

2. Rotary engines

It is a type of internal combustion engine with a radial configuration of cylinders, but in this type of engine the cylinders and combustion chambers rotate with a driven shaft and the pistons are fixed to a stationary crankshaft, which is attached to the frame. The crankshaft is not in the center of the engine and thanks to this the pistons are moving in the cylinder. These types of engines were air cooled and mostly used in aircraft. A propeller is mounted to the front of the rotating crankcase. Rotary engines have usually odd number of cylinders, so every other piston is firing, which results in smooth running and the crankcase acts as a flywheel. Rotary engines have a good cooling, because of the rotating movement and the walls of the case can be thinner, resulting in better power-to-weight ratio. [1] [2] [3]

2.1. Millet motorcycle

At the end of the 18th century Félix Théodore Millet put a five-cylinder rotary engine into a front wheel of his tricycle (Figure 1). A few years later he put the same engine in the rear wheel of a bicycle. The crankshaft is fixed to the frame of the bicycle and the cylinders are rotating with the wheel. The rear fender is also a fuel tank and a surface carburetor and air filter are placed between the wheels. It is an air-cooled engine with a displacement of 1925 cm³ and 1,2 HP. It has a clutch with rotary handle, controlled valves and a suspension. [4] [5]

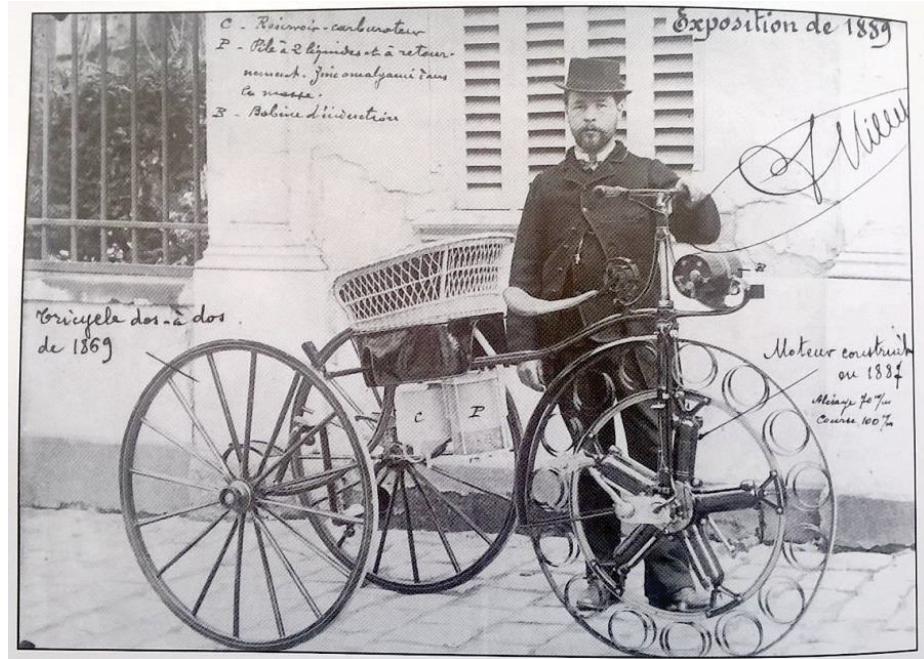


Figure 1 Millet's tricycle with rotary engine [5]

2.2. Hargrave's engine

In 1889 Lawrence Hargrave created a radial rotary engine with 3 cylinders (Figure 2). The cylinders rotate around its central axis while the crankshaft remains stationary. This engine is small, light, smooth running with good air cooling and has a great power-to-weight ratio. [6] [7]

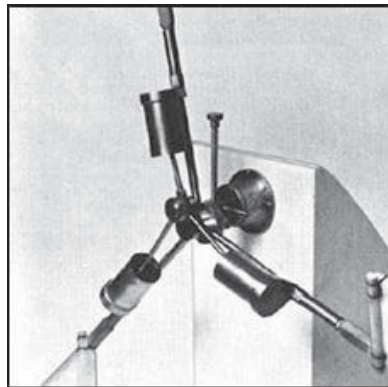


Figure 2 Lawrence Hargrave's engine [6]

