DYNAMIC PROPELLER BALANCING

AFTER RECENTLY COMPLETING A PROPELLER BALANCE FOR A HOMEBUILDER, THE RESULTS WERE VERY PLEASING. THIS ARTICLE ADDRESSES SOME PROPELLER BALANCING QUESTIONS AND FURTHER TECHNICAL DETAIL.

Is there really some merit in trim balancing the propeller?

The obvious answer is 'only if the propeller is unbalanced!' A near-new, certified, direct drive engine and propeller is unlikely to benefit very much from trim balancing and it is unlikely that an improvement will be noticeable to the aircrew, even if it is trim balanced. Static prop balancing is in fact very accurate if carried out with the right equipment and all new certified props are of course statically balanced. The sources of vibration and noise in the cockpit are various – exhaust pulsations beating on the fuselage, acoustic pressure pulsations from the propeller at blade-pass frequency, and the firing rate torque reaction on the engine mounts. The effect of propeller unbalance if superimposed on all this could be likened more to a shake or shudder, rather than a 'vibration'; it is often more noticeable at low rpm as the engine accelerates through engine mount resonance, which is typically around 1200 rpm. After trim balancing a significantly unbalanced prop, the pilot often remarks how much smoother the engine feels on start-up and as the engine is run up through this speed.

On the plus side, for an existing aircraft, trim balancing the prop is the only maintenance action (other than keeping the engine in good condition) that can potentially give you a smoother aircraft, quickly (a typical prop balance will take 1½– 2½ hrs), and at relatively small cost.

The table below shows some examples of a few recent aircraft balances I have been involved with. The two RV-10's are an interesting case – both were low airtime, and while the initial vibration levels were low, in both cases the owners commented favourably on the results. These are an already smooth aircraft (6-cyl IO-540), but the prop balance made them even smoother. I also recorded the vibration spectrum in flight on the cabin seat rail of one of these aircraft just after the prop balance – see fig.1 – this shows why there is little point in achieving very low 1/rev values. We can see here that although the 1/rev vibration is now low, vibration at other frequencies now start to dominate. These are from the inevitable slight engine unevenness, engine firing rate, and prop aerodynamic effects.

Aircraft	Vib level before. IPS	Vib level after. IPS	Comments by aircrew from cockpit impres-sions in flight
PA-28	.23	.01	Very marked improvement
Glastar	.24	.04	Near new – no discernible effect
Thorp T-18	.61	.02	Very marked improvement
RV-6	.08	-	No balance carried out
RV-3	.08	-	No balance carried out
RV-10	.21	.02	Owner pleased with result
RV-10	.14	.06	Owner pleased with result
Sonex	.59	.08	Very marked improvement
Sonex	.25	.05	No obvious change
RV-8	.15	.06	No obvious difference felt
Waiex	.17	.06	- (but no complaint!)

Is it likely that the result will be less wear on the engine, and less airframe degradation? The benefits of propeller balance in terms of reducing engine wear are sometimes exaggerated. For example, a significantly unbalanced propeller generating a vibration level of 0.5 IPS (in/sec peak) will generate an out of balance radial force of around 60 lbf. However, with an IO-360 Lycoming for example, the peak firing load on the same bearings that react the propeller out of balance load, are around 9 tons. So the propeller loads are insignificant compared to the internal engine loads.

However, the vibration from significantly unbalanced props can exacerbate cracking of engine cooling baffles, exhaust systems etc and engine mounts if susceptible to cracking. A geared prop engine however is a good candidate for trim balancing at any time – the closely spaced rolling element bearings do not have the same load carrying capacity to react unbalanced propeller loads as the crankshaft plain bearings in a non-geared engine, and anything we can do to reduce loads on the reduction gearbox and components will be a good thing.

What does propeller vibration level in IPS mean?

Propeller vibration amplitude levels are usually referred to as IPS, which is a velocity, inches/second, usually the peak level. This is the peak velocity of the engine casing, as measured by the transducer, which occurs as it oscillates through the midpoint of the casing vibration. For propeller vibration measurement, all frequency components other than those at propeller rotational speed are ignored. In the world of prop balancing, 0.10 IPS is very low, 1.0 IPS is very high. While 1.0 in/sec doesn't sound like much, at a prop speed of 2400 rpm, the casing is oscillating 40 times/second, but at a small amplitude of 8 thousandths of an inch peak-peak.

