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An Analytical Comparison and Contrast of the Automobile Rotary Combustion Engine and the Reciprocating Engine

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Abstract

The ReCE, although possessing many good characteristics as a motive source of power, is still somewhat far from achieving the desired efficiency in man's quest for better economical and practical means of transportation, due to the lack of higher speeds and its inability to burn all of the fuel admitted as a result of its large number of moving parts, their weight, size and reciprocating motion.

The design and development of the RCE has overcome many of the above problems inherent in the ReCE, and, therefore, has the potential of replacing the ReCE as the major source of automotive power and contribute to the conservation of the world's energy resources by making transportation a more viable and economic possibility for the future.

In researching the problem, the author will review previous literature on the development, operation, and application of the ReCE and RCE. Visits will be made to industry to interview service personnel and observe service and safety methods. The author will dismantle a RCE and ReCE and examining their design and wear characteristics.

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An Analytical Comparison and Contrast of the Automobile Rotary Combustion Engine and the Reciprocating Engine

A Research Paper for Presentation
to the Graduate Committee
of the
Industrial Technology Department
University of Northern Iowa

In Partial Fulfillment of the Requirements for
the Non-Thesis Master of Arts Degree

by
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Approved by:

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Date

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CHAPTER I

INTRODUCTION

Man's ability to cope with heavy loads and long distances has driven him to seek more efficient ways of overcoming these demands without expending much physical energy. In his search to achieve this phenomenon, much success was accomplished through the taming of suitable animals, enabling heavy loads to be carried greater distances at faster speeds, and the use of sledges, until the invention of the wheel, on which carts were constructed to carry even heavier loads.

The development of the steam engine during the eighteenth and nineteenth century led to its application to the driving of vehicles, but was more suited to the railroad than to road vehicles.

It was the successful development of the light-speed internal combustion reciprocating engine toward the end of the nineteenth century that really opened up the way to the power driven road vehicle. This source of power is the most convenient so far developed, deriving its power from the burning of fuel inside the engine itself, unlike the steam engine which requires a boiler to generate the steam, and the electric motor which needs an external supply of electrical energy for its operation.

The reciprocating combustion engine, (ReCE), has met to a large extent many of the physical and social requirements of transport and industrial growth. Nevertheless, its inability to completely burn the fuel admitted, makes it an economical failure, and a threat to the world's energy resources and the ecology of the environment.

The invention and development of the rotary combustion engine, (RCE), because of its mechanical design, has the potential of overcoming most of the above deficiencies inherent in the reciprocating engine. It should, therefore, be considered as a more viable means of motive power, replacing the very popular reciprocating engine.

Statement of the Problem

The ReCE, although possessing many good characteristics as a motive source of power, is still somewhat far from achieving the desired efficiency in man's quest for better economical and practical means of transportation, due to the lack of higher speeds and its inability to burn all of the fuel admitted as a result of its large number of moving parts, their weight, size and reciprocating motion.

The design and development of the RCE has overcome many of the above problems inherent in the ReCE, and, therefore, has the potential of replacing the ReCE as the major source of automotive power and contribute to the conservation of the world's energy resources by making transportation a more viable and economic possibility for the future.

In researching the problem, the author will review previous literature on the development, operation, and application of the ReCE and RCE. Visits will be made to industry to interview service personnel and observe service and safety methods. The author will dismantle a RCE and ReCE and examining their design and wear characteristics.

Importance of the Problem

The need to conserve the world's energy resources and maintain or improve the ecology and its environment is becoming more evident. This can be seen by the drive of technologists and governments to improve, develop or invent ways to successfully convert this energy more efficiently and effectively into motive power.

Limitations of the Problem

The applications of the RCE as a power source are wide and varied. It's the intention of this study to concentrate primarily on the history, the development and the principles of operation of the Wankel RCE as they compare and contrast with the internal combustion reciprocating engine.

The resulting unit of the study will be designed from materials, equipment and information available locally, from industries, the Department of Industrial Technology at the University of Northern Iowa, library resources and owners of rotary engines. The study will be limited to the undergraduate student, industrial personnel, vehicle owners, and any other interested bodies. Included in the study will be an instructional unit suitable as a guide for demonstrating and teaching the fundamental differences between the ReCE and the RCE.

Definition of Terms

Balance: Having equal weight on each side of a supporting point. No change in the position of the center of gravity when a part is in motion.

BDC: Bottom dead center. The lowest position of the piston.

BMEP: Brake mean effective pressure. The average pressure within a cylinder during the power stroke that would produce the horsepower determined on a dynamometer.

Centrifugal: A force in a direction away from turning center of an object moving in a curved path.

Combustion: A rapid chemical reaction between air and fuel releases heat.

Compression Ratio: A ratio between the volume above the piston when it is at bottom center to the volume above the piston when it is at top center.

Crankshaft: The part of an engine that changes the reciprocating motion of the pistons into rotating motion.

Cycle: A complete circle back to the beginning. In engines, a series of events; intake, compression, power, and exhaust.

Eccentric: Two or more circles, one surrounding the other and each having a different center.

Efficiency: Obtaining the highest possible output for a given input.

Engine: A prime power source.

Epitrochoid: The locus of a point on the radius of a circle which is rolling, without slip, round the outside of a base circle.

Flywheel: A weighted disc on a crankshaft that provides inertia to carry the crankshaft between power pulses.

Four-Stroke Cycle: An engine cycle consisting of a downward intake stroke, an upward compression stroke, a downward power stroke and an upward exhaust stroke. The cycle then repeats on the next four strokes.

Horsepower: A valve calculated from engine torque and rotating speed. One horsepower equals 33,000 ft-lbs per min.

Idle: Running freely with no power or load being transferred.

IMEP: Indicated mean effective pressure. The average indicated pressure in the combustion chamber during the power stroke as measured on a pressure-volume indicator card graph.

Inertia: The tendency of a body at rest to stay at rest or when moving to keep moving.

Journal: The surface on which a bearing operates.

Mean Effective Pressure: The calculated average pressure in the combustion chamber during the power stroke.

Mechanical Efficiency: Calculated as brake horsepower divided by indicated horsepower.

Oil Seal: A device to keep oil from leading out of a compartment. It usually refers to a dynamic seal around a rotating shaft.

Performance: Effectively operating at the maximum designed specification.

Piston: A short cylinder made to fit closely in a hollow cylinder.

Port: An opening through which liquids or gases flow.

Radiator: A thin metal heat transfer device that lowers the temperature of the engine coolant by air flow.

Reciprocate: Move back and forth.

Rotor: The rotating member of a rotor.

Rotary Engine: An engine in which its major components follows circular motion.

Scavenge: Clean out or remove either exhaust gas or sump oil.

Stroke: Piston movement in one direction, from one extreme to the other.

Surface to Volume Ratio: The ratio of all of the combustion chamber surfaces to its contained volume. The surface to volume ratio reduces as the shape approaches a sphere.

Thermal Efficiency: The equivalent heat energy of the brake horsepower produced divided by the total heat energy in the fuel used.

Torque: The twisting force on a shaft in lb-ft.

Turbine: A finned disc that is made to rotate by the force of a high velocity fluid stream.

Turbine Wheel: A wheel-shaped turbine.

Valve: A device that will open or seal an opening.

Valve Guide: A sized hole in the head to hold the valve in position.

Valve Seat: The surface of the head on which the valve rests when the port is closed off.

Variable Displacement: A chamber whose effective volume changes as it operates.

Vehicle: A self-propelled controllable conveyance.

Volumetric Efficiency: The actual air consumed by an engine compared to the cubic displacement of the engine.

CHAPTER II

HISTORICAL INFORMATION

The history of the rotary combustion engine, (RCE), may be seen as part of the continuous development of the internal combustion engine, (ICE). Its basic principles of operation are similar in theory, though, differing widely in its motion and structure.

The author felt it would be appropriate in the compilation of the historical facts in the development of the Wankel RCE to reflect on the invention and growth of the reciprocating combustion engine, (ReCE). It is from the fundamental principles of this engine that the Wankel RCE derived its cycle of operation.

Research has shown that "the first ICE was made by a Frenchman, Etienne Lenoir, in 1860. It ran on coal gas, but was not efficient as the gas was not compressed before it was ignited." (Hillier and Pittuck, 1975, p. 44.)

In 1875, a German engineer, Dr. N. A. Otto, took out a patent describing a method of carrying out the cycle. This method was identical to a previous patent by a Frenchman, Alphouse, Bean de Rochas. In this design, four strokes of a piston working in a cylinder was employed to complete the cycle of operation known as the Otto cycle. These were: inlet, compression, power and exhaust.

Other forms of motive power were being developed with the RCE. The electric car had reached equal status with that of the steam propelled vehicle, and all three sources of power were fairly even in prominence.

The early part of the twentieth century saw the petrol engine taking over the market due mainly to the bulk and plumbing problems of the steam engine and the lack of power of the electric motor.

This popularity of the ReCE continued and after a century of development, the conventional automobile engine became extremely versatile in many vehicle applications. The continuation of this growth saw bigger and more powerful engines, until the automobile was proved to be a major contributor to the photochemical smog, and there was talk of fuel shortage.

Pressures were brought to bear on the automobile manufacturers to find ways to solve the exhaust and other type of engine emissions. Drastic changes were made in engine design which reduced the horsepower, efficiency and fuel economy by 50 percent on some vehicles.

These measures to some extent halted the fuel wastage, but more fuel was being consumed due to engine modifications and the dramatic increase in vehicle sales. The piston engine was seen to be unsatisfactory and manufacturers were considering possible replacements to solve the high petrol consumption and pollution problems. "Car manufacturers and owners began taking great interest in the small car and by mid summer 1973, sales of small cars captured some 40 percent of the new car market." (Dark, 1974, p. 43.)

Among the imported small cars, Mazda was able to offer something different, a small, inexpensive RCE originally designed by the German inventor, Felix Wankel.

The Wankel RCE was not the first engine of its type to be developed. Felix Wankel was one of many engineers who saw the potential of the RCE. It was in the 1920's that he started development on the RCE, and it was in this period that other RCE's were attempted by other engineers and some became working engines.

The Eupene Kanertz, (German), engine with vane type rotors, resembling a pie with wedge-shaped pieces cut out of it, revolved in a circular chamber. Fuel mixture was compressed between the vanes, ignited, driving the vanes apart. The Trangott Tschudi, (Swiss), engine had four curved pistons that revolved inside a closed track called a toroid. The gasses were compressed between the pistons, ignited and expanded forcing the pistons apart.

The largest successful development of the RCE has been the eccentric rotor, shaped like a triangle and geared to move inside a housing having the outline of an epitrochoid. This design is used by Wankel, and manufactured by many engine makers.

The rotation of the rotor on the eccentric shaft in the epitrochoid performs the four strokes in the cycle of operations. Fuel is admitted to the working chamber, it's compressed, ignited, and the burnt mixture is released in readiness for another cycle of operation.

The development of the Wankel RCE, in comparison with the ReCE, is relatively new. Listed below are some of the key factors in its development:

1934	Wankel	Designs a functional rotary-piston engine in cooperation with BMW.
1951		First meetings between the TES Lindau (Lindau Research and Development Center) and the NSU Research Department. NSU is interested in the types of seals Felix Wankel has developed over the years for

	rotary-valve engines. Wankel's invention, sealing chambers which are not round, is an important factor for the development of rotary piston engines.
March 5-8, 1954	Felix Wankel, actively supported by NSU since the beginning of the year, discovers the ability of a three-cornered rotor to perform a volume change suitable for a four-stroke engine within a housing of appropriate shape.
April 13, 1954	After locations for inlet and exhaust ports are fully defined, the four-stroke capability of Felix Wankel's new engine concept is confirmed. First concepts show rotor and rotor housing revolving about their individual centers in the DKM manner.
February 1, 1957	The first NSU/Wankel engine, the DKM 54, is run for the first time in Neckarsulm, West Germany.
October 21, 1958	Curtiss-Wright is licensed by NSU/Wankel to develop and produce the Wankel engine.
November 23, 1959	At a press conference in New York, Curtiss-Wright makes public for the first time the existence of the NSU/Wankel engine.
1960	During the year, Curtiss-Wright completes and runs the first multi-bank Wankel engine, the RC4-60.

October 12, 1960	Toyo Kogyo and NSU/Wankel initial an agreement for cooperation in Wankel engine development.
1961	In the course of the year the first two-bank Wankel engines are built and run: the Curtiss-Wright RC2-602-A1 and the NSU KKM 2x300.
Early 1962	Single-bank experimental Wankel engine installed and tested in a car for the first time by Toyo Kogyo.
August, 1963	Toyo Kogyo completes the first prototype of the Mazda 110S sports car, powered by a two-bank Wankel engine.

(Ludvigsen, 1973, pp. 100-103.)

