PISTON POWER

Steve Brown describes how uprating his aircraft’s existing O-200 gave a performance increase equal to retrofitting a larger engine.

Francis Donaldson’s extensive engines article in last month’s LAA magazine very clearly set out the advantages, and disadvantages of changing engines in the search for better performance and the inevitable LAA processes that need to be followed to achieve this.

As Francis said, fitting a different (and usually bigger) engine impacts significantly on whole aircraft design, structural limits, cost, weight, centre of gravity, payload, fuel burns etc. Having these spelled out by Francis prompted me to consider writing a brief article on how we dealt with solving the problem in a different way.

We operate a Rutan Vari-Eze with a standard Teledyne Continental Motors (TCM) O-200 engine with a Hertzler Silver Bullet fixed-pitch propeller. As most will know, this is an extremely efficient aircraft with a wide range of cruise and take-off performance was only adequate, and worth improving.

Fitting a larger engine was out of the question for us, mainly due to our confidence in the attributes and good value of the O-200 but also because of cost, weight and C of G reasons. The O-200 is a superb engine which is relatively light so we resolved to keep it and try to make it even better.

The engine was originally designed to operate on 80/87 fuel which necessitated a relatively low compression ratio of 7:1. A comparison, standard compression ratios of the Lycoming O-235 engine vary between 6.75:1 and 7:1.

An internal combustion engine is really just a big air pump. It takes in air, the air is compressed and heated with burning fuel, the air expands against the piston and thus produces work.

Engine efficiency is broadly defined as the ratio of work output to fuel input. The maximum theoretical efficiency of an Otto cycle engine is defined by the formula:

\[\text{Efficiency} = 100 \times \frac{1 - \left(\frac{V_1}{V_2}\right)^{\Gamma}}{\Gamma - 1}\]

Where:

- \(V_1\) is volume of cylinder/combustion chamber
- \(V_2\) is the volume of the cylinder/combustion chamber at top of piston stroke
- \(\Gamma\) is the ratio of specific heat of air at constant pressure (\(C_p\)) and specific heat of air at constant volume (\(C_v\))

\(\Gamma\) for air is approximately 1.4. Trust me! This would bring a double benefit. The power available on take-off would increase, while the required power during cruise would be produced with less heat (fuel) input.

This conflict in performance requirements can be solved in two ways: the compression ratio could be increased, or the engine could be operated with less heat input. If we could increase the compression ratio of the engine, its efficiency would increase throughout its operating range and hence so would its power output for a given amount of heat (fuel) input.

Let’s look at some figures based on the above equation:

**Compression Ratio 7:1**

- Efficiency = 100 x \[\frac{1 - \left(\frac{V_1}{V_2}\right)^{1.4}}{1.4 - 1}\]
- Efficiency = 100 x \[\frac{1 - (10/1)^{1.4}}{1.4 - 1}\] = 54.1%

**Compression Ratio 8:1**

- Efficiency = 100 x \[\frac{1 - \left(\frac{V_1}{V_2}\right)^{1.4}}{1.4 - 1}\]
- Efficiency = 100 x \[\frac{1 - (8/1)^{1.4}}{1.4 - 1}\] = 56.9%

**Compression Ratio 9:1**

- Efficiency = 100 x \[\frac{1 - \left(\frac{V_1}{V_2}\right)^{1.4}}{1.4 - 1}\]
- Efficiency = 100 x \[\frac{1 - (7/1)^{1.4}}{1.4 - 1}\] = 58.3%

Note: these efficiencies are not achieved in practice but they are useful as relative comparators.

So all other things being equal, raising \(\Gamma\) to 9:1 should yield a 2.2% efficiency increase, while an increase of \(\Gamma\) from 7:1 to 7:2.

That we don’t spend much time travelling flat out and on the occasions we do, this can easily be controlled by the pilot through throttling back. However, since the power required increases by the cube of the airspeed, we felt any power increase would have very little effect at top-speed.

