# Wankel engine

The **Wankel engine** is a type of internal combustion engine which uses a rotary design to convert pressure into a rotating motion instead of using reciprocating pistons. Its four-stroke cycle is generally generated in a space between the inside of an oval-like epitrochoid-shaped housing and a roughly triangular rotor. This design delivers smooth high-rpm power from a compact, lightweight engine.

The engine was invented by engineer Felix Wankel. He began its development in the early 1950s at NSU Motorenwerke AG (NSU) before completing a working, running prototype in 1957. NSU then subsequently licenced the concept to other companies across the globe, who added more efforts and improvements in the 1950s and 1960s.

Because of their compact, lightweight design, Wankel rotary engines have been installed in a variety of vehicles and devices such as automobiles and racing cars, aircraft, go-karts, personal water craft, and auxiliary power units.

**History**

In 1951, the German engineer Felix Wankel began development of the engine at NSU (NSU Motorenwerke AG), where he first conceived his rotary engine in 1954 (DKM 54, "Drehkolbenmotor") and later the KKM 57 (the Wankel rotary engine, "Kreiskolbenmotor") in 1957. The first working prototype DKM 54 was running on February 1, 1957 at the NSU research and development department "Versuchsabteilung TX".
[ *[http://www.spiegel.de/auto/aktuell/0,1518,459789,00.html Wankel-Jubiläum: Warten aufs Wunder - Auto - SPIEGEL ONLINE - Nachrichten ]* ]

Considerable effort went into designing rotary engines in the 1950s and 1960s. They were of particular interest because they were smooth and quiet running, and because of the reliability resulting from their simplicity.

In the United States, in 1959 under license from NSU, Curtiss-Wright pioneered minor improvements in the basic engine design. In Britain, in the 1960s, Rolls Royce Motor Car Division at Crewe, Cheshire, pioneered a two-stage diesel version of the Wankel engine.
[ *[http://www.der-wankelmotor.de/Motoren/Rolls-Royce/rolls-royce.html R1 two stage compound diesel Wankel 1966]* . *Retrieved on September 27, 2008.* *de icon*]

Also in Britain, Norton Motorcycles developed a Wankel rotary engine for motorcycles, which was included in their Commander and F1; Suzuki also made a production motorcycle with a Wankel engine, the RE-5. In 1971 and 1972 Arctic Cat produced snowmobiles powered by 303 cc Wankel rotary engines manufactured by Sachs in Germany. Deere & Company designed a version that was capable of using a variety of fuels. The design was proposed as the power source for United States Marine Corps combat vehicles and other equipment in the late 1980s.
[*cite book*
*last = Hege*
*first = John B.*

*title = The Wankel Rotary Engine*
*publisher = McFarland*
*date = 2002*
*pages = 158-9*
*url = http://books.google.com/books?id=1UOduBQ8f7IC&pg=PA158&lpg=PA158&dq=Deere+%26+Company+Wankel+engine&source=web&ots=K3TRV__4Q-&sig=14mWkMQIbpb0Llmgl_pIT1xPpog&hl=en&sa=X&oi=book_result&resnum=1&ct=result#PPA158,M1*
*isbn = 9780786411771* ]

After occasional use in automobiles, for instance by NSU with their Ro 80 model, [ *[http://www.time.com/time/magazine/article/0,9171,899809,00.html "The Wankel Wager", "Time", September 08, 1967] , retrieved on September 27, 2008.*] Citroën with the M35, and GS Birotor using engines produced by Comotor, as well as abortive attempts by General Motors and Mercedes-Benz to design Wankel-engine automobiles, the most extensive automotive use of the Wankel engine has been by the Japanese company Mazda.

After years of development, Mazda's first Wankel engined car was the 1967 Cosmo. The company followed with a number of Wankel ("rotary" in the company's terminology) vehicles, including a bus and a pickup truck. Customers often cited the cars' smoothness of operation. However, Mazda chose a method to comply with hydrocarbon emission standards that, while less expensive to produce, increased fuel consumption, just before a sharp rise in fuel prices. Mazda later abandoned the Wankel in most of their automotive designs, but continued using it in their RX-7 sports car until August 2002 (RX-7 importation for North America ceased with the 1995 model year). The company normally used two-rotor designs, but the 1991 Eunos Cosmo used a twin-turbo three-rotor engine. In 2003, Mazda introduced the Renesis engine with the RX-8. The Renesis engine relocated the ports for exhaust and intake from the periphery of the rotary housing to the sides, allowing for larger overall ports, better airflow, and further power gains. The Renesis is capable of delivering Convert|238|hp|kW|0|abbr=on from its 1.3 L displacement with better fuel economy, reliability, and environmental friendliness than previous Mazda rotary engines. [ *[http://www.classicmazda.co.uk/1999_doc/rotary2.pdf rotary2.pdf Mazda's Rotary Engine for the Next Millennium RENESIS p.6 p.7 1999]* ]

