An Introduction to Combustion Engines

Sunny NARAYAN[1], Aman GUPTA[2]

[1] Indus University, India, sn2008@rediffmail.com

[2] Indus University, India

Abstract: *A numerical model for the skirt is studied to consider the effects of the connecting rod inertia on the piston skirt–liner system lubrication. The piston motion, the oil film lubrication model and the friction losses of the system have been studied and compared. The results on a dual cylinder diesel engine show that inertia of connecting rod also affects system lubrication as well as the piston motion, especially at higher speeds.*

Keywords: *Combustion engines*

1. Introduction

Most of the very earliest internal combustion engines of the 17th and 18th centuries can be classified as atmospheric engines. These were large engines with a single piston and cylinder, the cylinder being open on the end. Combustion was initiated in the open cylinder using any of the various fuels which were available. Gunpowder was often used as the fuel. Immediately after combustion, the cylinder would be full of hot exhaust gas at atmospheric pressure. At this time, the cylinder end was closed and the trapped gas was allowed to cool. As the gas cooled, it created a vacuum within the cylinder. This caused a pressure differential across the piston, atmospheric pressure on one side and a vacuum on the other. As the piston moved because of this pressure differential, it would do work by being connected to an external system, such as raising a weight [1]. Some early steam engines also were atmospheric engines. Instead of combustion, the open cylinder was filled with hot steam. The end was then closed and the steam was allowed to cool and condense [2]. This created the necessary vacuum. In addition to a great amount of experimentation and development in Europe and the United States during the middle and latter half of the 1800s [3], two other technological occurrences during this time stimulated the emergence of the internal combustion engine.

In 1859, the discovery of crude oil in Pennsylvania finally made available the development of reliable fuels which could be used in these newly developed engines. Up to this time, the lack of good, consistent fuels was a major drawback in engine development [4]. Fuels like whale oil, coal gas, mineral oils, coal, and gun powder which were available before this time were less than ideal for engine use and development. It still took many years before products of the petroleum industry evolved from the first crude oil to gasoline, the automobile fuel of the 20th century [5]. However, improved hydrocarbon products began to appear as early as the 1860s and gasoline, lubricating oils, and the internal combustion engine evolved together [6]. The second technological invention that stimulated the development of the internal combustion engine was the pneumatic rubber tire, which was first marketed by John B. Dunlop in 1888 [7]. This invention made the automobile much more practical and desirable and thus generated a large market for propulsion systems, including the internal combustion engine [8]. During the early years of the automobile, the internal combustion engine competed with electricity and steam engines as the basic means of propulsion. Early in the 20th century, electricity and steam faded from the automobile picture—electricity because of the limited range it provided, and steam because of the long start-up time needed.

Thus, the 20th century is the period of the internal combustion engine and the automobile powered by the internal combustion engine as shown in figures no 1,2,3 [9]. At the end of the century, the internal combustion engine was again being challenged by electricity and other forms of propulsion systems for automobiles and other applications [10].

