Exploring the Mazda Wankel rotary as an alternative aircraft engine

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COURTESY PAUL LAMAR

Why Not a Rotary?

Aviation headline nine years from now:

Rotary-Powered Racer Bests Warbirds at Reno
RENO, NV—Employing turbocharged, twin three-rotor engines, the Rotary Ranger demonstrated what a low cross section, lightweight, reliable, 1,000-horsepower engine can do....

Okay, so it hasn't happened yet. But let me convey why such a headline isn't that outrageous. When married with the proper airframe, a rotary engine could certainly give the old warbirds a run for their money. So why do engine experts seldom include the rotary engine when discussing the merits of auto engine conversions for aircraft? Most likely, it's lack of knowledge.

If I could define the criteria for a realistically "perfect" aircraft engine, I think you'd agree that the following attributes are desirable in *any* aviation powerplant: reliability; robustness; extended time between overhauls (TBO); damage tolerance; smoothness; no shock cooling; abil-

Perry Mick's Mazda-powered Long-EZ features a ducted fan shroud giving it an extra-futuristic profile.

ity to run low-cost fuel; low fuel consumption; low purchase cost; high horsepower-to-weight ratio; compact size; and simplicity.

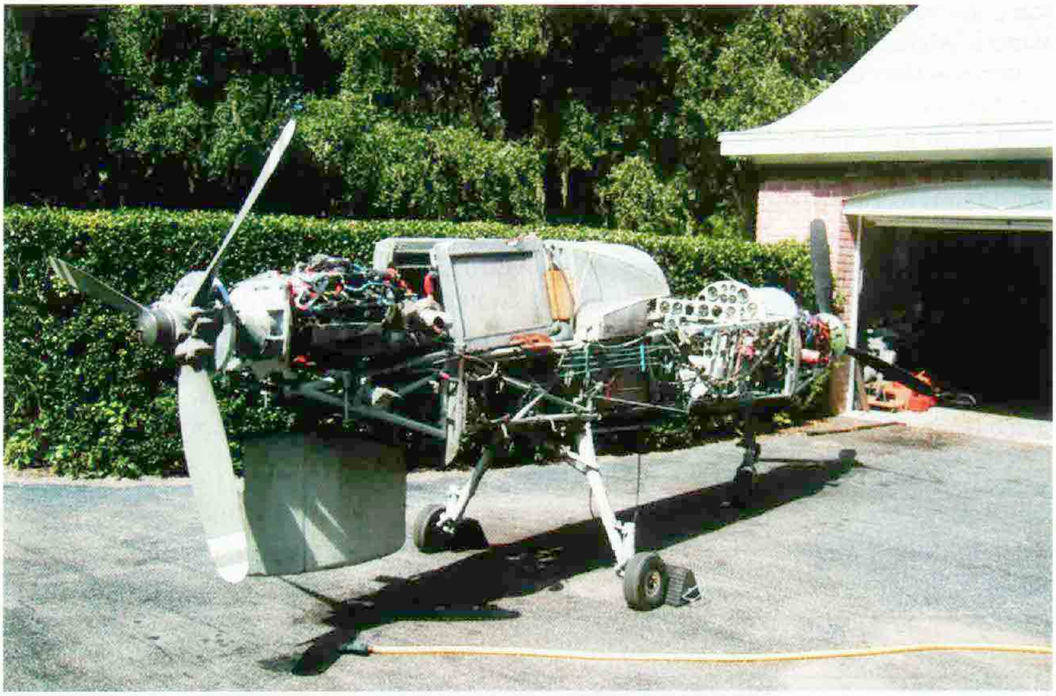
The Mazda Wankel rotary engine meets most of these criteria.

