HYPOTWISTED PROPS, HUNG'S PREFERRED ALTERNATIVE TO "THE AIRSCREW"

by Bruce Holbrook

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Part 1: From Airscrew to Propeller

The old story goes: "A prop-blade advances through the air like a screw twisting through wood, so it is best to make it helical. Otherwise, different sections between hub and tip would travel forward at different speeds, and efficiency would be lost through partial blade-stalling." For three-or-so aeromodeller-generations, those supposed to be in-the-know have prescribed would-be screw-sections, specifically in the form of one or another single "P/D": ratio of "Pitch", = 2 x pi x distance-from-axis x tangent of static angle of attack, to "Diameter", = span.

And when we turned from commercial (always helical) props of too little bite for usual FAC purpose to make our own, all we had had to go-by were building-instructions for helical props, and "tips": best blade size and planform, and adding, or not, some tip-washout to the tip-ward washout intrinsic to the helical configuration.

I take increasing Efficiency to be our species' sacred goal, and I am always looking for a new competitive edge for my models. So, several years ago, I gave the rubber-powered prop between one and two hundred hours of analytical consideration, before experimenting accordingly. I knew my mathematics to be hopelessly rudimentary. But I also knew that a non-expert may see what an expert won't, and go off in a new direction to something better. And I felt free to try, because technological history is largely one of the Official Authorities being off-the-mark for centuries at a time.

I recognized that a propeller is not an "airscrew" but a Wing, whose chords fly at widely-varying speeds, that pulls air toward its upper surface as it travels into that air's vector. I should therefore ignore the furniture-building metaphor and focus on the primary data in that light. Using realistic estimates of my planes' speeds and known rotational speeds of their props at different radial stations, I diagrammed such propellers' interactions with the invisible medium around them, and calculated relative thrust values of radial sections. Exploring with ignorant freedom, I drew three, enchained, conclusions which led me to design and test "hypotwisted" props.

1) Both the "wash-out" of a prop's static angles of attack and a helical prop's dynamic angles of attack are roughly helical, but a prop might attack the air non-helically. That is, dynamic angles of attack — what's left of static angles of attack after washout — need not decrease from hub to tip, and could, rather, be made constant or increasing from hub to tip.

2) The faster the bladespeed, the steeper could the non-stalling dynamic angle of attack be and so — to a point well within possible limits — the more efficient could the tipward sections of the blade be; and the slower the bladespeed, the shallower should the dynamic angle of attack be in order not to be stalling. As I knew from glide-trimming my models for maximum buoyancy and duration, a wing stalls when it flies too slowly for its angle-of-attack, and it yields maximum Lift-per-Drag ("L / D") just-below stalling speed-per-angle. What's more: accelerate the model beyond its glide speed, and it will lift at the angle of attack at which it stalled in the glide — and so, it was reasonable to suppose, lift more per drag than it did at its substalling best in the glide.

3) A helical design guarantees just the opposite of such maximally efficient distribution from hub to tip of dynamic angles of attack. What would do much better, if it were practical, would be a design for increasing dynamic angles of attack from hub to tip. And if that were not practical, at least the angles should less-decrease from hub to tip than they do on an "airscrew."

From a helical perspective, such a blade would be "hypotwisted." And rather than have a single P/D, it would have a range of P/Ds that increased tip-ward.

Before conducting my experiments I had found nothing in the literature favoring increasing P/Ds from hub to tip, with one exception. A Chinese Journal of FAI-type given me by a friend for unrelated reason contained a plan of such configuration for an optimal racer's prop. In view of the talent-pool size and historical fresh-mindedness implied, I took it to confirm my own "heretical" understanding. Then, years after my initial experiments, I found one professional discussion, more analytically detailed and realistic than most, which confirmed my understanding in principle but maintained that greater efficiency does not always result. It also excluded some relevant variables: "boundary-layering's change of effective dynamic angles of attack as an effect of airfoil-shape and speed, alteration by pressure-differential of airflow both around and to the blade, (and) non-predictable reduction of airspeeds under rotational speeds due to entrainment of air......

In any case, the hypotwisted design worked for me. And I have gathered that in the FAC, a significant percentage of perennial high-placers do, by accident or for unrevealed reasons, often or always use some form of hypotwisted prop.

Yet as though there were no alternative worth considering, "Which P/D is best?" is chronically debated by the experts whose interest and experience most closely relate to those of the FAC: "once-1.25-P/D — now-l.l-P/D" Wakefielders with advanced degrees in Aerodynamics or Physics.

So I think it's worthwhile to provide the full rationale for such prop-design, proof of its superiority at least for FAC-type rubber power. and instructions for making such props.