CHAPTER III

TECHNICAL INFORMATION

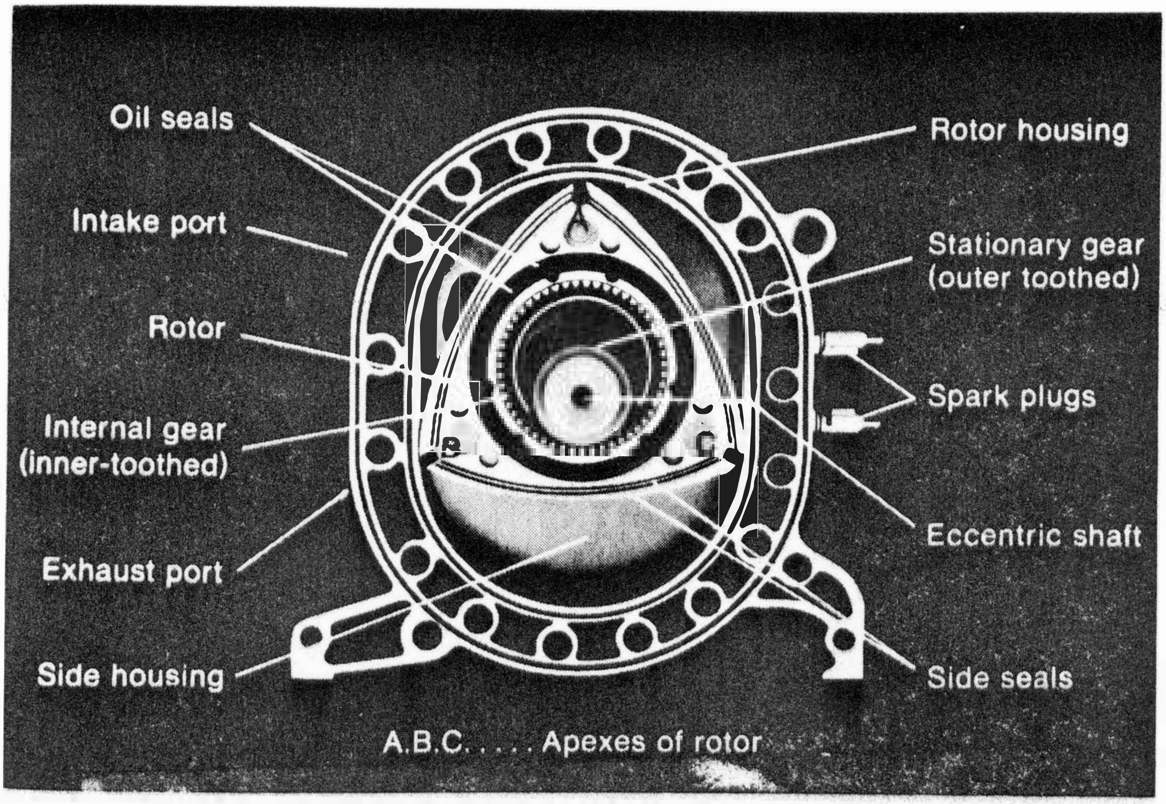
Main Components

The Wankel rotary combustion engine, (RCE), works on the principle of the four-stroke cycle, but employs only rotating parts consisting of three main components: a housing, a rotor and an eccentric shaft. See Figure 1.

The rotor housing. The rotor housing is the basic component of the RCE. It is made of an aluminum alloy casting with a shallow bore and epitrochoidal in shape. See Figure 2. The rotor housing is sandwiched between two side housings forming an airtight seal. This arrangement functions correspondingly to the cylinders and cylinder head of the reciprocating combustion engine, (ReCE).

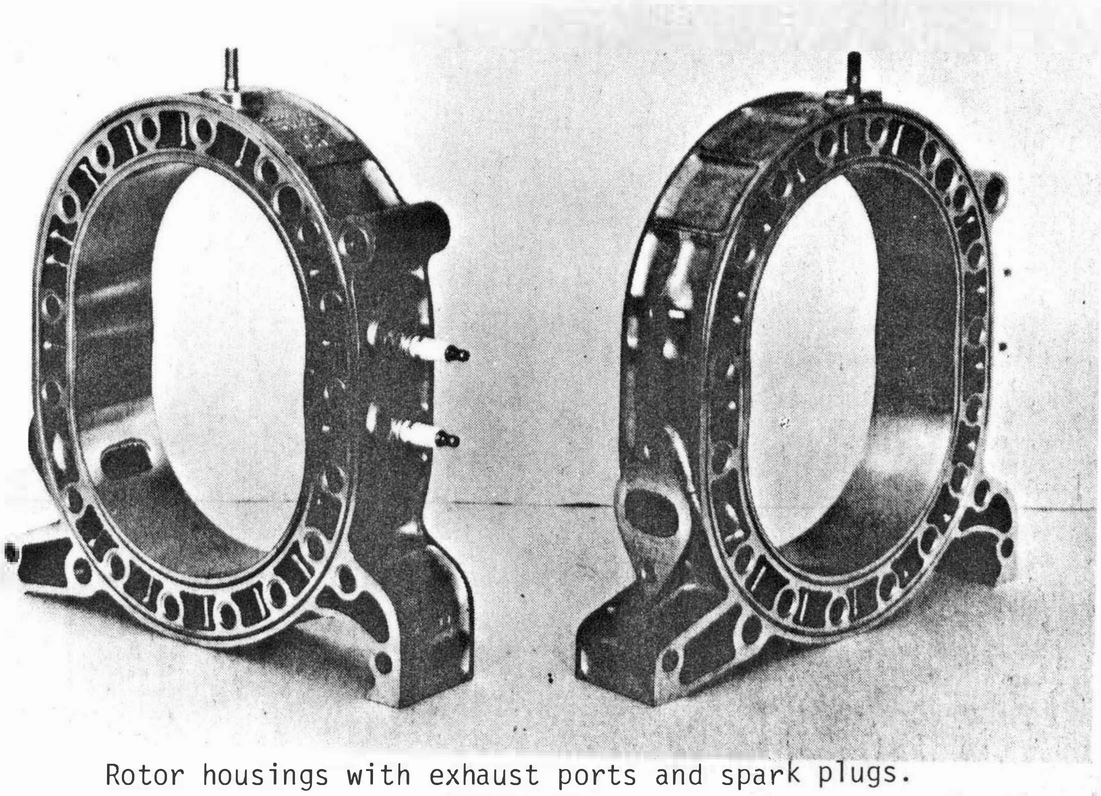
The rotor. The rotor is made of special cast iron functioning correspondingly with the piston in the ReCE. The rotor is triangular in shape with curved sides and flanks. Seals are fitted on the working pieces and sides of the rotor to secure airtightness between the working chambers, functioning similar to the piston rings in the ReCE. Indented on each flank of the rotor are combustion chamber recesses. The rotor is internally geared and engages on one side to a fixed gear on the housing. A pressed fit bearing in the rotor is mounted on an eccentric shaft carried on bearings coaxial with the center of the housing bore.

Side housing. Two side housings, finished to a flat surface, enables sliding motion of the rotor against the housing. When two rotors



The main components of a Mazda Wankel rotary engine.

Figure 1



Rotor housings with exhaust ports and spark plugs.
Figure 2

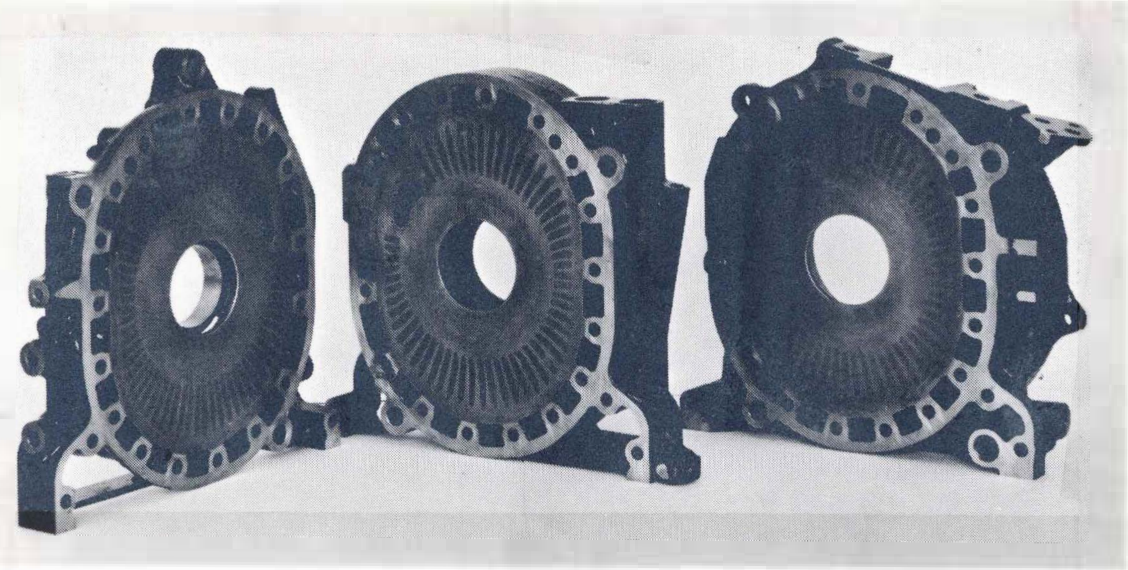
are used, a side housing is interposed between the two rotors and serves as the side housing for both rotors. Inlet and exhaust ports are fitted to the rotor housing or side housing, dependent on engine design. See Figure 3 and 4. Ports that are fitted on the rotor housing are peripheral ports. Some designs retain the exhaust ports in this position, but places the inlet port in the side of the side housing. Water passages communicate between the side and rotor housing through which the coolant is able to circulate, absorbing the heat and dissipating it into the atmosphere.

The eccentric shaft. The eccentric shaft is the power output shaft and can be related to the crankshaft in the ReCE. The shaft journals support the rotor and are positioned eccentrically on the shaft converting rotor force into torque. Main journals are located on both sides of the rotor journals, and are supported in the side housings by main bearings inserted into the center section of the stationary gear. Lubrication and cooling of the rotor and its bearing is made possible through a passage in the hollow shaft. Any out of balance motion of the shaft is corrected by the flywheel and balance weights mounted on the shaft.

Stationary gears. Stationary gears are external gears fitted on each housing and engaged with the interal gear fixed on the side of the rotor with a tooth ratio that is always 2:3.

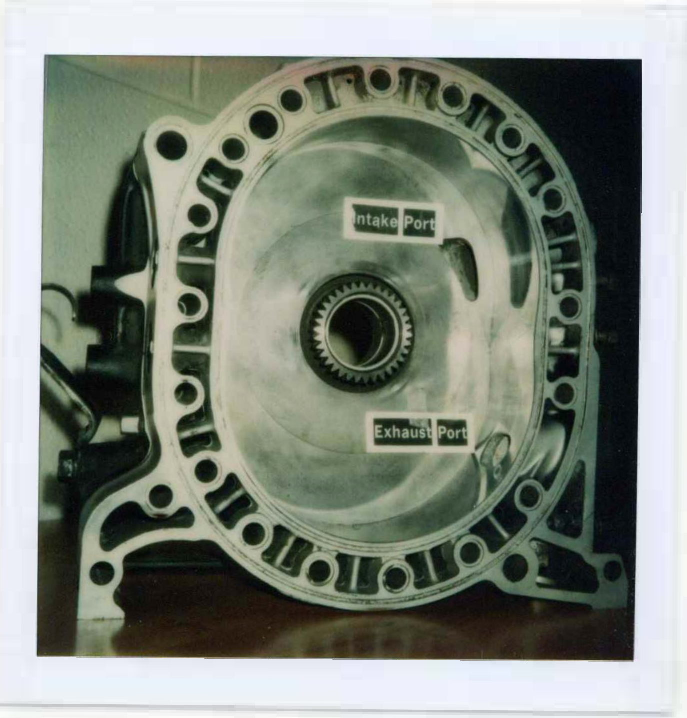
Operating Principles

The Wankel RCE, like the ReCE, is an internal combustion engine, working on the forth phase cycle: intake, compression, power and exhaust. Here the similarity ends. As in the ReCE, the cycle of



End covers and center side wall with intake ports.

Figure 3



Intake and Exhaust Ports.

Figure 4

operation is completed by a piston moving in a cylinder from top to bottom admitting a mixture of fuel and air through an open inlet valve.

Inlet stroke. At the bottom of the cylinder the piston changes its direction and moves to the top of the cylinder with the inlet valve closed and compressing the mixture.

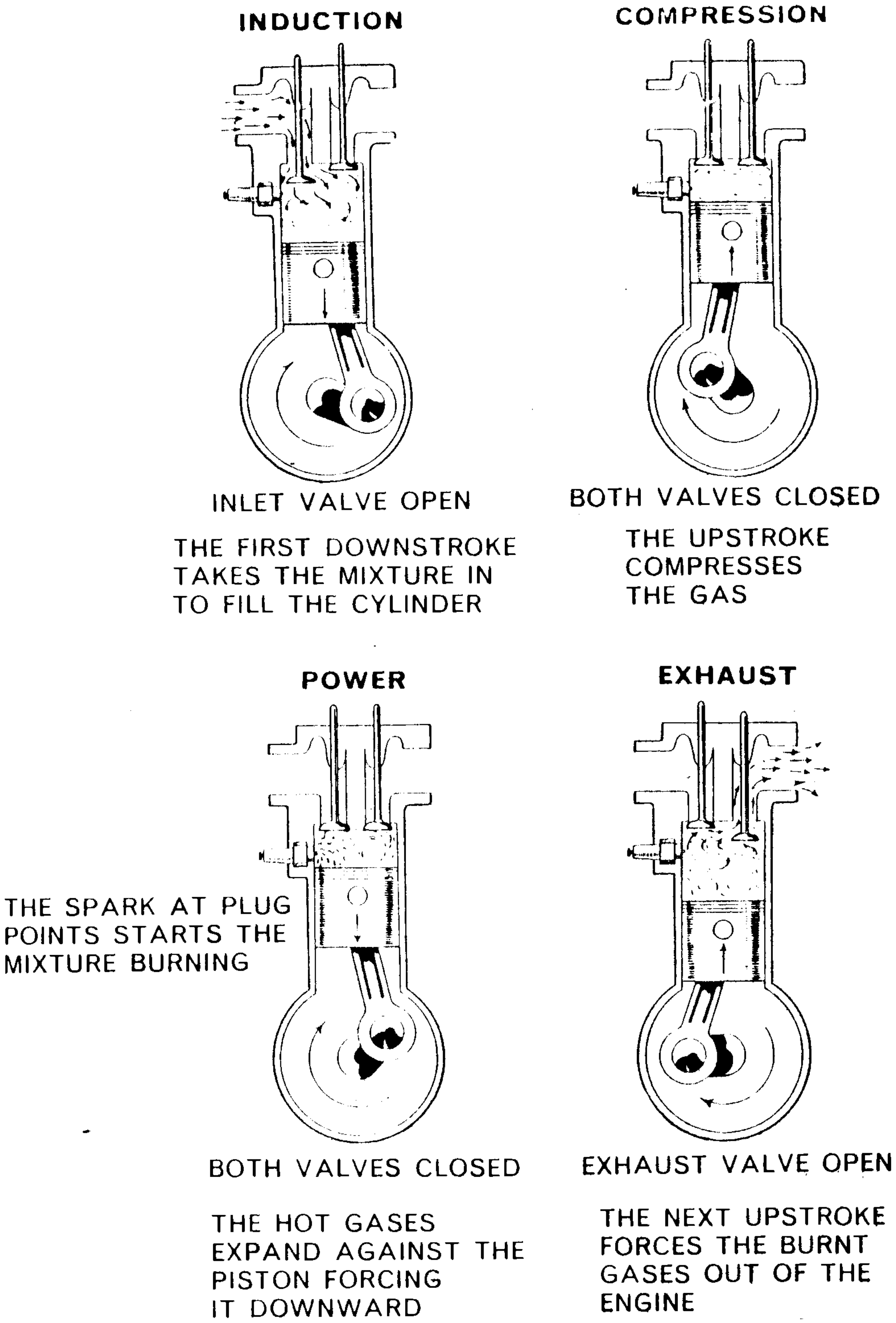
Compression stroke. The compressed mixture is ignited by a spark from a spark plug, the mixture expands and forces the piston toward the bottom of the cylinder completing the third and only working stroke in the cycle.