2.3. Balzer's rotary engine

Stephen M. Balzer created a vehicle in 1894 (Figure 3). It has an air-cooled rotary engine with 3 cylinders which are placed under the seat in a quadricycle. The crankshaft is stationary while the crankcase is rotating. It is equipped with a 3-speed transmission. This engine was lately modified by Charles M. Manly to a 5-cylinder radial engine, which has the best specifications in terms of power-to-weight ratio. [8] [9] [10] [11]



Figure 3 1894 Balzer's Cyclecar [12]

2.4. Adams-Farwell engine

Fay Oliver Farwell designed a rotary engine with 3 cylinders. This engine was redesigned to a 5-cylinder engine (Figure 4), which was also air-cooled and piston-driven. This engine was mounted horizontally with a vertical stationary crankshaft attached to a frame in a car. Each cylinder has its own exhaust pipe. Which are connected to the side of the cylinder. The engine speed is controlled by a variable control valve, when you operate the time opening of the valve during the compression. The cylinders are between two discs, the top disc is for the intake pipe and the bottom disc is used for a beveled gear which transfer the power to the transmission. This type of engine is well lubricated, but at higher speeds the consumption of oil increases, because of the centrifugal force.

This engine was also used for experiments in a helicopter for its light weight. In 1909 a helicopter with these two engines successfully took off the ground with a person in it. [13] [14] [15]

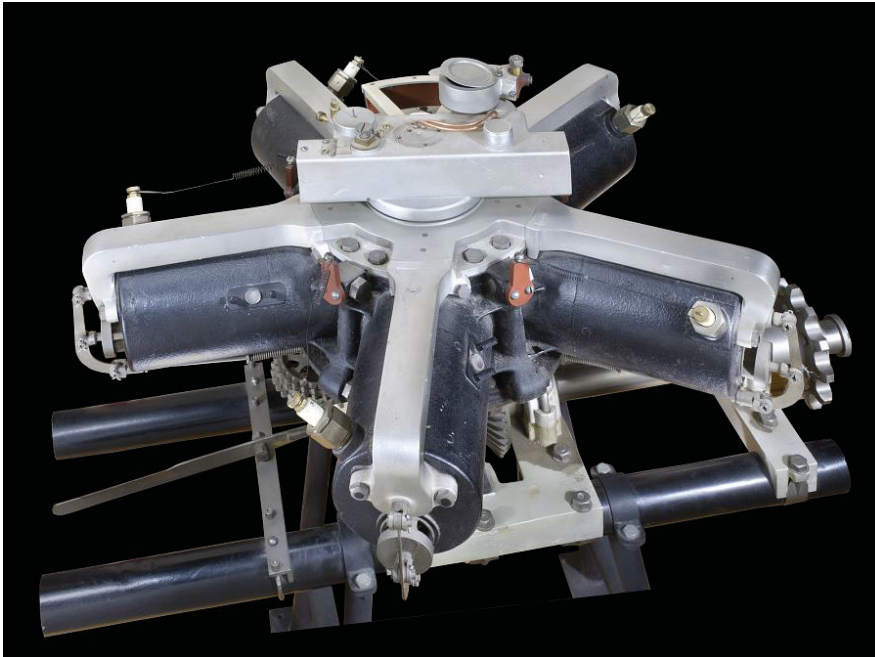


Figure 4 Adams-Farwell engine [13]

2.5. Gnome engine

The Seguin brothers developed the Gnome engine at the beginning of the 20th century. The first Gnome engine had two valves. The exhaust valve was placed in the cylinder head and the intake valve was placed in the piston crown. During the intake stroke the pressure in the cylinder drops and the intake valve opens, after the fresh charge with the fuel is drawn into the cylinder and after the pressure rises again the intake valve closes. Based on this principle the volumetric efficiency is lower because the intake valve opens later and closes sooner than in the ideal case.