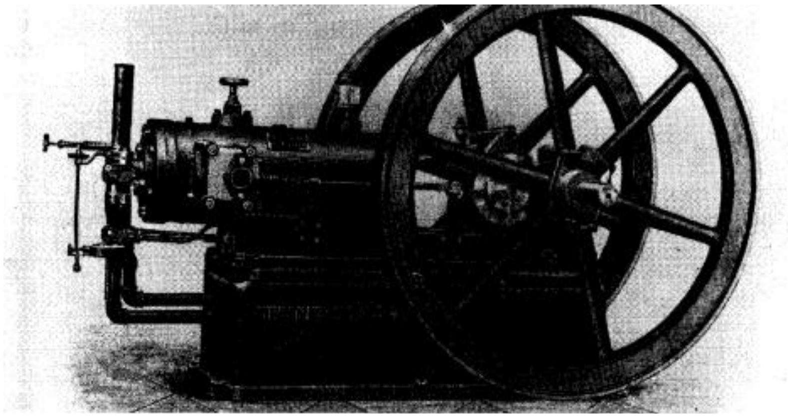

Fig. 1. Charter Engine

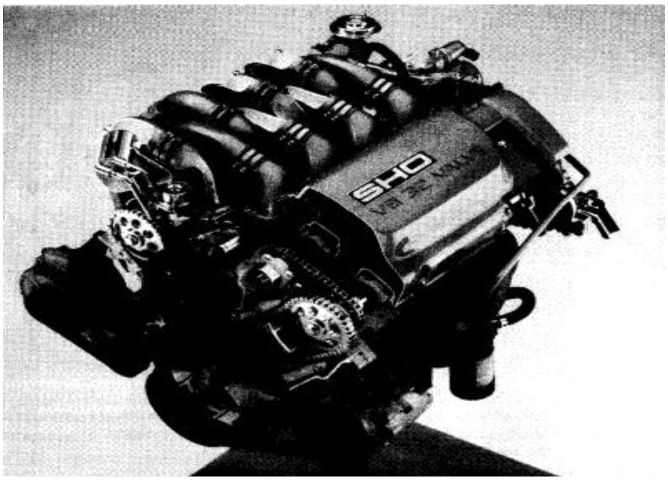

Fig. 2. Ford Engine

During the second half of the 19th century, many different styles of internal combustion engines were built and tested [11]. These engines operated with variable success and dependability using many different mechanical systems and engine cycles. The first fairly practical engine was invented by J. J. E. Lenoir [12]. During the next decade, several hundred of these engines were built with power up to about 4.5 kW (6 hp) and mechanical efficiency up to 5%.

In 1867, the Otto-Langen engine, with efficiency improved to about 11%, was first introduced, and several thousand of these were produced during the next decade. This was a type of atmospheric engine with the power stroke propelled by atmospheric pressure acting against a vacuum [13]. During this time, engines operating on the same basic four-stroke cycle as the modern automobile engine began to evolve as the best design. Although many people were working on four-stroke cycle design, Otto was given credit when his prototype engine was built in 1876 [14]. In the 1880s the internal combustion engine first appeared in automobiles [15].

Also in this decade the two-stroke cycle engine became practical and was manufactured in large numbers. By 1892, Rudolf Diesel had perfected his compression ignition engine into basically the same diesel engine known today. This was after years of development work which included the use of solid fuel in his early experimental engines [16].

Early compression ignition engines were noisy, large, slow, single-cylinder engines. They were, however, generally more efficient than spark ignition engines. It was not until the 1920s that multi-cylinder compression ignition engines were made small enough to be used with automobiles and trucks [17].

2. Classifications [18]

Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition (a) Spark Ignition (SI). An SI engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug. In early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame. (b) Compression Ignition (CI). The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.

2. Engine Cycle (a) Four-Stroke Cycle. A four-stroke cycle experiences four piston movements over two engine revolutions for each cycle. (b) Two-Stroke Cycle. A two-stroke cycle has two piston movements over one revolution for each cycle.

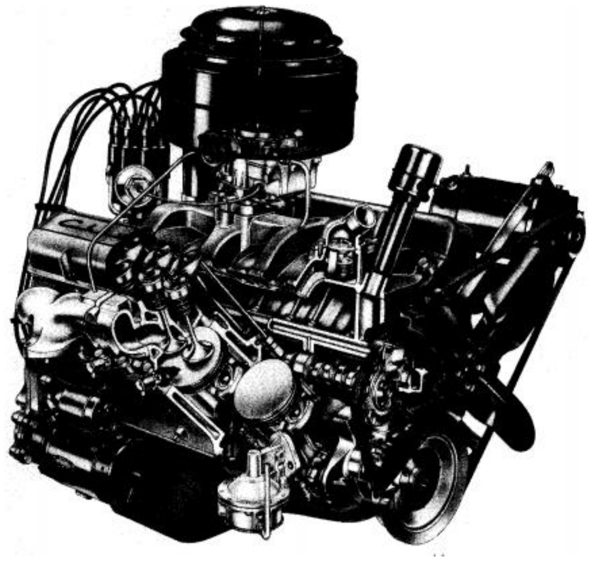

Fig. 3. Chevrlot Engine

Three-stroke cycles and six-stroke cycles were also tried in early engine development [19].

