



## OVERVIEW

### History of the Four-Stroke Wankel Rotary Engine from which the Five-Stroke Rotapower® Engine Evolved

Prior to 1963, there were four types of engines in worldwide production with each operating on a fundamentally different cycle. They included two and four-stroke piston engines operating on the Otto cycle, two and four-stroke piston engines operating on the Diesel cycle, turbine engines operating on the Brayton cycle and steam engines operating on the Rankine cycle. In 1963, after over 35 years of development, a new type of engine entered production in Germany.

It had been patented by Felix Wankel and became known as the Wankel rotary engine. It operated on either the Otto or Diesel cycle using the four-stroke principle. This engine has been described as the least complicated four-stroke engine to ever enter production. The worldwide automotive industry initially considered this remarkable engine to be the most important mechanical invention in the 20th century. However, despite having the automotive and recreational industries spend over \$10 billion in today's dollars on Wankel rotary engine powered products, only Mazda Motors in Japan and Outboard Marine Corporation (OMC) in the US put the Wankel Rotary engine into volume production. General Motors Corporation (GMC) had a production ready engine for installation in their 1975 Corvette, when concern over higher fuel consumption and emissions made it change priorities.

The Wankel rotary engine has many attractive features such as low weight and volume with only two moving parts and complete freedom from radial vibration. On the other hand, it has higher fuel consumption and emissions together with a high exhaust temperature and noise. These limitations resulted from the higher pressure and thermal energy that was lost in its exhaust.

### The Creation of Freedom Motors

Freedom Motors (FM) was formed in 1997 with the objective of overcoming the limitations of the Wankel rotary engine. In order to help achieve this objective, Freedom Motors acquired the intellectual property (IP) and the rotary engine physical assets of the four US companies that had put Wankel type rotary engines into some level of production. These companies included:

- 1) **Moller International:** MI had been engaged in the development of aircraft directed Wankel type rotary engines since the mid-1960s, when it obtained permission to import the first Wankel rotary engine allowed to enter North America. Subsequently, MI had developed and produced single and multi-rotor 530cc and 650cc liquid cooled Rotapower® engines based on the Wankel principle. These Rotapower® engines were deployed in numerous applications, including a gen-set, hybrid car, various watercraft, four different aircraft and numerous drones that were delivered to the US Army, Navy, and Air-force in the mid 1990's.
- 2) **Outboard Marine Corporation:** OMC had put a 530cc displacement rotary engine into volume production and had a 650cc production model ready for its marine market when it was sold and MI acquired OMC's entire rotary engine IP and physical assets, including production equipment and extensive inventory.
- 3) **General Motors Corporation:** GMC had a Wankel type rotary engine production ready in 1975 that was fully tooled. Emerging issues regarding fuel consumption and emissions made them change their priorities at that time. FM acquired GMC's rotary engine production equipment.
- 4) **Infinite Engine Company:** IEC contracted MI to produce a 1,500cc twin rotor Rotapower® engine to operate on diesel fuel. It was to be used to power a drone for the military. Following delivery, a dispute arose regarding the terms of the contract. In subsequent litigation MI prevailed and was awarded the entire rotary engine assets of this publicly traded company.

### **Freedom Motors Development of its Five-Stroke Rotapower® Engine**

The Wankel engine's major weakness is its higher fuel consumption which can be up to 20% compared to the best piston engine. This limitation arose primarily due to its unique combustion process, which inherently left a substantial amount of pressure and thermal energy in the exhaust. Many years of development and thousands of hours of dynamometer testing led to six Rotapower® engine patents being issued, with another five now in process. By forcing the exhaust gases to go through a second expansion stroke, much of previous lost exhaust energy was recovered. This fifth stroke was accomplished with the addition of only one moving part.

This additional stroke (second expansion stroke) achieved the following:

- Recovered exhaust thermal and pressure energy in the form of mechanical energy resulting in a potential 25% reduction in fuel consumption when fully optimized.
- Reduced the exhaust exiting pressure, which is the chief source of engine noise. The unmuffled noise was reduced by 24 dBA (94% reduction)
- Cooled the exhaust gases from 1600°F to between 800°F and 950°F.

The following Table compares the Rotapower engine with one of the lightest and smallest four-stroke piston engine (Rotax 912 ULS) per horsepower.

<b>Engine Type</b>	<b>Rotapower® (5-Stroke)</b>	<b>Piston (4-Stroke)</b>	<b>Rotapower® (4-Stroke)</b>
<b>Model</b>	<b>530-1C</b>	<b>Rotax 912 ULS</b>	<b>530-1</b>
<b>HP/lb.</b>	<b>160/60 = 2.67</b>	<b>100/114.8 = 0.87</b>	<b>125/40 = 3.13</b>
<b>HP/Ft<sup>3</sup></b>	<b>160/1.2 = 133</b>	<b>100/2.9 = 34.5</b>	<b>125/0.9 = 139</b>
<b>Price per HP</b>	<b>\$85</b>	<b>\$196</b>	<b>\$50</b>
<b>Radial Vibration</b>	<b>None</b>	<b>Significant (4 cyl.)</b>	<b>None</b>
<b>Exhaust Temp</b>	<b>800°F to 950°F</b>	<b>1,400°F</b>	<b>1,600°F</b>
<b>Unmuffled Noise</b>	<b>85 dBA (94% less)</b>	<b>106 dBA</b>	<b>109 dBA</b>
<b>Maximum RPM</b>	<b>9,000 RM</b>	<b>5,800 RPM</b>	<b>9,000 RPM</b>
<b>Specific Fuel Consumption</b>	<b>0.35 lb./HP.Hr</b>	<b>0.36 lb./HP.Hr</b>	<b>0.40 lb./HP.Hr</b>

The five-stroke Rotapower® engine became what the four-stroke Wankel engine was thought to be when it was introduced to the world in 1963.