# How to build a 650 HP, 250 pound, turbo charged Wankel aircraft engine.

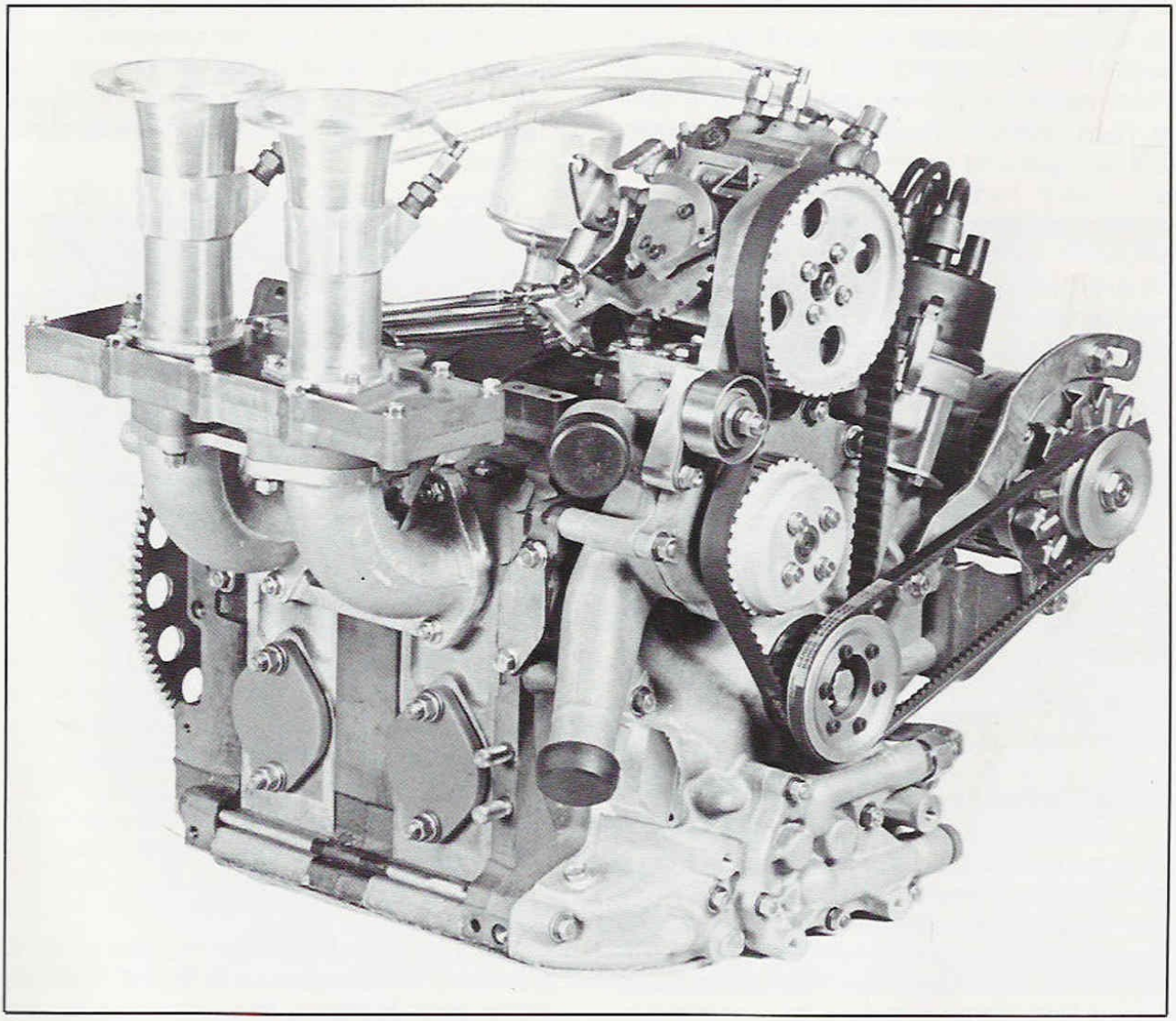
**Several years ago an American rotor head by the name of Russ MacFarlane living in Newcastle Australia decided to build a Mazda rotary powered world record attempt time to climb aircraft. Russ was a long time subscriber to the Rotary Engine News Letter.**



**The Mazda rotary car engine has a reputation for using more gas around town. That is true but the difference at aircraft power levels is only 3% or 5%. The RX8 is very powerful and quiet for its size and it is tempting to use the power around town. If you use the power it will burn the gas. In an aircraft this pails into insignificance as the big savings come from burning low cost car gas. Car gas is half the cost of aviation fuel 100LL in some states and up to $1 cheaper than diesel fuel in some states.**

**Back in the early 1970's and 1980's Mazda rotaries won more Daytona Beach 24 hour endurance racing than any other brand. Chevrolet, Ford and Toyota complained to the race organizer and they added penalties in later years. By the late 1980's if you wanted to race a rotary you had to carry 650 pounds of ballast. This is a picture of the 300 HP rotaries used at that time. It is a P-port, slide throttle, mechanical fuel injection and iron end housings. It weighed around 300 pounds. Not turbo charged so the iron apex seals had no problem living for 24 hours.**

**Finally in 1991 a Mazda four rotor won the Le Manns 24 hour race outright on the fixed amount of fuel all the other races had. The french organizer handicapped it so severely they were never able to compete after that..**



The workhorse 13B two-rotor Mazda engine with peripheral porting produced approximately 300hp and powered the early Mazda prototypes as well as many RX-7s. *BFGoodrich*

**A used flying Harmon Rocket home built aircraft was purchased and the Lycoming engine and instruments were removed and sold. The aircraft is very similar to a Van's RV4 with longer landing gear and shorter wings..**

**Dan Grey, owner of Aviation FX in Santa Paula California was chosen to finish the project and get it flying. I was the project engineer.  .Dan is a 787 captain for UAL.**



**The Wankel rotary has a much better power to weight ratio and power to size ratio than any automotive piston engine. It is also far more robust and will withstand ungodly amounts of turbo boost with out structural failure.**



**There is a certified version of the Wankel used in motor gliders built by Austro engines that have no TBO. Indefinite life. Over 500 have been sold.**

**Automotive piston engines are not designed for aircraft power levels and should not be used. The average power required for a car engine is 30 to 40 HP! In other words car piston engines are low duty cycle engines. Aircraft engines are high duty cycle. The Wankel rotary is an inadvertent high duty cycle exception for a car engine due to the unique mechanical geometry. I think this was unforeseen by Felix Wankel and most Wankel engine l manufactures.**