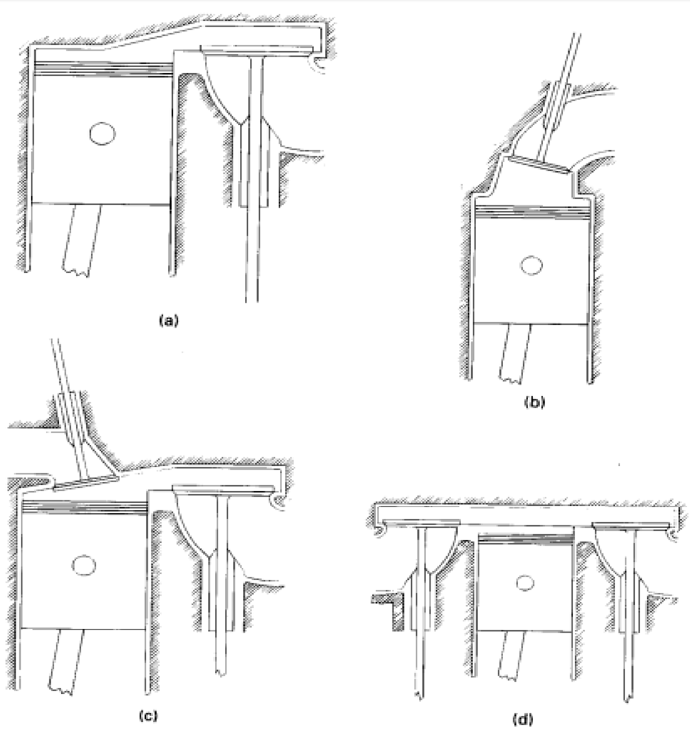

Fig. 4. Engine classification by valve location

3. Valve Location [20] – As seen from figure no 4, (a) Valves in head (overhead valve), also called I Head engine. (b) Valves in block (flat head), also called L Head engine. Some historic engines with valves in block had the intake valve on one side of the cylinder and the exhaust valve on the other side. These were called T Head engines. (c) One valve in head (usually intake) and one in block, also called F Head engine; this is much less common.
4. Design of Engine [21] – (a) Reciprocating. Engine has one or more cylinders in which pistons reciprocate back and forth. The combustion chamber is located in the closed end of each cylinder. Power is delivered to a rotating output crankshaft by mechanical linkage with the pistons. (b) Rotary-Engine is made of a block (stator) built around a large nonconcentric rotor and crankshaft. The combustion chambers are built into the nonrotating block.
5. Position and Number of Cylinders of Reciprocating Engines [18] – As seen from figure no 5 various systems can be:
(a) Single Cylinder. Engine has one cylinder and piston connected to the crankshaft.
(b) In-Line-Cylinders are positioned in a straight line, one behind the other along the length of the crankshaft. They can consist of 2 to 11 cylinders or possibly more. In-line four-cylinder engines are very common for automobile and other applications. In-line six and eight cylinders are historically common automobile engines. In-line engines are sometimes called straight (e.g., straight six or straight eight).
(c) V Engine – Two banks of cylinders at an angle with each other along a single crankshaft. The angle between the banks of cylinders can be anywhere from 15° to 120°, with 60°-90° being common. V engines have even numbers of cylinders from 2 to 20 or more. V6s and V8s are common automobile engines, with V12s and V16s (historic) found in some luxury and high-performance vehicles.
(d) Opposed Cylinder Engine – Two banks of cylinders opposite each other on a single crankshaft (a V engine with a 180°V). These are common on small aircraft and some automobiles with an even number of cylinders from two to eight or more. These engines are often called flat engines (e.g., flat four).