Soviet automobile manufacturer AvtoVAZ also experimented with the design of Wankel-engine cars without the benefit of a license. [*cite book | last = Hege | first = John B. | title = The Wankel Rotary Engine | publisher = McFarland | date = 2002 | pages = 75 | isbn = 9780786411771* ] In 1978, they designed an engine with two-rotors and, in the 1980s, started delivering Wankel-powered VAZ-2106s and Ladas, mostly to security services; about 200 were made.
[ *[http://digilander.libero.it/cuoccimix/ENGLISH-automotorusse4(lada2).htm "LADA - part II" Autosoviet, undated] , retrieved on September 27, 2008.*] [ *[http://www.zr.ru/articles/39278/ "ЛИНИЯ ЖИЗНИ - ЭПИТРОХОИДА" 01.07.2001] , retrieved on September 27, 2008. ru icon*] Aviadvigatel, the Soviet aircraft engine design bureau, is known to have produced Wankel engines for aircraft and helicopters, though little specific information has surfaced.

Although many manufacturers licensed the design, and Mercedes-Benz used it for their C111 concept car, only Mazda has produced Wankel engines in large numbers. American Motors (AMC) was so convinced "...that the rotary engine will play an important role as a powerplant for cars and trucks of the future...", according to Chairman Roy D. Chapin Jr., the smallest U.S. automaker signed an agreement in February 1973, after a year's negotiations, to build Wankels

for both passenger cars and Jeeps, as well as the right to sell any rotary engines it produces to other companies. [ *[http://wardsautoworld.com/ar/auto_rearview_mirror_15/ Ward's Auto World Staff, "Rearview mirror", Ward's Auto World, February 1, 2000] . Retrieved on: January 25, 2008.*] [*cite book | last = Faith | first = Nicholas | title = Wankel: The Curious Story Behind the Revolutionary Rotary Engine | publisher = Stein and Day | date = 1975 | pages = 219 | isbn = 978-0812817195* ] It even designed the unique Pacer around the engine, even though by then, AMC had decided to buy the Wankel engines from GM instead of building them itself. However, GM's engines had not reached production when the Pacer was to hit the showrooms. Part of the demise of this feature was the rising fuel prices and concerns about proposed emission legislation in the United States. General Motors' Wankel did not comply with emission standards, so in 1974 the company canceled its development. This meant the Pacer had to be reconfigured to house AMC's venerable straight-sixes with rear-wheel drive.

**Naming**

Since its introduction in the NSU Motorenwerke AG (NSU) and Mazda cars of the 1960s, the engine has been commonly referred to as the "rotary engine", a name which has also been applied to several completely different engine designs.

**Design**

[

> orbital revolution around the eccentric shaft.]

In the Wankel engine, the four strokes of a typical Otto cycle occur in the space between a three-sided symmetric rotor and the inside of a housing. In the basic single-rotor Wankel engine, the oval-like epitrochoid-shaped housing surrounds a rotor which is similar to a Reuleaux triangle, a three-pointed curve of constant width, but with the bulge in the middle of each side a bit more flattened. From a theoretical perspective, the chosen shape of the rotor between the fixed apexes is basically the result of a minimization of the volume of the geometric combustion chamber and a maximization of the compression ratio, respectively. Thus, the symmetric curve connecting two arbitrary apexes of the rotor is maximized in the direction of the inner housing shape with the constraint not to touch the housing at any angle of rotation (an arc is not a solution of this optimization problem).

The central drive shaft, also called an eccentric shaft or E-shaft, passes through the center of the rotor and is supported by bearings. The rotor both rotates around an offset lobe (crank) on the E-shaft and makes orbital revolutions around the central shaft. Seals at the corners of the rotor seal against the periphery of the housing, dividing it into three moving combustion chambers. Fixed gears mounted on each side of the housing engage with ring gears attached to the rotor to ensure the proper orientation as the rotor moves.