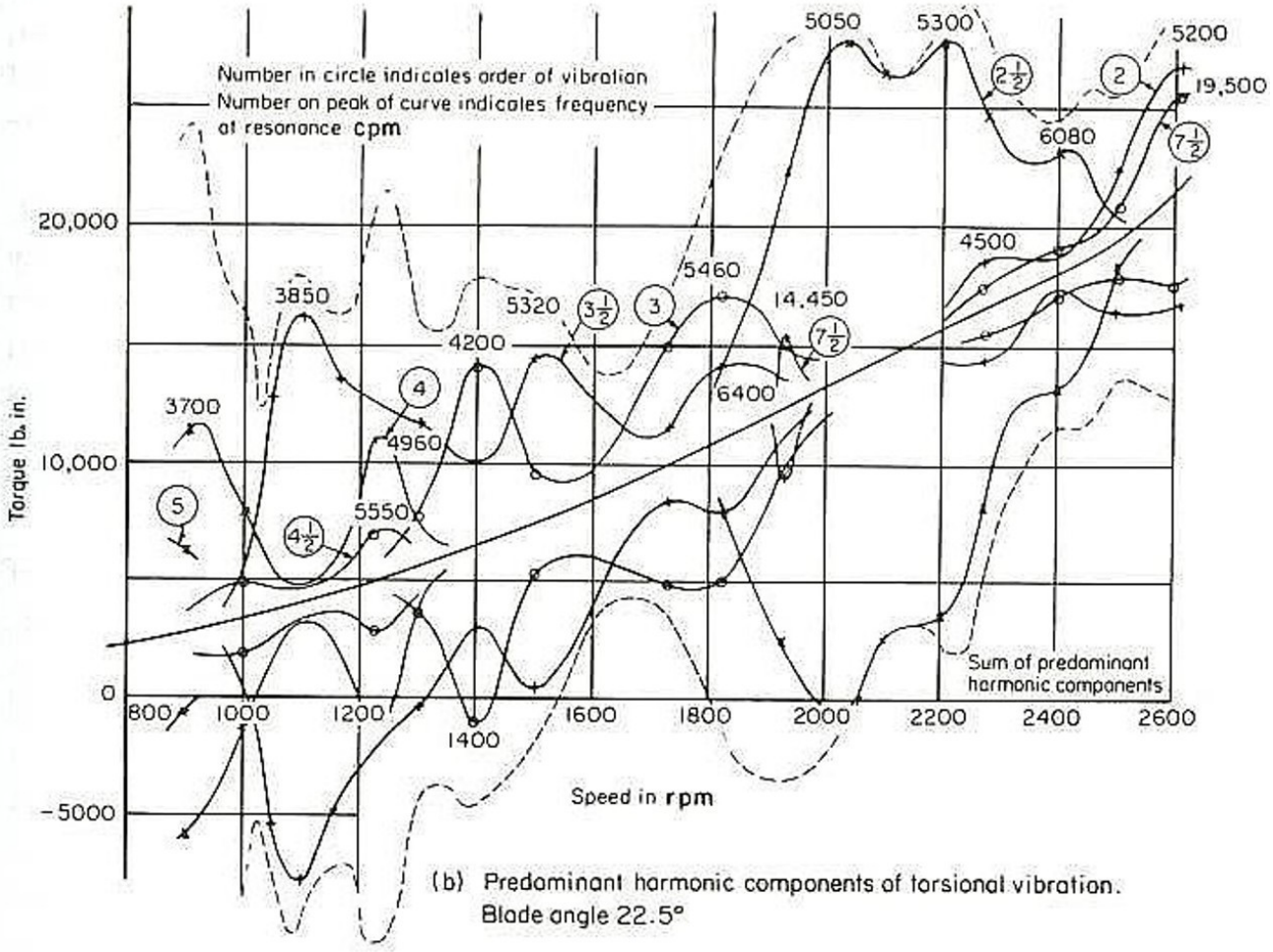



**Fig. 8–29.** Torque at drive end of crankshaft of Rolls-Royce *Merlin* II aircraft engine wit variable-pitch propeller, 1-to-2 reduction gear (Carter and Forshaw, 8.492).

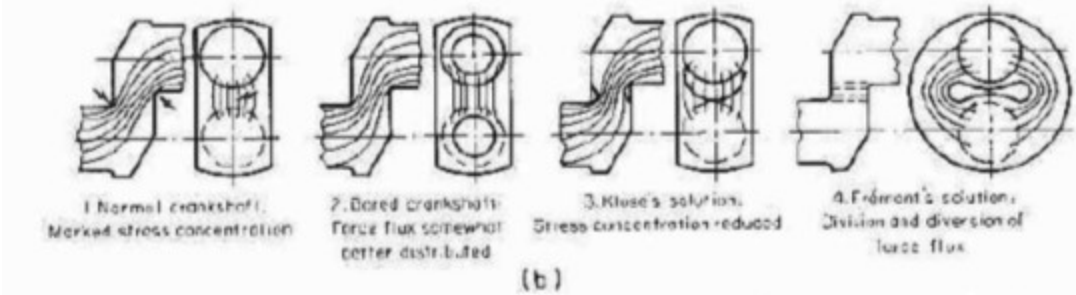



**Fig. 11–35.** Crank stress patterns (Matinaglia, 11.700). (*a*) Endurance-limit nominal stress in torsion ($\sigma$) versus fillet radius. Numbers are dimensions of test pieces in cm; (*b*) "flux" of force from pin to journal. Stress is smaller as flux lines are farther apart. (*c*) Effect of overlap on crank endurance strength in bending. The dimensions held constant, in millimeters are as follows: Crank throw 73; pin length 52; pin bore 40; journal length 37; journal bore 50; cheek thickness 22; cheek width 126. The dimensions varied, in millimeters, were as follows:

| *O/P* | *Pin diam* | *Journal diam* |
|---|---|---|
| 0.055 | 68 | 85 |
| 0.028 | 66.4 | 83.4 |
| 0.000 | 64.4 | 81.4 |
| -0.032 | 62.4 | 79.4 |

$\sigma$ nominal endurance stress O overlap P pin diam

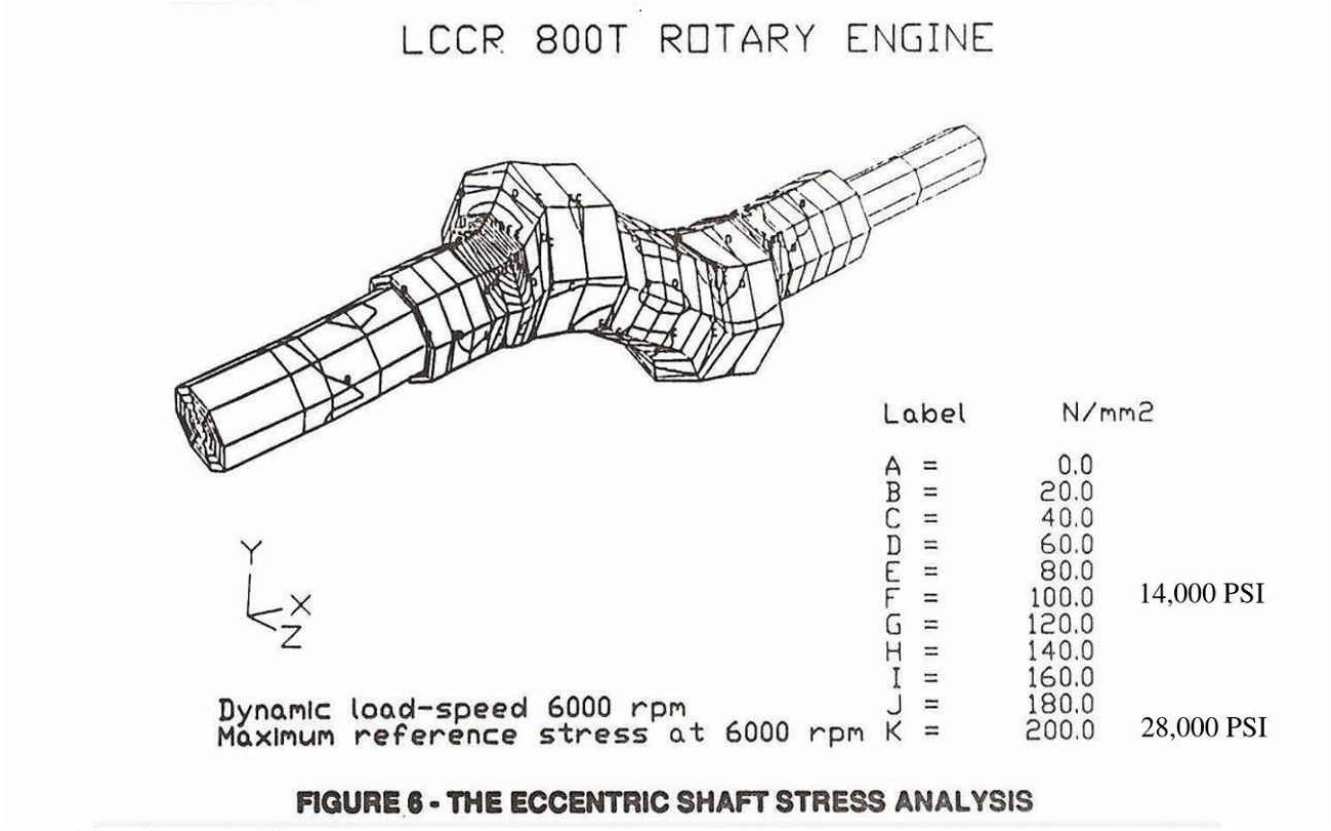
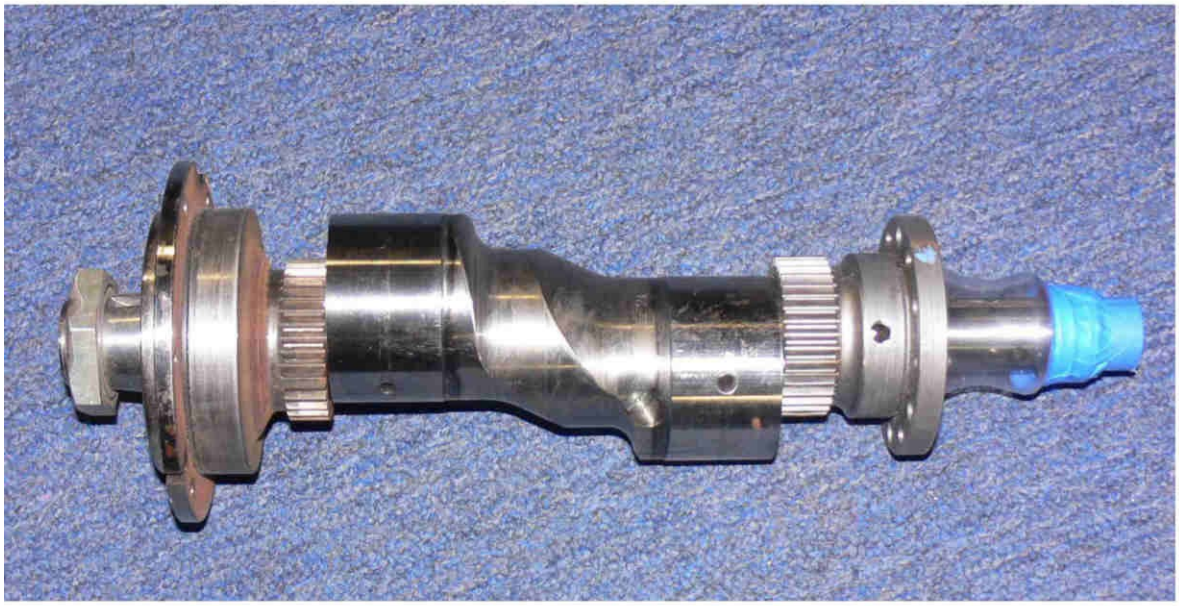