Wankel History

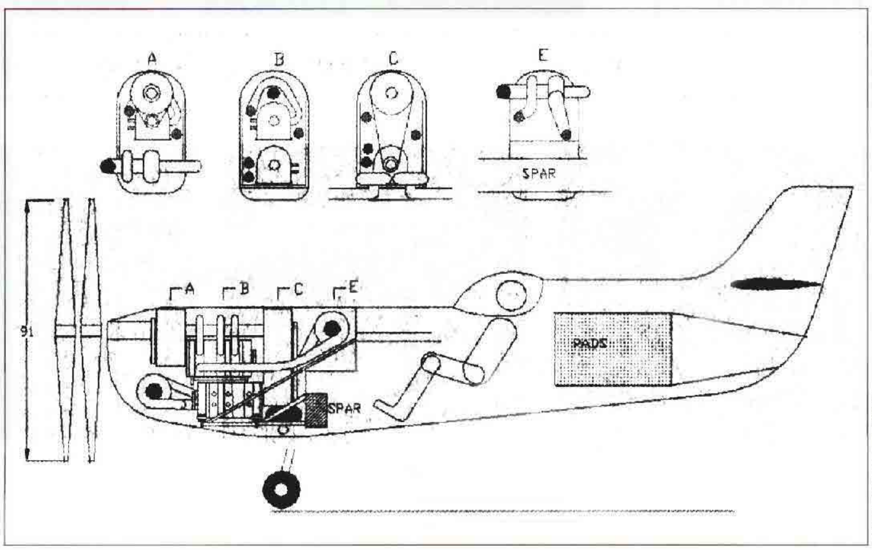
Dr. Felix Wankel invented the eponymous engine in the 1930s, and I use "Wankel engine" in the generic sense to differentiate it from all other rotary engines. Around 1950, Dr. Wankel built a running prototype, but it didn't generate much commercial excitement. Several companies were interested in the engine, however.

One of them was Toyo Kogyo, known to Americans as Mazda Motors, and it created a state-of-the-art computerized test facility expressly for developing the engine. After a lengthy development period, Mazda started selling cars with rotary engines in 1967.

Over the years engineering challenges continued to crop up, and the other rotary players gave up further development. But Mazda persevered.



TRACY COOK



COURTESY PAUL LAMAR

Top, Tracy Cook, of Real World Solutions (see sidebar page 48), is helping aircraft owner Dave Garber get his dual Mazda turbo engine-powered Reno racer back in shape. Note the dual radiators aft of the cockpit.

Bottom, concept of an over-and-under dual Mazda Cosmo turbocharged three-rotor engines of 1000 hp each installed in a custom-designed Reno racer.

It believed in the rotary engine and solidly understood its superior kinematics. Eventually, Mazda sold more than two million rotary engine-powered cars.

Why Rotary?

Kinematics is the science of mechanics that deals with motion, and poor kinematics and reciprocating motion have always been the bane of the piston engine. Things stop then start up again in the opposite direction twice per revolution.

This reciprocating action creates tremendous stress on connecting rods, pistons, piston pins, valves, valve springs, camshafts, lifters, pushrods, and crankshafts—especially at high rpm. The crankshaft in a piston engine, for example, is a stress analyst's worst nightmare with its twisting and turning every which way.

Wankel engines have no reciprocating motion because every part moves in a circle or moves in more or less the same direction. A two-rotor Wankel engine has only three moving parts: two rotors and the eccentric shaft, which is analogous to the piston engine's crankshaft. Unlike a crankshaft, however, the eccentric shaft is straight and extremely strong.

The turbocharged, 800-hp, two-rotor, 10000 rpm Mazda racing engine of stock displacement has demonstrated this strength. Not including the monster turbo and other accessories, this powerplant weighs a mere 200 pounds. This represents an unprecedented power-to-weight ratio for all but a turbine engine.

Nobody in his or her right mind would think of mounting an 800-hp Mazda Wankel engine in a light general aviation airplane, but it might make an ideal engine for Unlimited air racing. It does illustrate the robustness of the Mazda Wankel engine.

Because they do not reciprocate, the Wankel's rotors are made of rugged cast iron, and unlike the pistons in a piston engine, they are nearly impossible to melt. A rotary engine has no exhaust valves to melt or burn, a common problem in aircraft engines, and it has no camshafts to gall and no lifters to score.

Like the rotary itself, the engine's combustion cycle is unique.