Power. The piston changes its direction once more moving toward the top of the cylinder with the exhaust valve open and the burnt mixture is forced out into the atmosphere.

Exhaust. The completion of the fourth stroke, exhaust, ends the cycle of operation. See Figure 5. Energy from the expanding gases is transferred to a crankshaft, changing reciprocating motion of the piston into rotary motion of the crankshaft and flywheel, making the cycle of operation equivalent to two revolutions of the shaft, (720^{o}).

The Rotary Cycle

Inlet. The rotor, because of its location on the eccentric shaft, makes a planetary motion within the epitrochoidal rotor housing. Rotor movement uncovers the intake port and as the chamber volume increases and the pressure drops, the fuel, air and oil mixture enters until the inlet port is closed by the movement of the rotor.



The Otto cycle--intake stroke (1); compression stroke (2); power stroke (3); exhaust stroke (4)

Figure 5

Compression. The working volume of the chamber is reduced as the rotor rotates, compressing the mixture into the smallest volume of the chamber where it is ignited by a spark from the spark plug.

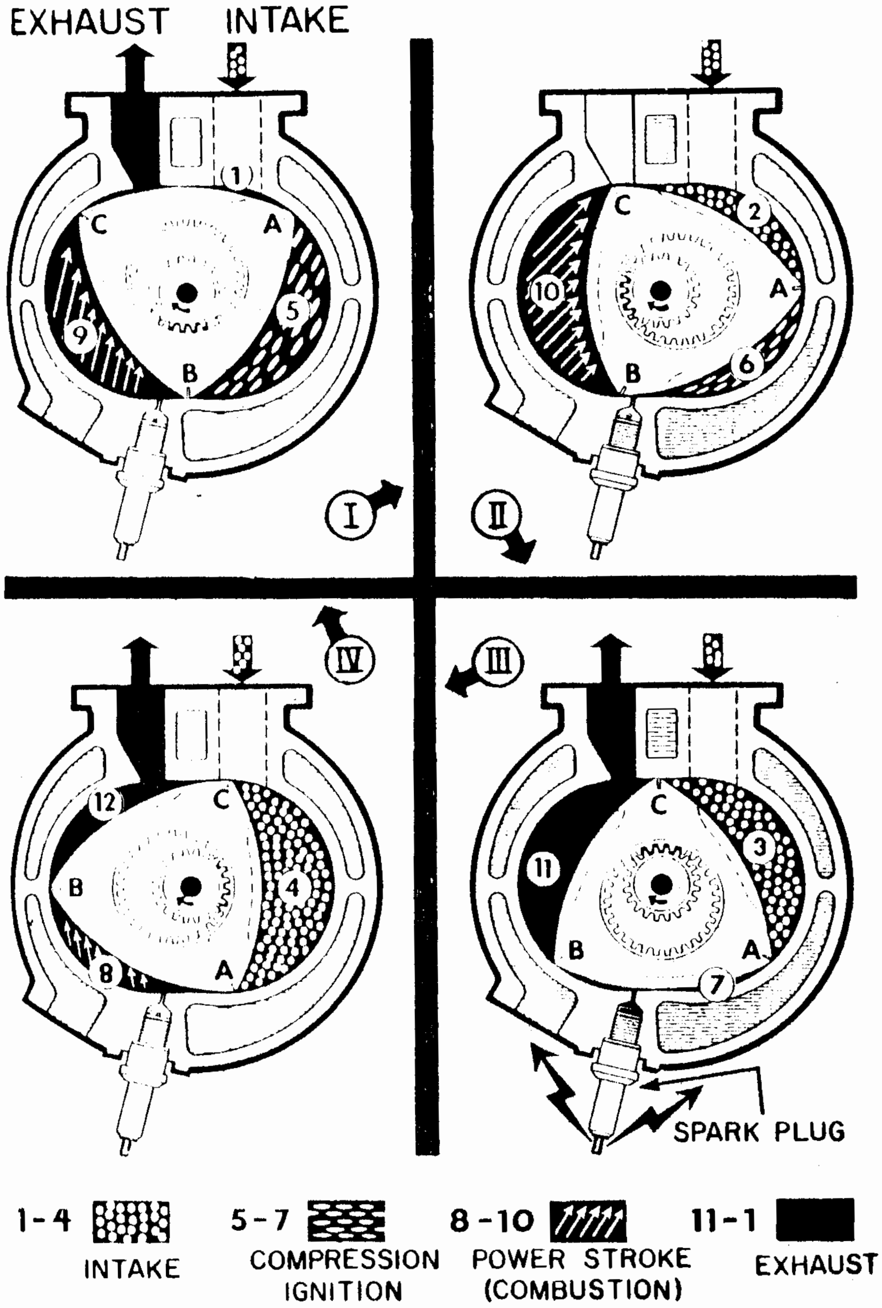
Power. The temperature of the ignited mixture rises, the mixture expands increasing the pressure in the chamber causing rotary motion of the rotor and shaft. Rotor movement increases the volume in the working chamber reducing gas temperature and pressure.

Exhaust. As the rotor continues to rotate, the exhaust port is uncovered and the burnt gases are forced through the exhaust ports into the atmosphere, completing the cycle of operation in one chamber. It must be appreciated that the cycle of operation described is also true for the other two working chambers, providing three working strokes are in one revolution of the rotor while the eccentric shaft turns three revolutions. One power stroke per revolution of the output shaft. See Figure 6.

The principles of operation explained above shows that although the cycle of operation is the same on both engine, inlet, compression, power, and exhaust, the RCE produces twice as many power strokes as the four-stroke ReCE, but the same as the two-stroke ReCE without the disadvantages of poor scavenging which is inherent in its design and has restricted its development as compared with the four stroke.

Advantages of the Wankel RCE

The major advantages of the Wankel RCE is its size and weight. Compared to the ReCE, the RCE is approximately half the size and weight.



Actions in the Wankel engine during one complete rotation.

Figure 6

Curtiss-Wright made a direct comparison between their RC 2-60 U5 Wankel engine and a Chevrolet 283 cubic inch V8 piston engine. The Wankel engine was rated at 185 horsepower and weighed 237 pounds compared with the Chevrolet at 195 horsepower weighing 607 pounds. These facts indicate superior power to weight ratios of the Wankel engine, (Norbye, 1971, p. 59.)

Simple Construction

"The ReCE has far more parts than the RCE; some 1,029 on the 283 cubic inch Chevrolet V8 compared with the Curtiss-Wright RC 2-60 U5 with only 633. There are 388 moving parts in the Chevrolet, while the RC 2-60U5 has only 154." (Norbye, 1971, p. 62.) This greater number of parts means higher production and maintenance cost per horsepower as indicated in the data in Table 1.

COST COMPARISON (IN U.S. DOLLARS)

	Wankel Engine 115 h.p.	Recip. Engine 100 h.p.	Wankel Engine 6 h.p.	Recip. Engine 6 h.p.
Accessories	$ 80.00	$ 87.00	$ 35.00	$ 29.00
Material	50.00	70.00		
Labor	17.50	25.00	7.50	10.00
Overhead	31.00	44.00	13.25	17.50
Total	$178.50	$226.00	$ 55.75	$ 56.50

COST COMPARISON (%)

	Wankel Engine 115 h.p.	Recip. Engine 100 h.p.	Wankel Engine 6 h.p.	Recip. Engine 6 h.p.
Accessories	100	104	100	61
Material	100	140		
Labor	100	142	100	133
Overhead	100	142	100	133
Total	100	126	100	100

Table 1

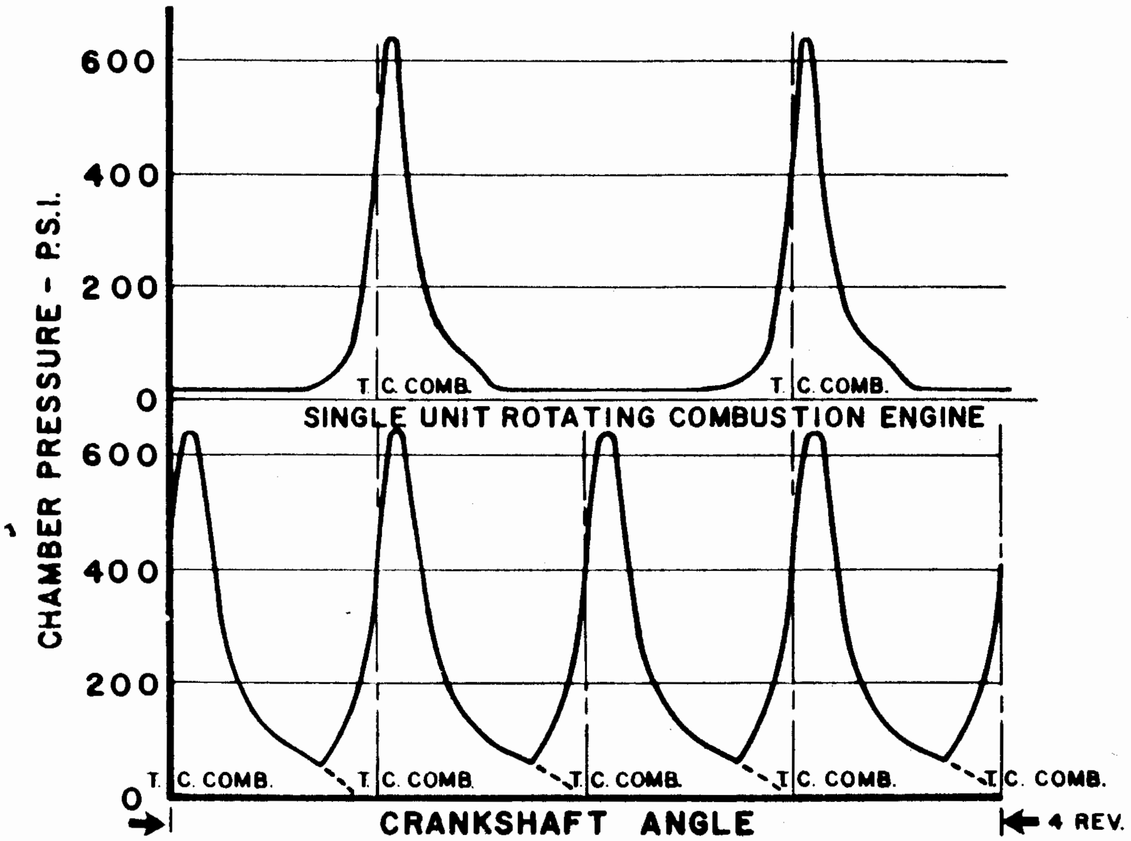
The reduction in weight and moving parts means better mechanical efficiency as inertia forces and frictional losses are reduced.

Higher volumetric efficiency is also possible when ports are used instead of valves, as gas flow to and from the combustion chamber is less restricted, and covers a greater angle of the output shaft rotation than the induction process on the ReCE. Volumetric efficiency is further improved by the thorough scavenging of the exhaust gases as there are no pockets in the working chambers of the RCE to encourage inert gases to remain and contaminate the fresh incoming mixture as experienced in the ReCE.

The RCE develops its power over two-thirds of its operating cycle and produces a powerstroke per revolution of the output shaft, and smooth torque output. Compared to the ReCE, the RCE develops its power over a quarter of its operating cycle and producing a power stroke every two revolutions of the output shaft. This means that in the ReCE there are fluctuations of gas pressures acting on the piston leading to a jerky driving effort at low speeds, requiring a heavy flywheel to give some smoothness to the developed torque. See Figure 7. "Other considerations to the advantages of the RCE, is less tooling, a smaller number of components to handle and ship. Fewer servicing problems. Finally the RCE can run on lower octane fuel making it possible to operate in any part of the world." (Dark, 1974, p. 34.)

Disadvantages of the RCE

Previous chapters have indicated few obvious disadvantages to the RCE, as it appears to have overcome the problems that are inherent in the ReCE. The Wankel RCE has experienced problems both in its design and development.

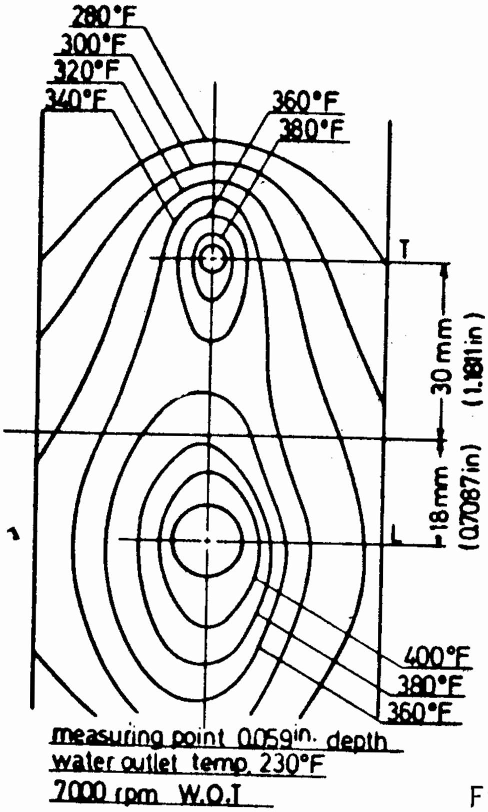


Torque fluctuations on the reciprocating engine shown above. Two power impulses during four crankshaft revolutions, compared with the rotary engine which has four impulses at the same time.

Figure 7

One of the major problems experienced in the development of the Wankel RCE is that of sealing; "which is provided to block the escape of gas and/or oil by way of the variable running clearances between the respective rotors and the chamber walls." (Ansdale, 1969, p. 70.)