**FIGURE 6 - THE ECCENTRIC SHAFT STRESS ANALYSIS**

**The stress on the eccentric shaft is remarable low. It is possible to hydroform it.**

**Tubular Hydroforming is gaining popularity in several markets for its track record of producing better quality components at a lower cost. Some of the benefits of Tubular Hydroforming over conventional tubular structure forming and welding include:**
**High Precision maintaining constant wall thickness. Unfortunately the Mazda E shaft is not hydroformed.**

**Here is a picture of the very robust eccentric shaft on a Mazda Wankel rotary.**



**Russ contacted Jim Mederer owner of Racing Beat. Jim holds the stock car body land speed record at Bonneville at 238 MPH in a Mazda RX7.**

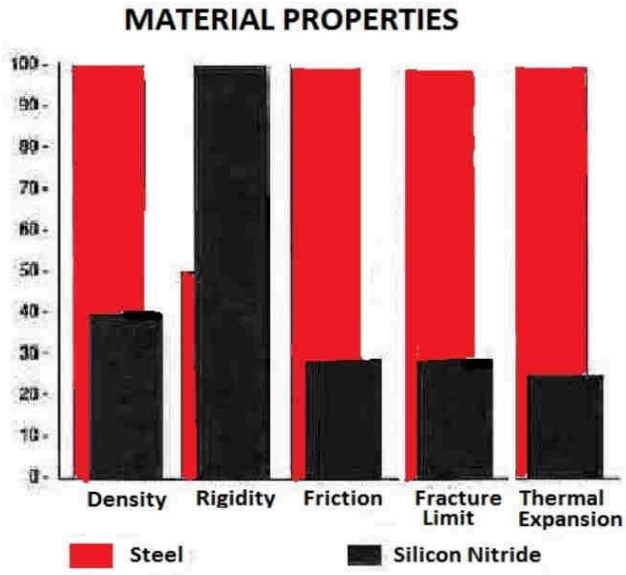
**Russ was counting on the high power to weight ratio of the Wankel and it's exceptionable robust nature.**

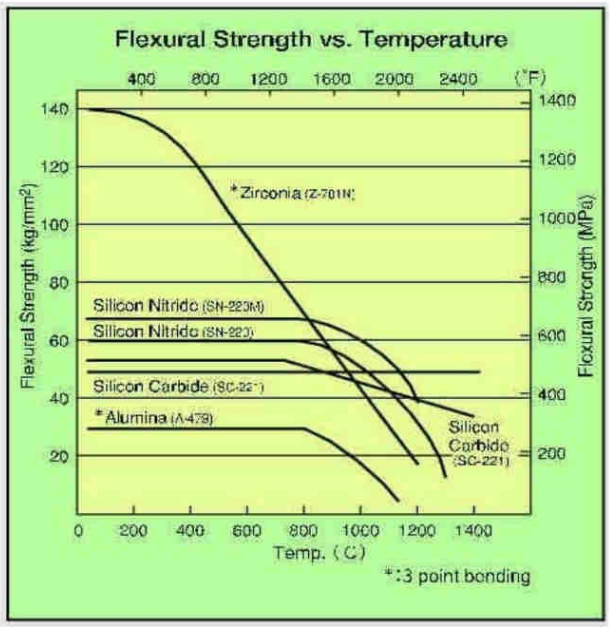
**Jim was able to extract 650 HP running on methanol from a two rotor. Jim also developed aluminum end housings that dropped the engine weight from about 300 pounds to less than 200 pounds less the gear box and including a huge turbo. A gear box typically weighs about 35 pounds.**

# THE OVER ALL KEY TO THIS PROJECT.

**The silicon nitride apex seals have a projected life of an extraordinary 20,000 hours. Not 2000 hours but 20,000 hours. These silicon nitride apex seals are the key to turbo charged Wankel engines. If you turbo charge a Wankel with cast iron or steel apex seals it will probably fail.**

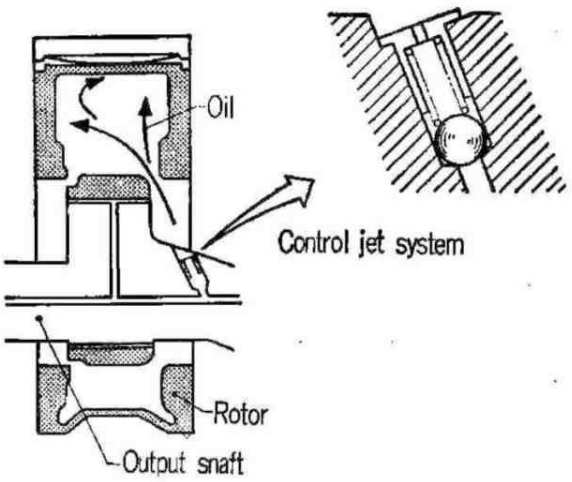
**Silicon nitride ball bearings are good to 1000 degrees Fahrenheit while steel ball bearings are limited to 500 degrees Fahrenheit.**