The engine discharges its exhaust gases as the rotor moves over openings in either the rotor housing or the end housings. This action is similar to that of a two-cycle piston engine, but the Wankel is a four-cycle engine, and like a four-cycle, four-cylinder engine, it fires twice per output shaft revolution.

Because nothing in the Wankel reciprocates, stops and starts moving in the opposite direction, it remains in perfect balance, just like a turbine or an electric motor. It's impossible to perfectly balance a piston engine because certain parts oscillate or reciprocate—by design—throwing off its center of gravity. Consequently, the rotary runs smoother than any piston engine.

Wankel engines cannot fail catastrophically in the "hand grenade" fashion, as sometimes occurs with piston engines. One of the worst things that can happen to a Wankel is an overheated engine caused by loss of coolant, but it will still run and usually will get you to a nearby airport. Cold pressure checking the coolant system before flight is important, and using high quality AN aircraft plumbing is a necessity.

Another testament to the engine's bulletproof design is Mazda's track record at the 24-hour endurance race in LeMans, France. Mazda was the only Japanese car manufacturer to win the race outright. In 1991 Mazda fielded a car with a four-rotor version of the two-rotor RX-7 engine, and it beat all comers, the who's who of exotic European carmakers.

Tearing down the engine after the race revealed little or no wear. The following year, LeMans banned rotary engines from the race. Now, roughly 10 years later, Mazda racing rotaries are either severely handicapped or limited to competing against other Mazda rotaries in auto racing.

In homebuilt aircraft, however, Mazda Wankel engines are seeing a renaissance of sorts for several reasons, low cost not being the primary driver. The main reason is durability. The stock engine will run for many hours at high power with little or no wear.

Recent Improvements

Subscribers to the *Aircraft Rotary En-*

1st Revolution | **2nd Revolution** | **3rd Revolution**

Shaft Rotation Angle 0 90 180 270 360 450 540 630 720 810 900 990 1080

CHAMBER 1		INTAKE	COMPRESSION	EXPANSION	EXHAUST	
CHAMBER 2	COMPRESSION	EXPANSION	EXHAUST	INTAKE	COMPRESSION	
CHAMBER 3	EXPANSION	EXHAUST	INTAKE	COMPRESSION	EXPANSION	

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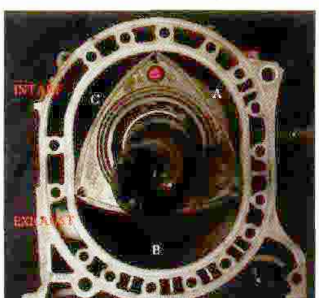
CHAMBER
A: INTAKE
B: EXPANSION
C: EXHAUST
OUTPUT SHAFT 000 DEGREES



CHAMBER
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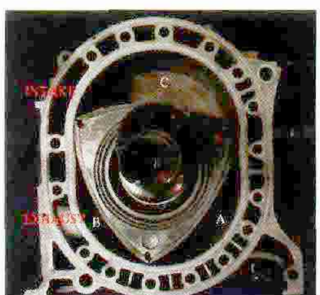
B: EXHAUST
C: INTAKE
OUTPUT SHAFT 180 DEGREES



CHAMBER
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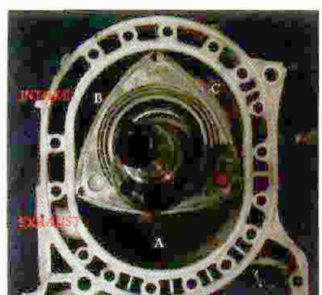
B: EXHAUST
C: INTAKE
OUTPUT SHAFT ANGLE 360 DEGREES