In 1913 a new type of the Gnome engine was introduced, the Monosoupape engine (Figure 7). The inlet valve was removed from the piston crown. It has only one valve on the top of the cylinder, which is used for intake and exhaust. The fuel-air mixture is mixed and delivered through the hollow crankshaft and then through the small ports (Figure 5 and 6) to the combustion chamber. These ports are similar as in the two-stroke engine and they are placed on the bottom of the cylinder. During the power stroke the exhaust valve is opened before the piston uncovers the ports, which reduces the pressure inside the cylinder so when the ports are opened, the pressure inside the combustion chamber and in the crankcase is the same so no mixture is drawn into the cylinder. During the intake stroke the inlet valve closes before the piston reaches the ports, which results in a pressure decrease, so after the ports are opened the rich mixture is drawn into the combustion chamber.

The Gnome engine was light and reliable with good power output. On the other hand, the engine was consuming a lot of fuel and oil. Because of the gyroscopic effect the airplanes were hard to control, while turning left was easy, turning right was difficult.

There were a few variants of this engine, but mostly with 9 cylinders and some other companies used this principle of mixture delivery, but they used more conventional pushrod operated valves. Manufacturers such as Le Rhone, Clerget, Oberursel and Bentley. [16] [17] [18] [19] [20]



Figure 5 Ports in cylinder [19]

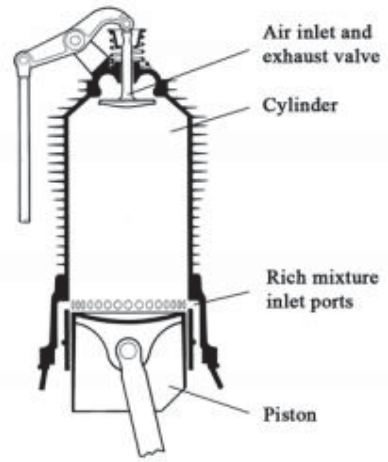


Figure 6 Gnome Monosoupape cylinder [16]