Part 2: Twisted Science

Let's take it from the top. Don't worry: it can be done almost math-lessly.

A prop is a number of "blades" — much more accurately, wing-panels — which are swung through the air by their roots and "attack" the air at a positive angle to direction-of-rotation so as to lift, aka "thrust", in oppositely directed reaction to their pushing-of-air vertically to direction-of-rotation. Therefore a prop is subject to two basic vectors which are at a right angle to each other. The panel's rotational speed is greatest at its tip and least at its root, and its basic forward speed, since it is that of the airplane (what else?), is the same from root to tip. The closer to its root, then, the more is the "static angle of attack", angle of blade to direction-of-rotation, "washed-out" by forward travel to yield a dynamic angle of attack. For convenience we may borrow a qualifier from the NASA Web-sub-site on this subject, and call this effect of vectors "alpha-washout".

There is also "beta-washout", which alone obtains when the prop runs but the plane is still. As the blades push air aft they also pull air toward themselves, at speeds basically determined by radial blade-station (the closer to the tip, the faster) and by dynamic angle of attack per any alpha-washout (the steeper the dynamic angle, the faster). So basically, dynamic angle of attack equals static angle of attack minus the sum of alpha-washout and beta-washout.

Beyond that there are at least three factors, already indicated, which non-predictably alter dynamic angle of attack from what the cybernetic feedback-loop of alpha-beta-washout would predict. But by combining a range of realistic assumptions about the unknowables with inferences from the knowables, a useful albeit approximate picture can be drawn. Of course, in view of the combination of rubber power's curve and the continually changing demands on thrust of continually changing attitude, all variables in question have to be averages.... It's all, ultimately, about more hitting and less missing.

The picture is: on a helical prop, dynamic angle of attack does approximately double as radial station is halved. So we do indeed have a dynamic airscrew, albeit an imperfect one. . We therefore also have an "airscrew-up". As explained, in providing for steepest angles of attack at slowest (rotational) airspeeds, such design is comparable in Efficiency to an X-Acto knife-blade applied dull-side down to carve a prop.

Let me specify that, as far as I can. Because lift varies as does area and velocity-squared, almost all thrusting occurs between 50% and 100% radius, wherefore the region around 75%-radius is called "the sweet-spot" and the entire sector from 50% radius to tip here is called "the sweet-sector". "Fuzzy" ranges of dynamic angles of attack in the outboard and inboard subsectors of the sweet-sector, then, are a negligibly oversimplified set of data for the whole prop. They tell that a typical helical prop's average dynamic angle of attack in the inboard sweet-subsector is about 1.4 times that of the adjacent outboard subsector. So there is about 1.7 times average angle per average speed in the inboard subsector as in the outboard one. And with constant chord the inboard sweet-subsector delivers about 18% more thrust (when it isn't stalling) at the price of considerably more than 18% more drag; more of each when blade-planform tapers.

So helical twist guarantees that while some very-small sector of the blade flies with maximum possible Efficiency, the average rest of it flies with much less, due to stalling and / or lesser "L/D".

You are probably thinking, "This makes a lot of sense, but how could it be, that those most professionally qualified to design and explain propellers — and who profess concern about "partial bladestalling" — have 'screwed-up' for generations?" Two of the more interesting reasons are: 1) Where the exact values of the dynamic interactions between a propeller and the air around it are as elusive as the cause of human perversity, it is easier for a scientist to imagine s/he knows something — say, dynamic angles of attack and their radial distributions — than to recognize that s/he doesn't. 2) As propagandists know too well, people normally question the validity of what is meant by someone's sentences, but — an advanced degree in this or that not-at-all withstanding —they very rarely question the truth-value of the meanings of the words themselves — here, "the airscrew" in English and '*helisse*' ("the helix") in French. The "basic building-blocks" of communication and systematical thinking are tacitly treated as true, and regiment minds, until someone may blow the whistle on those who invented and popularized them in the first place.

Part 3: Hypotwisted Prop-Design and Test-Results

Now let's explore for invisible silver if not gold. We'll "use what we do know to get-at what we don't", as the Chinese philosopher Juang-Dze put it where — when Science was appropriately humble vis-a-vis Nature, including its human transformations.

The ideal would seem to be to "trim" our props for max L/D in faithful accord with Bizarro-World parameters. Dynamic angles of attack would vary as do rotational speeds per radial blade-stations: the farther toward the tip, the steeper. Then, every square nanometer of blade would deliver maximum possible Thrust per Drag. Thrusting would cease at every station simultaneously -- no partial bladestalling here!, but its sum-total per totality of revs would be much more than with a helical configuration, so Efficiency would be a whole lot greater.