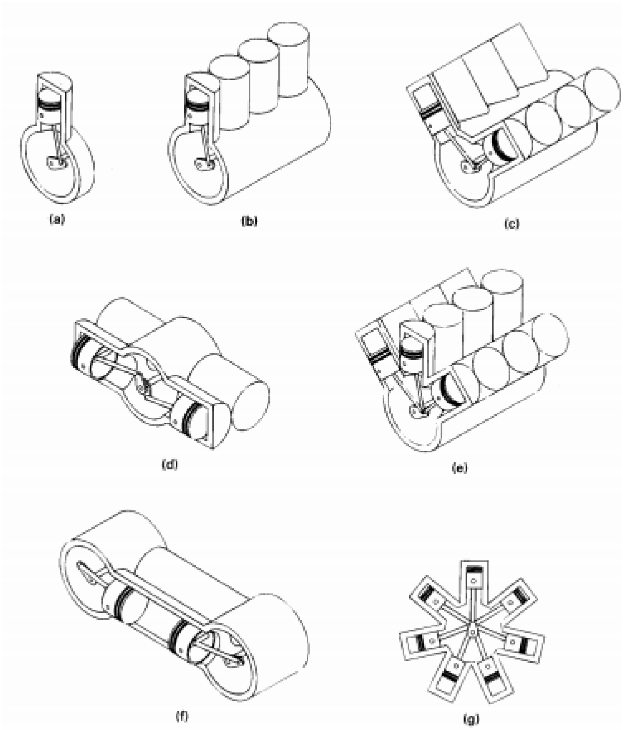

Fig. 5. Various engine arrangements a-Single, b-In line, c-V block, d-Opposed cylinder, e-W type, f-opposed piston, g-Radial

(e) W Engine-Same as a V engine except with three banks of cylinders on the same crankshaft. These are not common, but some have been developed for racing automobiles, both modern and historic. Usually 12 cylinders with about a 60° angle between each bank.
(f) Opposed Piston Engine – Two pistons in each cylinder with the combustion chamber in the center between the pistons. A single-combustion process causes two power strokes at the same time, with each piston being pushed away from the center and delivering power to a separate crankshaft at each end of the cylinder. Engine output is either on two rotating crankshafts or on one crankshaft incorporating complex mechanical linkage.
(g) Radial Engine – Engine with pistons positioned in a circular plane around the central crankshaft. The connecting rods of the pistons are connected to a master rod which, in turn, is connected to the crankshaft. A bank of cylinders on a radial engine always has an odd number of cylinders ranging from 3 to 13 or more. Operating on a four-stroke cycle, every other cylinder fires and has a power stroke as the crankshaft rotates, giving a smooth operation. Many medium- and large-size propeller-driven aircraft use radial engines. For large aircraft, two or more banks of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful, smooth engine. Very large ship engines exist with up to 54 cylinders, six banks of 9 cylinders each.

3. Engine components [22]

The following is a list of major components found in most reciprocating internal combustion engines, as shown in figure no 6.

a. Block – Body of engine containing the cylinders, made of cast iron or aluminum. In many older engines, the valves and valve ports were contained in the block. The block of water-cooled engines includes a water jacket cast around the cylinders. On air-cooled engines, the exterior surface of the block has cooling fins.

b. Camshaft [22] – Rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage (push rods, rocker arms, tappets). Most modern automobile engines have one or more camshafts mounted in the engine head (overhead cam). Most older engines had camshafts in the crankcase. Camshafts are generally made of forged steel or cast iron and are driven off the crankshaft by means of a belt or chain (timing chain). To reduce weight, some cams are made from a hollow shaft with the cam lobes press-fit on. In four-stroke cycle engines, the camshaft rotates at half engine speed.

c. Carburetor [24] – Venturi flow device which meters the proper amount of fuel into the air flow by means of a pressure differential. For many decades it was the basic fuel metering system on all automobile (and other) engines. It is still used on low-cost small engines like lawn mowers but is uncommon on new automobiles. Catalytic converter Chamber mounted in exhaust flow containing catalytic material that promotes reduction of emissions by chemical reaction.

