Company founder Rupert Wasey puts the finishing touch to a Hercules propeller

Building a better prop

There's a revolution going on in propeller design and manufacturing – meet the man behind the new, computer-designed, tailor-made airscrews

Words and photography *Bob Grimstead*

A propeller is often the most neglected major component on an aeroplane. And yet any prop is a sinuous, multi-curved, three-dimensional sculpture – an artefact of functional beauty. A wooden propeller can be a 'joy forever' – so you should inspect and admire yours more often.

An airscrew converts your engine's power into the vital thrust needed for flight, and your aeroplane's efficiency (in terms of both performance and economy) depends upon that propeller's effectiveness. Your prop is essentially a rotating wing (although its aerodynamics and rotational dynamics are of course more complex) and, like a low-drag aeroplane's wing, for real efficiency the propeller's blades need to be long, slim and thin. Unfortunately, and again like your wing, structural considerations force compromise.

Metal propellers (usually forged aluminium) have the strength to be thin and fairly efficient (up to a maximum of around eighty per cent efficiency) but they have significant disadvantages when compared with wooden airscrews. They are heavy, expensive (often more than three times the price of a wooden prop), prone to fatigue and corrosion, and particularly vulnerable to stone-chip damage. Metal props are also poor at absorbing your engine's vibration, and often subject to resonance problems – evinced by a red *no continuous operation* segment on your tachometer.

Alternatively, wooden propellers cost a lot less, are much lighter (an important consideration for a major component bolted to the very front of your airframe), and are far better vibration absorbers. Unfortunately, until very recently wooden airscrews were significantly less efficient than metal ones, because prop carvers made them comparatively broad and chunky to be certain of providing enough strength to combat the enormous bending and centrifugal forces they must withstand. Luckily for us, the advent of cheap, powerful computers has now changed all that.

Previously, accrued empirical wisdom plus tabular and slide-rule calculations deemed that wooden airscrews should be thick and wide. You will never have heard of structural failure in an undamaged wooden propeller. It just didn't happen, mostly because they were way over-strength (but unfortunately, commensurately under-efficient). But at last, modern computers have the power to integrate the large number of variables needed to match a wooden propeller precisely to not only its engine, but also to a particular airframe. Moreover, computer-aided manufacturing now enables such a sophisticated design to be machined very precisely, to provide the required strength and prescribed safety margins while allowing the blades to be slim enough to minimise drag.

Now I shall introduce Rupert Wasey, whom I first met when I was invited to fly his beautifully-finished, award-winning and impressively-performing Staaken Flitzer for a flight test article. Understanding the theory behind the less-than-perfect propeller his Flitzer originally used, Rupert was dissatisfied with his shiny new aeroplane's performance. Unable to obtain a wooden prop of the specification he required, Rupert decided to develop a sophisticated Computer Aided Design (CAD) program which integrates many parameters to design tailored propellers for any application.

As Rupert says, "My program allows me to manufacture the optimum propeller for your engine and airframe combination. Most prop carvers offer one blade shape for all Gipsy Majors, regardless of whether they're in a comparatively clean Chipmunk or a draggy old Tiger Moth. They may have just a half-dozen models of propeller altogether, perhaps one for Gipsies, two for small and bigger Continentals, two for Lycoming O-320s and O-360s, and one for all Volkswagens. If you're lucky, they may offer two blade pitches for each engine – a coarse or 'cruise' setting and a fine or 'climb' pitch, and that's it."

Let us consider some parameters that affect fixed-pitch propeller design – all of which are accounted for in Rupert's CAD. They include (but are not limited to): airscrew diameter, nominal blade pitch (normally measured at 70 per cent radius), blade chord, thickness/chord ratio, aspect ratio, twist, pitch distribution or helix angle, the aerofoil or combination of aerofoils, camber, planform, tip shape, the number of blades, true engine horsepower and rpm in the climb, cruise, and at top speed, and maximum blade tip speed (ideally below 820ft/sec to minimise Mach effects).

Each variable is affected by practical and theoretical considerations. For instance, a prop's diameter is limited by the required ground clearance (nine inches in the most limiting attitude under normal conditions, but also positive separation even with a flat tyre and a deflated shock strut, or with spring gear legs deflected under 1.5G). Blade chord and root twist can be limited by airframe clearance considerations, and so on throughout the list.

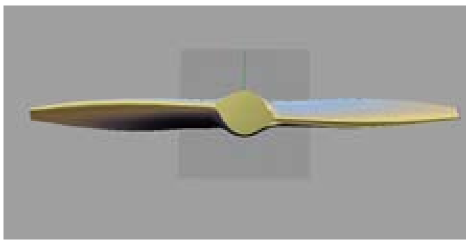
Rupert's program takes all these factors into consideration, but also integrates airframe drag with engine power and thrust, accounting for wing-span, wing area, aspect ratio, root chord, turbulent or laminar aerofoil, skin material, strutted or cantilever configuration, fuselage length, width and height, undercarriage type, cowling shape, windscreen profile, and a host of other variables. Most importantly, it constantly monitors the design's strength margins, ensuring they always exceed the statutory requirements by a generous percentage.