Once I saw that, I got excited, and designed and built a certain form of "anti-helical" propeller. Common sense advised that if too-far a step were taken toward the "Bizarro-World configuration", tip-ward boundary-layering would become problematic: most of the prop's work — if it didn't snap — would be performed quite near its tips so that (there being no Thrust without Drag) torqueover would be impractically huge; and the thrust-differential during the "power-burst" would require too much downthrust for subsequent buoyancy on the part of a model which spends a good portion of its flight in the "cruise"; make the model "fly too hot" post-burst, as our too-soon-departed Benefactor, Bob Thompson, with poetic economy used to put it.

It stood to reason, then, that some cross between a helical and "Bizarro-helical" confIguration was indicated. In-effect, a helical blade would be partially un-twisted and restored to its original static angle of attack at its 75%-radius, center of the "sweet-sector", or to somewhat more than that angle, to accommodate its greater efficiency (as specified in Part 4) .

I conducted numerous "minimal-pair" experiments that pitted various formed or carefully sculpted props of such hypotwisted design against first-class helical ones equal-to or comparable-to them in "sweet-chord" P/D. For its relative amenability to exact measurement, I initially used a rubber-powered tethered car with a typical model airplane's dragging-profile and weight,.

Being unable to determine dynamic angles of attack. I could only know that they were fractions of the static ones, and that relative to helical parameters I was increasing the ratios of those at the tip to those at 50%-radius. probably in some cases to greater-than-l. But that was all I really needed to know.

Per the car-experiments. my hypotwisted props excelled comparable helical ones by 7-to-8%; and by less controllable experiments with outdoor airplanes. more like 10%. That seems little until you realize that it means 8 momentous seconds counted v-e-r-y s-l-o-w-l-y after the mass-launched model which will place Second or Third with an 80-second flight has landed. Of course there is unknowable room for improvement. And others more favored inspirationally by Hung (Whom we should now suspect is Chinese -- Sounds like it) may already have found better versions.

I specify a special and colorful case, because it best supports the hypotwisted design-strategy, as one of success (in powered, not also gliding, flight) via extreme violation of helical convention. My apparently most efficient prop, an adventure into the liminal zone between This- and the Bizarro Worlds, like a kiddie-prop was not at all twisted, but unlike a kiddie-prop was set at a 45º static angle of attack. For stiffness it was undercambered. 10 degrees on-average. and for minimal drag with very wide tip-chords. the blades were of formed laminated card like Mark Fineman's display-props. At its 87.5%-radial "sweet-spot" -- it was fan-shaped to compensate for its short span, P/D far exceeded maximum conventional high-ceiling indoor magnitude. at a sacrilegious 2.75.

At Pinkham Field I had launched a prototype Embryo propelled by two such, counter-rotating, fans. It caught Dave Stott's eye, then Airdevilishly astute ear; and he observed, "You can hear them pumping the air." Its climb was the steepest I've ever seen on the part of a rubber-powered non-Wake nonhelicopter. and its pre-glide altitudes certainly were extraordinarily high even in view of the greater than-usual ratio of motor-weight to total weight that its torque-over-less counter-rotation afforded. ("The Transcender" was privileged to be photographed and written-up by that master of both forms of communication, Dave Dodge. whom I also thank for patiently and informally guiding me through said NASA site. See his Web-site, "Twin Pushers and Other Free-Flight Oddities".

Part 4: Choosing and Making a Hypotwisted Prop

So, how do you choose and construct a "hypotwisted prop" that's best for a given model? As it has always been for helical props, on the objective side there is an empirical set of good options associated with plane-types, prop-size per wing-area. and aggressivity of powering, and on the subjective side there is one's intuitive ability and willingness to experiment. Here are some attested guidelines and two ways to actualize them at your flying model's busy end(s).

Unless you have counter-(not contra-)rotation to neutralize the torque-over otherwise entailed by an an average-70-degree climb: for a rubber-powered outdoor-flying Scale or Embryo model, use some twist and 1.3 to 1.7 P/D at 75%-radius — 1.5. nominally. Where to my mind the set for outdoor helical props of nominal size is 1.2 to 1.6 P/D, the hypotwist-set is a bit steeper because ratio of plane-speed to blade-speed. "basic alpha-washout" is greater when Efficiency is. The blades spin slower (and the prop runs longer while delivering same average thrust) while the plane flies at the same speeds, so optimal "sweet-spot-P/D" is greater.

Easiest Construction: Make a jig of a wooden plank or a metal sheet with shaft-wire vertical to it at one end and a right-triangle out from the shaft at 75% of prop's radius at the other. which sets the blade at the 32.52º angle and .64 tangent (triangle-height is .64 x its width) of 1.5 P/D at 75%-radius. Hairdryer-heat (I am indebted to "Grayhawk" Lawton for this technology) a Peck plastic prop at its roots and twist just-above the roots until 75%-rads fit the jig.