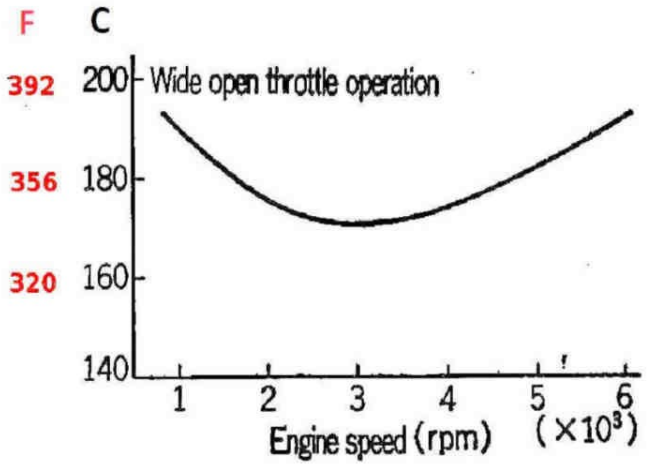



**I had a friend that road raced rotaries. He ran out of cooling liquid at a race one time and he decided to keep running. The engine overheated of course and got so hot it melted a hole in the .05 inch thick steel liner in the aluminum rotor housing near the spark plug . When he disassembled the engine the silicon nitride apex seals looked OK so he used them in another engine. It ran fine for a long time.**

**Anything you can do to improve the volumetric efficiency lowers the fuel burn per HP. This is called BSFC in the industry which stands for Brake Specific Fuel Consumption. It is given in pounds of fuel burned per HP per hour. Charge cooled rotors are typically over .52 pounds per HP per Hour while oil cooled rotor are .47 or below. Point Four Seven is the same BSFC as my six cylinder Continental 230 HP engine in my Cessna 182.** s
**It is therefore absolutely necessary to cool the rotor with oil. That has another important effect on the temperature of the apex seal slot. There is a spring in the apex seal slot that keeps the apex seal in contact with the rotor housing. The spring losses its temper if it gets too hot. The spring must be kept cool.**



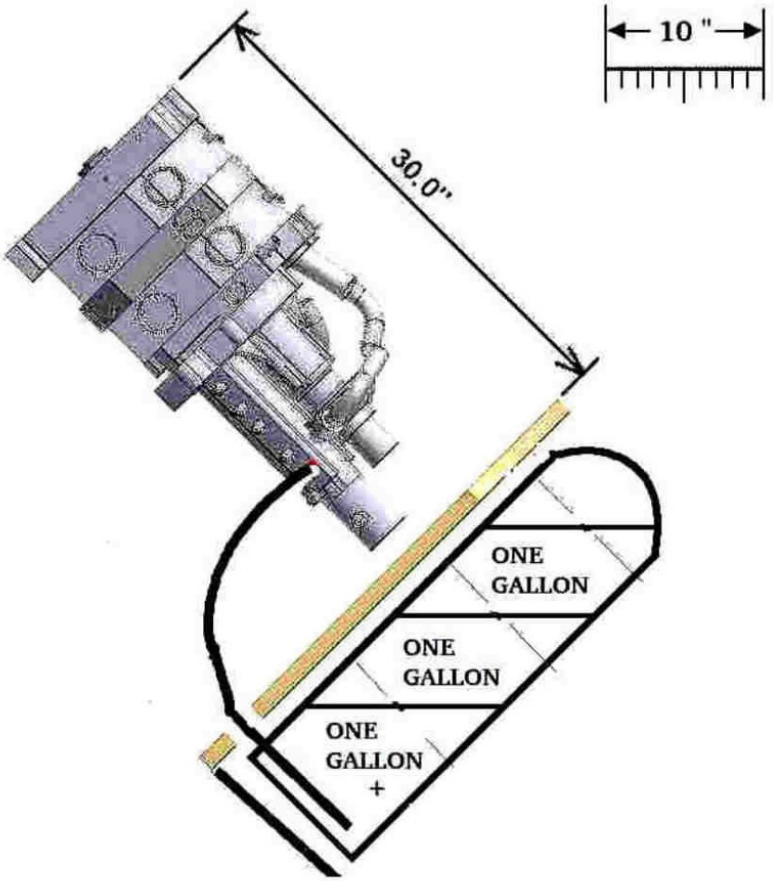

Control of lubricating oil injection




Change in rotor surface temperature

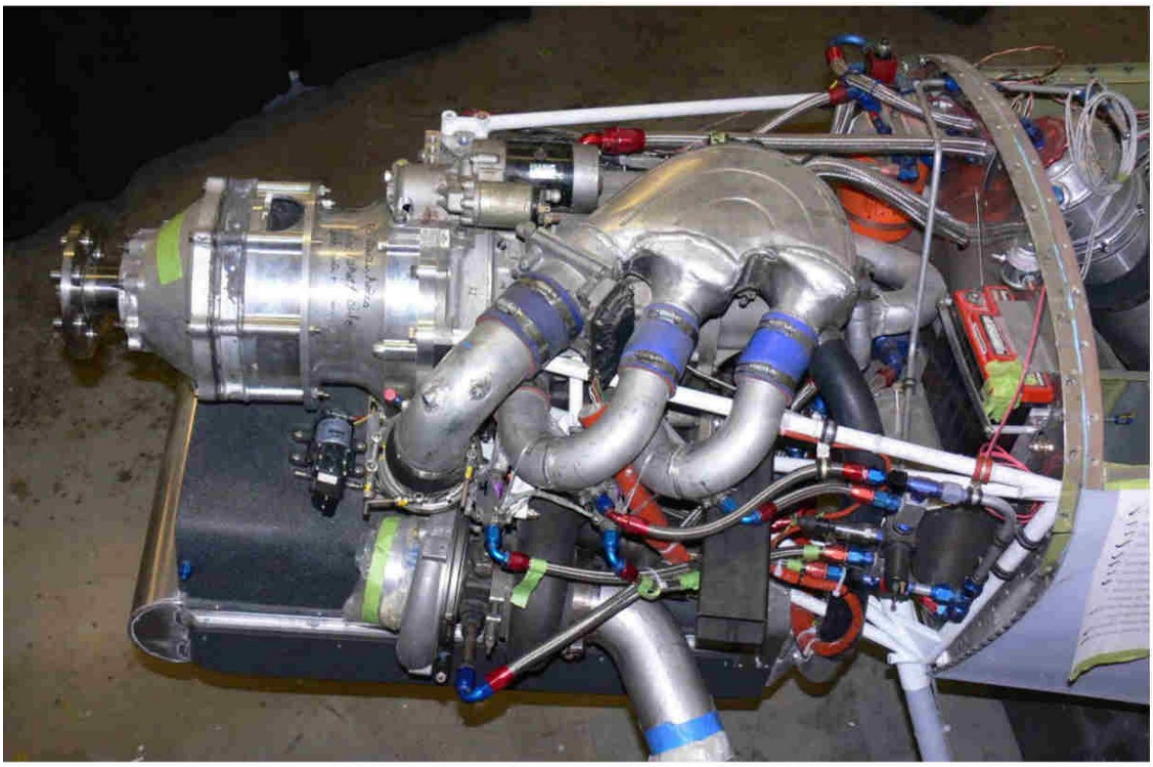
**Lubrication Oil Volume for a Bank (CC/Hr)**

**Lots of other engine changes were made. A dry sump oil system was needed so the oil pan was done away with and replaced with AN pluming that extracted oil directly from the center and end housings and sent it to the oil reservoir. The pressure pump was in this groupe.**




**A new larger capacity water pump was used.**
**A tuned intake p-port was chosen which is very streamlined on the inside with the fuel air mixture entering**