For those interested, Gamma is the ratio between \(C_p\) and \(C_v\) at maximum theoretical efficiency of an Otto cycle engine. It is defined by the formula:

\[\text{Efficiency} = 100 \times \frac{1 - \left(\frac{V_1}{V_2}\right)^{\Gamma}}{\Gamma - 1}\]

So all other things being equal, raising \(\Gamma\) to 9:1 should yield a 2.2% efficiency increase, while an increase of \(\Gamma\) from 7:1 to 7:2.

Main photo: the O-200 powered Vari-Eze is an incredibly efficient aeroplane.

Right: LAA Inspector Don Foreman, left, and the author carry out initial engine runs.
In summary, we preferred a simple approach to the compression ratios inevitably impose more stress on the engine and due to the increased heat production, require more cooling.

SIMPLE APPROACH

In summary, we preferred a simple approach and not being after every ounce of power, wanted to be very conservative and retain full reliability.

The O-200 is a development of the earlier C75/85. We found that, apart from the number of valve springs, the C75 engine uses the exactly the same cylinders as the O-200 (even the ring set is the same) but with a shorter crankshaft stroke. To achieve the desired compression ratio, the C75 piston’s gudgeon pin is positioned 0.110in lower down the piston than on the O-200. Therefore installing standard TCM C75 pistons in an O-200 will result in the piston travelling a little further up the bore, so reducing the combustion space at TDC.

This has the effect of raising the compression ratio, while leaving the cylinder swept capacity unchanged. This option would have added the advantage that we would be using original TCM standard parts.

My engine displacement calculations concluded that the O-200 would rise from 7:1 to around 8.2:1 resulting in an approximate 5.5% increase in engine efficiency. The maximum power output of the engine should therefore rise to 302hp. A modest but useful increase, but we were predicting greater things at take-off - more on that later.

We sought advice from TCM and LAA Engineering and submitted an LAA Modification Application (now termed “Prototype” MOD 2 or MOD 3 forms). After the customary iterations, Francis was broadly convinced (actually, he was very supportive) that we were serious and knew what we were doing. A conditional Modification Approval was given subject to full LAA inspector oversight, five hours initial test flying, then a further 25 hours cruise and only 4-5hr after adjusting the idle mixture, we followed the TCM recommendations for breaking in an engine installed in an aircraft.

We then tried a full power static rpm test. The engine reached 2380 - 2400rpm (85% power) - a considerable increase from the 2220rpm (79% power) we had experienced previously. The static rpm had increased by 7.2% - better than anticipated but by virtue of the engine also moving up its power range, the engine take-off power available had increased from 350hp (95% of 350hp) to 380hp (95% of 390hp) - a 28% increase in take-off power.

FLIGHT TESTS

Nothing else for it but to fly it. Take-off was considerably more brisk than before, with a real push in the back right from opening the throttle. Previously the engine only really started to push after 50-70rpm take-off rot. Up and away while monitoring T & Ps very carefully, it was clear the engine had far more bite than previously and climb rate had improved considerably.

Break-in was achieved very quickly by flying around TCM’s recommended 3,000rpm (75% power) for a total of 4 hours, after which oil consumption started to stabilise at 4.9-5.1hr per litre, and better later. Highest CHTS soon dropped to a very acceptable 50 to 58deg F, cruise and only 40deg F on approach.

The ensuing flight tests showed that the aircraft was more economical in cruise, had a 5.4 mph higher top speed, climbed faster and took off much quicker - all with no weight or C of G penalty.

The engine idles very well, is crisp, smooth and purposeful. No problems have arisen and following full Mod approval, we are enjoying even greater efficiency, usability (shorter runways) and economy. In short, the aircraft has been transformed.

A few numbers:

- 2,500rpm cruise at 3,900ft DA: 176mph TAS at 14,500ft
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This modification goes some way to show that an ‘antiq’ robust design like the O-200 (which originated from the A65 first produced in 1939) can be updated to become more efficient, while still retaining simplicity and reliability. The O-200 compares very favourably with other more modern engines.

Interestingly, we recently spotted that TCM has Type-Certified an O-200D variant for likely use in the new LSA category with a compression ratio of 8.5. They still only claim 302hp though! Perhaps it made certification easier and possible future retrofits more viable.

Permit Maintenance Release checks were made and log books updated. It was soon clear aerodynamic lines are the secret of the Vari-Eze’s performance. Now it also has a bit more power!