How does Prop balancing work?

To fully describe the theory is outside the scope of this article however, the basis of all propeller trim balancing is unchanged from the influence coefficient procedure first published by E. L. Thearle in 1934, which is used in virtually all machinery trim balancing carried out today. Essentially, the process requires the use of a vibration sensor and the generation of a 1/rev tach pulse. The initial step is to obtain values of the base-line vibration amplitude and phase. The second step, in the absence of data on system sensitivity, is to attach a trial weight to the propeller hub. The engine is then run for a second time (at the same rpm), and the initial vibration is then subtracted vectorially from the value recorded from this second run, and the resulting value will be the contribution due only to the trial weight.

The mass and angular location of a balance weight to cancel the initial vibration is then computed by positioning the balance weight so that its influence is equal in magnitude, and 180 degrees out of phase with the initial vibration.

A typical setup of sensor and phototach is shown in fig 2; the output from these sensors is fed to a balancer-analyser. The engine speed used for balancing is not especially critical, we try to avoid engine mount resonances, and operate in the region 1800-2000 prop rpm. Higher rpm such as cruise settings are not necessary, and in fact are unhelpful due to the aircraft turbulence and bouncing at the higher rpm.

It could be said that this is a somewhat indirect way to balance a propeller. And that would be correct – trim balancing is not actually balancing the propeller. What we are really doing is to minimise the once/rev vibration signal at the vibration sensor, using the prop hub as a convenient place to attach a weight to generate 1/rev vibration. The tacit understanding of course is that any significant 1/rev vibration in this location will be caused by prop unbalance.

Would in-flight measurements provide better results?

Yes, but at the expense of significant increase in complexity, of course, unless using permanently installed sensors and analysers, such as we have on some commercial aircraft.

Tests I carried out some time back with Sam Richards in his RV-6 at Temora indicated that the propeller balance could certainly be refined using in-flight data; the prop vibration level in-flight was reduced from 0.21 to 0.11 IPS. During these tests a comparison was also made using two sensors – one attached in the usual balance location on the front of the engine, and the other in the aircraft interior. The results of these measurements in Fig 3 show why we have engine vibration isolating mounts. The effect of the vibration isolation is to halve the 1/rev engine vibration and virtually eliminate the higher frequencies - the train of ½ engine orders are characteristic of all aircraft piston engines.

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vibration sensor and phototach on an IO-320 engine

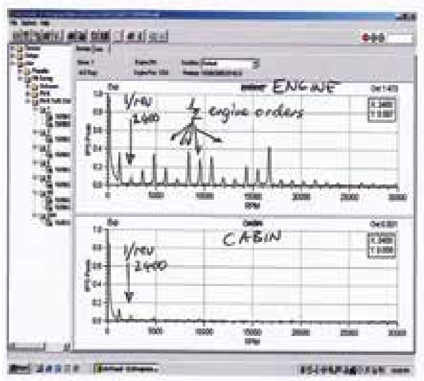

Fig 3 –A comparison in-flight of engine and cabin vibration at 2400 rpm, cruise, RV-6

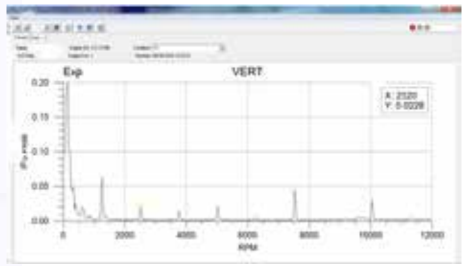

Fig. 1 RV-10 Cabin vibration – lower seat rail (vertical direction)

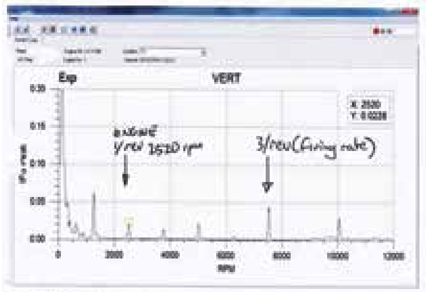

Fig 1 RV-10 Cabin vibration – lower seat rail (vertical direction)