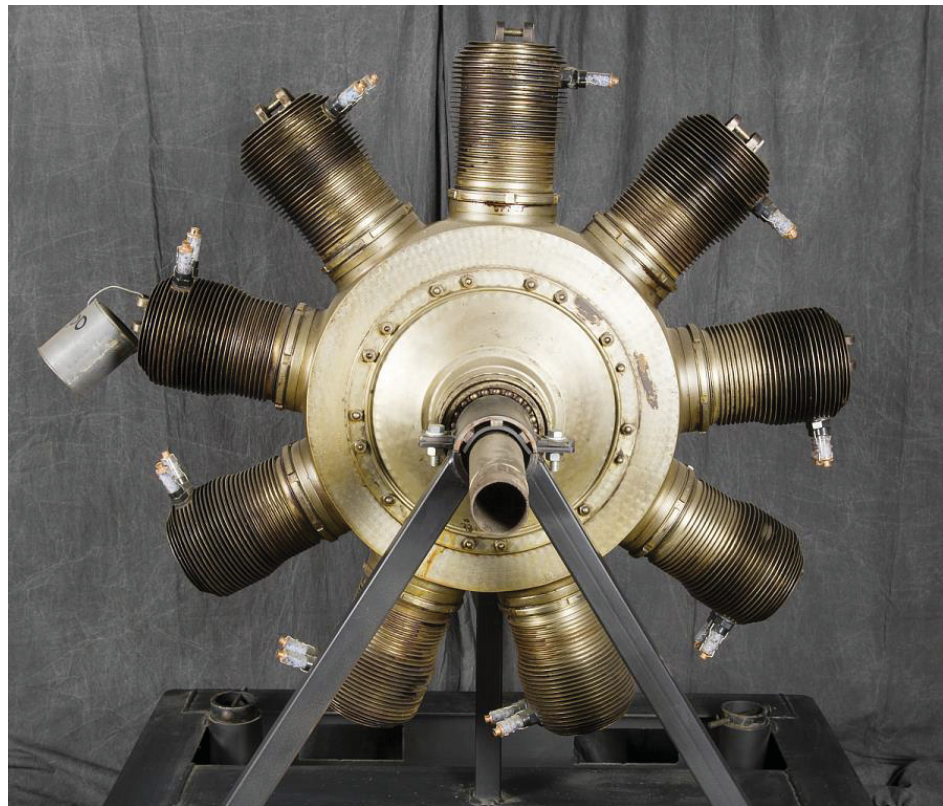


Figure 7 Gnome Monosoupape Type N engine [17]

2.6. Barry engine

In 1904 the Barry engine was introduced in the Barry motorcycle. It was a 2-cylinder supercharged opposed-piston rotary engine. The engine was placed between the knees of the driver. The mixture is getting into the crankcase through the hollow crankshaft and when the pistons are moving down, they act as a pump and the mixture is compressed and pushed into the storage chamber. This chamber is connected by pipes to the intake valve. [21] [22] [23]

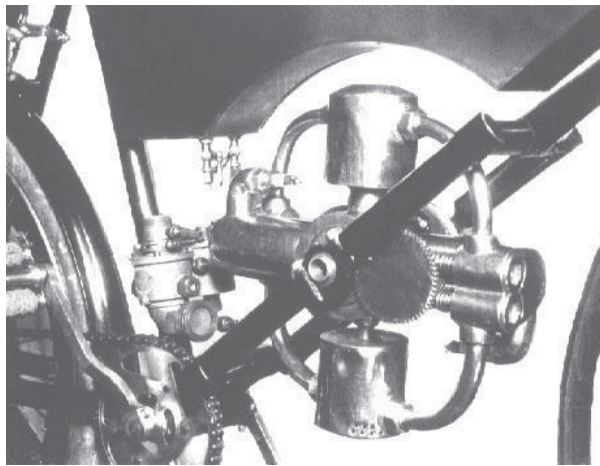


Figure 8 Barry engine [24]

2.7. Wankel engine

Felix Wankel created his first rotary engine in 1954 and was tested for the first time in 1957. The Wankel engine does not have usual pistons and cylinders like any other engine. It has an almost triangular rotor which rotates in an almost elliptical housing. The engine is equipped with 2 main gears. One small gear is mounted to the housing, while the second one is the inner gear inside the rotor. Thanks to this the rotor can turn on an eccentric shaft, which serves as an output shaft. The gear ratio is 1:3 which means that for one revolution of the rotor the eccentric shaft turns 3 times.

The three tips of the triangular rotor are in continuous contact with the closed housing. The rotor divides the closed chamber into 3 spaces. The three apexes of the rotor are fitted with seals to prevent leaking from one space to another. The volume of each chamber depends on the rotor position (Figure 9).