CHAMBER
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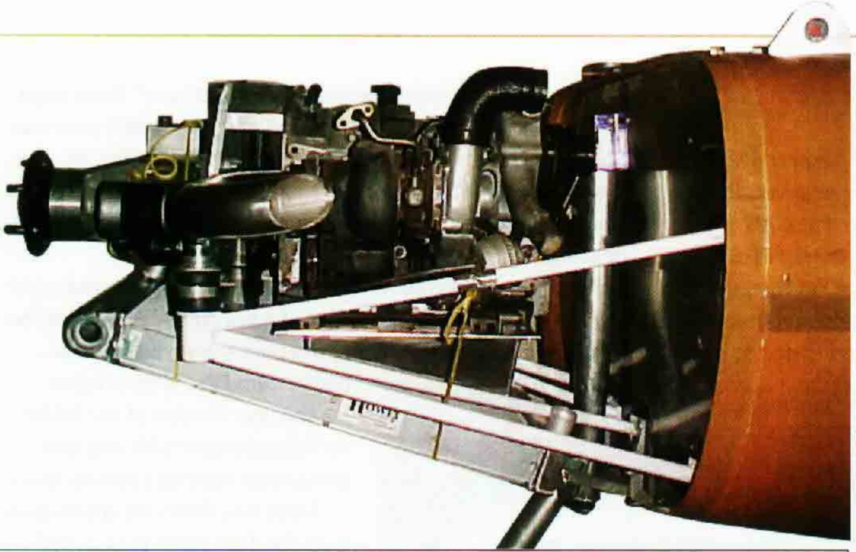
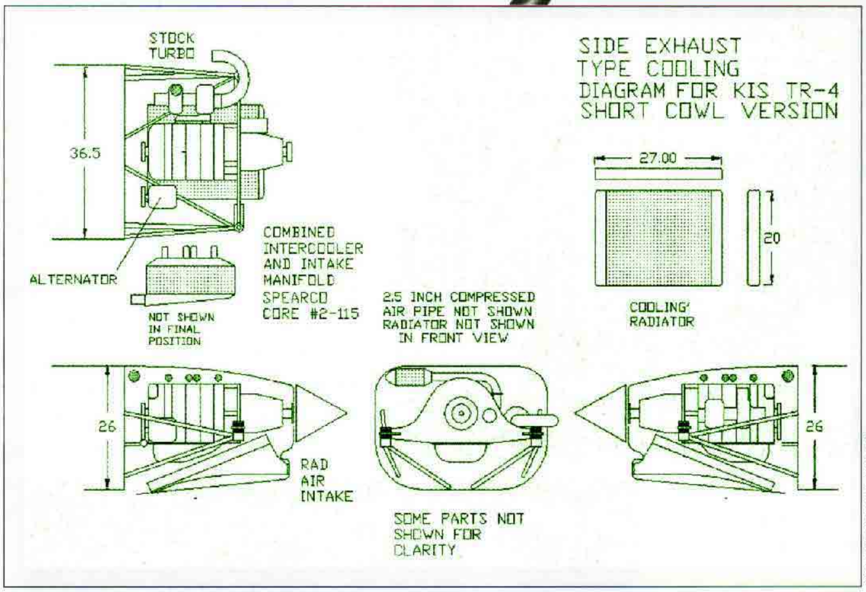
B: INTAKE
C: COMPRESSION
OUTPUT SHAFT ANGLE 540 DEGREES





COURTESY PAUL LAMAR

Turbocharged Mazda Wankel RX7 engine mounted on the author's Pulsar/KIS Cruiser with single radiator obliquely mounted under engine. Diagram is the author's installation drawings for his rotary powerplant.

gine Newsletter and others testing rotaries have further improved on what Mazda accomplished by using more costly high-tech materials for certain engine parts. Dr. Francisco Inanette, for instance, has developed a ceramic apex seal (which is affixed to the rotor) that's so hard and smooth it has no noticeable wear rate. Nobody has worn one out yet.

High temperature, 500°F Teflon encapsulated silicon water jacket seals and oil scraper O-rings have also been developed. These increase the engine's ability to withstand inadvertent overheating, which happens occasionally as homebuilders relearn pre-World War II lessons about liquid-cooled aircraft engines.

These costly materials, although improvements, are not required. Based on the wear rate of the stock apex seals and cruising at about 150 hp and 4500 rpm, the projected TBO of a stock Mazda two-rotor engine in aircraft use is about 3,000 hours.