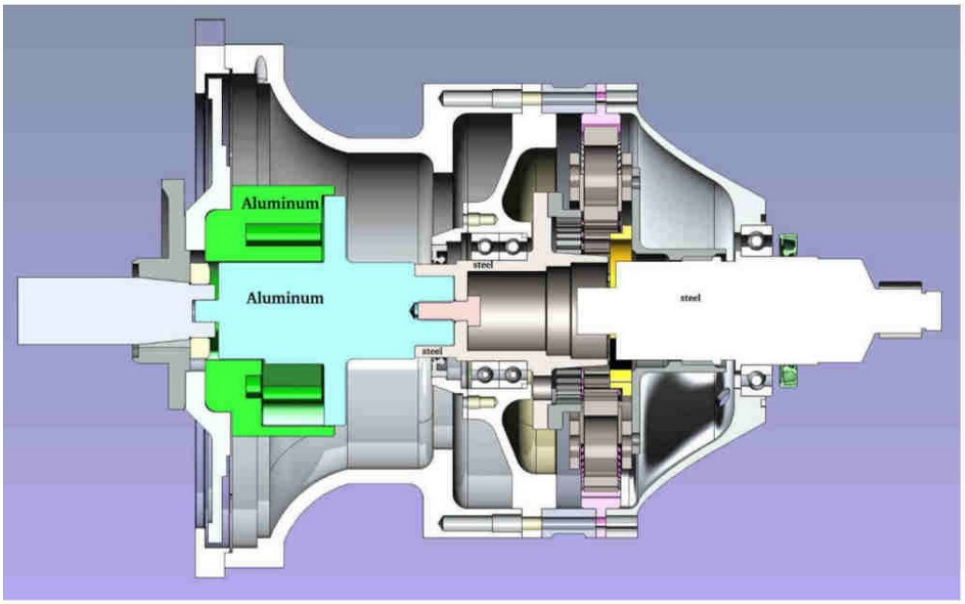
**the engine straight in directly. No intake valve to get in the way. This results in a volumetric efficiency of (believe or not) 120%. That means the engines gets 20% more air than the displacement with out a turbo. More air, more HP. An after market Motec EFI system was chosen to supply fuel to the engine. Modified stock rotors where used in combination with a stock eccentric shaft.**



**A Bell 47 helicopter final drive was used as a three to one gear box on the TTC. It weighs about 35 pounds. An extension housing was machined to accommodate a gear box cooling system. This turned out to be unnecessary so it was gutted to save weight. The extension was left in place giving more room for the engine cooling system.**





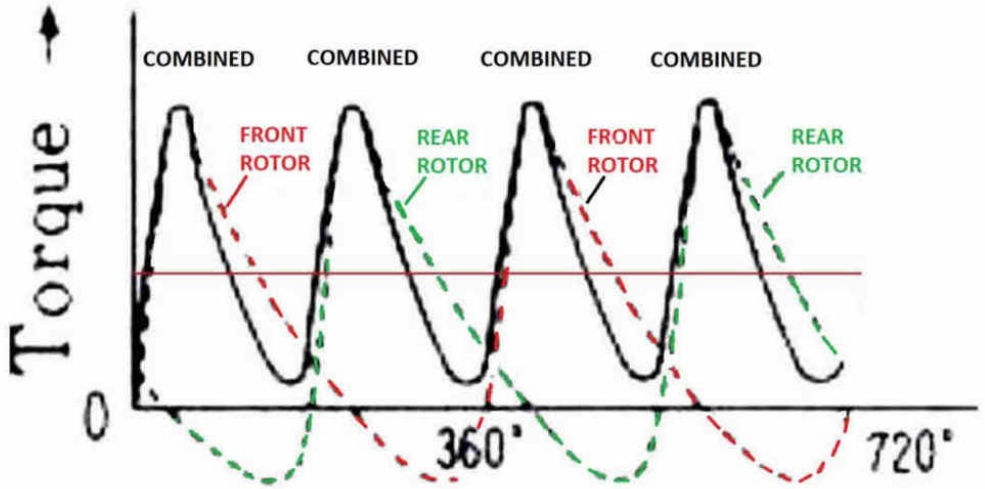


**Neil Ungar 12348ung@gmail.com in Australia is building a three to one gear boxes for the Mazda two rotor.**





**All intermittent internal combustion engines have torque pulses. The torque pulses on a two rotor rotary are less severe than a four cylinder piston engine. Never the less it is a good idea to use a rubber coupling between the engine and the gear box. Diesel engines are the worst for torque pulses and Diamond aircraft are having a lot of trouble with this. They have no rubber coupling either. The diesel torque pulse is severe.**




NOTE : FRONT AND REAR ROTORS ARE 180 DEGREES OUT OF PHASE TWO PULSES PER ENGINE REV.

**Lycoming does not have a rubber coupling on their geared versions and that limits the TBO to well under 2000 hours. In case you were wondering all radial aircraft engines used in WW II had planetary geared engines.**

**Here are some pictures of the TTC rubber coupling I designed to mitigate the shock load on the gears..**

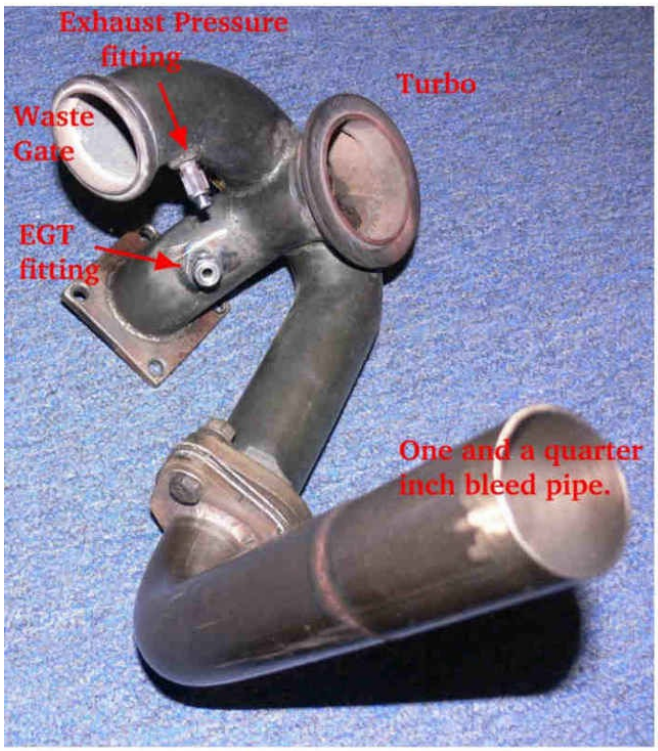




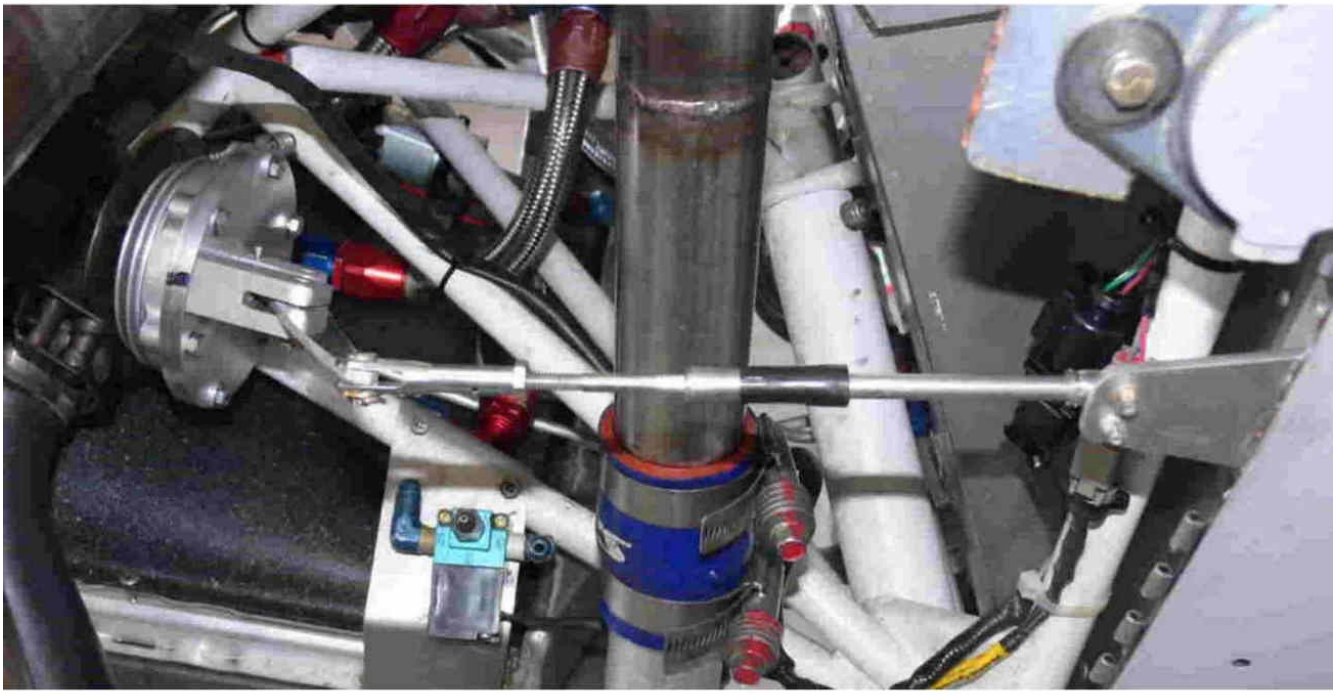

**The large turbo charger is operating in blow down mode. Ideal for two rotor Wankle. That means the high velocity exhaust pulses are 180 degrees out of phase. The larger the turbo the less affect of the high given exhaust temperatures have on turbo blade durability.**

