The 2-cycle Rotax 582 powered Pulsar in the foreground; and the 4-cycle Rotax 912 powered Pulsar XP.

2-CYCLE VERSUS 4-CYCLE

Comparing the Rotax 582 and 912 in the Pulsar

Editor's Note: Mark Brown is the designer of the highly efficient Pulsar and has done extensive test work with both 2-cycle and 4-cycle powered versions of the airplane.

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Every homebuilt airplane is a research vehicle to some degree and the Pulsar is no exception. Hundreds of hours of flight time on many different Pulsars have revealed some valuable information about engines and flying qualities.

Since the Pulsar has been flown extensively with both 2-cycle and 4-cycle engines, a side-by-side comparison is helpful. The Rotax 582 2-cycle is still the most popular engine for the Pulsar because of its low cost and simplicity. However, the Rotax 912 4-cycle is increasingly used in Europe and Australia where it is certified to JAR 22 motorglider standards.

Comparing the performance of the 582 to the 912 depends on the segment of flight being considered. Since takeoff and climb performance are directly influenced by weight and the 582 engine is 40 lbs. lighter, it has the advantage in this area. Surprisingly, even though the 912 has 14 more horsepower than the 582, the Pulsar actually takes off shorter using the 582 and climbs about the same on either engine.

Cruise performance isn't so sensitive to weight because the only force opposing thrust is drag and the only component of drag affected by weight is the drag due to lift (called induced drag). At low angles of attack induced drag is very small because the wing lift vector is almost vertical. Since the angle of attack in cruise is only about 2 degrees, the induced drag due to the extra weight of the 912 engine is practically negligible. Therefore, the extra power of the 912 remains the predominant effect in this segment of flight which gives the 912 powered Pulsar a 10 mph higher cruise speed than a Pulsar with a 582.

The primary advantages for the 582 are its low cost and its simplicity which are, of course, directly related. The 582 costs less than half as much as the 912, basically because it has about half as many parts. Correspondingly, the maintenance, installation and overhaul requirements are simpler and less expensive for the 582. All these factors are particularly important for the homebuilder to consider.

Of course not all of the advantages favor the 582. The 912 is a very sophisticated 4-cycle engine with many impressive characteristics of its own. First, it uses less fuel than the 582 while producing more horsepower. At 75% power the 912 burns 3.5 GPH at 140 mph while the 582 burns 3.8 at 130 mph. This fuel flow advantage for the 912 also increases the range of the Pulsar, so the benefit is two fold.

Another advantage for the 912 is how smoothly it idles. At 1100 rpm the instrument panel doesn't even shake. With its standard 2.27 to 1 gear ratio the prop is only turning 485 rpm which makes it an excellent airbrake for glide path control. On the other hand, as with most 2-cycle engines, the 582 doesn't idle very smoothly at low rpm. To compensate, Rotax has recently introduced a vibration damper for the 582 which now allows a reasonably smooth idle at 2200 rpm. Its 2.0 to 1 gear ratio gives 1100 rpm on the prop, but that's still too high a prop speed to help much as an airbrake. Fortunately, the Pulsar has large flaps that provide adequate glide path control even with the high idle speed of the 582.

Nose to nose, the Rotax 582 powered Pulsar on the left, and the Rotax 912 powered Pulsar XP on the right.

Comparing the vibration levels at cruise rpm is actually a lot more meaningful than comparing at idle speed because cruise is where an aircraft engine spends most of its life. In this comparison the results are a little surprising. The moving parts of the 582 are so light that it is just as smooth as the 4 cylinder 912. With respect to noise level, the 582 has another surprise. Most 2-cycle engines use a tuned exhaust pipe to maximize power which also maximizes noise. The 582 exhaust system is only mildly tuned and incorporates an after muffler that actually makes it as quiet as the 912. The only difference is the higher frequency sound of the 582 due to its higher rpm.

The most important issue in any engine comparison is in the area of reliability. Unfortunately, this is always a difficult subject because so many factors like maintenance and operator error are involved. In fact, all the failure studies done by Aero Designs indicate that the vast majority of engine failures are caused by system failures related to installation problems or operator error, not the basic engine. Clearly, a failure in any one of the systems such as fuel, ignition, cooling, lubrication, controls, or even instrumentation can lead to an engine failure.