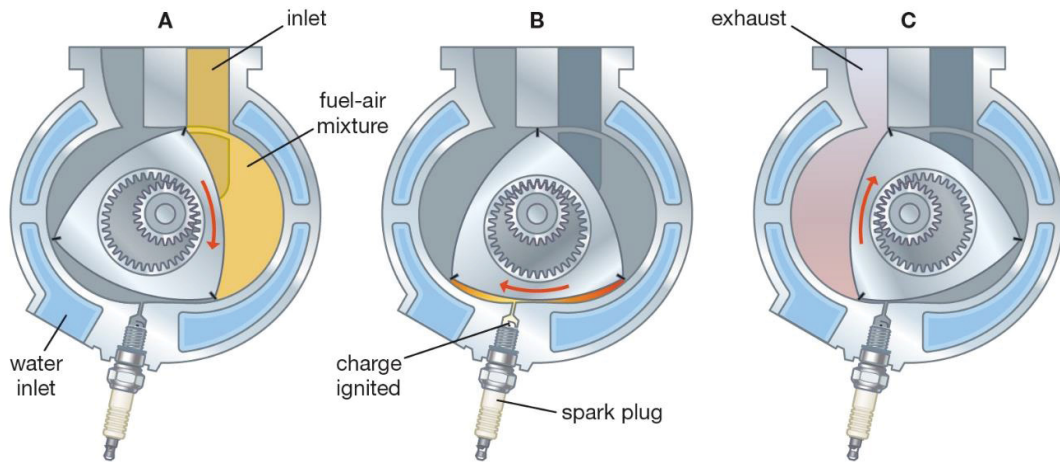


Figure 9 Wankel engine principle [26]

To produce power in a classic engine only one fourth of the crankshaft rotation is used, but in the Wankel engine it is more. There are 3 firing pulses per revolution of the rotor and the output shaft is three times faster, which results in one firing stroke per revolution of the output shaft.

The fuel is drawn into the engine through the intake port with a fresh charge. Not having valves results in lower weight of the engine and less moving components. The timing can be change by the shape of the intake and exhaust ports.

The lubrication and cooling of the rotor and its gears are done by oil circulation through the hollow rotor. Also, water is circulating through cooling jackets in the casing. A small amount of oil is added to the fuel to lubricate the three tips of the rotor. The sealing and wear are the major problem of the Wankel engine. Mazda modified the apex seal's shape to a cross-hollow seal with a cross-shaped hole near the apex of the seal, which brought improvements.

The Wankel engine is compact, smooth, without a big vibration, quite light, has a good power and lower costs for manufacturing. Also, it can operate at higher speeds than usual engines. [25] [26] [27] [28]

2.8. Bricklin-Turner Rotary Vee engine

This two-stroke engine was tested in the late 1970s. Inside the V-shaped case the V-shaped pistons are revolving. All the pistons are the same length, but because they are placed in the case with 135 degree, the distance from the top of the cylinder is different in each phase of the cycle (Figure 10). As the engine rotates and the piston is going down and making power, the exhaust gases are expelled through the port place at the bottom of the cylinder. Also, the fresh charge with the fuel is taken into the cylinder through another port operated by piston movement. The 2 output crankshafts are fixed to the rotating housing. It has 6 cylinders on each side, which results in 12 cylinders in total. This engine is light for its power and smooth running, because at every moment there are 6 cylinders out of 12 in a power stroke. [29] [30]

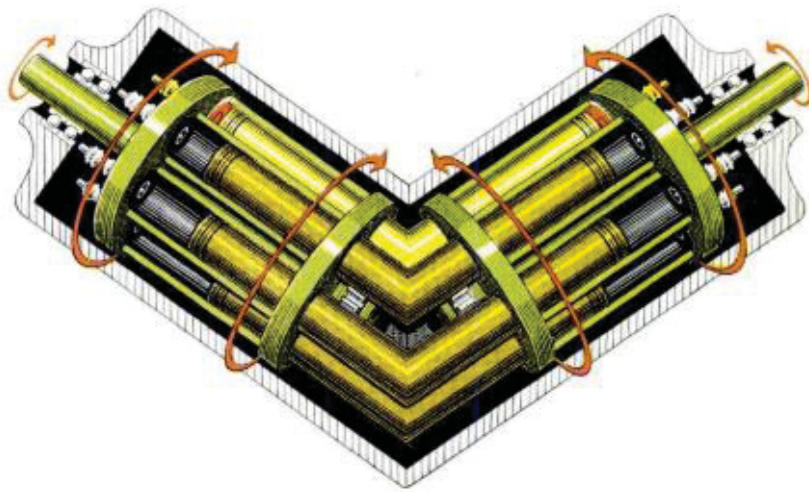


Figure 10 Rotary Vee engine [29]