**There is a turbo bypass pipe with a 1.25 inch diameter hole. This indicates the extraordinary additional energy in the exhaust common to all internal combustion engines.. If we had built a turbo compound version to recover some of this energy we would have had about 900 HP with the same fuel burn. The BSFC would be well below .40.**

**The excess energy was so much we installed an exhaust by pass pipe with a 1.25 inch hole in the restrictor plate. This hole is wide open at all times.**



**I converted the waste gate to manual control by the pilot. This turned out to be unnecessary as well. The pilot can control the power with throttle alone. The intake manifold blow off valve limits the boost to what ever is necessary.**

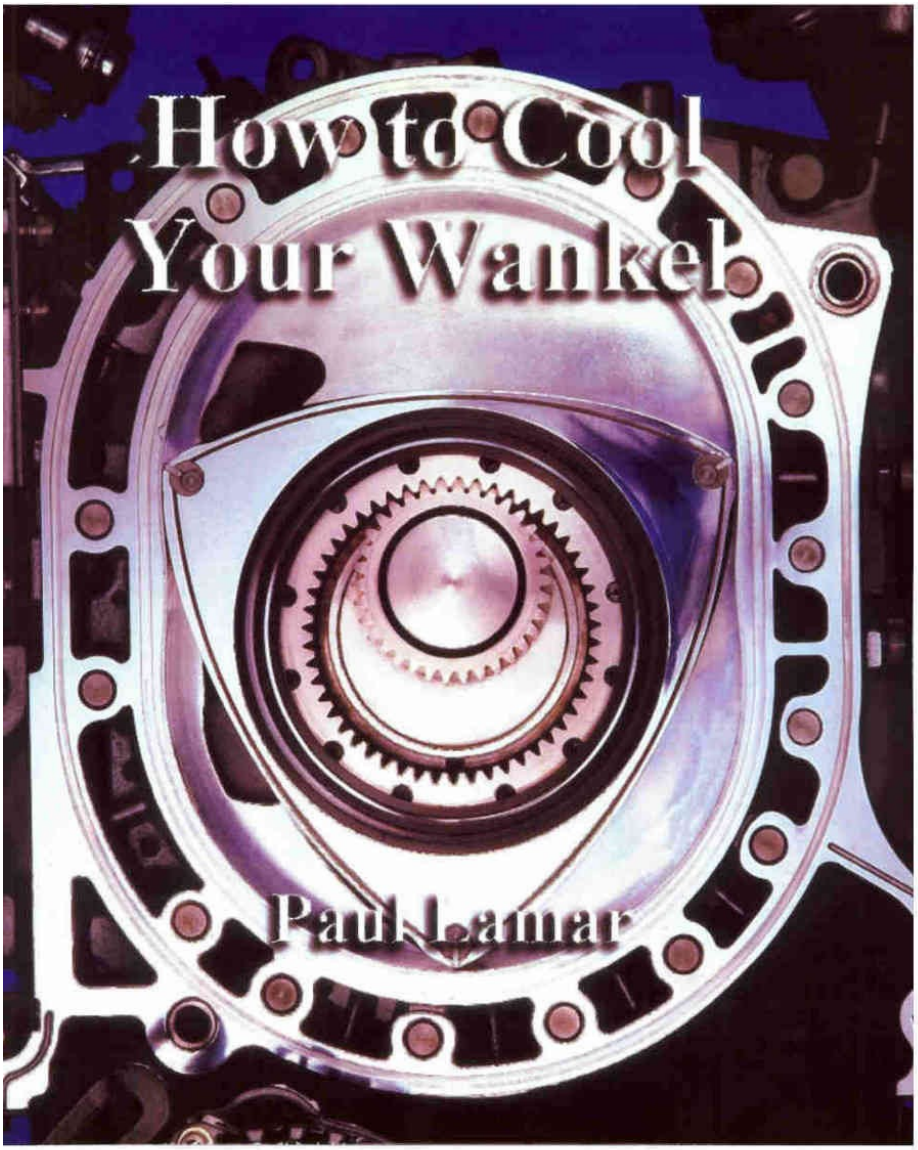


**The pilot was moved to the back seat and the 20 gallon methanol fuel, 10 gallon water and 4 gallon oil tanks were installed behind the stock firewall. The water was found to be unnecessary as the methanol cools the charge adequately . This saved 80 pounds.**

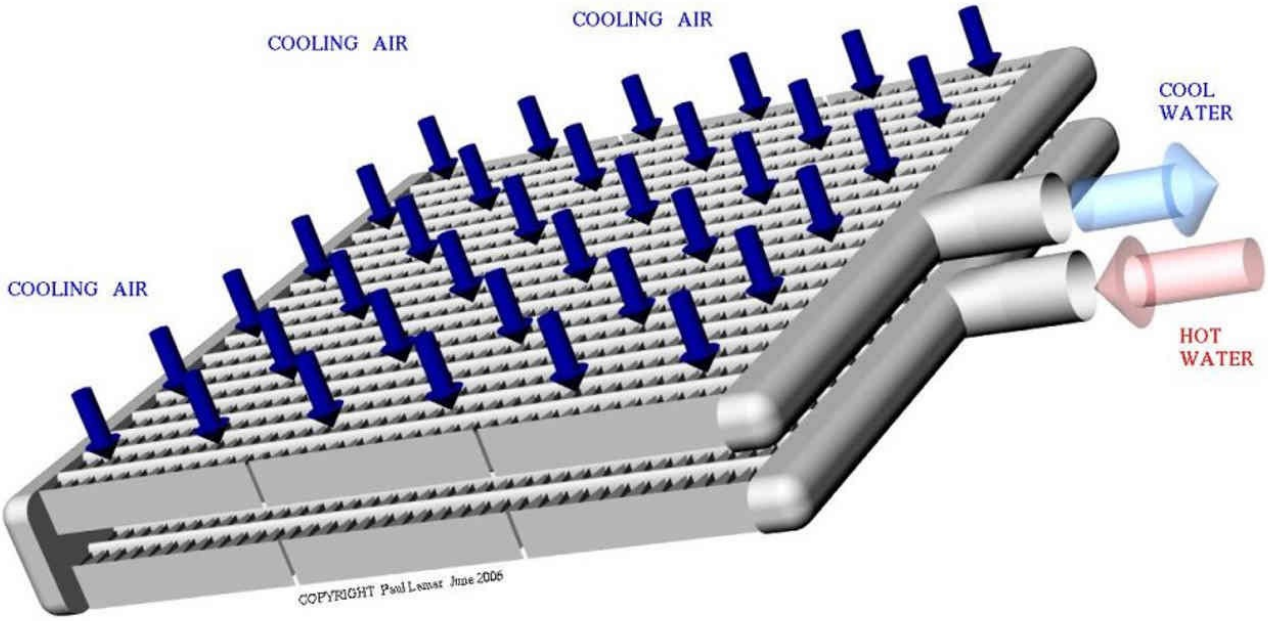
**It is impossible to over heat 4 gallons of Mobile One oil in 2 minutes of max power running so no oil cooler was required. We did install one and tested it. And it worked however.**