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Assuming for a minute that the installation is perfect, a basic comparison of the reliability of the 2-cycle and 4-cycle engine is still a valid (although sometimes controversial) question. Unfortunately, many opinions on the subject are more a matter of prejudice based on isolated cases than of actual facts. Everyone naturally has more confidence in the type of engine they are most familiar with. Because of this, the two-cycle has a distinct disadvantage since its application to aircraft (in any numbers) is relatively recent. Also, because of the high power to weight ratio, the 2-cycle engine is often used in racing and other demanding applications where the engines are pushed to extreme limits. Even applications in ultralight aircraft are demanding in their requirement for high continuous power levels to overcome their inherent high drag. Operating under such conditions, the 2-cycle engine has clearly suffered some abuse that has affected its reputation.

The Pulsar's prop was developed to match the aircraft's drag profile and engine variables. Note the narrow chord tips

Conversely, when 2-cycle engines are operated at 75% power as they are in the Pulsar, and given the same care as a 4-cycle engine, Aero Designs has found that the 2-cycle engine is just as reliable as the 4-cycle. Nothing in the 2-cycle has

The combination of the Pulsar's big plain flaps, NASA airfoil and high aspect ratio wing . . . and overall light airframe weight . . . give the Pulsar great short field performance and excellent cruise performance.

been found to be inherently unreliable. This evaluation is, of course, limited to engines specifically developed for aircraft, like the Rotax 582. Other engines that aren't adapted to tolerate the special cooling, loading and altitude conditions of aircraft operations are a different subject altogether.

One characteristic of the 2-cycle engine that concerns some people is its high operating rpm. Again, the anxiety is mainly due to comparison with the more familiar 4-cycle engine. Considering the small number of moving parts in the 2-cycle and the absence of valves and cams, the rpm is really conservative. In fact, some 4-cycle engines rev even higher than the Rotax 582. The primary consideration on this issue is propeller rpm because high tip speeds result in very noisy and inefficient operation. Of course, both the 582 and the 912 use gearboxes to keep the prop speed down while most aircraft engines are just designed to run, direct drive, at low rpm. However, the problem with low rpm engines is weight. Since horsepower is directly related to how many times the cylinder fires per minute, a slower engine is always heavier for the same power. That's why the 2-cycle engine has almost twice the power for a given weight as a 4-cycle engine and why a high rpm 4-cycle (even with a gearbox) has more power per pound than the typical low rpm aircraft engine.

For example, a typical 4-cycle, 80 hp aircraft engine weighs 175 lbs. compared to 124 lbs. for the Rotax 912 with comparable equipment. This 50 lb. additional engine weight increases the loads in every part of the airplane. In fact, the structure suffers six times the weight increase because of the G-load factor. This requires more structure which further increases the weight. In general, airplanes suffer from the "snowball" effect more than any other machine because every part is inter-related. A 50 lb. heavier engine typically requires another 50 lbs. of structure throughout the airplane. This 100 lb. increase in empty weight requires more wing area to maintain a safe stall speed which in turn takes more power to maintain the same cruise speed which takes a heavier engine and more fuel . . . and so on. That's why engine weight is so important. However, the snowball effect works just as well in reverse. A lighter engine requires less structure, which requires less wing area, which cruises faster, on less power, etc. If there's any secret to the Pulsar's outstanding performance on such low horsepower, the lightweight Rotax engines are it.

Getting back to the basic 2-cycle/4-cycle comparison. All 2-cycle engines have a reputation for being rather sensitive to operating conditions and loading. To a certain degree, this characteristic has proven to be true for the Rotax 582. The prop selection and design of the engine cooling system were

