes	45–2700	SI	4	A
	Helicopters	45–1500	SI	4	A
Home use	Lawn mowers	0.7–3	SI	2, 4	A
	Snow blowers	2–5	SI	2, 4	A
	Light tractors	2–8	SI	4	A
Stationary	Building service	7–400	D	2, 4	W
	Electric power	35–22,000	D	2, 4	W
	Gas pipeline	750–5000	SI	2, 4	W

SI = spark-ignition; D = diesel; A = air cooled; W = water cooled.

Table 1.3 Engine characteristics Emphasized by Type of Service

Service (Application)	Very Important	Moderately Important	Less Important
Small engines for home use, Outboard engines, Motorcycle engines	Light weight* Small bulk* Low first cost	Low noise level Reliability Low maintenance	Fuel economy Long life Vibration
Passenger automobile engines max 200 kmph speed max 200 Hp power	Low noise and vibration Low first cost Reliability Flexibility† Low maintenance	Fuel economy Weight Bulk	Long life
Engines for commercial vehicles, light marine, and industrial use	Reliability Fuel economy Low maintenance	Weight Bulk Low noise and vibration Long life	First cost
Locomotive engines	Small bulk Fuel economy Low maintenance Reliability	Long life	First cost Weight Noise Vibration
Aircraft engines	Light weight Small bulk High take-off power Fuel economy** Reliability	Low vibration Low maintenance	First cost Long life Noise
Racing engines max 220 to 300 mph speed 250 to 300 BHp - High o/p	High output within established rules	Reliability	All other
Large engines (over 12-in., 300-mm bore)	Fuel economy Long life Reliability Low maintenance	Low noise and vibration Bulk	First cost Weight

* Weight and bulk are considered in proportion to power

† Flexibility means smooth and efficient operation over a wide range of speed and load

** In relation to ton miles rather than horsepower

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