**I wrote a book called How to Cool Your Wankel so I designed the liquid cooling system.**

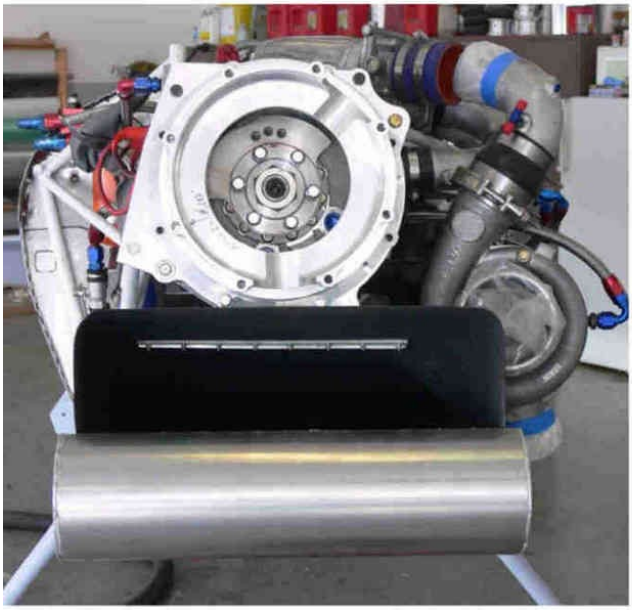


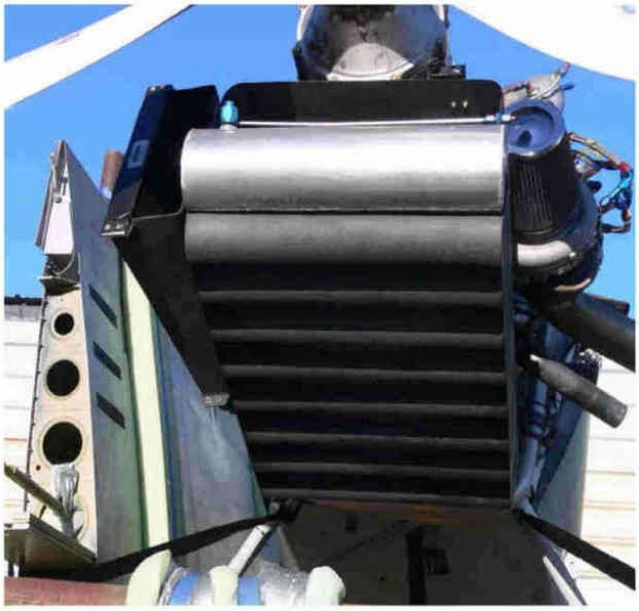

**The 650 HP Wankel was a real challenge to cool so I choose two large area thin core pick up truck radiators and TIG welded them back to back in what is known as a cross counter flow configuration. It cools extremely well.**




CROSS COUNTER FLOW EXCHANGER

**The cooling water temperature never gets over 150 F. A fiber glass tapered cooling diffuser and curved louvers on the bottom of the radiators were made by Aviation FX. The tapered intake diffuser is key to the excellent cooling efficiency. It was developed in the 1980's well after WW II.**





**A new larger capacity water pump was used.**
**A tuned intake p-port was chosen which is very streamlined on the inside with the fuel air mixture entering the engine through a p-port.**

# THE TIME TO CLIMB RECORD.

**The propeller driven absolute time to climb records is 120 seconds from a dead stop on the runway to 3000 meters. It is held by a Sport Class Reno racer with Turbo Lycoming. This is not a weight class record. This is an absolute record. The empty weight of the TTC aircraft is only 1000 pounds.**

**The power to weight ratio of the record holding Sport Class Reno Racer aircraft was approximately 2 pounds per HP. The power to weight ratio of this TTC aircraft is only 1.8 pound per HP. That all has to do with the extraordinarily exceptional power to weight ratio of the Wankel engine. 2.2 HP per pound of engine weight at the reduced level of 550 HP..**




**We are still fine tuning the Motec EFI which has been a real challenge.**

**A manifold blow off valve that can be adjusted up to 85 inches of mercury was installed and that was a huge simplification. The manual waste gate is not really needed as the blow off valve does enough of the boost control on an aircraft installation. Nothing the pilot can do with the throttle will damage the engine.**



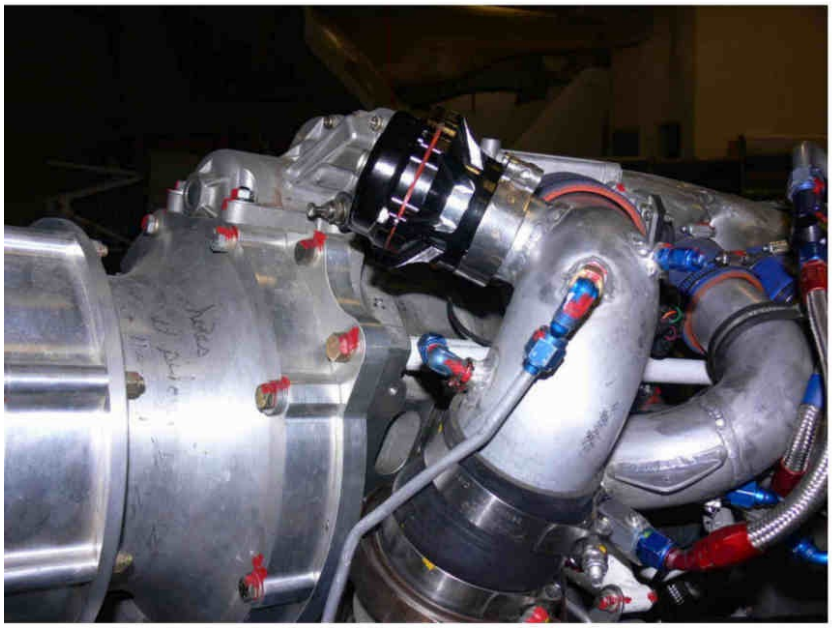
**Historically this engine development is on a par with the jet engine and the turbo prop engine on a engine power to weight basis. Pratt and Whitney Canada, manufacturer of the PT6 turbo prop engine, has filed well over a 30 Wankel patents in the past few years so they know the Wankel aircraft engine is inevitable. Even Rolls Royce is considering it for the core of a ducted fan jet engine due to a superior compression ratio.**

**Not only will it best a turbo prop on power to weight ratio but it will burn three quarters of the fuel for a given horsepower. The cost of the engine would be at least half of any turbo prop engine. In addition it would have higher altitude performance. Up to 50,000 feet.**

**We originally estimated the Harmon Rocket aircraft would climb vertically at 175 MPH based on the over all aircraft exceptional power to weight ratio. This should easily break the 2 minute record. A 84 inch diameter 3 blade Cato prop was chosen. Unfortunately this prop did not have enough blade area as this prop is only good for about 500 to 525 HP. At 2600 prop RPM 8,000 engine RPM the 84 inch prop tips are transonic.**

**No additional thrust is available regardless of the additional HP applied because it just heats the air around the prop tips. With a better prop and higher boost and 650 HP straight up at 175 MPH should then be possible. A financial decision was made to set the record with the prop we had.**