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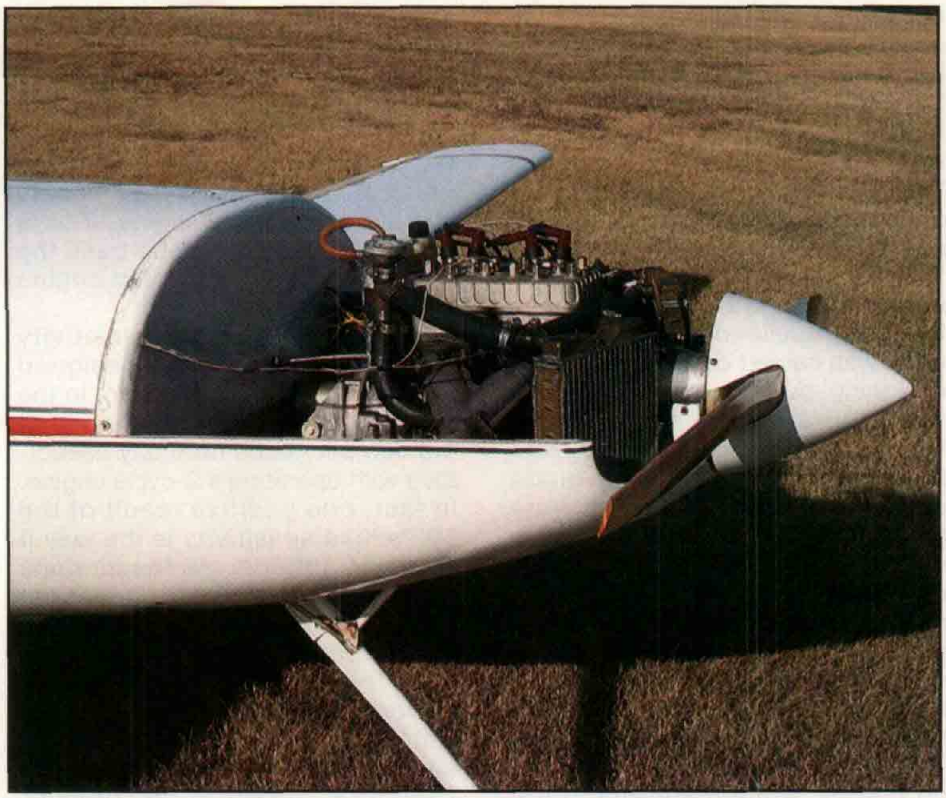
certainly more challenging than for the Rotax 912. The reason for the challenge lies in the basic function of the 2-cycle engine. Since it produces power on every stroke, it also produces heat on every stroke. However, if the engine overheats, the induction air passing through the crankcase heats up. This causes the induction air to expand, leaving less oxygen to mix with a set quantity of fuel. The result is an excessively rich mixture which causes the power output to drop.

This heat related power loss is no worse than operating a 4-cycle aircraft engine with the carburetor heat on. However, if the heat affects are combined with a heavy propeller loading and a narrow power band, then a real problem can develop. First let's consider the propeller load. A fixed pitch prop is a wonderfully simple and inexpensive device, but it's like having a car with only one gear. The engine is overloaded as it tries to accelerate and get underloaded at high speed. Of course, the effect is less severe for a propeller than for an automobile, but the same forces are at work. A low pitch prop is needed for takeoff, while a high pitch improves cruise. Obviously a compromise is in order but the point to remember is that the engine is still always loaded to its limit on takeoff.

Next, the narrow power band of the 2-cycle must be brought into the picture. The timing required to expel the exhaust gas and induct a new fuel/air charge is very critical since both events must occur on the same stroke. In fact, the pressure pulses in the exhaust system are an important part of the cycle. Unfortunately, these pressure pulses only occur at one discrete frequency which means a 2-cycle engine only puts out its best power at a specific rpm. If the engine is not allowed to operate at its best rpm, its power output is severely reduced.



The Rotax 582 installation in the Pulsar.

The Rotax 912 installation in the Pulsar XP.

Now consider what would happen if the engine were loaded right to its limit on takeoff by a propeller selected to maximize cruise speed. Then add to that the induction air heating effect. As the engine heats up and loses a little power, the prop loading is too high, so the rpm drops off. As the rpm drops off, the power output continues to decrease. Of course, the load from the prop also decreases as its speed is reduced, but what would happen if the power output is falling faster than the prop load? Well, that's just what can happen on a 2-cycle engine if it's not set up correctly, and needless to say the takeoff doesn't get very far. The equilibrium load where the drag on the prop equals the engine output is typically around half power.

The Pulsar's solution to this difficult situation is two-fold. First, a lengthy propeller development program was carried out which involved designing, building and flight testing many different types of props. Various combinations of blade planform, twist distributions, blade sweep, diameter and pitch were tested until, after more than a year of work, a very specialized prop was developed. This prop uniquely matchs the Pulsar's drag profile and engine variables, to provide a more consistent load on the engine. One noticeable characteristic of this special prop is its very narrow tip chord. This reduces the drag of the blades on takeoff while maintaining the large disk area needed for good static thrust and efficient cruise. The final result is a prop that doesn't overload the engine at any temperature.