The best way to visualize the action of the engine in the animation at left is to look not at the rotor itself, but the cavity created between it and the housing. The Wankel engine is actually a variable-volume progressing-cavity system. Thus there are 3 cavities per housing, all repeating the same cycle. Note as well that points A and B on the rotor and e-shaft turn at different speed,

point B moves 3 times faster than point A, so that one full orbit of the rotor equates to 3 turns of the e-shaft.

As the rotor rotates and orbitally revolves, each side of the rotor gets closer and farther from the wall of the housing, compressing and expanding the combustion chamber similarly to the strokes of a piston in a reciprocating engine. The power vector of the combustion stage goes through the center of the offset lobe.

While a four-stroke piston engine makes one combustion stroke per cylinder for every two rotations of the crankshaft (that is, one half power stroke per crankshaft rotation per cylinder), each combustion chamber in the Wankel generates one combustion stroke per each driveshaft rotation, i.e. one power stroke per rotor orbital revolution and three power strokes per rotor rotation. Thus, power output of a Wankel engine is generally higher than that of a four-stroke piston engine of similar engine displacement in a similar state of tune; and higher than that of a four-stroke piston engine of similar physical dimensions and weight.

Wankel engines also generally have a much higher redline than a reciprocating engine of similar power output, mostly because of the gearing from the rotor to the e-shaft; and also because the smoothness inherent in the circular motion, which eliminates dangerous vibration that can occur in reciprocating engines due to the nature of their operation.

National agencies that tax automobiles according to displacement and regulatory bodies in automobile racing variously consider the Wankel engine to be equivalent to a four-stroke engine of 1.5 to 2 times the displacement; some racing sanctioning bodies ban it altogether.
[ *[http://argent.fia.com/web/fia-public.nsf/C5F0793AC322A70CC125732900339466/$FILE/04F1_TECHNICAL_REGULATIONS.pdf? Openelement FIA Reglement 5 engine: Only 4-Stroke engine with reciprocating piston are permitted, see page 12]* . *Retrieved on: January 25, 2008.*]

**Engineering**

Felix Wankel managed to overcome most of the problems that made previous rotary engines fail by developing a configuration with vane seals that could be made of more durable materials than piston ring metal that led to the failure of previous rotary designs. [ *[http://www.freedom-motors.com/history.html Moller Freedom Motors formerly Outboard Marine Corporation (Evirude/Johnson) Rotary engines] Moller Skycar*]

Rotary engines have a thermodynamic problem not found in reciprocating four-stroke engines in that their "cylinder block" operates at steady state, with intake, compression, combustion, and exhaust occurring at fixed housing locations for all "cylinders". In contrast, reciprocating engines perform these four strokes in one chamber, so that extremes of "freezing" intake and "flaming" exhaust are averaged and shielded by a boundary layer from overheating working parts.

The boundary layer shields and the oil film act as thermal insulation, leading to a low temperature of the lubricating film (max ~200°C/400°F) on a water-cooled Wankel engine. This gives a more constant surface temperature. The temperature around the spark plug is about the same as the temperature in the combustion chamber of a reciprocating engine. With

circumferential or axial flow cooling, the temperature difference remains tolerable. [*1971 Rotary Engine Kenichi Yamamoto, Toyo Kogyo LTD p.67 Fig 5.10 and 5.11*] [*1981, Rotary Engine Kenichi Yamamoto, Toyo Kogyo LTD p.32 p.33 Fig3.39 Fig3.40 Fig3.41* ] [*Richard F. Ansdale Der Wankelmotor Motor Buch Verlag p.141-150* ] [*Wolf-Dieter Bensinger Rotationskolben - Verbrennungsmotoren Springer-Verlag Berlin Heidelberg ISBN 3-540-05886-9*]

Four-stroke reciprocating engines are less suitable for hydrogen. The hydrogen can misfire on hot parts like the exhaust valve and spark plugs. Another problem concerns the hydrogenate attack on the lubricating film in reciprocating engines. In a Wankel engine this problem is circumvented by using a ceramic apex seal against a ceramic surface: there is no oil film to suffer hydrogenate attack. Since ceramic piston rings are not available as of 2008, the problem remains with the reciprocating engine. The piston shell must be lubricated and cooled with oil. This substantially increases the lubricating oil consumption in a four-stroke hydrogen engine.

