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 burn etc. Having these spelt 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 100hp Teledyne Continental Motors (TCM) O-200A engine with a Hertzler Silver Bullet fixed-pitch propeller. As most will know, this is an extremely efficient aircraft with a wide speed range.

Chris Lodge outlined in his recent article that propeller designers seek to achieve a propeller diameter and pitch that is fine enough to allow sufficient engine rpm to be developed on take-off when the airspeed is low, while still being sufficiently coarse to allow the full power of the engine to be absorbed at high airspeeds without exceeding the engine red line.

This conflict in performance requirements is a challenge for any propeller manufacturer but particularly so when the speed range is wide. Although our Hertzler 63in diameter x 69in pitch propeller was perfect in cruise and top speed, 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. As a comparison, standard compression ratios of the Lycoming O-235 engine vary between 6.75:1 and 9.7:1.

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/heat (fuel) input. The maximum theoretical efficiency of an Otto cycle engine is defined by the formula:

Efficiency = $100 \times [1 - (V1/V2)^{1-\text{Gamma}}]$

Where:

V1 is volume of cylinder/combustion chamber at bottom of piston stroke

V2 is the volume of the cylinder/combustion chamber at top of piston stroke

Gamma for air is approximately 1.4. Trust me!

V1/V2 is usually known as the compression ratio of an engine.

For those interested, Gamma is the ratio between Cp (the Specific Heat of air at constant pressure) and Cv (the Specific Heat of air at constant volume) relevant because the Otto cycle operates under (nearly) constant pressure and volume at different periods of the cycle.

Specific heat is simply the amount of energy that is required to heat a mass by a certain temperature (eg, it takes 380 kJoules of energy to raise a Kilogram of brass by 1 degree Centigrade and similarly 900 kJoules of energy to raise a Kilogram of aluminium by 1 degree Centigrade).

So the engine efficiency is dependent upon the compression ratio. 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.

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 and hence the fuel consumption would decrease.

There would be a risk of over-speeding the engine at maximum power but we reasoned that we don't spend much time travelling flat out and on the occasions when 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.

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

Compression Ratio 7:1
Efficiency = $100 \times [1 - (7/1)^{1-1.4}]$ = 54.1%
Compression Ratio 8:1
Efficiency = $100 \times [1 - (8/1)^{1-1.4}]$ = 56.5%
Compression Ratio 9:1
Efficiency = $100 \times [1 - (9/1)^{1-1.4}]$ = 58.5%
Compression Ratio 10:1
Efficiency = $100 \times [1 - (10/1)^{1-1.4}]$ = 60.2%

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

So all other things being equal, raising a 7:1 CR engine to 8:1 should yield a 4.4% efficiency increase, while an increase of CR from 7:1 to 9:1

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.

should yield an 8.1% increase in efficiency.

We did some research and found that aftermarket high compression pistons for the O-200 that give compression ratios of up to 10:1 are available in USA. However, some of these pistons require machining of the connecting rod which we wanted to avoid. We were also wary of committing to an unknown piston assembly that may not be supported by the manufacturer in the future.

At compression ratios above 8.5:1, it is generally necessary to use 100LL Avgas to prevent the risk of detonation and we were keen to retain the flexibility to use Mogas if circumstances made it necessary. The higher 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/C85. We found that, apart from the number of valve springs, the C85 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 C85 piston's gudgeon pin is positioned 0.110in lower down the piston than on the O-200. Therefore installing standard TCM C85 pistons in an O-200 will result in the piston travelling 0.110in 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 the added advantage that we would be using original TCM standard parts.

My engine displacement calculations concluded that the CR would rise from 7:1 to around 8.2:1 resulting in an approximate 5.2% increase in engine efficiency. The maximum power output of the engine should therefore rise to 105hp. 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 & 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 monitoring period with a full flight test and submission of a summary report before Full Mod approval could be granted. The engine modifications were undertaken under the watchful eye of our suitably qualified Inspector, Don Foreman.

It is very important to realise that every cylinder head casting and its attachment to the cylinder is unique. Also, aircraft engines typically have pretty wide piston/cylinder clearances which allow the piston to tilt slightly during their travel over TDC, moving them very close to the cylinder head and this has to be taken into account.

It was therefore essential that great care was taken to ensure that adequate clearances (0.045-0.050in) existed between each piston

Clean aerodynamic lines are the secret of the Vari-Eze's performance. Now it also has a bit more power!

and the cylinder head.

The cylinders were well honed, both to aid ring break-in and remove any carbon build up or any small steps in the area not previously swept by the rings. New balanced C85 pistons and accurately gapped rings were then installed, and the ignition timing retarded slightly from 28 deg BTDC to 24-25 deg BTDC to allow for the faster, more efficient combustion process.

After completing the remaining engine assembly and connections, the necessary Permit Maintenance Release checks were made and log books up-dated. It was soon time to fire her up. She started first time and 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 (65% power) - a considerable increase from the 2220rpm (53% 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 53hp (53% of 100hp) to 68hp (65% of 105hp) - 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 50-70m take-off roll. 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 at TCM's recommended 2,500rpm (75% power) for a total of 3-4 hours, after which oil consumption started to stabilise at 4-5hr per litre, and better later. Highest CHTs soon dropped to a very acceptable 320 to 380 deg F in cruise and only 410 deg F flat out.

The ensuing flight tests showed that the aircraft was more economical in cruise, had a 5-6 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:

2,250rpm cruise at 1,500ft DA:
159mph TAS at 13.5l/hr
2,380rpm cruise at 1,500ft DA:
167mph TAS at 14.5l/hr
2,500rpm cruise at 4,500ft DA:
174mph TAS at 16l/hr
2,500rpm cruise at 11,000ft DA:
176mph TAS at 14.5l/hr

This modification goes some way to show that an 'antique' 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 Certificated an O-200D variant for likely use in the new LSA category with a compression ratio of 8.5. They still only claim 100hp though! Perhaps it made certification easier and possible future retrofits more viable. Few details (or spare parts!) are available as yet but it is clear our thinking was aligned with TCM's and gives further confidence.

It should go without saying that a modification of this type has great significance to the safety and reliability of an aircraft so it must be well thought out, documented properly and, crucially, fully approved by LAA Engineering before installation.

We are therefore extremely grateful for the support of Francis Donaldson and LAA Engineering for being willing to consider, support and approve this modification, which clearly was not without some risks for them. Very well done guys & gals, as Rutan may say.

Roger Hopkinson has highlighted on the LAA website recently that the European Parliament voted (87%) for the Resolution: "Agenda for a Sustainable Future in General and Business Aviation", (2008/2134/NIN).

I am pleased that we have, in our own small way, contributed to the Resolution's stated environmental goal, "to reduce emissions through further enhancing the environmental performance of smaller aircraft by using cleaner fuels and by promoting research, technological development and innovation", while we also benefit through lower costs and better performance/utility.