To eliminate even the small power loss due to induction air heating, a special cooling system was designed that incorporates dual radiators located directly inside the air inlets of the cowling. The location, size and design of these radiators are all key elements of the system. The location is important because the full force of the incoming air is directed squarely into the face of the radiators. The size of the radiators and this high energy air directly behind the prop provides so much cooling capacity that a max performance climb on a 100 degree day will not produce more than a 165 degree F. coolant temperature. In cruise the temp stays around 140 degrees F. Such effective cooling virtually eliminates the problem with induction air heating.

To prevent over-cooling at cruise speed, the airflow through the radiator is restricted by the design of the cooling core. As the speed increases, the back pressure in the radiator increases, which keeps the airflow fairly constant. This constant airflow results in a very consistent coolant temperature.

On a side issue, all air-cooled aircraft engines suffer severe thermal stresses due to the large temperature variations. The engine temperature can change as much as 250 degrees F. in less than a minute. Such thermal shock can and does cause cylinders to crack and many other problems. Liquid cooled engines in general run much cooler and maintain a more constant temperature which greatly improves the longevity and efficiency of the engine. This is why the Voyager's flight around the world used a liquid cooled engine for its primary power.

Back to the 2-cycle sensitivity question. The specially designed propeller and cooling system in the Pulsar effectively eliminate any of the complications normally associated with operating a 2-cycle engine. In fact, one positive result of the 582's load sensitivity is the way it reacts to altitude. As the air thins out at altitude, the prop unloads, which allows the engine to turn a higher rpm for a given throttle setting. This causes the engine to pull in more air for a set amount of fuel, which makes the engine lean out automatically at higher altitudes. Therefore, the Rotax 582 doesn't have and doesn't need a mixture control when operated below about 12,000 ft. For operations above this altitude, Rotax sells an optional altitude compensating carburetor which has been tested on the Pulsar to 16,000 ft. with excellent results.

> ***"...all air-cooled aircraft engines suffer severe thermal stresses due to the large temperature variations."***

The only real limitation caused by load sensitivity is in the use of a controllable pitch propeller. If a pilot ever tried to execute a go-around with a controllable prop set at cruise pitch, a 2-cycle engine will suffer the overload syndrome described earlier. Of course, this is such a dangerous situation that Aero Designs strongly opposes the use of a controllable pitch prop with a 2-cycle engine unless some automatic system is employed to reduce the prop pitch when full throttle is applied. A 4-cycle engine would also suffer from this type of pilot error, but not to such a dangerous degree.

To summarize, the Rotax 582 has advantages in simplicity and economy while the 912 offers higher performance, smoother idle and better fuel economy. In the view of Aero Designs, the engines are equally reliable. Since both engines are very light weight for their respective power, either engine will given the Pulsar the high efficiency and performance it was designed for. Therefore, either engine will continue to be available in the Pulsar kit depending on individual preference.

On a new subject, but still strongly related to light weight engines, is the STOL capability of the Pulsar. The light weight along with high lift and controllable drag are the most important factors for short takeoffs and landings and these are all strong ponts in the Pulsar design. In fact, with respect to light weight, the Pulsar is one of the lightest two place airplanes in the world. In its performance class, it may be the lightest.

High lift is even more important in STOL performance but this factor must be considered carefully to limit the compromises in other areas. For example, increasing the wing area reduces cruise speed and causes a rough ride in bumpy air. More significantly, a very large wing on a very light airplane can be a dangerous combination in strong gusty winds. In the Pulsar design, a new high lift airfoil from NASA Langley and effective flap system provide good STOL performance without the penalties of an oversize wing.

Of course, a high lift airfoil and effective flap system are no excuse to undersize a wing either. A careful balance is necessary to maintain a safe stall speed in the rare case of a forced landing off field. The occupants can usually walk away from an off field landing at 45 mph but at 65 the risk is much higher because the kinetic energy to dissipate is more than double.

For the landing segment of STOL operation, drag is even more important than high lift or light weight. Sailplanes are a good example. All sailplanes have high lift wings and may are light weight, but without spoilers for drag, a sailplane might use more runway than a 747. Drag dissipates energy and that's almost as important to a landing as getting on the ground. Of course, in most other phases of flight drag is totally undesirable. Consequently, the controllable drag produced by an effective flap system is the most desirable because flaps also increase lift exactly when you need it. The Pulsar uses the simplest form of flap design called plain flaps. These flaps are hinged on the bottom so even small deflections increase drag immediately by opening a large gap on the top of the wing. With this system, and a slow approach speed, the Pulsar can maintain a steep, controllable glide path for a very predictable spot landing and short ground roll.