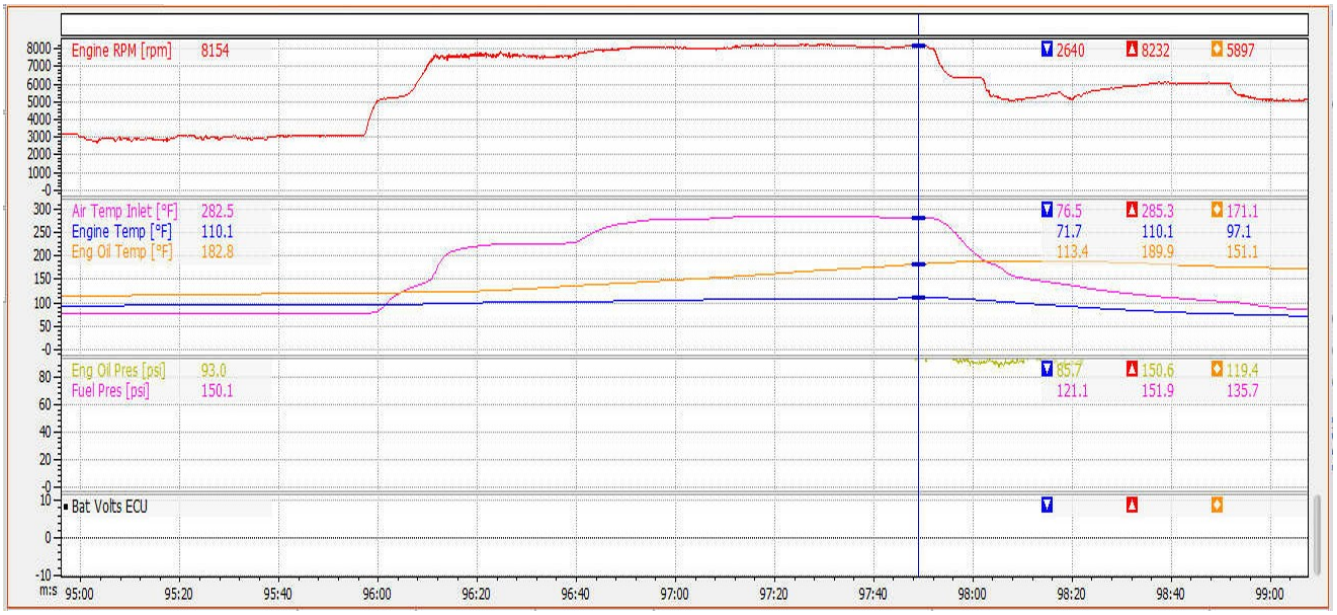
**Consequently we had to set the blow off valve to 73 inches of HG while we had run the engine as high as 85 inches of HG at 8000 RPM. The blow off valve will be all that is needed to control a Wankel rotary engine as it is not possible to over boost it and damage it.**

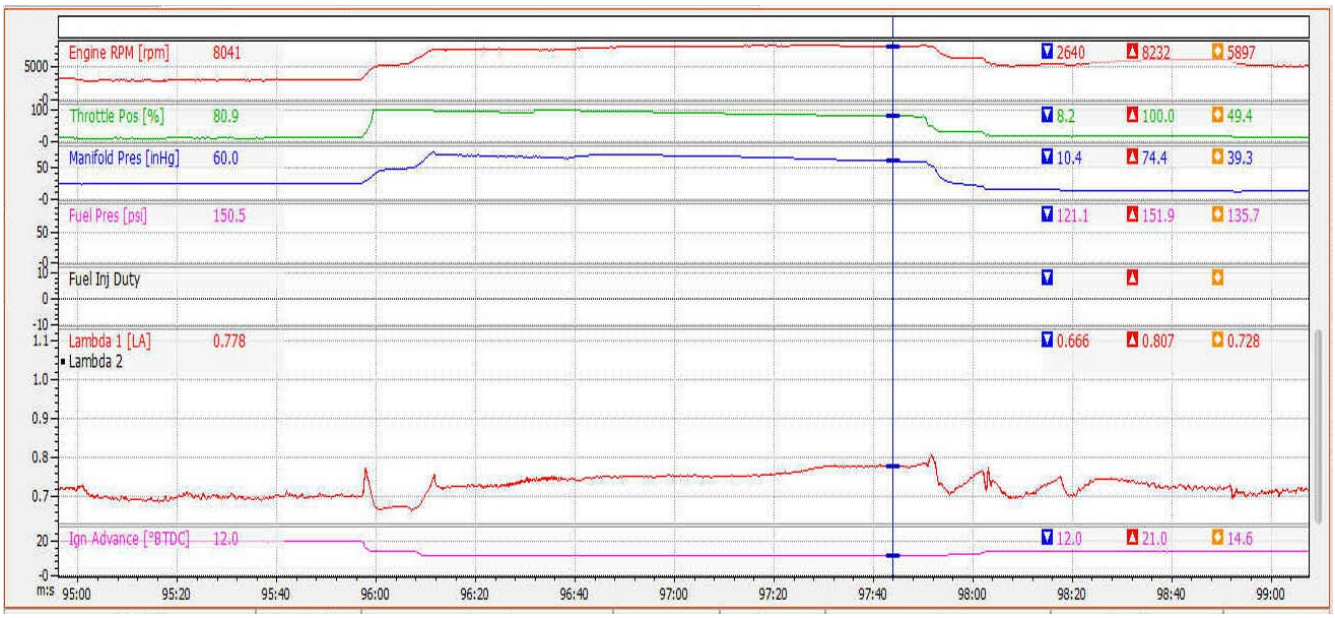




**Dan Gray test flew the aircraft for ten minutes at California City in the desert and here in Santa Paula California. We have run the engine for several hours on the ground with many runs at full power for more than 5 minutes at a time.**

**Coincidentally this is part of the FAA certification procedure required for aircraft engines. Dan has test flown the aircraft to 10,000 feet at least half a dozen times and broken the record each time. The best test flight we have had so far is one minute forty seven seconds. The record is just under 2 minutes. It started right up like a car engine and always ran at full power.**






**Motec recorded data during the actual time to climb record. It would be better to record the exhaust temperature as well. One can set the mixture to 50 degrees Fahrenheit lean of peak to optimize the BSFC. It is also a good idea to record the air temperature out of the turbo charger and after the fuel injector. Note the throttle backed off to 80% open and the manifold pressure backed off to 60 inches.**

# THE IMPORTANCE OF ENGINE POWER TO WEIGHT RATI0

**To illustrate how important the power to weight ratio of the aircraft engine I will give you a few crude calculations.**

**The Wankel's excellent power to weight ratio will eventually result in air craft with more range. My C182 has a 1000 mile range roughly with a 230 HP 500 pound engine. About half a HP per pound of engine weight.**

**Lets figure out how far it would go with a 250 pound 230 HP Wankel engine. A piece of cake for a NA Wankel 2 rotor engine. We could move the engine forward to make room for a tank in the nose with out affected the balance too much..**

**So with 40 gallons more the range would increase to 1,444 miles. Almost 50% more range. Non stop across the Atlantic with the same payload. Not quite to Hawaii. A turbo compound version would probably make Hawaii.**

**Another example is a Super Connie. The Supper Connie had four turbo compound radials that weighed 4000 pounds each and put out 4000 HP roughly. One HP per pound of engine weight . A world record for piston aircraft engines. It could fly 4660 miles SFO to London Heathrow non stop with 100 passengers.**



**It had about 5,000 gallons of fuel that weighed 31,000 pounds with a 5,000 mile max range roughly.**

**The total weight of the engines was 4 times 4,000 pounds each or 16,000 pounds total engine weight.**

**If Wankel type engines were used with a two HP per pound instead of one HP per pound that would be 8,000 pounds of additional fuel. In other words, in theory, the range would be 6,250 miles. One quarter of the way around the world non stop. Of course that is not going to happen as a B747, B777 or B787 now have close to that range.**

**I was at Aero in Friedrichshafen in germany giving a presenation on the time to climb project.**

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**I received this email message from Dan Gray**

**3:49 AM  Europe time. 4/19/2018**

**“100 seconds**
**Beat it by 19 seconds**
**Could not have done it without you**
**Best**
**Dan”**

**The success of this TTC  project proves beyond a shadow of doubt the Wankel rotary engine will be  the light  aircraft engine of the future.**

**Paul Lamar**

**rotaryen@earthlink.net**