**Materials**

Unlike a piston engine, where the cylinder is cooled by the incoming charge after being heated by combustion, Wankel rotor housings are constantly heated on one side and cooled on the other, leading to high local temperatures and unequal thermal expansion. While this places high demands on the materials used, the simplicity of the Wankel makes it easier to use alternative materials like exotic alloys and ceramics. With water cooling in a radial or axial flow direction, with the hot water from the hot bow heating the cold bow, the thermal expansion remains tolerable. [*Kenichi Yamamoto Rotary Engine Side 32 cooling system*]

**ealing**

Early engine designs had a high incidence of sealing loss, both between the rotor and the housing and also between the various pieces making up the housing. Also, in earlier model Wankel engines carbon particles could become trapped between the seal and the casing, jamming the engine and requiring a partial rebuild. (This can be prevented in older Mazda engines by always allowing the engine to reach operating temperature.) It was common for very early Mazda engines to require rebuilding after convert|50000|mi|km. Modern Wankel engines have not had these problems for many years. Further sealing problems arise from the uneven thermal distribution within the housings causing distortion and loss of sealing and compression. This thermal distortion also causes uneven wear between the apex seal and the rotor housing, quite evident on higher mileage engines. Attempts have been made to normalize the temperature of the housings, minimizing the distortion, with different coolant circulation patterns and housing wall thicknesses.

**Fuel consumption and emissions**

Just as the shape of the Wankel combustion chamber prevents preignition, it also leads to incomplete combustion of the air-fuel charge, with the remaining unburned hydrocarbons released into the exhaust. While manufacturers of piston-engine cars were turning to expensive catalytic converters to completely oxidize the unburned hydrocarbons, Mazda was able to avoid this cost by enriching the air/fuel mixture and increasing the amount of unburned hydrocarbons

in the exhaust to actually support complete combustion in a 'thermal reactor' (an enlarged open chamber in the exhaust manifold) without the need for a catalytic converter, thereby producing a clean exhaust at the cost of some extra fuel consumption. World gasoline prices rose sharply at the time Mazda introduced their Wankel engine, making the cleaner exhaust/increased fuel consumption tradeoff an unwelcome one for consumers.Fact|date=December 2007

In Mazda's RX-8 with the Renesis engine, fuel consumption is now within normal limits while passing California State emissions requirements. The exhaust ports, which in earlier Mazda rotaries were located in the rotor housings, were moved to the sides of the combustion chamber. This approach allowed Mazda to eliminate overlap between intake and exhaust port openings, while simultaneously increasing exhaust port area. The Renesis engine even meets California's Low Emissions Vehicle or LEV standards.

**Advantages**

Wankel engines have several major advantages over reciprocating piston designs, in addition to having higher output for similar displacement and physical size.

Wankel engines are considerably simpler and contain far fewer moving parts. For instance, because valving is accomplished by simple ports cut into the walls of the rotor housing, they have no valves or complex valve trains; in addition, since the rotor is geared directly to the output shaft, there is no need for connecting rods, a conventional crankshaft, crankshaft balance weights, etc. The elimination of these parts not only makes a Wankel engine much lighter (typically half that of a conventional engine of equivalent power), but it also completely eliminates the reciprocating mass of a piston engine with its internal strain and inherent vibration due to repeated acceleration and deceleration, producing not only a smoother flow of power but also the ability to produce more power by running at higher rpm.

In addition to the enhanced reliability by virtue of the complete removal of this reciprocating stress on internal parts, the engine is constructed with an iron rotor within a housing made of aluminium, which has greater thermal expansion. This ensures that even a severely overheated Wankel engine cannot seize, as would likely occur in an overheated piston engine. This is a substantial safety benefit in aircraft use since no valves can burn out.

A further advantage of the Wankel engine for use in aircraft is the fact that a Wankel engine can have a smaller frontal area than a piston engine of equivalent power. The simplicity of design and smaller size of the Wankel engine also allows for savings in construction costs, compared to piston engines of comparable power output.