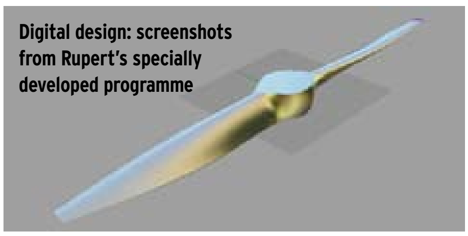
Investing months of effort and lots of capital, Rupert built a Computer Numerically Controlled (CNC) router for machining wooden airscrews to fine dimensional tolerances, and set up Hercules Propellers.

A tailor-made test

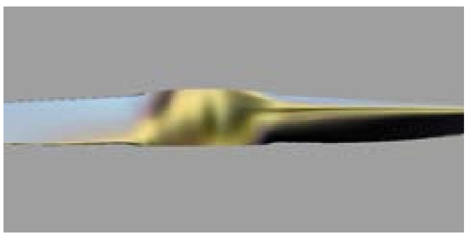
I was impressed by this attention to detail, but still sceptical that a Hercules propeller could improve my aeroplane's performance: after all, I've conducted eight years of experimentation and meticulous test flying to establish that my Fourniers' current →

Quality control - a stylish sticker shows that final balancing has been completed





Digital design: screenshots from Rupert's specially developed programme



propellers are the best available. I own two Fournier RF4Ds, one in Britain and the other in Australia. I use my English one for formation aerobatics, for which I need the maximum possible thrust and acceleration or climb capability in the speed range from 60 to 120mph, ideally with minimum noise.

"Rupert made me an offer: 'I'll make a propeller for your Fournier... if it doesn't improve your aircraft's performance, you don't have to buy it'"

I've found over the years that there is no better way of comparing propellers from different manufacturers than bolting them on to the engine flange and seeing how well they perform. Since buying my first Fournier, I have experimented with no fewer than nine propellers. It has become a family joke that I always seem to travel between hemispheres with a propeller in my luggage. I have tried short and long Hoffmann props, Lodge and Newton props, non-commercial props from Andy Szep, Formula One champion Steve Thompson and an anonymous carver. All were adequate, but some performed less well than others. The best of that lot was a long Hoffmann off an RF5, but because it lacked 1cm of ground clearance in the flat-tyre, snapped suspension case, the LAA would not allow me to fly that one here, although it worked very well in Australia.

I eventually found an Australian propeller maker, formerly employed by Dowty Rotol, who made what I thought was the ideal prop. He carved me two with different pitches, and I brought the better one to England. After two seasons, I was very happy with its performance. I told Rupert there was no chance his propeller could do better.

We've known each other for years, so because I was writing this article and Rupert is confident in his product, he made me a unique offer: "I will design and make a propeller for your Fournier. You can try it, and if it doesn't improve your aircraft's performance, you don't have to buy it."

A couple of days later I received an email from Hercules with some complex calculations and three-dimensional

PROPELLER FLIGHT TESTING

Like everything else in flying, you only get good results if you are careful and meticulous. Your flights and figures must be repeatable or they are useless.

First, it is vital to compare like with like. You just cannot compare Fred's standard aeroplane at maximum weight on a hot day with Joe's modified, big-engined one in mid winter with a nearly empty tank.

If you want to compare propellers, it is really only possible to do so on the same aeroplane – there are just too many variables. For instance, we flew a formation of four Fourniers recently to compare our instantaneous airspeed readings. They varied by over 10mph! My British Fournier's electronic tachometer reads more than 400rpm different from my Australian one's original mechanical one with the same propeller, in identical conditions.

Comparing speeds at anything other than full throttle is even more fraught with variability. Add in altimeter errors and the varying drags, weights and centres of gravity of different aircraft of identical type, and you just cannot compare apples with oranges.

Don't even start considering VSI readings. Your VSI is by far the most inaccurate instrument ever devised by man. Climb rates can only be assessed accurately by using altimeter and stopwatch (there's usually one in your mobile phone).

When I fly to compare propellers, I try to make both flights on the same day, and one after the other in as quick succession as safely possible, so that ambient pressure and temperature are the same or very similar. I fly at a constant weight (with radio, headset, helmet, charts, battery and full fuel plus me, normally dressed, but without any baggage).

If your spinner won't fit over both propellers you're comparing, remove it for both flights to ensure similarity.

I set 1013 HPa on the altimeter, to eliminate that variable, and airspeed checks are always flown at 1,500 feet, the upper limit of my aerobatic display.