Through real-world testing homebuilders have found that mixing two-cycle oil with the fuel reduces the apex seal wear and the carbon deposits inside the engine. The ratio used is about one ounce of two-cycle oil to one gallon of gas. The stock engine injects oil from the crankcase into the combustion chamber. Crankcase oil contains certain wear additives that really make it unsuited to this task, and users disable the oil injector when using the engine in a race car or airplane.

Rotary Specifics

Power-to-Weight Ratio

The power-to-weight ratio of the stock Mazda engine is excellent. Despite its mostly cast iron housing parts, the bare engine weighs 200 pounds. Expensive aluminum end housings cut this weight by about 50 pounds.

The firewall forward installed weight of a normally aspirated two-rotor Mazda engine with propeller speed reduction unit (PSRU), coolant, and radiators runs about the same as a Lycoming O-320 or O-360—right around 300 pounds. With non-stock peripheral intake ports, a normally aspirated rotary can generate 240 hp on takeoff with excellent durability.

PSRUs

Several popular propeller speed reduction units are available. Weighing 40 pounds each, most

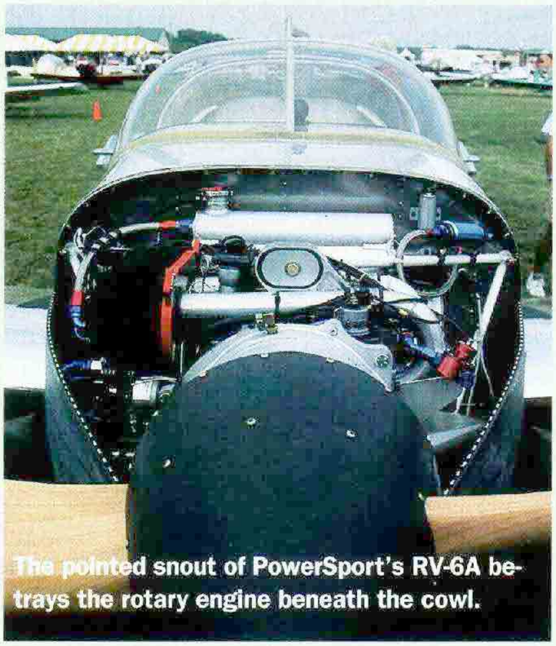
CHAMBER
A: EXHAUST
B: INTAKE
C: EXPANSION
OUTPUT SHAFT ANGLE 720 DEGREES

CHAMBER
A: INTAKE
B: COMPRESSION
C: EXHAUST
OUTPUT SHAFT ANGLE 900 DEGREES

CHAMBER
A: INTAKE
B: EXPANSION
C: EXHAUST
OUTPUT SHAFT ANGLE 1080 DEGREES

Rotary Suppliers Speak Out

The homebuilt industry supports several aftermarket and accessory suppliers for rotary engines. PowerSport Inc. in Osceola, Wisconsin, has been diligently working on a more highly engineered reduction drive. "This seems to be the main deterrent in using the rotary engine in aircraft," says PowerSport Manager Keith Holm. Since the Mazda 13B engine is torsionally stiff, it produces a specific resonant frequency at certain power settings that can rattle a poorly engineered reduction drive. "Our RD-300 drive has been available for more than a year now," Keith says, "and solves that problem."



The pointed snout of PowerSport's RV-6A betrays the rotary engine beneath the cowl.

PowerSport's drive is rated for 300 hp continuous at 2,000 hours at an 80 percent duty cycle. The 2.29-to-1 reduction ratio turns the prop at 2620 rpm at its engine's 6000-rpm limit. PowerSport currently has its rotary engine conversion with its proprietary electronic engine management system and tuned intake and exhaust systems installed in an RV-6A test aircraft (displayed at EAA AirVenture Oshkosh 2001). PowerSport's engine produces 215 hp continuous at 6000 rpm—far below the limits of the stock Mazda 13B. You can find out more about PowerSport at its website: *www.powersportaviation.com.*

PowerSport engines are all built from modified new parts directly from Mazda, but other engine builders—and home craftspeople with an engineering bent—start at the salvage yard. Companies like Atkins Rotary Specialties Inc. produce some solid aircraft engines from the bulletproof Mazda 13B. But even a seasoned auto racing pro like Dave Atkins is impressed by the PowerSport reduction drive because of its ability to handle high-torque loads.