Of perhaps the most importance is that Wankel engines are almost immune to catastrophic failure. A Wankel that loses compression, cooling or oil pressure will lose a large amount of power, and will die over a short period of time; however, it will usually continue to produce some power during that time. Piston engines under the same circumstances are prone to seizing or breaking parts that almost certainly results in complete internal destruction of the engine and instant loss of power. For this reason Wankel engines are very well suited to aircraft. However, a

Wankel is extremely susceptible to damage from pre-ignition, also known as detonation or "knocking".Fact|date=July 2008

Due to a 50% longer stroke duration compared to a four stroke engine, there is more time to complete the combustion. This leads to greater suitability for direct injection. A Wankel rotary engine has stronger flows of air-fuel mixture and a longer operating cycle than a reciprocating engine, so it realizes concomitantly thorough mixing of hydrogen and air. The result is a homogeneous mixture, which is crucial for hydrogen combustion.
[ *[http://www.rx8club.com/attachment.php?attachmentid=112341&d=1198188722 RENESIS hydrogen rotary engine, p.2]* ]

**Disadvantages**

Although in two dimensions the seal system of a Wankel looks to be even simpler than that of a corresponding multi-cylinder piston engine, in three dimensions the reverse is the case. As well as the rotor apex seals evident in the conceptual diagram, the rotor must also seal against the chamber ends.

Piston rings are not perfect seals. Each has a gap in fact to allow for expansion. Moreover the sealing at the Wankel apexes is less critical, as leakage is between adjacent chambers on adjacent strokes of the cycle, rather than to the crankcase. However, the less effective sealing of the Wankel is one factor reducing its efficiency, confining its success mainly to applications such as racing engines and sports vehicles where neither efficiency nor long engine life are major considerations. In earlier models, the Wankel engines should never be started and run unless the engine has reached operating temperature; most such instances of jammed engines occur when a car is started and moved a few yards, e.g. from a garage to a driveway. In these situations it is better to push the car and not start the engine. This is due to the engine flooding with fuel and essentially "hydrolocking" the motor. This "flooding" is caused by the excess amount of fuel injected into the engine in its "cold" running circuit. The flooding issue has been largely fixed through changes in the ECU programming and a faster starter motor.Fact|date=June 2008

Compared to four stroke piston engines, the time available for fuel to be port injected into a Wankel engine is significantly shorter, due to the way the three chambers rotate. The fuel-air mixture cannot be pre-stored as there is no intake valve. Also the Wankel engine, compared to a piston engine, has 50% longer stroke duration.

The surface/volume-ratio problem is so complex that one cannot make a direct comparison between a reciprocating piston engine and a Wankel engine in relation to the surface/volume-ratio. The flow velocity and the heat losses behave quite differently. Surface temperatures behave absolutely differently; the film of oil in the Wankel engine acts as isolator. Engines with higher compression ratio have a worse surface/volume-ratio. The surface/volume-ratio of a Diesel engine is much worse than a gasoline engine, but Diesel engines are well known for a higher efficiency factor than gasoline engines. Thus we should compare engines with equal power: a naturally aspirated 1.3 liter Wankel engine with a naturally aspirated 1.3 liter four stroke reciprocating piston engine with equal power. But such a four stroke engine is not possible and needs twice the displacement for the same power as a Wankel engine. The extra or "empty"

stroke(s) we should not ignore, as a 4-stroke cylinder produces a power stroke only every other rotation of the crankshaft. In actuality, this doubles the real surface/volume-ratio for the four stroke reciprocating piston engine. [*ANSDALE, R. F. (1971). Der Wankelmotor Konstruktion u. Wirkungsweise. Stuttgart, Motorbuch-Verlag., p. 73, 91-92, 200, Verhältnis Oberfläche zu Volumen; German*]

The trailing side of the rotary engine's combustion chamber develops a squeeze stream which pushes back the flamefront. With the conventional two-spark-plug or one-spark-plug system and homogenous mixture, this squeeze stream prevents the flame from propagating to the combustion chamber's trailing side in the mid and high engine speed ranges. This is why there can be more carbon monoxide and unburnt hydrocarbons in a Wankel's exhaust stream. A side port exhaust, as is used in the Mazda Renesis, avoids this because the unburned mixture cannot escape. The Mazda 26B avoided this issue through a 3-spark plug ignition system. (As a result, at the Le Mans 24 hour endurance race in 1991, the 26B had significantly lower fuel consumption than the competing reciprocating piston engines. All competitors had only the same amount of fuel available, because of the Le Mans 24h limited fuel quantity rule.
[ *[http://www.deanq.com/stuff/rotary/r26b_paper.doc Mazda 26B 4-Rotor Rotary Engine for Le Mans] (4) 3-Plug Ignitions System*] )

All Mazda-made Wankel rotaries, including the new Renesis found in the RX8, burn a small quantity of oil by design; it is metered into the combustion chamber in order to preserve the apex seals. Owners must periodically add small amounts of oil, slightly increasing running costs—though it is still reasonable when compared to many reciprocating piston engines.

