AVweb

Pelican's Perch
by John Deakin

Those Marvelous Props

In this month's column AVweb's John Deakin moves from the black knobs (MP) to the blue ones (RPM). He starts with a history lesson about how we got from windmills to fixed-pitch propellers, adjustable and controllable ones, and ultimately to constant-speed props. John then explains how they work, why they work the way they do, and how you can tell if they're working the way they're supposed to. He even answers that age-old conundrum: how many times should you cycle the prop at runup?

Like manifold pressure (see my previous column, "Manifold Pressure Sucks!"), propeller systems are often not well understood by those who depend on them. But there is no part of the airplane more critical, or that endures more stress and abuse. We really ought to know more about our props in order to get the best service and performance out of them. This is even more important on the feathering props found on twins, and of paramount importance on the big radials where prop systems become much more complicated and have many more failure modes. When something goes wrong with these systems, failure to take prompt and correct action with them can be deadly. A DC-3 was lost with all aboard in Holland just a couple of years ago, probably from simple ignorance of a common failure mode.

For most mechanical failures on aircraft, it is possible to "check the book," run a checklist, or carefully consider what action should be taken. In fact, most emergencies need to be handled slowly and thoughtfully. But prop failures rarely allow this privilege, and usually need to be handled promptly and correctly, from memory and from knowledge.

> ***NOTE:*** *I am indebted to the Hamilton Standard Division of United Technologies, Hartford Conn., for their kind permission to reprint and use their wonderful little 60-page booklet "Prop to Pilot" first published in 1948. Many of the pictures in this column have been scanned from that booklet. It does a marvelous job of explaining the old props on big airplanes. This booklet is no longer in print, but if there is sufficient interest, I'm willing to have a batch of copies made and make them available to seriously-interested AVweb members for $20 each (to cover the cost of color duplication). Many of the principles explained in the book are applicable to modern small props on general aviation aircraft, but the mechanical descriptions can be very different. For warbird/antique aircraft folks, this booklet is a must. If you'd like a copy, drop me an email at jdeakin@avweb.com and I'll give you the ordering details.*

I'd like to get into this subject via the back door, so to speak, by starting with a common windmill. If you put one of these in a breeze, it will spin. Moreover, the speed of the wind directly affects the speed of rotation. Obvious, you say? Well, yes -- but humor me, there's a point.

There are major similarities between the windmill and that big buzz saw hung on the front of your airplane. Even with an aircraft engine shut down in flight, you can vary the RPM of a fixed-pitch prop by changing your airspeed. We call this "windmilling," of course.

A Little History

All the early props were fixed-pitch, and there was always a lot of discussion among pilots over just what that pitch should be. There were "power props," "climb props," and "cruise props." For power, they needed a prop that would turn pretty fast right from the beginning of the takeoff roll, but such props would increase RPM with increasing airspeed (like the windmill), soon going out of RPM limits, and losing efficiency, too.

Put a "climb prop" on the airplane, and you wouldn't get as much RPM early in the takeoff roll. Acceleration would be slower, making the takeoff roll somewhat longer, but you'd see full RPM at the normal speed for climb. At cruise speed, the prop (and the engine, of course) would tend to overspeed (windmill effect again), and the throttle would have to be pulled back to avoid going over redline. This imposed a limit on cruise power, of course. Finally, a "cruise prop" would turn just about the right RPM at normal cruise airspeed. This did wonders for gas mileage, but would not get the airplane off without a very long ground run, and the RPM at the start of the takeoff would be very low.

We still see this today on the small aircraft used for trainers. Most of them are equipped with "middle of the range" fixed-pitch props, neither optimized for takeoff nor for cruise. The only reason these work as well as they do is because the speed range of the aircraft they haul around is so limited, from about 50 to 100 knots, and runways are more than adequate, having been built for larger aircraft.

With a fixed-pitch prop, RPM varies with engine power and airspeed.

Please be sure you understand this concept before going on. The engine power concept is intuitive, but "the windmill effect" is sometimes not. This is also often spoken of as "prop load" because with a large blade angle, the prop "loads" the engine, slowing it down. With a smaller blade angle, the prop "unloads" the engine, allowing the engine to speed up.

Variable Pitch Props

It didn't take long for early aviators to invent a "Ground Adjustable" prop. With only a few tools, working directly on the prop hub, the barnstorming pilot could set his prop for "power" to get out of a small farmer's field and do local rides at slow speeds, or perhaps tow a banner to advertise something. For the cross-country flights to the next town -- or for racing (popular in those days) -- the pilot might want to set a better pitch for cruising. This prop is nothing more than a fixed-pitch prop in-flight, so again, power and airspeed control RPM directly.