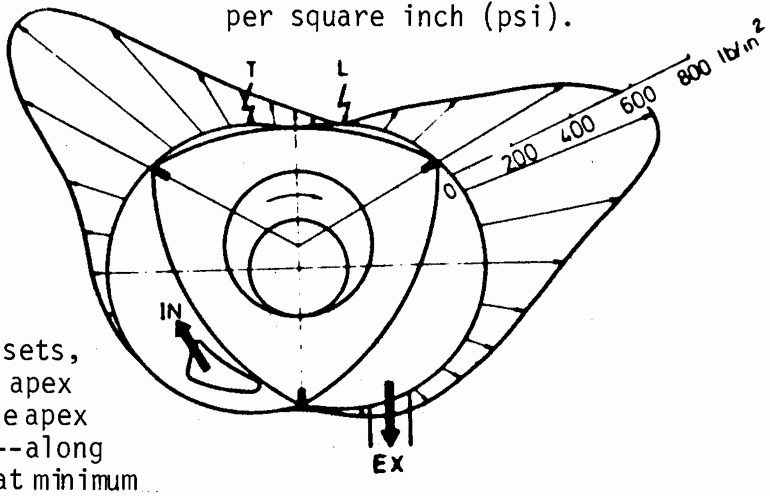
Sealing problems continued throughout the development of the RCE, due mainly to the wide phase angle (angle between the tips of the rotor). This wide angle caused high pressures to act on the apex seals, forcing them to lean in their recesses. This resulted in excessive wear on the seals. Figure 8 and 9 illustrates the high temperatures around the leading and trailing plugs, and the variation in pressure on the apex seals. The insets show the variations in apex sealing angles.

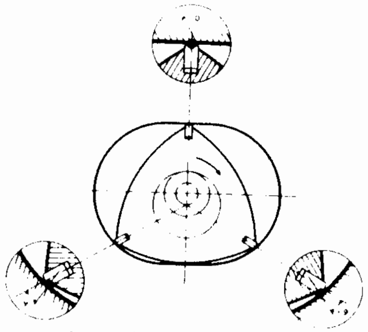


Temperature recordings around the spark plug holes

Figure 8

Gas pressure differences between the three working chambers, measured in lbs. per square inch (psi).



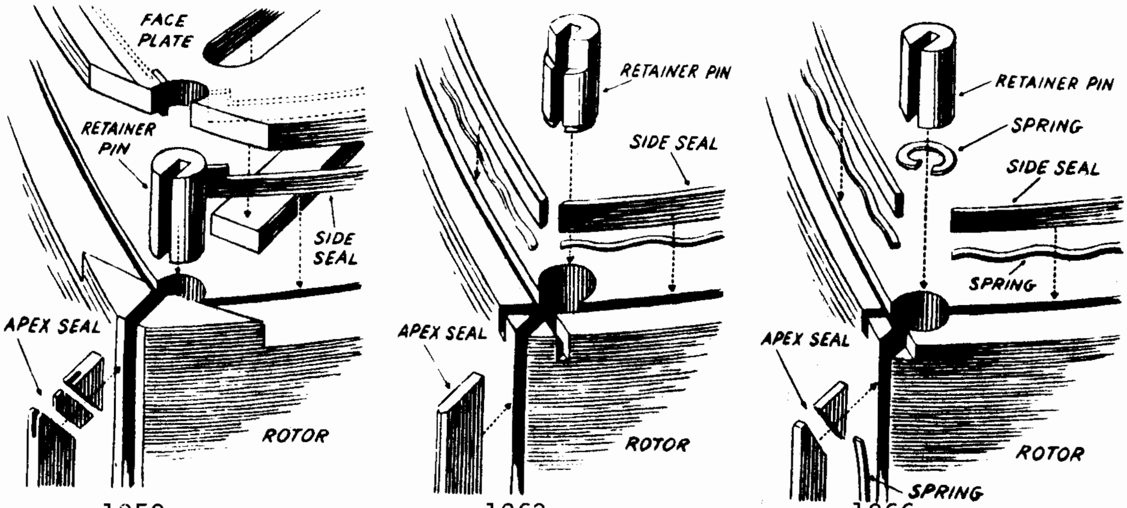


This sketch, and the three insets, illustrate the variations in apex seal leaning angles. When one apex has zero leaning angle (right--along minor axis), the other two are at minimum leaning angles, one negative & one positive.

Figure 9

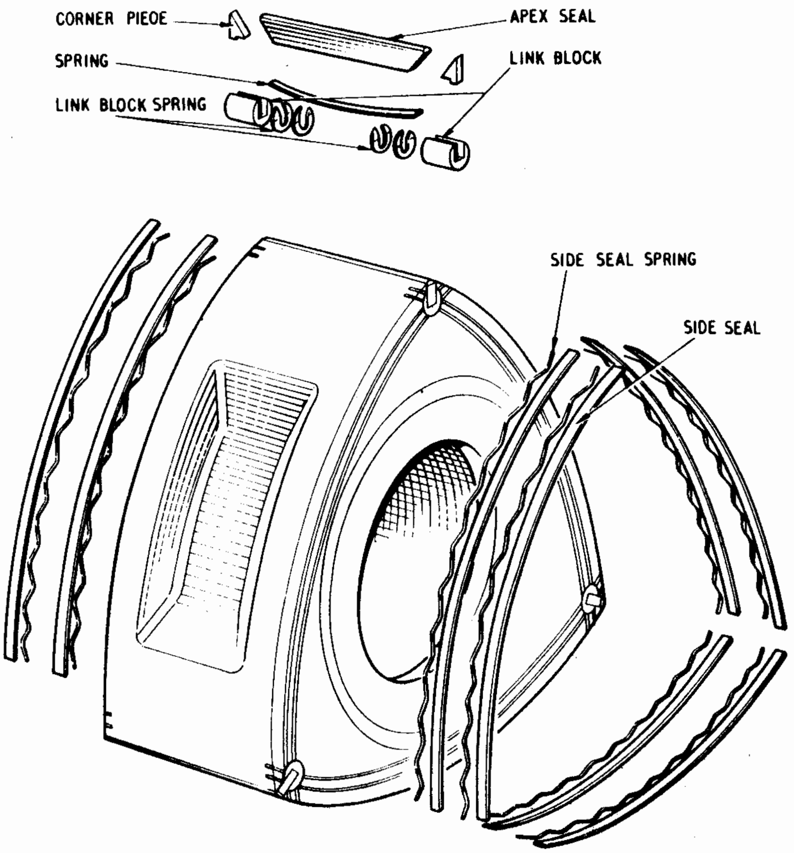
Figure 10a shows a variety of sealing systems used by NSU in overcoming the problem of sealing. The 1959 version (left) was inefficient because of its fragile corners. The 1963 version (center) did not provide proper corner sealing. The 1966 version (right) was simpler in design and more effective.

Figure 10b shows the current preferred sealing arrangement. Double side seals are used to improve sealing.



1959 1963 1966

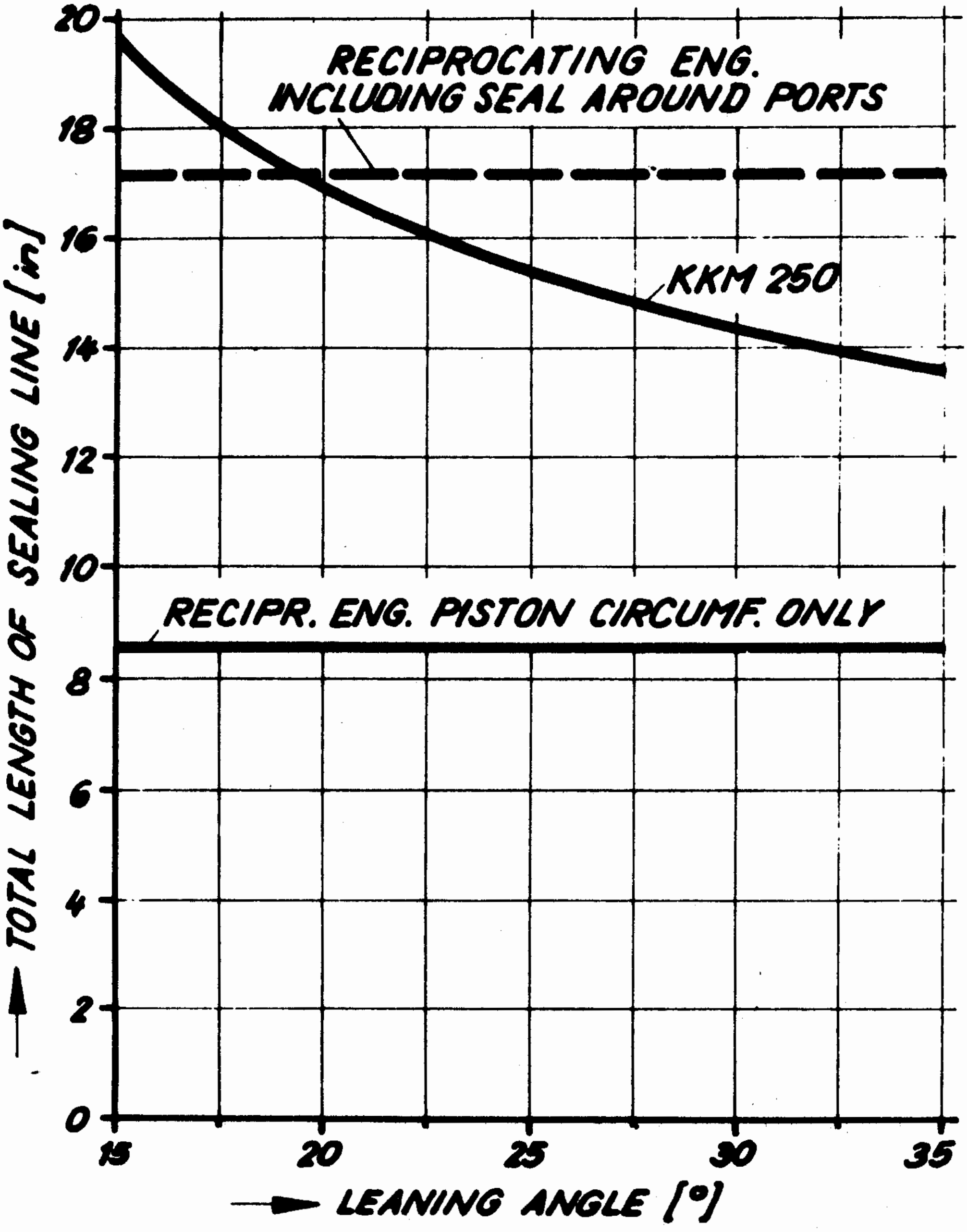
Figure 10a



This is a currently preferred sealing arrangement, double side seals were incorporated to improve sealing and facilitate easier interchangeability.

Figure 10b

Figure 11 shows the comparison of sealing line length between the ReCE and the RCE. Note that fall off efficiency of sealing in the RCE as the leaning increases.



Sealing line length comparison between simple cylinder piston engine, and single rotor rotary engine.

Figure 11

Other sealing problems existed in the development of the RCE as the O-ring, the main engine shaft designed to prevent the cooling oil from seeping through, was breaking down until the Mazda replaced the rubber seal with one made of Teflon.

Sealing continued to be the major setback to the development of the RCE and modern testing methods of endurance test cells, computers and industrial television played important roles in expediting research and development in the hope of curing serious problems. One of which was "chatter" marks discovered in earlier testing. These were wave-like patterns that built up from vibration on contacting metal parts. After much research and testing, a series of carbon compounds that had imbedded specks of aluminum was used to strengthen and lubricate the seals overcoming the sealing and, therefore, "chatter" problems.

The breaking down of the internal gears was corrected by electrically measuring the forces acting on the gear teeth and alternating the design accordingly to cope with the stresses involved.

Other areas of concern included the fuel consumption and instability at low engine speeds. The Environmental Protection Agency, (EPA), in 1973 published figures of 10.7 MPG for the Mazda fuel consumption. These figures were later proven to be erroneous by further EPA tests which produced improved figures of 18 MPG. Nevertheless, this consumption was not considered acceptable for the size and weight of the car. Stronger alloys like Titanium Nitride were used by NSU to cure the gas leakage past the seals, but the public's image of the RCE declined and production was drastically reduced.

Related Information (Technical)

The ignition system. The ignition system on the RCE is similar in design and operation to that on the ReCE, in that each system incorporates the same type of components working on the said fundamental principles except that on the RCE, two independent ignition systems are used to supply a spark to two spark plugs in the working chambers. One ignition system is above the minor axis which is called the trailing side and the other is below the minor axis, the leading side, of the epitrochoid surface. This arrangement enables the engine to obtain the optimum combustion efficiency under all operating conditions. The leading plug initiating the flame front while the trailing plug assists in the completion of combustion. "Perhaps the most significant difference between conventional piston engines and the Wankel RCE configurations is that the spark plug is not cooled to the same extent by the incoming gasses. Hence the RCE requires spark plugs of relatively high heat rating despite any problems which might arise during cold starting under part load operating and under overrun conditions." (Ansdale, 1969, p. 109.)

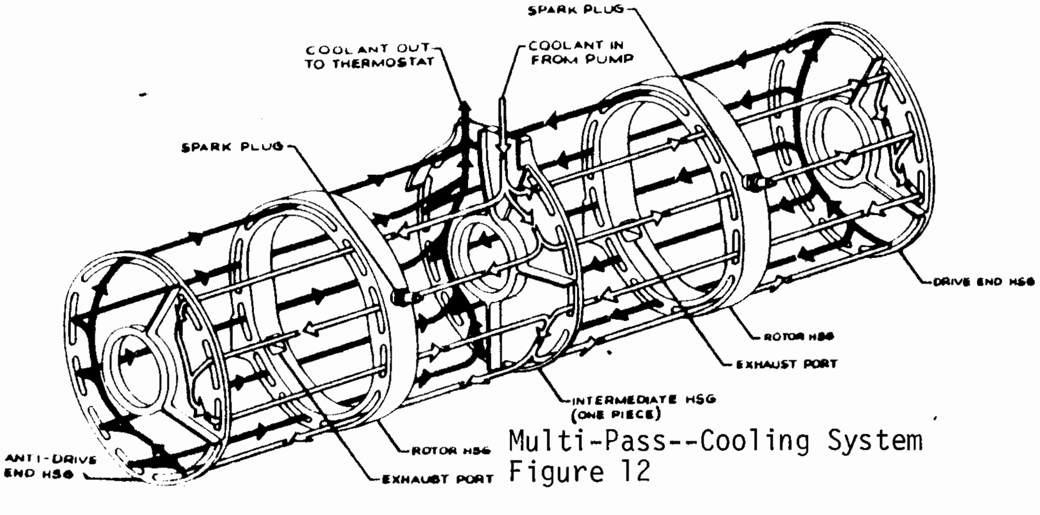
The cooling system. Like the ReCE, the RCE can be adapted to either air or liquid cooling but with very different cooling problems.