**Applications**

**Automobile racing**

In the racing world, Mazda has had substantial success with two-rotor, three-rotor, and four-rotor cars. Private racers have also had considerable success with stock and modified Mazda Wankel-engine cars, see video clip. [ *[http://www.metacafe.com/watch/88644/mazda_rx_3_triple_turbo/ Mazda RX-3 Triple Turbo in action (video clip)]* ]

The Sigma MC74 powered by a Mazda 12A engine was the first engine and team from outside Western Europe or the United States to finish the entire 24 hours of the 24 Hours of Le Mans race, in 1974. Mazda is the only team from outside Western Europe or the United States to have won Le Mans outright and the only non-piston engine ever to win Le Mans, which the company accomplished in 1991 with their four-rotor 787B (convert|2622|cc|cuin|0|abbr=on|disp=/- actual displacement, rated by FIA formula at convert|4708|cc|cuin|0|abbr=on|disp=/). The following year, a planned rule change at Le Mans made the Mazda 787B ineligible to race anymore. Mazda is also the most reliable finisher at Le Mans (with the exception of Honda, who has entered only three cars in only one year), with 67% of entries finishing.Fact|date=February 2008

The Mazda RX-7 has won more IMSA races in its class than any other model of automobile, with its one hundredth victory on September 2, 1990. Following that, the RX-7 won its class in the IMSA 24 Hours of Daytona race ten years in a row, starting in 1982. The RX7 won the

IMSA Grand Touring Under Two Liter (GTU) championship each year from 1980 through 1987, inclusive.

Formula Mazda Racing features open-wheel race cars with Mazda Wankel engines, adaptable to both oval tracks and road courses, on several levels of competition. Since 1991, the professionally organized Star Mazda Series has been the most popular format for sponsors, spectators, and upward bound drivers. The engines are all built by one engine builder, certified to produce the prescribed power, and sealed to discourage tampering. They are in a relatively mild state of racing tune, so that they are extremely reliable and can go years between motor rebuilds. [*http://www.starmazda.com/index.html*]

The Malibu Grand Prix chain, similar in concept to commercial recreational kart racing tracks, operates several venues in the United States where a customer can purchase several laps around a track in a vehicle very similar to open wheel racing vehicles, but powered by a small Curtiss-Wright rotary engine.

In engines having more than two rotors, or two rotor race engines intended for high-rpm use, a multi-piece eccentric shaft may be used, allowing additional bearings between rotors. While this approach does increase the complexity of the eccentric shaft design, it has been used successfully in the Mazda's production three-rotor 20B-REW engine, as well as many low volume production race engines. (The C-111-2 4 Rotor Mercedes-Benz eccentric shaft for the KE Serie 70, Typ DB M950 KE409 is made in one piece! Mercedes-Benz used split bearings.)

**Motorcycle engines**

From 1974 to 1977 Hercules produced a limited number of motorcycles powered by Wankel engines. [*http://www.der-wankelmotor.de/Motoraeder/Hercules/hercules.html Hercules W2000*] The motor tooling and blank apex seals was later used by Norton to produce the Norton Commander model in the early 1980s. [ *[http://www.der-wankelmotor.de/Motoraeder/Norton/Motorraeder_Triumph/motorraeder_triumph.html Thriumph-Norton Wankel] [http://translate.google.de/translate?u=http%3A%2F%2Fwww.der-wankelmotor.de%2FMotoraeder%2FNorton%2FMotorraeder_Triumph%2Fmotorraeder_triumph.html&sl=de&tl=en&hl=de&ie=UTF-8 Translation]* ]

The most common example of a Wankel-powered motorcycle, however, was the Suzuki RE5, produced in 1975 and 1976. This 500cc (actual) displacement motorcycle could have been a great touring bike except for the poor fuel mileage of 32-36 mpg. Examples can still be found on auction sites.Fact|date=May 2008

**Aircraft engines**

The first Wankel rotary-engine aircraft was the experimental Lockheed Q-Star civilian version of the United States Army's reconnaissance QT-2, basically a powered Schweizer sailplane, in 1968 or 1969. It was powered by a 185 hp (138 kW) Curtiss-Wright RC2-60 Wankel rotary engine. [ *[http://www.der-wankelmotor.de/Motoren/Curtiss_Wright/curtiss_wright.html Curtiss & Wright ]* ]

Aircraft Wankels have made something of a comeback in recent years. None of their advantages have been lost in comparison to other engines. They are increasingly being found in roles where their compact size and quiet operation is important, notably in drones, or UAVs. Many companies and hobbyists adapt Mazda rotary engines (taken from automobiles) to aircraft use; others, including Wankel GmbH itself, manufacture Wankel rotary engines dedicated for the purpose. [*http://members.aol.com/rotaryroster/index.html?f=fs The Aviator's Rotary Engine Roster* ] [ *[http://www.uavenginesltd.co.uk/ UAV Engines Ltd]* ] One such use are the "Rotapower" engines in the Moller Skycar M400.