d. Combustion chamber [25] – The end of the cylinder between the head and the piston face where combustion occurs. The size of the combustion chamber continuously changes from a minimum volume when the piston is at TDC to a maximum when the piston is at BDC. The term "cylinder" is sometimes synonymous with "combustion chamber" (e.g., "the engine was firing on all cylinders"). Some engines have open combustion chambers which consist of one chamber for each cylinder. Other engines have divided chambers which consist of dual chambers on each cylinder connected by an orifice passage. Connecting rod – Rod connecting the piston with the rotating crankshaft, usually made of steel or alloy forging in most engines but may be aluminum in some small engines.

e. Connecting rod bearing [26] – Bearing where connecting rod fastens to crankshaft. Cooling fins – Metal fins on the outside surfaces of cylinders and head of an air cooled engine. These extended surfaces cool the cylinders by conduction and convection.

f. Crankcase [27] – Part of the engine block surrounding the rotating crankshaft. In many engines, the oil pan makes up part of the crankcase housing. Crankshaft – Rotating shaft through which engine work output is supplied to external systems. The crankshaft is connected to the engine block with the main bearings. It is rotated by the reciprocating pistons through connecting rods connected to the crankshaft, offset from the axis of rotation. This offset is sometimes called crank throw or crank radius. Most crankshafts are made of forged steel, while some are made of cast iron.

g. Cylinders [28] – The circular cylinders in the engine block in which the pistons reciprocate back and forth. The walls of the cylinder have highly polished hard surfaces. Cylinders may be machined directly in the engine block, or a hard metal (drawn steel) sleeve may be pressed into the softer metal block. Sleeves may be dry sleeves, which do not contact the liquid in the water jacket, or wet sleeves, which form part of the water jacket. In a few engines, the cylinder walls are given a knurled surface to help hold a lubricant film on the walls. In some very rare cases, the cross section of the cylinder is not round.

h. Exhaust manifold [29] – Piping system which carries exhaust gases away from the engine cylinders, usually made of cast iron. Exhaust system – Flow system for removing exhaust gases from the cylinders, treating them, and exhausting them to the surroundings. It consists of an exhaust manifold which carries the exhaust gases away from the engine, a thermal or catalytic converter to reduce emissions, a muffler to reduce engine noise, and a tailpipe to carry the exhaust gases away from the passenger compartment.

i. Fan [31] – Most engines have an engine-driven fan to increase air flow through the radiator and through the engine compartment, which increases waste heat removal from the engine. Fans can be driven mechanically or electrically, and can run continuously or be used only when needed.

j. Flywheel [30] – Rotating mass with a large moment of inertia connected to the crankshaft of the engine. The purpose of the flywheel is to store energy and furnish a large angular momentum that keeps the engine rotating between power strokes and smooths out engine operation. On some aircraft engines the propeller serves as the flywheel, as does the rotating blade on many lawn mowers.

k. Fuel injector [31] – A pressurized nozzle that sprays fuel into the incoming air on SI engines or into the cylinder on CI engines. On SI engines, fuel injectors are located at the intake valve ports on multipoint port injector systems and upstream at the intake manifold inlet on throttle body injector systems. In a few SI engines, injectors spray directly into the combustion chamber. Fuel pump – Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine. Many modern automobiles have an electric fuel pump mounted submerged in the fuel tank. Some small engines and early automobiles had no fuel pump, relying on gravity feed.

