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The Rotapower® rotary engine (basic and compounded)

Background of the Rotary Engine Using the Wankel Design

When the rotary engine was first introduced in the early 1960s, it was thought by many to be the most important mechanical invention of the 20th century. With two or three moving parts it seemed to be the perfect replacement for the complex piston engine with over fifteen moving parts. It was also less than one half the weight and volume of a competing piston engine.

Virtually every automobile and aircraft company became enraptured by its potential and during the following 20 years spent an estimated $2-$3 billion trying to get the rotary engine to match the fuel consumption of the automotive piston engine.

There are two fundamentally different rotary engine designs depending on the method used to cool the rotor:

- Oil cooled rotors used by GMC, Mazda, NSU, Syrano, and Ingersoll-Rand
- Charge or air-cooled rotors were used by Outboard Marine Corporation (OMC), Norton Motors, Infinite Engine Company (IEC), Fichtel-Sachs, and currently by our company Freedom Motors

The oil cooled rotor requires complex composite side-seals to retain the oil in the rotor. Power is lost as the cooling oil is accelerated in the rotor. For a given displacement an oil cooled rotor produces more power due to the lower volumetric efficiency of the charged cooled rotary engine.

The charge cooled rotor is much simpler and weighs significantly less for a given horsepower. As a result, it produces a higher horsepower to weight ratio than either the oil cooled rotary or four stroke piston engine.

Following its acquisition of all rotary engine assets of GMC, OMC and IEC, Freedom Motors developed a family of charge cooled basic rotary engines ranging from single-rotor 27cc and 150cc displacement engines to multi-rotor 530cc and 650cc displacement engines. These Rotapower rotary engines have been successfully demonstrated in a number of utility, recreational, and commercial products.

Attributes of all rotary engines are:

- High power for its weight and volume
- Few moving parts
- Operate on the four-stroke principle
- Very low vibration

Limitations of the basic rotary engine are:

- Loud exhaust due to rapid opening of the exhaust port
- High surface to volume of the combustion chamber increases SFC due to combustion quenching.
- Compression ratio is limited to 9 to 1 to minimize combustion quenching
- Charge cooled rotor raises SFC through lower volumetric efficiency
- Oil cooled rotor results in a power loss as oil is accelerated in rotor
- Exhaust temperature is high due to slower combustion process

Compounding an Engine

Compounding involves not only using exhaust energy to supercharge the intake charge, but also to extract mechanical energy directly from the exhaust as well.

A compound rotary engine is created by using two rotors in series where the first compression/expansion (CE) rotor supercharges a second power rotor. Following combustion in the power rotor, the exhaust gases reenter the CE rotor where additional energy is extracted. Rolls-Royce (RR) was the first company to demonstrate a compound rotary engine. In the RR design, a large compression/expansion rotor was used in conjunction with a smaller power rotor. The two rotors were connected by a chain drive and operated on separate crankshafts as shown in Figure 1. The resulting engine was substantially smaller than the diesel fueled piston engine RR was hoping to replace. Unfortunately, RR was forced into a Chapter 11 reorganization which prevented further development. It did achieve a SFC of 0.375 lb/hp·hr which is the lowest SFC recorded for a rotary engine.

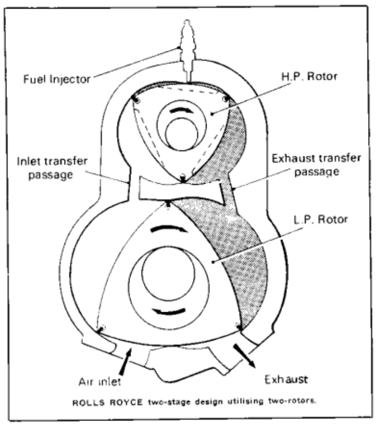
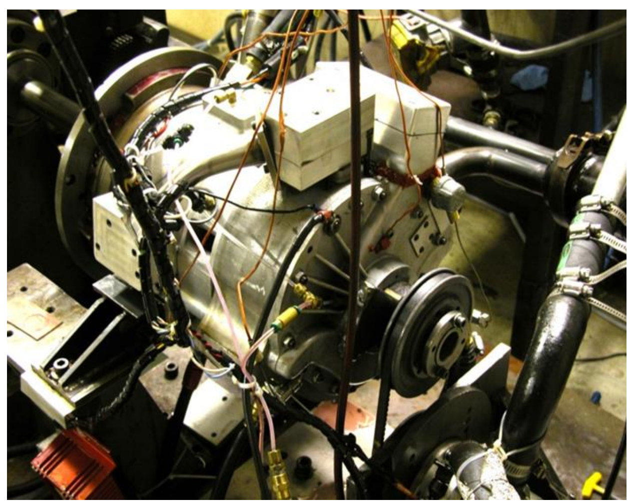