The purpose of the cooling system is to remove enough heat from the engine to prevent overheating, distortion of components, seizure and cracking. This is achieved on the ReCE by passing water through water jackets on the outer surfaces of the cylinder and cylinder head to absorb the heat from these components which is given up to the cooler atmosphere as it passes through the radiator. Problems exist mainly around the exhaust valve which experiences the highest temperatures in the combustion chamber area as the valve is only cooled mementarily when closed and in contact with the cooler valve seat. On some designs, the valve stem is hollow and partly filled with sodium, which transfers the heat from the head of the valve to its stem and on to the cooler valve guide. Distortion is only experienced on the ReCE on extreme conditions of temperature change, as temperatures are effectively controlled by regulating the circulation of the coolant and the air flow through the radiator.

On the RCE, problems of cooling exist mainly around the plug area of the combustion chamber due to the high temperature difference of the combustion chamber and the cooler remaining working surfaces. This difference in temperature sometimes leads to distortion affecting efficient oil and gas sealing.

High acceleration on cold engines causes local overheating, destroying surface lubrication. This is a problem on the RCE as the combustion chamber walls of the rotor housing are exposed to very large, sudden thermal loads. The combination of overheating, temperature difference and high thermal loads lead to metal fatigue which causes cracks to form around the spark plug bosses.

Figure 12 shows the Curtiss-Wright multi-pass, force-flow cooling system. The coolant if forced back and forth through the housing parallel

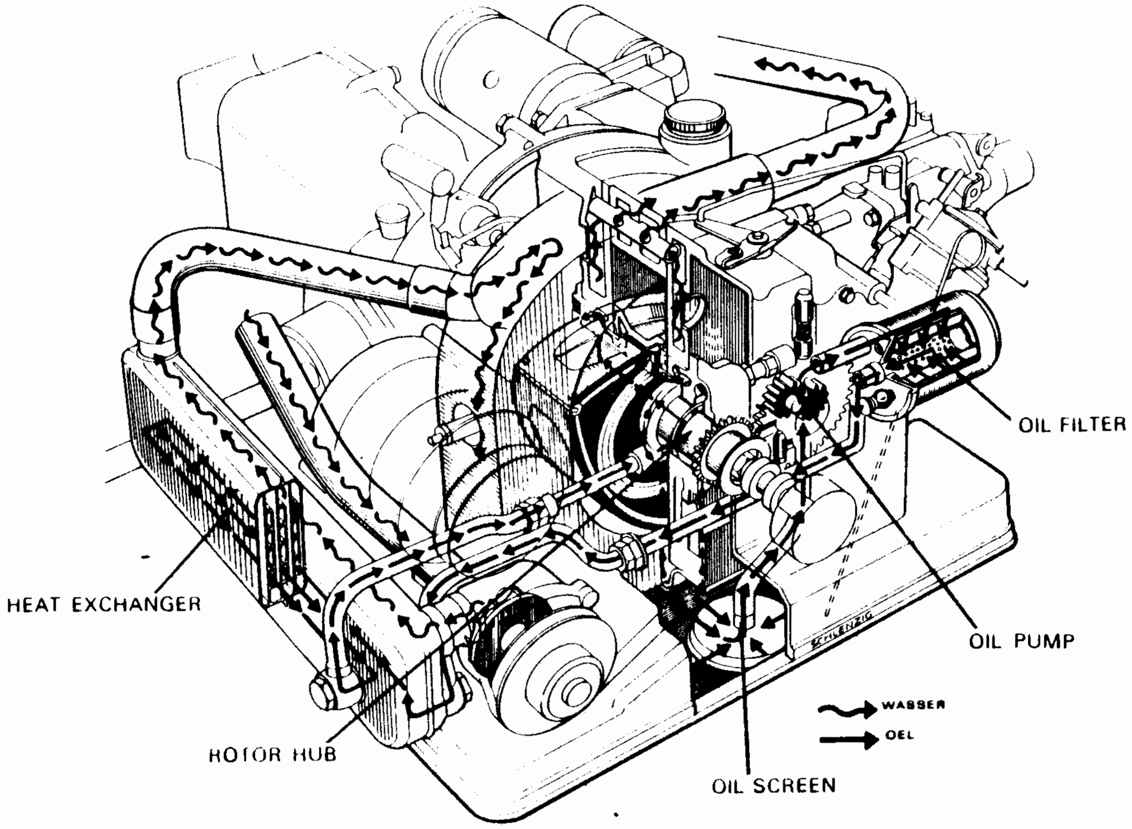


Multi-Pass--Cooling System
Figure 12

to the output shaft. The flow velocity is controlled and varies according to the temperature of the specific areas, assuring that heat is dissipated evenly, reducing possible distortion.

Air cooling the RCE was determined to be inadequate for the Wankel automotive, and water cooling would cause great mechanical complications, but development of the cooling system has overcome the above difficiencies. "The cooling system of the Mazda rotary is fairly conventional (with water pump, thermostat, radiator, cooling jacket, associated hoses for radiator and hot water heater) and differs from the cooling system for a piston engine in only a few respects." (Dark, 1976, p. 124.)

> Oil is taken from the sump through a strainer, and then forced through a filter and on to a heat exchanger. The oil under pressure is then forced into the rotor and returned to the sump.



NSU KKM Cooling System

Figure 13

Lubricating system. The lubricating system of the RCE shown in Figure 13 is somewhat similar to that of the ReCE differing only in the supply of lubricant to the rotor and the carburetor. A two rotor-type pump installed inside the front cover and driven by gears on the eccentric shaft supplies oil under pressure to the engine components through a full-flow filter located on the rear housing of the engine. "The main differences between the lubricating system of the RCE and that of the ReCE are that an oil cooler and a metering oil pump are used on the rotary engine." (Carroll, 1972, p. 172.)

Rotor cooling. The rotor in the RCE, like the piston in the ReCE, is exposed to very high pressures and temperatures. These high temperatures are dissipated in the ReCE by means of the piston being in contact with the cooler cylinder walls that are in direct contact with the coolant

Cooling the rotor is more difficult, as the only contact with the cooler rubbing surface is through its seals. To compensate for this inadequacy, the rotor is cooled internally by oil force fed from the oil sump by the pump. The oil acts in a cooling, not lubricating capacity.

CHAPTER IV

RELATED INFORMATION

Industrial

World motor vehicle production and assembly increased some 16 percent in 1976, in comparison with the decline in the two previous years. This increase was very general. In the United States, car and truck production climbed 28 percent. A similar increase in production was also evident in Japan and Europe, but in South America there was a decline in both Argentina and Mexico.

In 1976, Mazda Motors sold 35,373 cars and 5,829 pickups compared to 65,650 cars and 9,535 pickups in 1975. This decline in sales was due to the reputation of the poor fuel and oil consumption the rotary combustion engine earned in 1974.

> "Reports from Toyo Kogyo, Audi NSU, and places in between indicate that the rotary concept is far from camatose. Toyo Kogyo began rotary engine production in 1976. The Mazda was placed on the American market in 1970. Since 1974, two twin-rotor power plants have been in production: the 12 A displaces 573 cc per rotor, has a maximum power of 90 k W (120 hp) at 7000 rpm, and delivers 140 N:m (110 lb-ft) torque at 4000. Corresponding data for the 13 B are 654 cc per rotor, 100 k W (135 hp) at 6500 rpm, and 174 N:m (128 lb-ft) at 4000, respectively." (Automotive Engineering, February, 1978, pp. 32.)

In the mid 1950's NSU began activities with the rotary engine, and in 1963 became the first producer of the single rotor rotary powered automobile. In 1969, NSU merged with Audi and formed Audi NSU Auto Union AG. The company has produced a new generation of rotary engines, one of which is the two rotor, fuel injected lean-combustion power plant.

Other Rotary Combustion Engine (RCE) developments are taking place by Curtiss-Wright, the principal U. S. Wankel license, with their direct injection stratified charge engine. Ingersoll-Rand's rotary, running on natural gas, Out Board Marine in their development of RCE for outboard application, and Toyota dual-inducted, stratified charge carbureted design.

Geographical

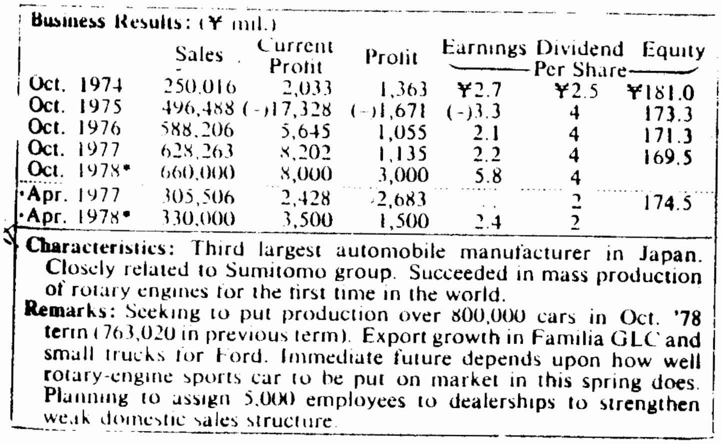
Japan and Germany are the world's major contributors in the production of the RCE. In the U. S., Mazda Motors of America, a subsidiary of Toyo Kogyo Co., Ltd., is by far the biggest distributor of the rotary powered motor vehicle, with locations throughout each state. Main offices are in Compton-California, Elk Grove Village-Illinois, and Jacksonville-Florida. Figure 14 shows the distributors in the state of Iowa.

Burlington	Import Motors, Ltd. Highway 61 South Burlington, IA 52601
Cedar Falls	Friedley Lincoln-Mercury 4227 University Avenue Cedar Falls, IA 50613
Cedar Rapids	Bruce McGrath Pontiac, Inc. 4610 Center Point Road Cedar Rapids, IA 52402
Clinton	Bickelhaupt Motor Co. 127-33 6th Avenue South Clinton, IA 52732
Council Bluffs	Downtown Chrysler-Plymouth-Mazda, Inc. 3501 W. Broadway Council Bluffs, IA 51501
Davenport	Jugenheimer Motors, Inc. 5405 Brady Street Davenport, IA 52806
Des Moines	Des Moines Mazda 90th and Hickman Road Des Moines, IA 50322
Dubuque	Riley's Auto Mart, Inc. 800 Rhomberg Ave. Dubuque, IA 52001
Fort Dodge	V W Fort Dodge Highway 20 East Fort Dodge, IA 50501
Mason City	Sedars Pontiac-Cadillac GMC 307 N. Federal Mason City, IA 50401
Sioux City	Senftner Volkswagen Corp. 1909 6th Street Sioux City, IA 51101

Mazda Motors distributed in Iowa.
Figure 14

Financial

Toyo Kogyo Co., Ltd. is the third largest automobile manufacturer in Japan, largely due to its success in mass production of rotary engines. The company closely related to the Sumitomo banking trust group which holds yearly 40 percent of its shares outstanding. Subsidiaries include: Toyo Coated Sand Co., Ltd., Mazda Seiki, Co., Ltd. (100%-owned), Takaya Industries Co., Ltd., (83.7%-owned) and Toyo Rock Drill Sales Co., Ltd., (60%-owned). Figure 15 below shows the Business Results: (¥ mil.) 1974-78.



Business Results: (¥ mil.)

	Sales	Current Profit	Profit	Earnings	Dividend	Equity
				Per Share		
Oct. 1974	250,016	2,033	1,363	¥2.7	¥2.5	¥181.0
Oct. 1975	496,488	(-)17,328	(-)1,671	(-)3.3	4	173.3
Oct. 1976	588,206	5,645	1,055	2.1	4	171.3
Oct. 1977	628,263	8,202	1,135	2.2	4	169.5
Oct. 1978*	660,000	8,000	3,000	5.8	4	
•Apr. 1977	305,506	2,428	2,683	..	2	174.5
•Apr. 1978*	330,000	3,500	1,500	2.4	2	

Characteristics: Third largest automobile manufacturer in Japan. Closely related to Sumitomo group. Succeeded in mass production of rotary engines for the first time in the world.

Remarks: Seeking to put production over 800,000 cars in Oct. '78 term (763,020 in previous term). Export growth in Familia GLC and small trucks for Ford. Immediate future depends upon how well rotary-engine sports car to be put on market in this spring does. Planning to assign 5,000 employees to dealerships to strengthen weak domestic sales structure.

Toyo Kogyo Co. Ltd. Business Results

Figure 15

The author in his research on the topic, was unable to find any specific financial information on Mazda Motors of America, a subsidiary of Toyo Kogyo Co., Ltd. But the figures given on page 34 and other research on Mazda's sales indicates a 46% drop in 1976. This decline may have ceased, as the introduction of the GLC, a piston engine offering the rotary '77 "SP" version of the RX-3, and the RX-7 plus the very attractive guarantee Mazda's are offering, points the way to recovery of its sales market in the U. S.