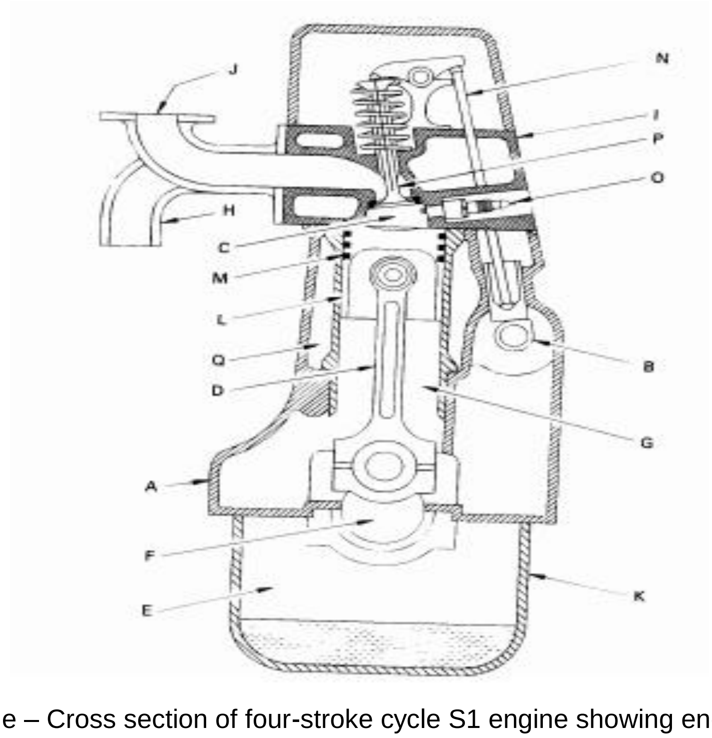

Fig. 6. Parts of Engine – Cross section of four-stroke cycle S1 engine showing engine components; (A) block, (B) camshaft, (C) combustion chamber, (D) connecting rod, (E) crankcase, (F) crankshaft, (G) cylinder, (H) exhaust manifold, (I) head, (J) intake manifold, (K) oil pan, (L) piston, (M) piston rings, (N) push rod, (0) spark plug, (P) valve, (Q) water jacket.

l. Glow plug – Small electrical resistance heater mounted inside the combustion chamber of many CI engines, used to preheat the chamber enough so that combustion will occur when first starting a cold engine. The glow plug is turned off after the engine is started.

m. Head – The piece which closes the end of the cylinders, usually containing part of the clearance volume of the combustion chamber. The head is usually cast iron or aluminum, and bolts to the engine block. In some less common engines, the head is one piece with the block. The head contains the spark plugs in SI engines and the fuel injectors in CI engines and some SI engines. Most modern engines have the valves in the head, and many have the camshaft(s) positioned there also (overhead valves and overhead cam).

n. Head gasket – Gasket which serves as a sealant between the engine block and head where they bolt together. They are usually made in sandwich construction of metal and composite materials. Some engines use liquid head gaskets. Intake manifold – Piping system which delivers incoming air to the cylinders, usually made of cast metal, plastic, or composite material. In most SI engines, fuel is added to the air in the intake manifold system either by fuel injectors or with a carburetor. Some intake manifolds are heated to enhance fuel evaporation. The individual pipe to a single cylinder is called a runner.

o. Main bearing– The bearings connected to the engine block in which the crankshaft rotates. The maximum number of main bearings would be equal to the number of pistons plus one, or one between each set of pistons plus the two ends. On some less powerful engines, the number of main bearings is less than this maximum.

p. Oil pan – Oil reservoir usually bolted to the bottom of the engine block, making up part of the crankcase. Acts as the oil sump for most engines.

q. Oil pump – Pump used to distribute oil from the oil sump to required lubrication points. The oil pump can be electrically driven, but is most commonly mechanically driven by the engine. Some small engines do not have an oil pump and are lubricated by splash distribution. Oil sump – Reservoir for the oil system of the engine, commonly part of the crankcase. Some engines (aircraft) have a separate closed reservoir called a dry sump.

r. Piston – The cylindrical-shaped mass that reciprocates back and forth in the cylinder, transmitting the pressure forces in the combustion chamber to the rotating crankshaft. The top of the piston is called the crown and the sides are called the skirt. The face on the crown makes up one wall of the combustion chamber and may be a flat or highly contoured surface. Some pistons contain an indented bowl in the crown, which makes up a large percentage of the clearance volume. Pistons are made of cast iron, steel, or aluminum. Iron and steel pistons can have sharper corners because of their higher strength. They also have lower thermal expansion, which allows for tighter tolerances and less crevice volume.