Next came the "controllable pitch" prop, a primitive device at best, but an improvement. It didn't require tools, and the blade pitch could be changed from the cockpit in flight. The pilot directly set the pitch angle of the prop blades, so at any given pitch setting, RPM still varied with power and airspeed.

Now I wasn't there (contrary to the opinions of some), but I'm sure it wasn't too long before pilots were whining about how much trouble it was to control the prop. Pilots are never satisfied. Make their jobs easier and they want more money. Cut their required flying hours and they whine about the loss of *per diem*. But, I digress.

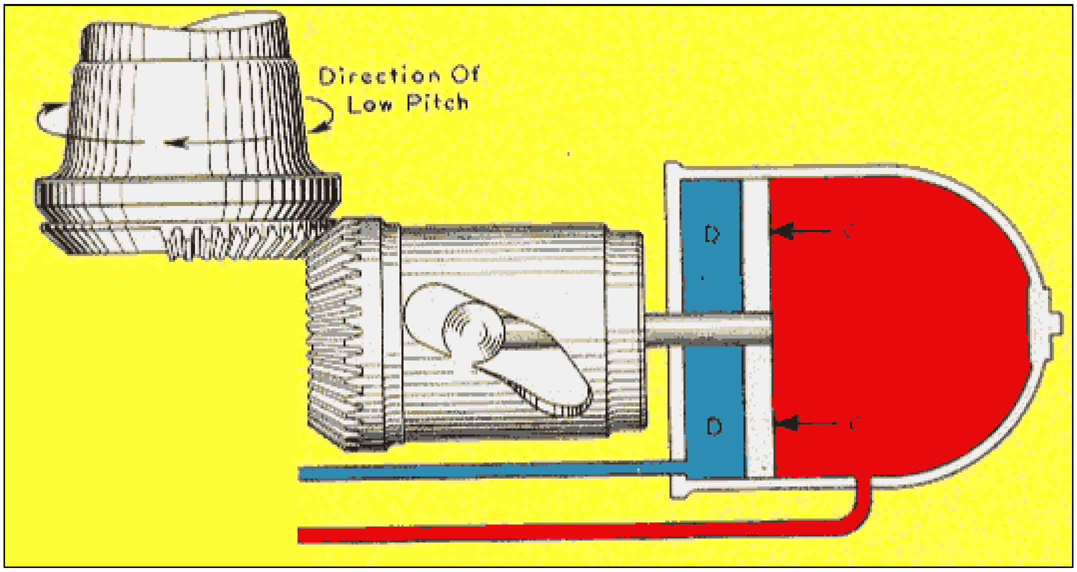
It is important to note the concept here. With this old prop, the pilot sets the pitch angle of the blades directly. Once the pitch is set, RPM remains a function of power and airspeed.

The picture below shows a rough idea of a controllable pitch prop, with our hero the pilot manually setting the pitch angle. If anyone had bothered, they might have marked the prop control with settings in degrees, perhaps 15 degrees for the flattest angle and 30 degrees at the other extreme. Some of these would be set to one extreme for takeoff and climb and the other extreme for cruise, for there were no manifold pressure indicators in those early days.

A number of solutions were tried to reduce the pilot whining ... er, workload, with varying degrees of success. Some props used counterweights to balance aerodynamic forces so that if the prop were under a load, the blades would flatten out automatically, increasing RPM and power. If the pilot increased the airspeed or reduced the power, the load would drop, the blade angle would increase, and the RPM would drop. This automated the process somewhat, but left the pilot with no options: The prop pretty much did what it wanted to do. These old self-adjusting props can be distinctly odd to fly, as the prop will do its own thing, changing pitch (and RPM) when it wants to. Most of them worked pretty well, though.

Constant Speed Props

Finally, the constant-speed prop was developed. The remainder of this column will be confined to this type, for this is what we see on the vast majority of propeller-driven airplanes today. Again, there are many variations in the actual mechanism. Some -- including most of the Hamilton-Standard props used on radial-engined aircraft -- look something like the diagram below, particularly the gearing between the blades and the rotating sleeve. A few props have used an electric motor right in the prop hub to rotate that sleeve, but the vast majority use some combination of engine oil pressure, springs, boosted oil pressure from a governor, air pressure, or aerodynamic loads to move the mechanism that changes the pitch on the blades.