Dave typically uses a highly modified Ross drive, but his high-torque engines can be hard on them. Atkins has presented the Rotary Engines in Aviation forum at EAA AirVenture and says, "A lot of people are still afraid of the rotary from the bad press the engine received in the early '70s. But Mazda fixed most of those problems in 1974."

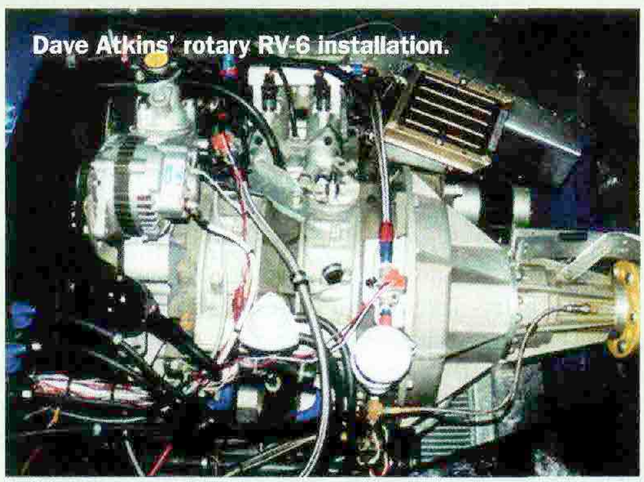
Dave's RV-6, which has flown from the Seattle area to Oshkosh a half-dozen times, cruises at 160 knots and 8 gph of unleaded auto fuel. Drag racing in the early 1980s taught him a lot about the Mazda, and Atkins Rotary Specialties (*www.atkinsrotary.com*) uses custom manufactured parts, factory parts, and modified parts to build its enhanced aviation powerplants. One Atkins customer has more than 2,500 hours on his engine, and Dave has never had a customer experience an in-flight failure.

"You install a rotary because you want one," Dave says. "I'm saving $8 an hour in fuel, and my annual last year was $50. A total rebuild would cost me around $2,000. Overall, it's a cheaper way to go. But don't try to build the engine yourself, and don't just go to your local garage. They won't do it right."

Tracy Crook of Real World Solutions Inc. (*www.rotaryaviation.com*) says, "I've done a lot of work on the PSRU and the EFI/ignition controller during the past three years and recently came out with a higher horsepower version of the PSRU for turbocharged 13B and 20B three-rotor engines (300-hp max)."

Tracy has flown his rotary-powered RV-4 for more than 1,000 hours, and he's building an RV-8 that's about a year away from its first flight. "There were six rotaries at EAA AirVenture 2001, and there are at least 100 rotary projects currently underway and more starting all the time," Tracy says. "The auto fuel capability is definitely a factor in many builders deciding to look at alternatives."

Keith Holm of PowerSport warns that plenty of challenges exist for homebuilders considering rotary power. "Do as much research as possible to be well informed about the options available. Be honest with yourself about your mechanical abilities and your project goals."



Dave Atkins' rotary RV-6 installation.

Homebuilders should also check with their insurance carriers to see how a particular engine/airframe combination will affect their rates.

Next year Mazda is introducing the RX-8 to the U.S. market with an updated and more powerful rotary engine, known as the Renesis. Even though the engine won't be available to the aftermarket for quite some time, it does indicate a bright future for the rotary.

—Mike DiFrisco

Rotary User Groups

Fly Rotary Website (pilots and their projects)—*www.members.home.net/flyrotary/*
Rotary Engine Website (Paul Lamar)—*http://home.earthlink.net/~rotaryeng/*

of them are based on the Ford truck automatic transmission planetary gear set. Ford recently beefed up this transmission by changing the number of pinion gears from four to six, making it suitable for the three-rotor engines or the higher power turbocharged two-rotors.