Aluminum pistons are lighter and have less mass inertia. Sometimes synthetic or composite materials are used for the body of the piston, with only the crown made of metal. Some pistons have a ceramic coating on the face.

s. Piston rings – Metal rings that fit into circumferential grooves around the piston and form a sliding surface against the cylinder walls. Near the top of the p usually two or more compression rings made of highly polished hard chrome steel. The purpose of these is to form a seal between the piston and cylinder walls and to restrict the high-pressure gases in the combustion chamber from leaking past the piston into the crankcase (blowby). Below the compression rings on the piston is at least one oil ring, which assists in lubricating the cylinder walls and scrapes away excess oil to reduce oil consumption.

t. Push rods – Mechanical linkage between the camshaft and valves on overhead valve engines with the camshaft in the crankcase. Many push rods have oil passages through their length as part of a pressurized lubrication system. Radiator – Liquid-to-air heat exchanger of honeycomb construction used to remove heat from the engine coolant after the engine has been cooled.

The radiator is usually mounted in front of the engine in the flow of air as the automobile moves forward. An engine-driven fan is often used to increase air flow through the radiator.

u. Spark plug – Electrical device used to initiate combustion in an SI engine by creating a high-voltage discharge across an electrode gap. Spark plugs are usually made of metal surrounded with ceramic insulation. Some modern spark plugs have built-in pressure sensors which supply one of the inputs into engine control. Speed control; cruise control – Automatic electric-mechanical control system that keeps the automobile operating at a constant speed by controlling engine speed. Starter – Several methods are used to start IC engines. Most are started by use of an electric motor (starter) geared to the engine flywheel. Energy is supplied from an electric battery. On some very large engines, such as those found in large tractors and construction equipment, electric starters have inadequate power, and small IC engines are used as starters for the large IC engines. First the small engine is started with the normal electric motor, and then the small engine engages gearing on the flywheel of the large engine, turning it until the large engine starts. Early aircraft engines were often started by hand spinning the propeller, which also served as the engine flywheel. Many small engines on lawn mowers and similar equipment are hand started by pulling a rope wrapped around a pulley connected to the crankshaft. Compressed air is used to start some large engines. Cylinder release valves are opened, which keeps the pressure from increasing in the compression strokes. Compressed air is then introduced into the cylinders, which rotates the engine in a free-wheeling mode. When rotating inertia is established, the release valves are closed and the engine is fired.

v. Supercharger– Mechanical compressor powered off of the crankshaft, used to compress incoming air of the engine. Valve is mounted at the upstream end of the intake system, used to control the amount of air flow into an SI engine. Some small engines and stationary constant-speed engines have no throttle.

w. Turbocharger Turbine – Compressor used to compress incoming air into the engine. The turbine is powered by the exhaust flow of the engine and thus takes very little useful work from the engine.

x. Valves – Used to allow flow into and out of the cylinder at the proper time in the cycle. Most engines use poppet valves, which are spring loaded closed and pushed open by camshaft action. Valves are mostly made of forged steel. Surfaces against which valves close are called valve seats and are made of hardened steel or ceramic. Rotary valves and sleeve valves are sometimes used, but are much less common. Many two-stroke cycle engines have ports (slots) in the side of the cylinder walls instead of mechanical valves.

y. Water jacket – System of liquid flow passages surrounding the cylinders, usually constructed as part of the engine block and head. Engine coolant flows through the water jacket and keeps the cylinder walls from overheating. The coolant is usually a water-ethylene glycol mixture.

z. Water pump – Pump used to circulate engine coolant through the engine and radiator. It is usually mechanically run off of the engine. Wrist pin – Pin fastening the connecting rod to the piston (also called the piston pin).

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