Even at gross weight with no wind the Pulsar uses no more than 800 feet for either takeoff or landing. Also, obstruction clearance is very good because the climb angle and approach path are relatively steep. To open up even more fields to the Pulsar, Aero Designs now has a taildragger option for grass runway operation and also a large tire option for the tri-gear version to allow operation on smooth grass runways. The large tires do slow the Pulsar down about 4 mph in cruise but in combination with the flexible fiberglass main gear, the shock loads are reduced considerably. A recording accelerometer in the cockpit measure 2.1 G's with the standard five inch wheels but only 1.6 G's with the optional six inch wheels. Both tests were done at the same speed on the same grass runway for comparision.

On the general subject of handling qualities, we've learned a good bit from the literally hundreds of pilots who have flown the Pulsar demonstrator. Almost without fail they make some comment on how easy it is to fly, and how responsive and maneuverable it is. Most pilots are understandably surprised that an airplane can have both qualities. Stability and maneuverability are usually opposing characteristics.

The reason the Pulsar is so stable is strictly a function of its tail volume and center of gravity position. Tail volume is the area of the empennage multiplied by its distance to the CG of the airplane. The effect it has on stability is exactly like feathers on an arrow. A large tail volume does compromise cruise speed slightly but since it is the key element in stability, the Pulsar doesn't cut corners here. As a result, the Pulsar will fly hands off in smooth air for as far as you want to go.

Such high levels of stability are great for flying in straight lines but most airplanes with this much stability don't maneuver very well. The controls are heavy and sluggish and very tiring for the pilot in bumpy air just to keep the wings level. The reason the Pulsar remains so maneuverable is strictly due to its light weight. Newton's laws define how objects in motion tend to maintain that motion. This affect is called inertia and the less an object weighs the less inertia it has. Being so light in weight, the Pulsar has very little inertia so it offers little resistance to changes in its motion. Consequently, the controls feel very light and crisp making maneuvers a joy and corrections in bumpy air almost effortless.

Aside from its excellent handling qualities, the Pulsar has also proven over time to be a true traveling machine. Many single day trips of over 1200 miles have been accomplished in the demonstrator Pulsar enroute to the airshows. Even these lengthy trips aren't really tiring because the seats are reclined about 30 degrees which helps to prevent pressure points and fatigue. The pilot and passenger can just sit back, relax and enjoy the excellent visibility of the countryside through the large single piece canopy. As the ol' saying goes - Time flies when you're having fun.

For a complete information package on the Pulsar, send $5 to Aero Designs, Inc., 11910 Radium, San Antonio, TX 78216, phone 512-308/9332.

PULSAR SPECIFICATIONS

	PULSAR	PULSAR XP
EXTERNAL DIMENSIONS		
Wing Span	25.0 Feet	25.0 Feet
Length Overall	19.5 Feet	19.5 Feet
Height Overall	6.3 Feet	6.3 Feet
Wing Area	80 Sq. Ft.	80 Sq. Ft.
Wing Aspect Ratio	7.8	7.8
WEIGHTS AND LOADINGS		
Empty Weight	460 Pounds	510 Pounds
Useful Load	440 Pounds	450 Pounds
Gross Weight	900 Pounds	960 Pounds
Power Loading	13.6 Pounds/HP	12 Pounds/HP
Wing Loading	11.2 Pounds/Sq. Ft.	12 Pounds/Sq. Ft.
Fuel Capacity	16 Gallons	18 Gallons
G Limits (tested)	+6.0 and -4.0	+6.0 and -4.0
Seats	2	2
POWER PLANT		
Engine	Rotax 582	Rotax 912
Max. Power	66 HP	80 HP
Propeller	56 in. Wood Laminate	60 in. Wood Laminate
PERFORMANCE		
Cruise Speed	130 MPH	140 MPH
Stall Speed	45 MPH	46 MPH
Rate-of-Climb	1000 Feet/Minute	1000 Feet/Minute
Service Ceiling	15,000 Feet	15,000 Feet
Takeoff Roll	800 Feet	800 Feet
Landing Roll	800 Feet	800 Feet
Range	400 Miles	500 Miles