Calendar Year Import U.S. Car Sales by Models

	1976	% Tot.	1975	% Tot.
Toyota	**346,900**	**100.00**	**233,909**	**100.00**
Corolla	187,321	54.00	151,177	53.25
Corona	38,632	11.14	44,156	15.56
Celica	100,438	28.95	64,922	22.87
Mark II	5,064	1.46	8,736	3.08
Land Cruiser	9,236	2.66	9,050	3.18
Others	1	—	62	0.02
Hawaii	6,203	1.79	5,806	2.04
Datsun	**270,103**	**100.00**	**263,192**	**100.00**
F-10	14,730	5.46	—	—
B-210	147,643	54.66	140,039	53.21
710	35,327	13.08	50,914	19.35
610	13,912	5.15	18,527	7.04
280 Z	54,838	20.30	50,142	19.05
Others	—	—	220	0.08
Hawaii	3,653	1.35	3,350	1.27
Volkswagen	**203,144**	**100.00**	**268,751**	**100.00**
Type 1	27,009	13.29	92,037	34.25
Rabbit	112,056	55.16	98,215	36.54
Type 2	19,464	9.58	21,547	8.02
Dasher	27,715	13.65	33,271	12.38
Type 4	—	—	6,552	2.44
Scirocco	15,426	7.59	16,108	5.99
TD's	1,474	0.73	1,021	0.38
Honda	**150,929**	**100.00**	**102,389**	**100.00**
Civic	132,286	87.65	102,389	100.00
Accord	18,643	12.35	—	—
British Leyland	**65,164**	**100.00**	**70,839**	**100.00**
Austin	1,118	1.72	13,262	18.72
MG	28,426	43.62	27,946	39.45
Jaguar	7,382	11.33	6,799	9.60
Triumph	28,238	43.33	22,803	32.19
Land Rover	—	0.0	29	0.04
Fiat	**66,295**	**100.00**	**102,831**	**100.00**
X 1/9	10,647	16.06	15,832	15.40
128	20,596	31.07	39,655	38.56
124	11,721	17.68	32,238	31.35
131	18,576	28.02	12,786	12.44
850	—	—	—	—
Lancia	3,710	5.60	1,011	0.98
TD's	1,045	1.58	1,309	1.27
Colt	**48,542**	**100.00**	**60,356**	**100.00**
Subaru	**48,928**	**100.00**	**41,587**	**100.00**
Std. 2 Door	4,731	9.67	233	0.56
2-Door Sedan	8,474	17.31	7,524	18.09
4-Door Sedan	6,853	14.00	8,085	19.44
Sta. Wagon	8,190	16.74	10,926	26.27
4-WD Sta. Wag	7,934	16.22	3,009	7.54
Coupe	5,778	11.82	8,904	21.41
Hardtop	6,968	14.24	2,906	6.99
Volvo	**43,887**	**100.00**	**60,338**	**100.00**
142/242 2-Door	8,469	19.28	11,846	19.64
144/244 4-Door	9,575	21.80	12,839	21.28
145/245 Sta. Wag	9,962	22.70	18,532	30.71
164 4-Door	5,576	12.71	15,997	26.51
264 4-Door	7,272	16.60	159	0.26
265 Sta. Wag	2,515	5.73	35	0.06
TD's	518	1.18	930	1.54
Mercedes-Benz	**43,205**	**100.00**	**45,259**	**100.00**
240D	7,359	17.03	9,809	21.67
300D	9,544	22.09	6,648	14.69
230	1,248	2.89	2,058	4.55

	1976	% Tot.	1975	% Tot.
Mercedes-Benz Continued				
280 280E	2,745	6.35	4,035	8.91
280C	1,495	3.46	2,176	4.81
280S SE	2,594	6.00	3,007	6.64
450SE	1,693	3.92	2,651	5.86
450SEL	4,925	11.40	4,270	9.44
450SL	5,893	13.63	6,015	13.29
450SLC	1,578	3.65	1,563	3.45
Misc	1	0.02	—	—
TD's	4,130	9.56	3,027	6.69
Mazda	**35,350**	**100.00**	**65,650**	**100.00**
RX4	10,137	28.68	32,589	49.64
RX3	4,309	12.19	19,589	29.84
RX2	101	0.29	5,701	8.68
808	6,340	17.93	7,343	11.19
Cosmo	2,819	7.97	428	0.65
Mizer	11,644	32.94	—	—
Arrow	**30,430**	**100.00**	**—**	**—**
Capri	**29,904**	**100.00**	**54,585**	**100.00**
Audi	**33,316**	**100.00**	**50,784**	**100.00**
Fox	21,763	65.32	30,305	59.67
100	11,553	34.68	20,479	40.33
BMW	**26,509**	**100.00**	**19,738**	**100.00**
2002	16,123	60.82	13,614	68.97
530i	6,606	24.92	3,169	16.06
3.0Si	1,375	5.19	732	3.71
3.0 S/CS	11	0.04	577	2.92
Bavaria	144	0.54	1,327	6.72
320i	1,763	6.65	—	—
Other	18	0.07	—	—
TD's	469	1.77	319	1.62
Porsche	**14,476**	**100.00**	**16,497**	**100.00**
914	3,181	21.98	11,200	67.89
912	1,551	10.71	—	—
911	4,300	29.70	5,024	30.45
Turbo	626	4.32	—	—
924	4,534	31.32	—	—
TD's	284	1.96	273	1.66
Opel	**10,483**	**100.00**	**39,730**	**100.00**
Manta	4,022	38.37	39,730	100.00
Isuzu	6,461	61.63	—	—
Saab-Scania	**9,855**	**100.00**	**13,731**	**100.00**
97	79	0.80	908	6.61
99LE 2-D	2,712	27.52	4,944	36.01
99LE 4-D	2,745	27.85	3,722	27.11
99LE 3-D Wag	2,214	22.47	2,003	14.59
EMS	1,595	16.18	1,965	14.31
GLE	396	4.02	—	—
TD's	114	1.16	189	1.37
Peugeot	**9,497**	**100.00**	**11,850**	**100.00**
504 Gas Sed	4,094	43.10	4,731	39.92
504 Gas Wag	861	9.07	1,232	10.40
504 Diesel	3,540	37.27	4,487	37.86
504 Diesel Wag	1,002	10.56	1,400	11.82
Renault	**6,819**	**100.00**	**5,780**	**100.00**
R-5	4,214	61.80	—	—
R-12 Sedan	1,191	17.47	2,705	46.80
R-12 Sta. Wag	729	10.68	1,479	25.59
R-15	152	2.23	381	6.59
R-17	533	7.82	1,215	21.02
Alfa Romeo	**5,327**	**100.00**	**5,372**	**100.00**

Table 2

Career Information

Automobile mechanics keep the Nation's automobiles in good operating condition. They perform preventive maintenance, diagnose breakdowns, and make repairs.

Employment of automobile mechanics is expected to increase moderately through the mid-1980's. In addition to the job openings from employment growth, several thousand openings are expected each year from the need to replace experienced mechanics who retire or die. Job openings also will occur as some mechancis transfer to other occupations. Employment is expected to increase because expansion of the driving age population, consumer purchasing power, and multi-car ownership will increase the number of automobiles.

Most training authorities recommend a 3- or 4-year formal apprenticeship program as the best way to become an all-round mechanic. These programs include both on-the-job training and classroom instruction in nearly all phases of automobile repair.

Skilled automobile mechanics employed by automobile dealers in 34 cities had estimated average hourly earnings of $6.15 in 1972. Generally, a mechanic works indoors. Modern automobile repair shops are well ventilated, lighted, and heated, but older shops may not have these advantages. About 700,000 persons worked as automobile mechanics in 1972. Most worked for automobile dealers, and automobile repair shops.

Tools and equipment. Tools and equipment in the automotive service industry are easily available from most automobile parts service equipment suppliers. Equipment is supplied by the company, but the mechanics are expected to purchase hand tools which can cost an average of $1,500.

Materials. The fight to improve fuel consumption is forcing manufacturers to consider other suitable materials to replace the more conventional heavy steel. The trend at the moment is toward aluminum and lower carbon steel, but this is expected to change in favor of plastics.

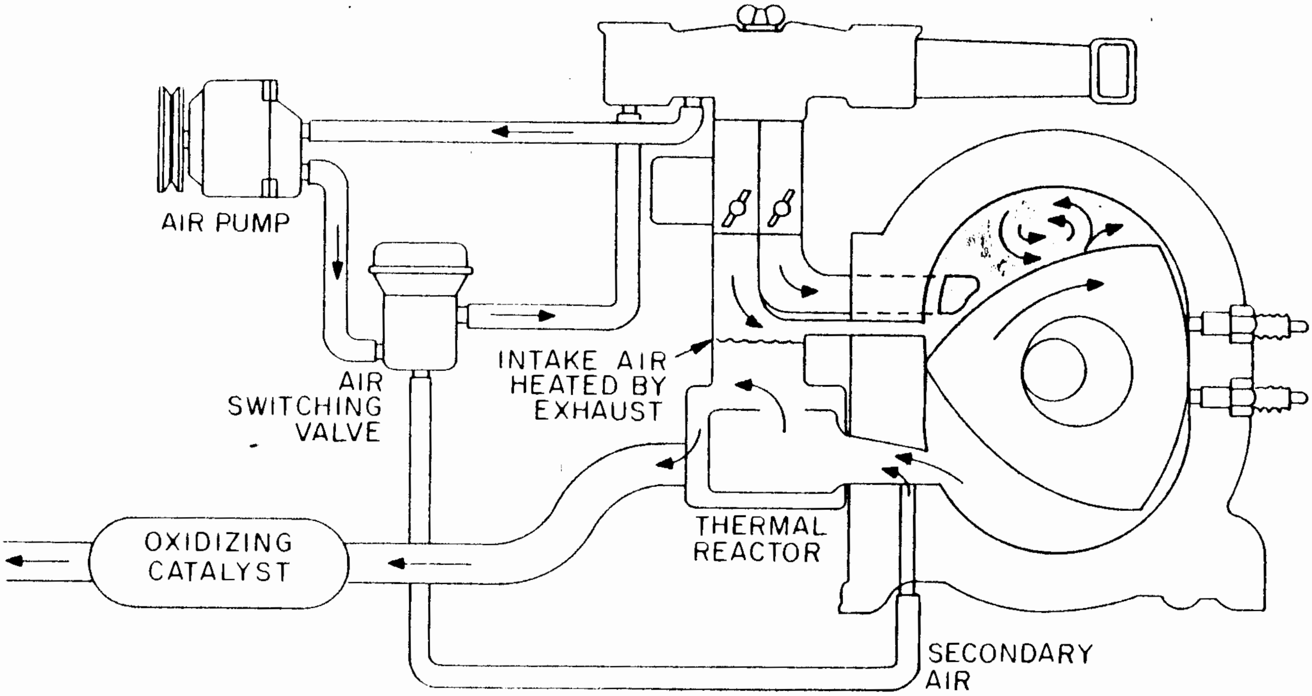
Mass production. This topic is mainly analytical, and, therefore, does not lend itself to the possibility of being mass produced; nevertheless, mass production is very much a part of the automobile industry, and students should be given the opportunity to appreciate the extent of its involvement. This could be done through the showing of films or field trips to industry.

CHAPTER V

FUTURE DEVELOPMENTS

Future developments in automobile engine design will be controlled to a large extent by the energy conservation and exhaust emission control requirements. The current trend is to develop engines which offer good fuel economy and a clean exhaust.

To meet these requirements, designers are concentrating their efforts on the Stratified Charge, (SC), engine. This concept utilizes a rich, easily ignited, oil/fuel strata surrounding the spark plug, while the remaining volume is filled with a clean burning, efficient lean ratio mixture. This combination results in improved fuel consumption with low exhaust emission. Figure 16 shows the Toyota's stratified-charge rotary



Toyota's stratified-charge rotory.

Figure 16

features carbureted dual induction, incorporating a thermal reactor and a oxidizing and exhaust emissions.

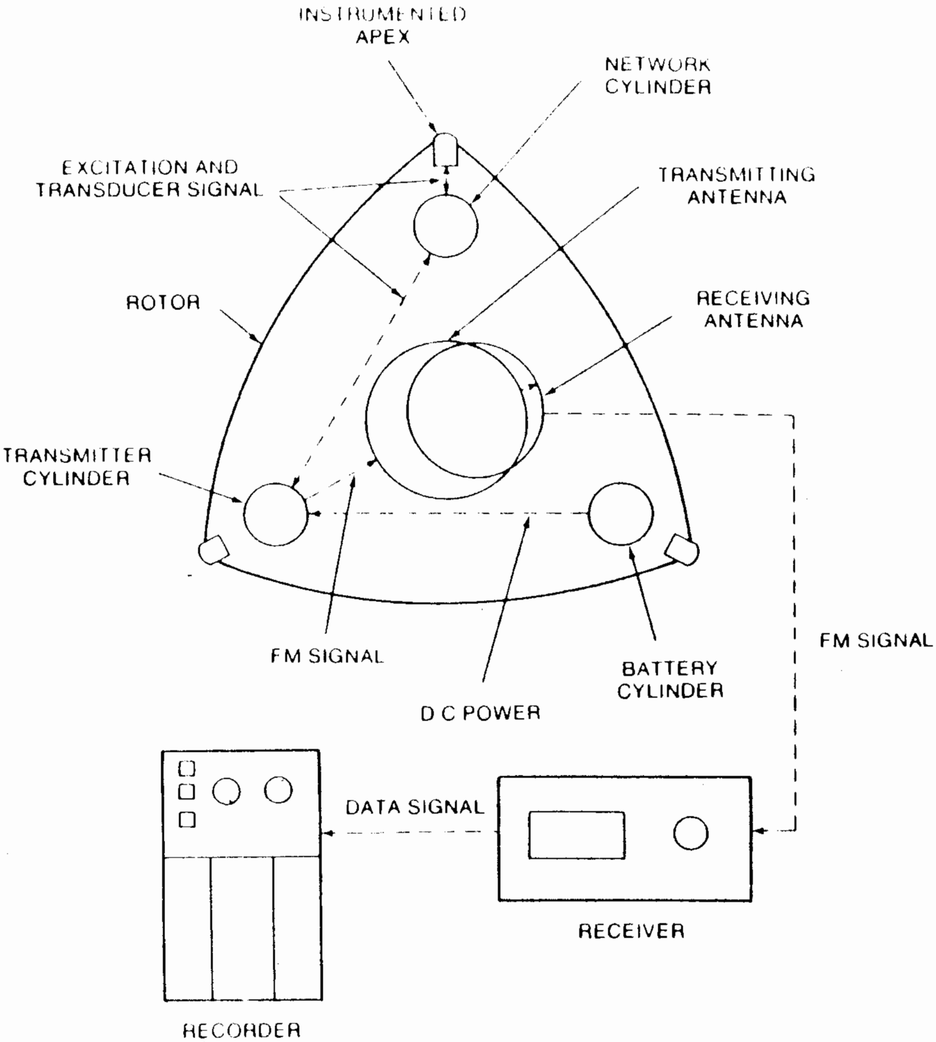
The SC concept can be adapted to both the reciprocating combustion engine, (ReCE), and the rotary combustion engine, (RCE). J. Hartley, (1973, p. 33) comments: "The implications for the motor (sic) and component-making industries committed to the reciprocating engine are clear. Production of the SC engine involves little retooling; only the cylinder head and induction system need extensive redesign tooling.