To get a true maximum static rpm on the ground, you should be facing exactly across the wind. If you head into the wind the rpm will become artificially high, and the converse is true if you wish to apply full throttle facing downwind (but why would you?) If your brakes won't hold you against full power, use chocks.

The same is true of a timed climb. It is important to fly in a straight line at a steady airspeed at right angles to the prevailing wind. Otherwise the 'kiting' effect of positive windshear will skew your readings. Those of you who've flown glider winch launches on a breezy day will be well aware of this effect. You should also stay well away from thermals, ridge or wave lift and cloud streets. No fair cheating now!

The more still the air, the more accurate your readings will be, so try to pick a calm day and fly perhaps either early in the morning or late in the afternoon.

It is important to hold your airspeed accurately, to within +/- 2mph/kt, and ideally to climb at your best climb-rate speed (V_Y).

Climb checks are generally timed from 500ft, because that gets you out of ground effect and the most turbulent lower levels. It also enables you to establish steady flight at the correct climbing speed and to get trimmed and settled. Simply hit the stopwatch as the altimeter's big hand swings past 500ft. Check the height gain after sixty seconds and you will have a useful comparative climb rate.

For a 'proper' test, climb at full throttle for five minutes. Note your height at every minute (or every thirty seconds if you want to be really accurate), and then draw a graph of your heights against time. You should get a gently sloping curve as your climb rate drops off with height. If your calculation is accurate enough, you could presumably extrapolate to get your service ceiling (that altitude, with standard altimeter setting, when your climb rate drops off to 100fpm).

The most important speed check is at full throttle, although partial power speeds might be of personal interest. Again, it is important to get your aeroplane exactly trimmed out, and to let the speed settle. You should fly exactly level (+/- 10ft) for a minimum of two full minutes before reading your airspeed, in order to let everything stabilise. If you cannot do that, then you can get an approximate reading by averaging your maximum and minimum speeds as you float up and down around your datum altitude. Note, however, that this reading will be no good for comparison with any other props or aeroplanes.

Happy customer: Bob signals his approval after careful back-to-back flight testing proved Hercules Propeller's performance claims. (In case you wondered, the Fournier's spinner had to be left off throughout because it did not fit the new propeller.)

representations of my new propeller. Not surprisingly, its pitch and diameter were extremely close to those of my current prop. A week afterwards I received photos of the laminated hardwood blank being machined, and days later that I was invited to Nympsfield to sample it. Ensuring my LAA inspector was on hand to supervise, and choosing a clear, cool, fairly calm day, I topped up my tank on arrival and wiped the bugs off my prop's leading edges. I then flew the LAA's two-page propeller flight test schedule out in the calm air over the River Severn. Its format basically calls for a five-minute full-throttle climb, a V_{NE} dive and some stabilised cruise figures (see 'Propeller Flight Testing', opposite).

After landing we quickly swapped my existing propeller for Rupert's noticeably narrower, thinner one, I refilled the fuel tank to ensure that both weight and ambient conditions were comparable, and tried again. Flying an identical profile over the same route, the first thing I noticed was how very smooth this prop was – and that there was a significant improvement in climb performance. I always avoid taking previously noted figures aloft for fear of slewing the readings by comparison, so I dutifully completed the climb, high-speed and cruise segments of the test schedule without reference to my first flight.

"The first thing I noticed was how very smooth the prop was – and that there was a significant improvement in climb performance"

Then I essayed some aerobatics, and the change was immediately apparent. I had previously been unable to complete a 180-degree half vertical roll unless I was down at 1,000ft, where full throttle is nearly full power. Today, already being at 5,000ft for the V_{NE} dive, I tried one at this giddy height, and made it all the way around on my first attempt. As I aerobatted lower, I was able to get further and further around the evolution, until I could complete nearly 220º of vertical rotation. And I was way out of practice at solo aeros! After a ten-minute wring-out confirming the prop's strength, I landed with a smile, shook Rupert's hand and gave him his money.

Not one of those earlier propellers had ever shown such a marked performance improvement. This time my Fournier's climb had increased by a significant 160fpm, with an improvement of 1mph in top speed, and 2mph in both high- and low-speed cruises (using carefully marked throttle positions rather than unreliable rpm readings). I had wanted optimum climb performance, and I got it.

A speed increase of just 1mph may not seem a lot, but this was specifically a 'climb' propeller, and increased airspeed derives mostly from reduced drag rather than increased power, so 1mph *is* noteworthy. And all this improvement comes at no greater running cost, while bringing with it a considerable increase in safety, operating as we do from a short, sloping, tree-fringed airstrip. I immediately ordered a second propeller for my flying partner, Matthew.