Figure 1

Freedom Motors has developed and dyno tested a compound version of its charged cooled rotary engine. It is considerably simpler than the RR design. The compound Rotapower® engine as shown in Figure 2, has both rotors operating on the same shaft which are charge cooled. The dyno tests have demonstrated that compounding the Rotapower engine eliminates the following limitations of the basic version:

- **Noise.** The very extended expansion cycle reduces the exhausting gases to near atmospheric pressure and thereby eliminating over 95% of the noise (120 dba reduced to 75 dba).
- **High Surface to Volume Ratio.** Supercharging allows the power rotor compression ratio to be reduced which lowers the surface to volume ratio, while maintaining a high pre-combustion pressure. The C\E rotor allows a high total expansion ratio despite a low power rotor compression ratio (extended Atkinson cycle).
- **High Effective Compression Ratio**. Sufficient to provide auto-ignition in the diesel cycle.
- **Oil Cooling Loss is Avoided**. (10% improvement in SFC).
- **Lower Exhaust Temperature.** Reduced from 1,500°F to 800°F.
- **Fuel consumption was reduced.** Minimizing SFC will require the port timing and sizes to be optimized. This will require an extensive gas dynamic analysis using computer aided modeling.



Freedom Motors 530cc Compound Rotary Engine on Dynamometer

Figure 2

Projected SFC Based on Available Data

Figure 3, taken from NASA TM 105562, shows that NASA was able to match the SFC of RR at 0.375 lb/hp·hr for a turbo-charged rotary engine. Both the NASA and RR engines used oil-cooled rotors. Figure 4 shows that using a charge cooled rotor results in a 10% reduction in SFC versus an oil cooled rotor. Based on this reduction, the projected SFC would be 0.34 lb/hp·hr. NASA had planned to undertake a number of improvements that were projected to lead to a further 15% reduction in SFC.

Unfortunately the test program was terminated at this point due to lack of funds. If only one-half this reduction were to be achieved, the SFC would be 0.31 lb/hp·hr. The best SFC recorded for an automobile engine is 0.326 lb/hp·hr for the Audi 2.5 L TDI.

BSFC Improvement Steps: Past and Potential

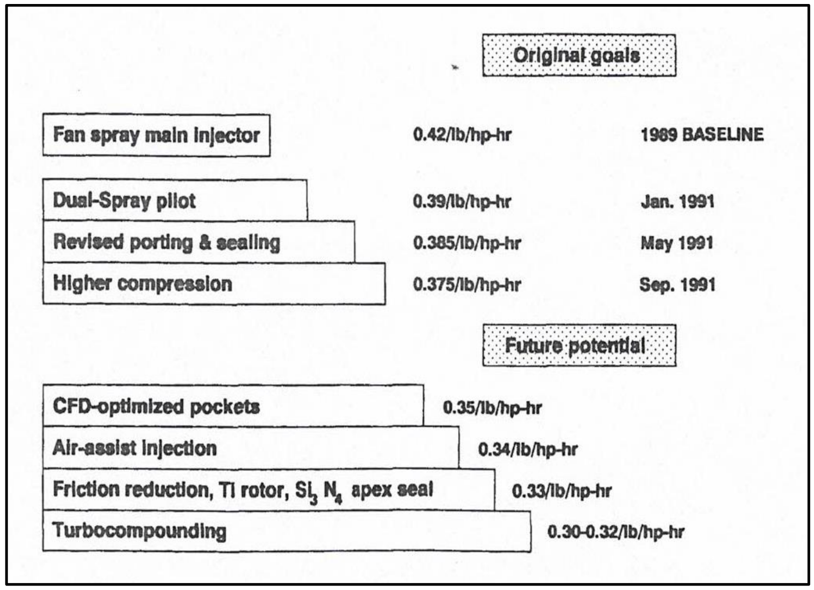


Figure 3

Comparison of Friction Loss Between Mazda 500cc and Freedom Motors 530cc Single Rotor Engines