The extra cost of the new engines would be small. Applying SC to Wankel engines would involve considerably more problems."

Other engine developments continue in an effort to reduce fuel consumption. Ford has plans for a unique 6-cylinder engine that can be switched to 3-cylinder operation to save fuel for its '79 light trucks. Development of the RCE continues with the use of Telemetric procedures for measurement of motion, temperature, and pressure inside the engine. This development by General Motors engineers, is a short-wave wireless link permitting the various transducers on the moving rotor to communicate with the stationary engine housing. Figure 17 shows the telemetric measurement system.

The Stirling Engine

Research done by Eaton Corporation, favors the Stirling external combustion engine and the Gas Turbine, (GT), as future possibilities. The Stirling is smooth and flexible, with low emission and superior efficiency and output. "Because it is an external combustion engine, it has great fuel versatility--it can burn anything that can be provided through a torch." (Dark, 1975, p. 135.)



Telemetry measurement system.

Figure 17

In the Stirling cycle, a volume of cool gas is compressed by a piston and then heated by an external heat source. When heated, the pressure of gas increases and the expanding gases force the piston downward turning the crankshaft. As the gas expands, its pressure and temperature drops. Cooling is further assisted by an external heat exchange. The gas is often transported between heating and cooling areas by a "displacer" piston. See Figure 18.

Some of the disadvantages of the Stirling engine, (SE), in its motor vehicle application, are the use of hydrogen as a high pressure.

THE STIRLING CYCLE

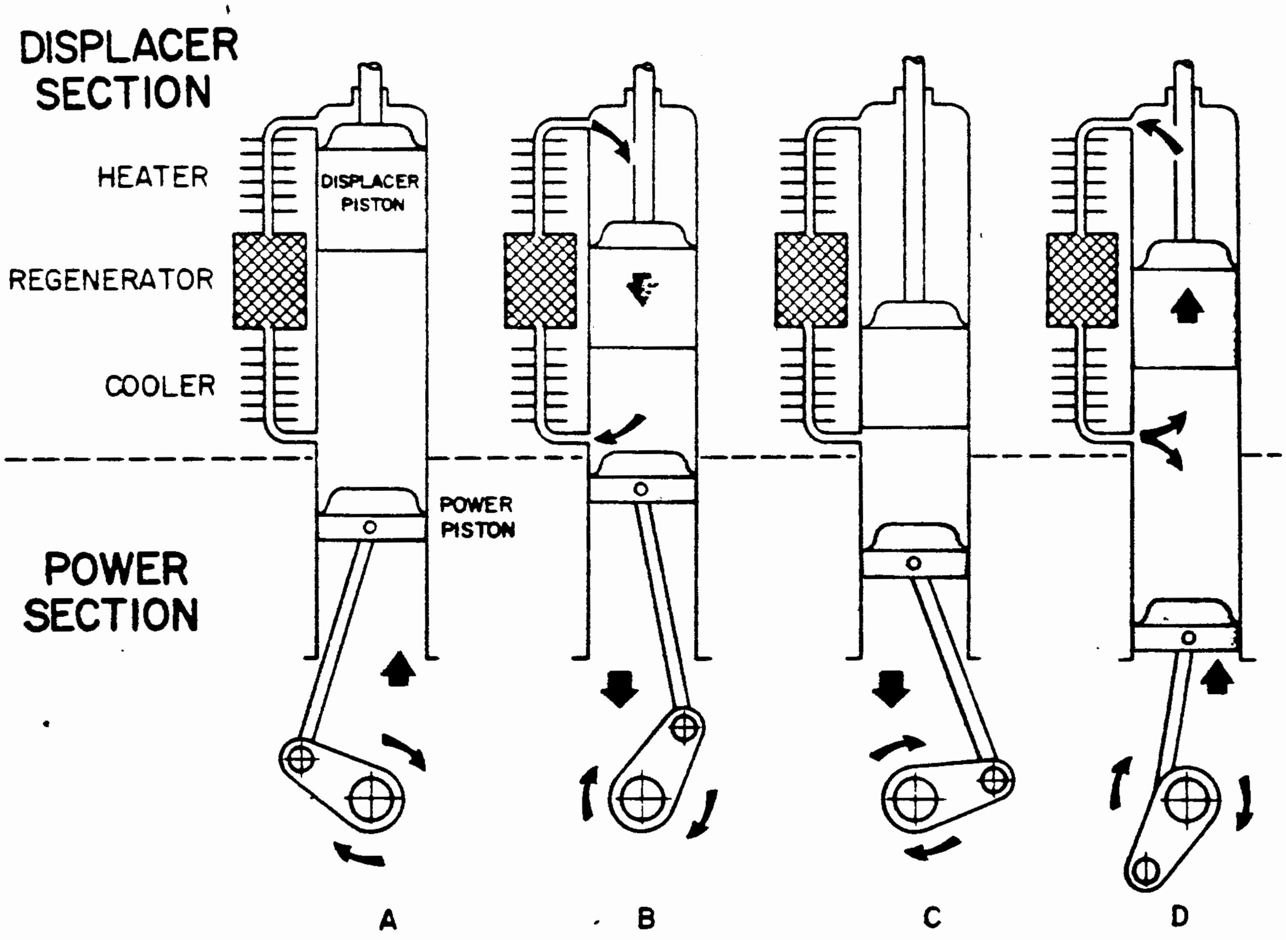


Figure 13

working fluid. Over 200 brazings per cylinder and high cost super-alloys for cylinder head and heat exchanger tubes. "The need for heat-resistant alloys in the heater head means that the Stirling is certain to cost more than a petrol engine. But it holds out the tantalizing offer of very low fuel consumption." (Harley, 1973, p. 32.)

The Gas Turbine

The gas turbine, (GT), is firmly established in aircraft, marine, and industrial applications. Its progress has been relatively slow in the motor vehicle field, being directed mainly toward heavier vehicles.

Research carried out by Chrysler Corporation as early as the thirties, showed that the turbine had possiblities of being an ideal automobile engine. Unfortunately neither materials nor technique had been brought to the point where there was justification for more indepth research.

Continued research on the turbine was conducted by Chrysler Corporation, Rover of England, and Renault of France. By 1973, Chrysler had eliminated the major problems of special materials, acceleration time lag and high fuel consumption. Other problems soon became evident; replacement of current manufacturing techniques with techniques never previously used in large-volume manufacturing, cost of labor, and production processes.

In the GT's cycle, a burner provides expanding gases which react against the blades of the turbine wheel. Fuel is sprayed from the injection nozzle into a compressor driven air stream which supplies oxygen for combustion as well as reaction mass. The turbine is geared to the wheels via a transmission and conventional drive line.

The chief advantages claimed for the GT are:

1. High power output from a given weight engine.
2. Smooth vibrationless running.
3. Low internal friction - little wear.
4. Easy starting.
5. Can use a wide range of fuels.
6. Low oil consumption.
7. No water cooling system.
8. Low emission.
9. Requires little routine as maintenance.

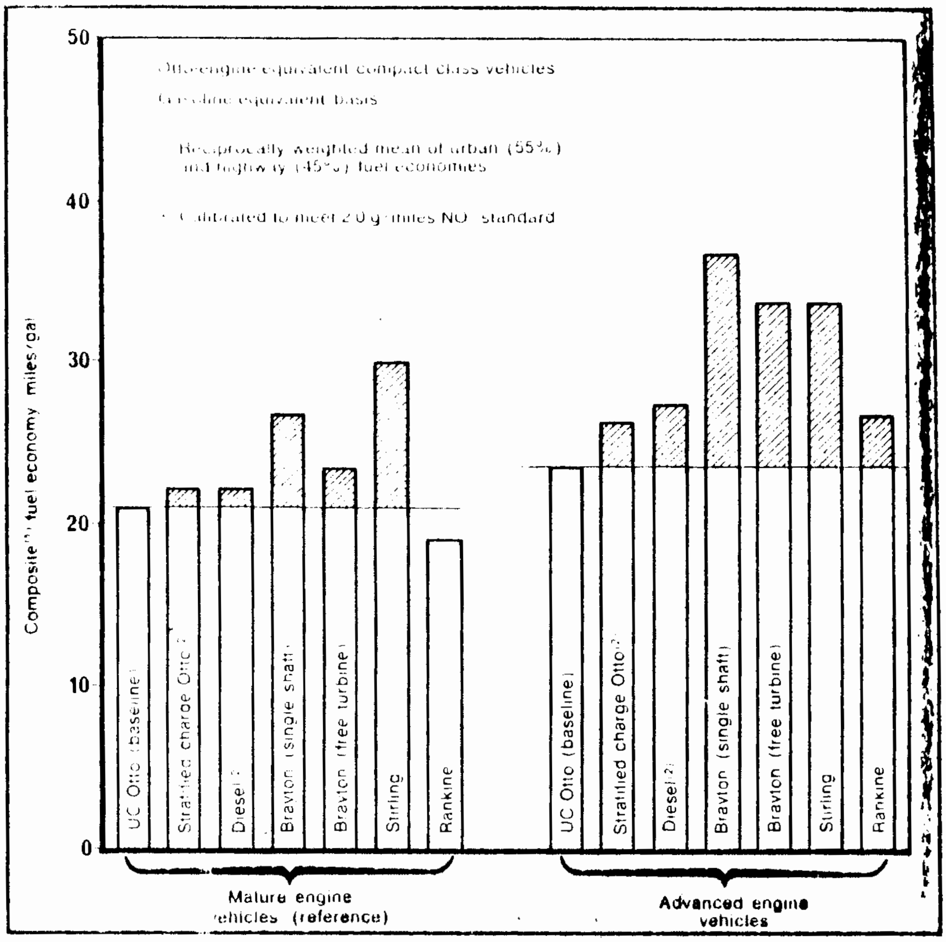
Engines of the future. Ford Motor Company funded a study, by a team of an engineer and scientist, to evaluate whether the U. S. should, could or is likely to have a new type of engine to replace the conventional piston engine. The team confined itself to what should be happening, as what could be done was limited to technical feasibility. The teams most confident prediction was that the engine of the future will be an improved version of the conventional Otto-cycle engine.

In the course of study, several fundamental realizations emerged:

1. The car will maintain its dominant role in personal transport.
2. Major changes cannot happen overnight regardless of money.
3. Liquid fuel will continue to be used to the end of the century at least.
4. Financial resources will be available for change.
5. Emissions controls must become more stringent.

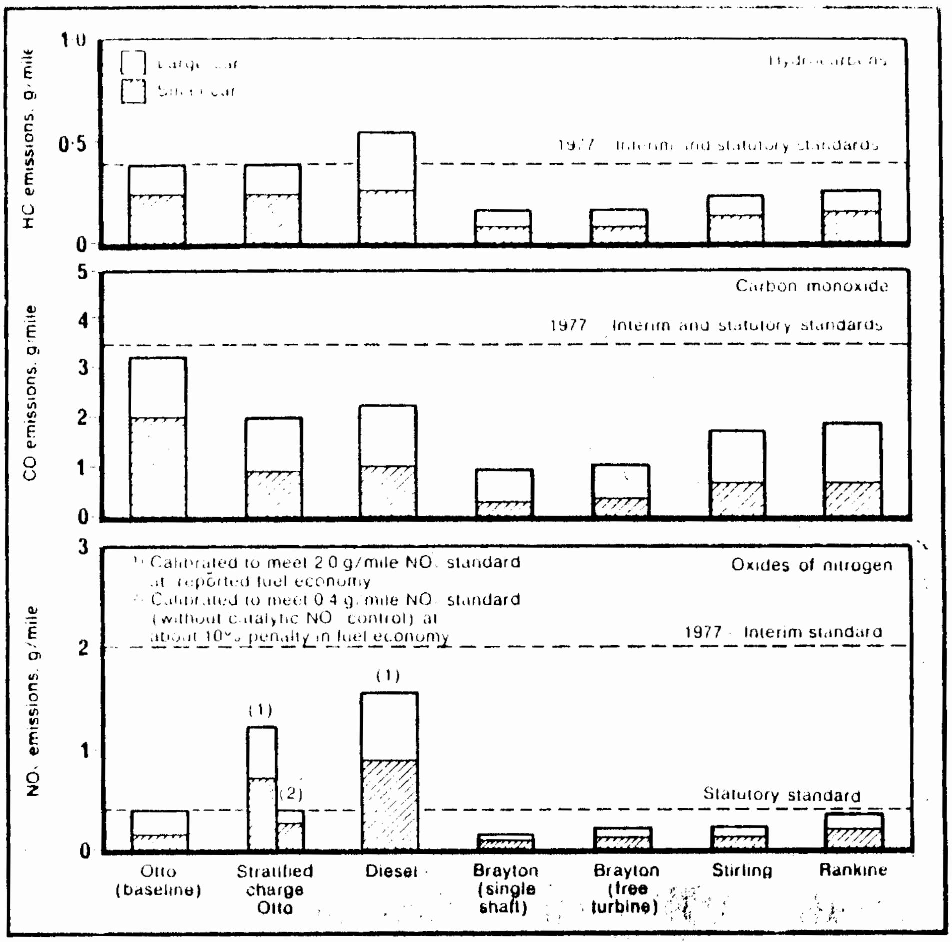
Figure 19 shows the emission levels for mature engine cars.

The team also projected that weight reduction and the adoption of four-speed automatic transmission will be introduced. Other major find-



Emission levels for mature engine cars.
Figure 19

show that vehicles powered by the gas turbine and the Stirling engine can reduce fuel consumption by about one-third that of conventional engines, and at emission levels below the strictest present standards. Figure 20 shows the fuel economy potential of advanced configuration engines.



Fuel economy potential of advanced configuration engines.

Figure 20

CHAPTER VI

SUMMARY

This study presents a comparative and contrasting view of the design and operating principles of the internal rotary combustion engine,(IRCE). with those of the rotary combustion engine, (RCE). The study included both present and predicted future engine design trends, and the factors that will influence these trends.

Reference was made to the working, safety and employment conditions that are in the automotive industry. This was made possible by visits to local industries, and the cooperation of staff personnel.

From the study, it was possible to develop an instructional unit which will be of benefit to students, apprentices, mechanics, instructors and others who are interested in improving the efficiency of automotive power. It is also hoped that the study unit, would bring about an awareness of the extent to which the automobile engine effects our environment.