Turbochargers

Turbochargers, which maintain engine power at high altitudes, weigh about 35 pounds. To my knowledge, the upper horsepower limits of the turbocharged versions are unknown because nobody has run one in an airplane for more than about 100 hours.

Engine Size

The two-rotor engine is comparatively tiny. Without any accessories it measures about 12 inches wide, 14 inches high, and 18 inches long. It's quite possible to squeeze a turbocharged two-rotor engine, including radiators, inside a stock kit airplane cowling. (I've done it with my KIS Cruiser. By comparison, the room in a Van's RV cowling would be considered voluminous.)

Three-Rotor Engines

Three-rotor engines develop 50 percent more power than two-rotor engines, and you can import them from Japan. Bare three-rotor engines weigh less than 300 pounds, and a firewall forward installation would weigh around 400 pounds without a turbocharger. Racing Beat in Anaheim, California, has a three-rotor turbocharged aircraft engine on the dyno generating 900 hp with about 200 hours of dyno runs so far.

The eccentric shaft in the three-rotor is the same diameter as the one in the two-rotor, and it gives no trouble. With exactly the same eccentric shaft diameter, the Mazda LeMans engine was a four-rotor, normally aspirated unit developing 690 hp at 9500 rpm. Many of the other three- and four-rotor parts were similar if not identical to the two-rotor RX-7 engine.

Fuel Consumption

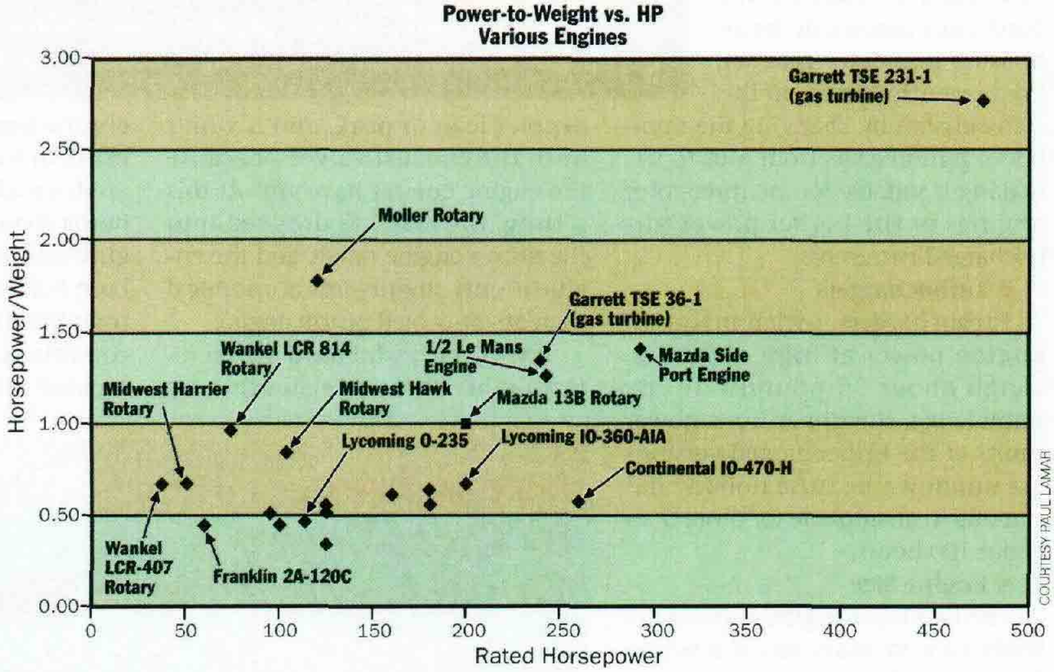
The Mazda will happily run 100 degrees lean of peak, and it won't burn the exhaust valves—because the engine doesn't have any. At this setting, the EGT has dropped into the piston engine range, and the engine is only slightly less economical than an air-cooled piston engine.

Tracy Crook, who has a Mazda rotary on his RV-4, estimates that his engine burns 0.47 pounds of fuel per hour for each horsepower generated; an air-cooled piston engine burns about 0.45. If you run the engine full rich at peak power, it will burn 0.65, just like an air-cooled piston aircraft engine under the same conditions. The new RX-8 engine is reputed to be much more economical. The Mazda happily runs on autogas that, right now, is about half the cost of avgas.