Wankel engines are also becoming increasingly popular in homebuilt experimental aircraft, due to a number of factors.Fact|date=May 2008 Most are Mazda 12A and 13B automobile engines, converted to aviation use. This is a very cost-effective alternative to certified aircraft engines, providing engines ranging from 100 to 300 horsepower at a fraction of the cost of traditional engines. These conversions first took place in the early 1970s. With a number of these engines mounted on aircraft, as of 10 December 2006 the National Transportation Safety Board has only seven reports of incidents involving aircraft with Mazda engines,Fact|date=February 2008 and none of these is of a failure due to design or manufacturing flaws. During the same period they have issued several thousand reports of broken crankshafts and connecting rods, failed pistons and incidents caused by other components which are not found in the Wankel engines. Rotary engine enthusiastsWho|date=May 2008 derisively refer to piston aircraft engines as "reciprosaurs", and point out that their designs have remained essentially unchanged since the 1930s, with only minor differences in manufacturing processes and variation in engine displacement.

Peter Garrison, Contributing Editor for "Flying" magazine, has said that "the most promising engine for aviation use is the Mazda rotary." Mazdas have indeed worked well when converted for use in homebuilt aircraft. However, the real challenge in aviation is producing FAA-certified alternatives to the standard reciprocating engines that power most small general aviation aircraft. Mistral Engines, based in Switzerland, is busy certifying its purpose-built rotaries for factory and retro-fit installations on certified production aircraft. With the G-190 and G-230-TS rotary engines already flying in the experimental market, Mistral Engines hopes for FAA and JAA certification in 2007 or early 2008. Mistral claims to have overcome the challenges of fuel consumption inherent in the rotary, at least to the extent that the engines are demonstrating specific fuel consumption within a few points of reciprocating engines of similar displacement. While fuel burn is still marginally higher than traditional engines, it is outweighed by other beneficial factors. [ *[http://www.mistral-engines.com/index_files/Page599.htm Technology - Mistral Engines ]* ] [ *[http://www.mistral-engines.com/docs/weightchart.jpgMistral Engines - Error kernel (20) ]* ]

Since Wankel engines operate at a relatively high rotational speed with relatively low torque, propeller aircraft must use a Propeller Speed Reduction Unit (PSRU) to keep conventional propellers within the proper speed range. There are many experimental aircraft flying with this arrangement.

**Other uses**

Small Wankel engines are being found increasingly in other roles, such as go-karts, [ *[http://www.aixro.de/ aixro Kart Engines ]* ] [*http://www.italsistem.com/saetta-eng.htm Italsystem*

*Wankel*] personal water craft and auxiliary power units for aircraft. [ *[http://www.der-wankelmotor.de/Motoren/UAV/Pats/pats.html Pats APU]* ] [ *[http://www.l3com.com/products-services/productservice.aspx?type=p&id=124 High-power density rotary diesel engine.. as well as Auxiliary Power Units.]* ] The Graupner/O.S. 49-PI is a 1.27 hp (947 W) 5 cc Wankel engine for model airplane use which has been in production essentially unchanged since 1970; even with a large muffler, the entire package weighs only 380 grams (13.4 ounces). [ *[http://www.der-wankelmotor.de/Motoren/Graupner/graupner.html Graupner/OS-Wankel]* ]
[ *[https://shop.graupner.de/webuerp/servlet/AI?ARTN=2717 OS MAX RE 49 PI-II]* ]

The simplicity of the Wankel makes it ideal for mini, micro, and micro-mini engine designs. The MicroElectroMechanical Systems (MEMS) Rotary Engine Lab at the University of California, Berkeley has been developing Wankel engines of down to 1 mm in diameter with displacements less than 0.1 cc. Materials include silicon and motive power includes compressed air. The goal is to eventually develop an internal combustion engine that will deliver 100 milliwatts of electrical power; the engine itself will serve as the rotor of the generator, with magnets built into the engine rotor itself. [ *[http://www-bsac.eecs.berkeley.edu/groups/bmad/mems_reps/home.htm MEMS Rotary Engine Power System]* ] [ *[http://www.me.berkeley.edu/cpl/media/memsff01.pdf Berkley-MEMS-Wankel engine]* ]