Conclusion

Research from this study has shown, that the RCE because of its design characteristics including rotary motion, simple construction, fewer parts, and better power to weight ratios; has the potential of being a more suitable choice of motive power than the reciprocating combustion engine, (ReCE). Disadvantages seem to be in the cost of changes in production techniques to accommodate the new design, rather than poor performance which can be solved by further development.

Future trends in engine design will be influenced by: the cost of the engine, fuel consumption; and exhaust emissions. There is a disparity of opinion among the experts as to the engine of the future, but the majority favors the stratified charge piston engine to be dominate, at least to the end of this century.

The study also shows the dilemma that many designers and manufacturers experience, when the cost of change restricts progress. This situation can force decision makers to settle for second best.

Recommendation

The results of the study and the teaching unit could be improved by including an experiment in which the ReCE and the RCE could be tested. Tests could include performances of break horsepower, specific fuel consumption and thermal efficiency.

The test could be made more meaningful by including in the experiment, problems areas of sealing, exhaust emissions under various engine working conditions. As these areas are topical, students would be motivated by the possibility of matching their results with other findings.

To ensure that the experiment is of full benefit to the participants, each student should be responsible for a specific result of a test. Results of the test should be of special interest, as it's from such results that the future trend in engine design may depend.

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Mortimer, J. Research and development. The Engineer, May 13, 1976, 33-37.

APPENDICES

PATENT PROCEDURE

Practical Patent Procedure is the same sort of logical procedure that followed in any regular business enterprise. Certain fundamental practices st be followed if we hope to receive our Letters Patent.

WHAT IS PATENTABLE

Any invention or discovery that is new and useful — that is not patented or described in any printed publication or publicly used before your invention or discovery for more than one year prior to your application.

Any person who invents or discovers any new and useful process, manufacture or composition of matter or any new and useful improvement thereof, may obtain a Patent, subject to conditions and requirements of the law.

By NEW it means —

The invention was not known or used by others in this or a foreign country before the inventor made his application.

The invention was not patented or described in a publication, or in public use, or on sale in this country more than one year prior to the application date in the United States. It is immaterial if the publication, public use or sale was by the inventor or someone else. The subject matter sought to be patented must be sufficiently different from any invention over the prior art — for example, not just a change in size or material.

Small advances that would be perfectly obvious to one skilled in the art are not considered inventions and are not patentable.

By USEFUL it means —

That the invention performs the service it was intended to perform.

Alleged inventions of perpetual motion machines are refused patents.

What is granted to the Patentee is not the right to make use and sell the invention but the right *to exclude* others from making, using and selling the invention.

PETITION, SPECIFICATION AND OATH

In The
United States Patent Office

IN THE MATTER OF THE APPLICATION OF

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FOR

Letters Patent

FOR

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FILED BY

The Form your Patent Attorney will mail you to sign

WHAT AN APPLICATION COMPRISES

IN BRIEF

Fee —

I.	Petition . .	Citizenship — name — address — Power of Attorney on filing application for the inventor.
II.	Specification .	must be written in the English language. State object of the invention, nature of the invention (kind). Drawings — describing different views (if drawing necessary). Detailed description. Claim or claims
III.	Oath . . .	Signature of applicant, legibly written. Sworn to before a Notary Public.

IN DETAIL

See "General Information Concerning Patents"
Patent Office
Free Booklet

If Patent is granted, final fee of $100 must be paid within six months.

Patents will ordinarily be issued about 30 days after final fee is paid

PLANT PATENTS

Application and drawings must be in duplicate when color is necessary for its patentability.

DESIGN PATENTS

The design must be represented by a drawing made to conform to the rules laid down for mechanical inventions.

FOREIGN PATENTS

The Patent Office cannot assist in the filing of Applications for Patents in foreign countries. If an inventor wishes protection in other countries he must apply for the patent in the other countries. They each have their own Patent Laws.

Visits to Industry

In conducting the research for my study, I visited the local automobile service workshops of Hanawalt Ford, Schukei Chevrolet, John Deery Motors and Friedley Lincoln Mercury. At these workshops I observed the processes, practices, and methods of service and repair. I also conducted a number of interviews with reference to the trend toward the small car, the rotary engine compared with the piston engine, tools, equipment, and wages for the automobile mechanic.

The majority of the personnel interviewed, felt that the trend by the consumer will be toward the small car for local motoring and the larger car for long distances. This may encourage each family to own two cars, which may be an advantage for the car industry, but may increase the overall fuel consumption.

There was some difference of opinion as to the merits and faults of the rotary combustion engine, (RCE), compared with the reciprocating combustion engine, (ReCE). This contrast of opinion appeared to be dependent on the individual's committment to the particular engine. Lee Gardines, a Mazda trained technician at Mercury Lincoln, is very hopeful for the rotary engine. Sales are on the increase and the rotary RX7 is very much in demand. Major problems have been solved since the introduction of new sealing methods and gas nitraded housings. Duane Carpenter, a sales representative and previous owner of a 1973 RX3 rotary Mazda, had no complaints with the rotary engine in his RX3. Its performance was excellent with no sealing or maintenance problems, other than when incorrect spark plugs were installed.

UNIVERSITY OF NORTHERN IOWA · Cedar Falls, Iowa 50613

July 25, 1978

The Personnel Manager
Mazda Motors of America, Inc.
P. O. Box 36527
Houston, Texas 77036

Dear Sir or Madam:

I am a final year graduate student at the University of Northern Iowa, pursuing a Master's degree in Industrial Technology.

For my research paper I have chosen my topic on an analytical comparison and contrast of the rotary combustion engine with the reciprocating engine. In my research, your company was recommended by a representative of one of your dealerships: Friedley Motors of Cedar Falls.

I would be obliged if you would forward to me, in connection pertaining to the history, principles, and development of the rotary engine.

Any information that you may forward will be confidential, and only used for the purpose intended. Thanking you for your prompt cooperation.

Sincerely,

Eric K. Earle

EKE/kg

UNIVERSITY OF NORTHERN IOWA · Cedar Falls, Iowa 50613

July 25, 1978

Mr. R. Beck, Department Chairman
Hawkeye Institute of Technology
1501 E. Orange Road
P. O. Box 8012
Waterloo, IA 50704

Dear Mr. Beck:

Thank you for the information you forwarded to me in reference to the rotary combustion engine. It was of great importance to the content of my research paper and the presentation of the study.

Thank you again for your assistance in this matter.

Sincerely,

Eric K. Earle

EKE/kg

UNIVERSITY OF NORTHERN IOWA · Cedar Falls, Iowa 50613

July 25, 1978

Mr. Lee Gardines
Friedley Lincoln-Mercury
4227 University Avenue
Cedar Falls, IA 50613

Dear Mr. Gardines:

Many thanks for the cooperation and information you have given me in reference to the rotary combustion engine. It was of great assistance to the content and presentation of my research paper.

Thank you again for your assistance in this matter.

Sincerely,

Eric K. Earle

EKE/kg

UNI

UNIVERSITY OF NORTHERN IOWA · Cedar Falls, Iowa 50613

July 28, 1978

The Personnel Office
Chilton Book Co.
Philadelphia, PA 19100

To Whom It May Concern:

I am a graduate student at the University of Northern Iowa, pursuing a Master's degree in Industrial Technology. I am writing a research paper comparing and contrasting the internal combustion engine, with the rotary combustion engine.

In my paper, I have used the book titled "The Wankel Engine" extensively, and I would like your permission to use some of the illustrations.

Sincerely yours,

Eric K. Earle

University of Northern Iowa
Cedar Falls, IA 50613

EKE/kg

INSTRUCTIONAL UNIT

Fuel economy and exhaust emissions have made the design of the automobile engine a very topical subject. It is the purpose of vocational education to prepare a person for socially useful employment. This could only be achieved, if the educators in vocational education are aware, and kept abreast of the design changes and predictions in industry.

The instructional unit below, was developed to meet the practices in industry. This should assist the instruction in reaching objectives that are meaningful to the student.

Unit Outline

I. Broad Objectives

(a) The student will be able to identify the structural difference between the rotary combustion engine (RCE) and the reciprocating combustion engine, (ReCE).

(b) The student will be able to explain the design characteristics of the RCE and the ReCE.

(c) The student will be able to explain the operation of the RCE and the ReCE.

(d) The student will be able to state the advantages and disadvantages of the RCE and the ReCE.

(e) The student will be able to dismantle and assemble RCE and ReCE

(f) The student will be able to explain future design engine trends.

(g) The student will be able to define the following terms:

1. torque
2. brake horsepower
3. volumemetric efficiency
4. comparison ratio
5. thermal efficiency
6. mechanical efficiency

II. <u>Introduction</u>

(a) Pretest.

(b) Safety procedures.

(c) Tools and materials.

(d) Historical information.

III. <u>Behavioral Objectives</u>

(a) Identify from a selection of engines, those that are RCE and those that are ReCE, by labeling each engine correctly.

(b) Explain in essay form the design characteristics to meet the standards set by the college.

(c) describe in essay form the operation of the RCE and ReCE to meet the standards set by the college.

(d) state the advantages of the RCE and ReCE by correctly selecting 80% of the matching answers in the test.

(e) dismantle and assemble the RCE and ReCE in a given time, to meet the standards set by the college.

(f) Identify future design trends by correctly matching 80% of the test questions, to answers given.

IV. <u>Preparation</u>

Technical Information (classroom)

(a) The basic components of the RCE and ReCE, their materials, functions and location.

(b) The operating engine cycle of the ReCE and RCE.

(c) The advantages and disadvantages of the ReCE and the RCE.

(d) Calculations relating to compression ratio, torque and brake horsepower.

Workshop Exercise

(a) Identify tools and their correct selection.

(b) Identify workshop safety practices.

(c) Identify engine components and their locations.

(d) Remove and dismantle engine components.

(e) Clean and inspect engine components.

(f) Repair, replace or adjust components as necessary.

(g) Reassemble engine.

(h) Start, test, and adjust engine as required.

(i) Clean tool and work area.

Sample Lesson Plan

SUBJECT: Auto Mechanics

TOPIC: Basic Engine Components

NO. OF STUDENTS: 18 DATE: 2/7/78 DURATION: 1½ hours

AGE: 17-21

OBJECTIVES:

Students at the end of the lesson should be able to:

(a) Identify the basic components of the engine by labeling each component correctly.

(b) Explain in essay form the materials that are used in engine components with 80% accuracy.

(c) Explain in essay form the function of each component as described by the class text.

Previous knowledge: Students are able to identify engine, chassis and and transmission in their location.

Introduction:	Aids:
The Topic briefly explain	Verbal exposition (VE)
Main component shown in assembled state and then separately	Overhead projector O·H·P some engine parts
Construction and Operation	
Each component introduced, its material and function explained, until a picture of the whole engine is developed	O·H·P
Application (Workshop)	
Demonstrate how these components are assembled	Cut away engine model

Sample Lesson Plan Continued

Introduction	Aids
Evaluation	
Students will complete incomplete handout	Incomplete handout
Summary	
Name basic components and materials	VE

Evaluation

Student:

The performance of each student is checked against the instructional objectives. This performance is measured:

(a) through oral questions before, in, and after each lesson.

(b) by test given at the end of each topic.

(c) by a final overall test on the subject.

(d) by having each student perform task in the workshop to meet the requirements set by the college. These tasks would relate as closely as possible to the work carried out in industry.

Course:

An evaluation would be made to check the objectives against the job done in industry. This could be done through:

(a) visits to industry.

(b) interviewing present and former students in industry, about their job, and how well they are coping.

(c) interview the supervisor on the job, to find out how the student is performing, new equipment, and changes in industry.

SAMPLE TEST

Date: Time: 1½ hours Attempt all questions.

Questions: Each question has equal marks.

1. List the main components of:
    (a) the rotary combustion engine (RCE).
    (b) the reciprocating engine (ReCE).
2. Explain the operating cycle of:
    (a) the RCE.
    (b) the ReCE.
3. Show by means of a sketch the inlet and exhaust port location on the RCE.
4. Explain the following terms:
    (a) Compression ratio.
    (b) Horsepower.
    (c) The stroke.
    (d) Mechanical Efficiency.
    (e) Cycle.

Workshop Safety Precautions

1. Know the procedure in switching equipment off before switching it on.
2. Wear protective clothing and eye protection supplied.
3. Ensure working area is clean and free from grease and other unnecessary obstacles.
4. No smoking allowed in workshop area.
5. Large quantities of petrol and other volatile substances are kept a safe distance from the work area.
6. Adequate ventilation must be provided.
7. Become acquainted with the use and location of fire extinguishers.
8. Know the correct procedure in first aid.
9. Always select the correct tool for the job.

Textbooks

Textbooks on automobile engineering are numerous, unfortunately there are comparatively few on the Wankel engine. Indications are that this may change as the controversy of the engine continues. Fortunately there are several good articles written in journals, in which there is adequate information. The following are some of the books and journals that are recommended as reference material:

Norbye, J. P. The Wankel Engine. 1971. Chilton Book Co., 401 Walnut St., Philadelphia, Pennsylvania.

Ansdale, R. F. The Wankel RC Engine. 1970. Iliffe Book Ltd., 42 Russel Square, London, W.C.I.

Ludvigsen, K. Wankel Engines A to Z. 1973. Ludvigsen Publications, Pelham, New York.

Dark, H. E. Auto Engines of Tomorrow. 1975. Indiana University Press, Bloomington & London.

Journals

Automotive Engineer

Department 2

P. O. Box 2709

Clinton, Iowa 52732

The Engineer

Morgan-Grampian (Publishers)Ltd.

Morgan-Grampian House

Calderwood St.

London, SE 18 6 QH

Visual Aids

Film: The Rotary Engine:

Cardinal Associates, Inc.

Charlotte, North Carolina 28202

Transparencies

Rotary Engines

DCA Educational Products

424 Valley Road

Warrington, Pennsylvania 18976

VITA

Eric K. Earle was born in West Indies

Education: Westley Hall Secondary School - Barbados
Action Technical College - England
Paddington College of Higher Education - England
Garnett College of Education - England

Experience: Apprentice Mechanic
Mechanic
Reception Engineer
Works Controller

Professional Bodies: City and Guilds of London Institute--Full Technological Certificate.
Associate Member of Institute of Motor Industry AMIMI.
Associate Member of Institute of Road Transport Engineers, AMIRTE.

Marital Status: Married with two children.