Maybe you've already done that or something quite like it. If so, you already know how well it works, but perhaps not that you did not "increase the prop's P/D" — any more than a full-scale "variable-pitch" propeller has a single P/D, is helical in static angles-of-attack., at other than one setting. Rather, you created from a helical prop a more-efficient hypotwisted one by introducing a range of P/Ds which increased toward the tips. whose average was about 50%-higher than the prop's previously single one. Of course. such a prop is to be compared not to its commercial ancestor of too-low P/D for usual FAC purpose, but to helical ones (same planform and airfoil) of 1.5 and 1.4 P ID with the same motor and model.

More work. greater advantage: Carve a prop with a cylindrical hub to 25%-radius, of .55 x the P/D of a helical one that has proven to work well or best for a certain model or for another model of its type, then reset the blade at 75%-radius. per 1.1 x 75%-tangent of that P/D. For example. if 1.3 P/D looks good, carve a (.55 x 1.3.) = .715-P/D prop. — "X-block" prop-blank is (.715/pi.) = (only) .23 times as high as wide at its tips. (Saves good wood!) Cut the blades off the hub at 25%-radius, slot them along their centerlines from 37.5% radius to roots for music-wire or carbon-rod joining-spars and epoxy-in the spars cut to nearly reach O%-radius. Drill spar-diameter holes in the hub down-to its bearing. drip slightly acetone-thinned epoxy into the holes, plug-in the spars, and set the blades at 75%-radius using a jig-angle whose tangent is (1.1 x 1.3/(pi x .75. =) .607 — The right-triangle is .607 times as high as wide.

To clarify the intended result: If 1.3 P/D was your basis, at 50%-radius P/D will be 1.19. at the tip. 1.67. and on-average in the sweet-sector 1.43. If. rather. 1.7 P/D was the basis. P/Ds will range from 1.56 P/D at 50%-rad via 1.87 at 75%-rad to 2.18 at the tip. — Fear not. If the prop is of normal proportions relative to wing-area and wing-span and thin-of-airfoil, it will work especially well for (lightly-built) planes which are more streamlined than average and which, barring thermals, spend most of their air-time in "the cruise".

I do not know how close such hypotwisted props come to being optimal, but I am very happy with them and maintain that they will "give you an edge" that is lacking with "airscrews". So if your Joy is (in Ernst Udet's noble sense) "to contest", select a hard C-grain balsa block, — launch, and watch your model climb higher and fly longer.

A Postscript in a subsequent issue of the FAC Newsletter:

Hypotwisted Props Made Clear
by Bruce Holbrook, March 2005

Web-posted reactions to my recent FAC News article on "hypotwisted props" have mad me realize that literary play has no place in, and humor does not ease, the presentation of what for most is a new and difficult topic. My apologies for having confused. Here is a succinct and forthright representation.

What does "hypotwisted" mean? By reference to a helical blade, a hypotwisted one of same P/D at the nominal 75% station is insufficiently twisted: angular difference between chords at 50% and 100% stations is less. Accordingly whereas a helical blade has a single pitch and P/D, those of a hypotwisted one graduate from some lowest value near its hub to some highest value at its tip.

What is the purpose of hypotwisting? By way of improving efficiency-in-flight (by about 10%) per my experiments): where "dynamic angle of attack" refers to airflow to the airfoil's undersurface when the prop is moving the plane through the air, to provide steeper dynamic angles of attack above the nominal blade-station and shallower ones below it, than obtain with a helical prop.

Why does hypotwisting improve efficiency? The pros think it provides for a single dynamic angle of attack which is optimal at any airspeed. I think it more likely that it better fits dynamic angle(s) of attack to airspeed as determined by blade station, than can helical pitch distribution.

How is a hypotwisted prop specifically designed and manufactured (for a rubber powered scale model with a climb of normal steepness)? Best bet if one version is to be tried: 1) A normal nominal P/D is selected for a give type of model, and halved. If it's 1.5, the blades are then those of a .75 P/D helical prop. 2) A music-wire or carbon-rod joint and a jig are used to set the blade at its 75% station at stipulated (here, 1.5) P/D.

Nominal P/D may be experimentally varied just as with a helical prop. A 10% increase is a smart first move.

For more on selection and manufacture, see my "Hypotwisted Props, What, How and Why" on Dave Dodge's website at http://home.att.net/~dannysoar/home.htm, or just Google "Hypotwisted Propellers." Ed. Note: You'll see diagrams there which make this more understandable.