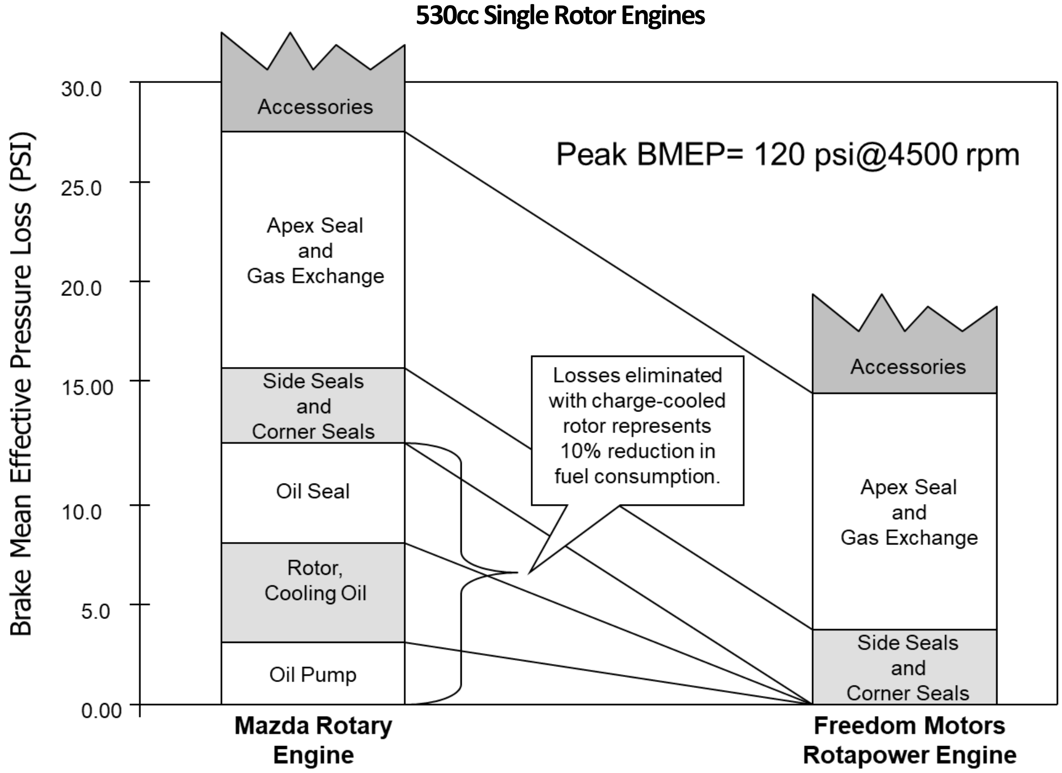


Figure 4

Market Opportunities where the Attributes of a Compounded Rotapower® Engine are Uniquely Applicable

- **Powering gensets by sourgas or biogas.** Forty percent of the world's natural gas is primarily methane (CH_4) contaminated by hydrogen sulfite (H_2S). This contaminated natural gas is referred to as sourgas. A second source of methane called biogas is manmade. Biogas is generated anaerobically from landfills, wastewater plants, animal manure, and as a byproduct of the petroleum industry. Biogas is more contaminated than sourgas, but generally both need to be cleaned at considerable cost prior to being utilized for energy production. The Rotapower engine can use either gas as sources of energy at less than one-third the installed cost of piston or microturbine engines and is also much more tolerant of H_2S and silica. Compounding allows the intake pressure to be increased enough to take advantage of the very high-octane rating of biogas/sourgas which improves the thermal efficiency and ability to use biogas with lower methane content.

- **Hybrid automobiles.** A compound rotary engine requires less than one-third the volume of a piston and has one-tenth the moving parts. Low noise, vibration, fuel consumption and emissions are additional attributes of a compounded Rotapower® engine.

- **Powering personal use vertical take-off and landing (VTOL) aircraft.** An often-repeated comment is "where is my flying car". The answer: "When a quiet, low cost engine is developed with a high enough power to weight ratio to make a flying car practical". Aircraft piston engines produce about one horsepower per pound of weight. Aircraft versions of the Rotapower® engine have demonstrated a power to weight ratio exceeding three. This, together with its other attributes, makes the *longed for* flying car possible.

- **Powering a one-kilowatt genset**. The US Government has established that a genset engine producing one kilowatt of electrical energy produces enough energy from its exhaust and cooling to provide the hot water needs of the average US home. This $240 billion program is being implemented to place a one-kilowatt genset in every home with access to natural gas. The performance goals are: 40% thermal efficiency from the engines/generator at a noise level of 55 dba. The Rotapower® engine can meet the noise requirement and should substantially exceed the thermal efficiency of a piston powered genset.

- **Powering the world motorcycle and motor scooter market.** Many countries eliminate or reduce the vehicle license fee if the engine displacement is low enough. As a result, these low powered motorcycles and scooters have poor performance. The compounded Rotapower engine can produce three times as much power as a piston engine for the same displacement. The worldwide market for engine driven motorcycles/scooters is over $125 billion annually.