A few weeks later I went to visit Rupert at Hercules Propellers' premises near Stroud in Gloucestershire, where he took me though the whole process step by step. Every bespoke propeller is for a particular engine/aeroplane combination, so he starts by entering all of the engine- and airframe-specific parameters into his computer. He experiments with various changes to optimise the result, using different aerofoils for the inboard and outboard blade ➔

Use of numerically-controlled machinery at Hercules ensures that the production item conforms with the computer model. Very little hand-finishing is required, such is the precision (inset photo)

portions. Throughout this process the blades' strength margins are monitored, and a red warning comes up if any factor drops below the minimum requirement.

Next he uses a three-dimensional drawing program to visualise the result and tailor it to an appropriate hub. Now he can scrutinise the propeller's surface and form for incongruities and anomalies, both from outside and throughout each virtual blade's interior. From this finalised design he compiles 10,000 lines of data for the prop's first rough-cut, and then 80,000 more lines for the much more precise finishing cut on each propeller face.

The 24mm (1 inch) beech boards from which Rupert machines his laminates are sourced from sustainable forests certified by the Forest Stewardship Council. They are kiln-dried and tested for moisture content, grain straightness and density. Prop makers used to work with mahogany, but this rainforest timber is now banned — although Rupert can easily stain his beech product to resemble mahogany. He planes and surfaces the boards to one-fifth of the eventual blank thickness, roughens, and glues them together with Dynea Prefere 4050F (which we once called Aerodux) and clamps them overnight at one Newton per square millimetre (twenty tons of total force) in his purpose-built press.

Once this blank has set, Rupert fits it into his CNC machine, which makes a fast rough-cut in about twenty minutes per side. When that is done, the final-cut data are input. This takes around an hour to complete, to one-tenth of a millimetre accuracy. By then the propeller looks pretty much finished and the machine is ankle-deep in sawdust. After removal from the CNC machine, the tip holding pieces are cut away to be tested for glue strength, while Rupert uses one of an assortment of parabolic templates to shape the curvaceous, slender tips.

Final surface finishing is completed by hand, although the CNC machine works to such close tolerances there is little to be done. The next step might seem surprising, for with what is apparently a beautiful, laminated, perfect propeller in his hands, Rupert now cuts away most of its leading-edge. In place of the wooden surface, which is surprisingly vulnerable to damage not just from stones and other ground debris, but apparently innocuous grass seeds and, worst of all, rainwater, Rupert moulds a new leading-edge of polyurethane resin.

Hercules uses several resins, most of which are brown, but some can be coloured to match the customer's chosen paint finish. I was sceptical about the adhesion of this butt-fitted resin strip, but Rupert immediately dispelled my reservations by grabbing a test piece of resin glued to wood, dropping it into a vice so that the resin was clamped and the wood protruded and then clouting it with a two-pound hammer. To my amazement, the hammer bounced off!

Undeterred, Rupert smacked it harder, and this time it broke. Close examination showed the wood had snapped a quarter-inch above the joint, leaving a long shard solidly glued to the resin strip, proving the strip's adhesion is better than the wood's internal cohesion. Rupert explained that they have done everything practical they can to damage this resin – testing has included sand-blasting and even shooting it with a high-velocity air rifle. I was soon convinced it would stand up to any kind of mere atmospheric precipitation.

Once this resin has set, the whole propeller is finished with several coats of two-pack epoxy primer, topped off with a tough, transparent, two-pack polyurethane lacquer. Finally, it is meticulously statically balanced, and corrected with small lead weights over which go a covering sticker. The Hercules logos are applied and the propeller is finished.

When running at full capacity, this one-man Hercules factory can turn out up to ten completely different propellers per week. At the time of my visit there were no fewer than nineteen examples either in various stages of construction or awaiting collection or delivery.

As well as custom-designed propellers, Hercules can copy an existing blade design, either by laser-scanning an actual propeller (even if it's damaged) or working from drawings. They have already made replica warbird propellers, and recently finished a prototype Spitfire blade. This was machined to the original Rotol ordinates from the authentic dense, laminated, compressed timber-based material still manufactured in Gloucestershire, and is currently undergoing compliance testing. Assuming that this is successful (as it assuredly should be) Rupert hopes to go into production so that future Spitfire propellers can be made in England rather than Germany as they have been for the past few decades!

As a finishing touch, Hercules also makes spinners. Typically of Rupert, his spinners are superior to conventional ones, incorporating a central supporting column welded to the prop crush plate and fitting into a recessed spinner front plate to give increased stability and prevent cracking.

I was so impressed, not only with my Fournier's performance improvement, but with the whole Hercules set-up, that I have since ordered a spinner and a third propeller for our Champ. That's called 'putting your money where your mouth is'!

To order your own bespoke airscrew, or for more details, visit **hercprops.com**

The finishing touch: Rupert also designs and makes a superior Hercules-brand spinner

A selection of Hercules products. At present, the one-man operation is geared to turn out up to ten propellers a week