Cooling

The total heat rejected by a Mazda rotary is only slightly higher than a piston engine. All engines have a heat balance, which is the distribution of energy contained in the fuel due to burning it. Some energy is rejected to the coolant as waste heat, some goes out the exhaust, and the remainder comes out the shaft as mechanical energy. One horsepower is equal to 746 watts, and an engine generating about 200 hp would be rejecting about the same amount of horsepower to the coolant, about 150 kilowatts.

This is not unique to the Wankel! All internal combustion engines do the same more or less by only a few percentage points. A Wankel engine's heat balance differs by only single-digit percentages compared to all other forms of internal intermittent combustion engines. (A gas turbine is an internal continuous combustion engine, in case you were wondering.)



So Why Not a Wankel?

To be frank, you'll have a considerable engineering challenge installing a rotary engine in your airplane. The engine itself is not the problem; careful planning is absolutely necessary with any non-aircraft or auto engine conversion. You can ease this challenge by making mechanical drawings and mock-up models before starting the building and installation process.

You may have to design and build component parts like the motor mount, oil pan, alternator mount, and intake manifold and modify the water pump inlets and outlets. As the engine becomes more popular, many of these unique aircraft-specific parts should eventually become available to home craftspeople.

On the upside, overhauling the rotary engine is trivial by Lycoming or Continental standards.

Strict attention to cooling details is essential. Most rotary homebuilders have trouble with cooling, and many have simply given up. The exact shape of the ducting to the radiator is critical, and sealing the cowl properly to prevent back pressure on the radiator is essential. The design of the cowl flaps and the opening around them are other important considerations. Wankel engines reject a third of their cooling heat through the oil, so a good oil cooler is mandatory, and the stock Mazda RX-7 oil cooler works well.

The Wankel engine is ideal for turbocharging because of the shape of the combustion chamber, the inherent low compression ratio, and the lack of exhaust valves. You'll need an intercooler to keep the intake temperature down. High intake manifold temperatures lead to detonation, which can fracture apex seals with consequent scoring of the rotor housing and rotors. The engine will not fail catastrophically under this scenario, but it will run somewhat low on power.

A good muffler is essential with a Wankel because the exhaust port opens much more rapidly than in a piston engine and emits supersonic shock waves. This will not be a problem on the new Mazda RX-8 motor, which has side housing exhaust ports that open and close more gradually.

A turbocharger helps quiet the engine and adds no weight because it replaces the muffler. In the 1989 to 1992 RX-7 model years, Mazda built a good turbocharger for aircraft use. Later, dual turbochargers were too complicated and less reliable, while earlier ones just plain cracked.

When purchasing a Mazda engine for aircraft use, it's best to buy a running car because it comes with a lot of parts you can use, including the alternator, ignition coils, fuel injectors, starters, oil coolers, etc. Good Mazda vintages are 1989 and later. 1992 and earlier second-generation RX-7s can be had for less than $3,000. The 1993 models and later sell for more than $15,000 because they were more expensive and sophisticated cars to begin with.

With all it has going for it, the Wankel rotary just may be the light aircraft engine of the future. EAA

A former aerospace and Chaparral race car engineer, Paul Lamar invented and manufactured computerized automotive performance test equipment. Paul has been an EAA member for 25 years, owns a Cessna 182, and has logged about 3,000 hours. Now retired, he's building a KIS Cruiser with a Mazda turbocharged two-rotor rotary engine.

Paul edits the 3-year-old e-mail Aircraft Rotary Engine Newsletter, *which has about 1,000 subscribers. He is married to Robin Lamar, a full-time United Airlines mechanic, sometime A&P teacher, president of the Association of Women Aircraft Mechanics, and winner of the prestigious Aviation Technician of the Year award given by Women in Aviation International. Robin has no time left over to help Paul build his airplane.*

For more information visit http://home.earthlink.net/~rotaryeng/.