The largest Wankel engine was built by Ingersoll-Rand; available in 550 hp (410 kW) one rotor and 1100 hp (820 kW) two rotor versions, displacing 41 liters per rotor with a rotor approximately one meter in diameter, it was available between 1975 and 1985. It was derived from a previous, unsuccessful Curtiss-Wright design, which failed because of a well-known problem with all internal combustion engines: the fixed speed at which the flame front travels limits the distance combustion can travel from the point of ignition in a given time, and thereby the maximum size of the cylinder or rotor chamber which can be used. This problem was solved by limiting the engine speed to only 1200 rpm and the use of natural gas as fuel; this was particularly well chosen, as one of the major uses of the engine was to drive compressors on natural gas pipelines. [ *[http://www.der-wankelmotor.de/Motoren/Ingersol_Rand/ingersol_rand.html Ingersol Rand]* ]

**Non-internal combustion**

Aside from being used for internal combustion engines, the basic Wankel design has also been utilized for air compressors, and superchargers for internal combustion engines, but in these cases, although the design still offers advantages in reliability, the basic advantages of the Wankel in size and weight over the four-stroke internal combustion engine are irrelevant. In a design using a Wankel supercharger on a Wankel engine, the supercharger is twice the size of the engine.

Perhaps the most exotic use of the Wankel design is in the seat belt pre-tensioner system [ *[http://www.google.com/patents?vid=USPAT5485970&id=N6QhAAAAEBAJ&printsec=abstract&zoom=4&dq=5485970#PPA1-IA1,M1 TRW Wankel pre-tensioner system]* ] of some Mercedes-Benz cars. [*cite web*
*url=http://www.mercedestechstore.com/pdfs/507%20Systems%20I/507%20HO%20SRS%20(GC%20ICC)%2010-30-02.pdf*
*title=Occupant Safety Systems*
*author=Mercedes-Benz*
*pages=11-12*

*accessdate=2007-12-31*] In these cars, when deceleration sensors sense a potential crash, small explosive cartridges are triggered electrically and the resulting pressurized gas feeds into tiny Wankel engines which rotate to take up the slack in the seat belt systems, anchoring the driver and passengers firmly in the seat before any collision. [*cite web*
*url=http://www.google.com/patents?vid=USPAT5485970&id=N6QhAAAAEBAJ&dq=5485970*
*title=Seat belt pretensioner*
*author=Charles E. Steffens, Jr*
*pages=*
*accessdate=2007-04-11*]

**See also**

* Mazda Wankel engine
* Pistonless rotary engine
* Jonova engine
* RKM engine
* Gunderson Do-All Machine

**Notes**

**References**

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**External links**

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* [*http://www.carbibles.com/fuel_engine_bible.html The Fuel and Engine Bible*] - A good resource for different engine types and fuels
* [*http://www.rebuildingrotaryengines.com Rebuilding Rotary Engines Videos*] - Informational Videos on rebuilding a rotary engine
* [*http://www.rotaryeng.net/ The Mazda Wankel Rotary Engines For Aircraft Website*]
* [*http://www.rotaryengineillustrated.com/ Rotary Engine Illustrated*] - Animations of Engines, Evolution of Engine Parts, Pieces of Engine Pieces
* [*http://www.karting1.co.uk/wankel-kart-test.htm Wankel Kart Engine in Action on Video*]
* [*http://www.howstuffworks.com/rotary-engine.htm/printable How Wankel Engines Work*]
* [*http://www.keveney.com/Wankel.html Animated Engines: Wankel Engine*]
* [*http://www.aktuell-online.info/srv/wankel/englisch/ Wankel's biography and engine*]
* [*http://www.citroenet.org.uk/miscellaneous/wankel/wankel1.html How and why an engine must rev smoothly*]
* [*http://www.wankelsupertec.de/index.htm Wankel Supertec*] Spark ignition Diesel Wankel
* [*http://www.youtube.com/watch?v=YNU1wBhIVWc Wankel rotary engine*]
* [*http://www.deanq.com/stuff/rotary/r26b_paper.doc Mazda 26B 4-Rotor Rotary Engine for Le Mans*] DOC document