An oil-operated constant-speed propeller contains a mechanism to convert movement of the piston in the propeller dome into blade pitch changes. In the Hamilton-Standard design pictured above, a roller and cam arrangement rotates a central sleeve in the hub, which is coupled to the base of the blades by bevel gears. In the picture above, oil pressure is used to drive the piston back and forth within the prop dome, which drives a cam roller, which rides in the slot in the sleeve, causing the sleeve to rotate. Bevel gears on the sleeve and at the base of each prop blade translate rotation of the sleeve into pitch changes of the blades. This particular picture shows a feathering prop, with the cam roller in the normal range. The angled portion of the slot to the right and down is the feather range, and requires extra high pressure from a supplemental pump, to gain enough mechanical advantage to drive the cam "over the hump." This is a common installation on a big radial engine, like the superb Pratt and Whitney R-2800.

The Hartzell and McCauley props used with most flat piston engines and many turboprops use a slightly different mechanism in which the piston changes the blade pitch by means of a pushrod-and-bellcrank arrangement instead of bevel gears. (The pushrods are actually called "pitch links.") This design allows for a lighter and more compact prop hub, but the principle of operation remains the same.

The normal aerodynamic force on any airfoil tends to pitch it down (to a lesser angle of attack). Props are no exception, since they are rotating airfoils. Aerodynamic forces tend to drive all props to the flat pitch position.

> ***A NOTE ABOUT TERMINOLOGY:*** *This is a good time to mention that "flat" pitch is the same thing as "low" pitch (a low blade angle, in degrees), or as our British friends say "fine" pitch. This generally implies a higher RPM, all else being equal. I find it very easy to get confused (and to confuse others!) if I don't think very carefully when talking about prop pitch, because "Low Pitch" goes with "High RPM." You need to listen very carefully, too!*
>
> *The opposite is of course "high" pitch (British "coarse" pitch). Again, easily confused, as "High Pitch" generally implies "Lower RPM."*

In most of the big radials both normal "pitching moments" of the blades and normal engine oil pressure drive the prop towards the "Low (flat) Pitch" position. On such installations, there must be a force that is capable of overcoming this tendency to "go flat" or we'd have no control at all. This force usually comes from oil pressure from a prop governor, which is capable of supplying much greater oil pressure to the other side of the piston in the prop hub.

The constant-speed props used on most single-engine general aviation aircraft use a very powerful internal spring to drive the blades to flat pitch, with governor oil pressure used to oppose that force.

In either case, a governor failure causes the prop simply to go to full low (flat) pitch, whereupon it becomes just another fixed-pitch prop (of the "power" type).

By contrast, the full-feathering props used on most general aviation twins work differently -- almost the exact opposite, in fact. The hub of such a prop contains a very powerful spring (called the "feathering spring") that drives the prop towards "high pitch" ("low RPM" or "coarse pitch"), while governor oil pressure (and pitching moments) oppose this. This means that a governor failure -- or loss of oil pressure -- in a light twin will drive the prop towards low RPM (high pitch), and right on into feather, which is nothing more than extremely high pitch. The theory is that with a loss of oil pressure due to engine or governor failure, you'll want the prop feathered in order to keep flying on the other engine.

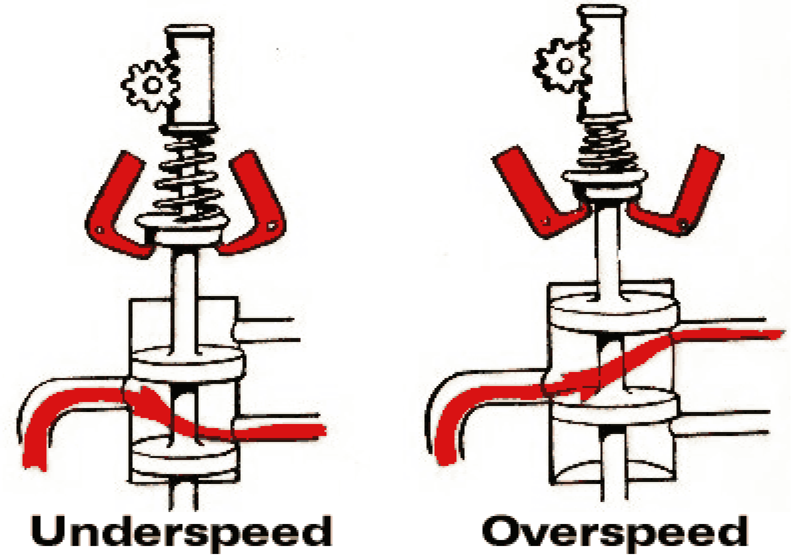
Why don't these full-feathering props drop into feather at shutdown, when the oil pressure goes away? Well, in fact, the ones used with free-turbine engines like the Pratt & Whitney PT6 do exactly that -- take a look at a King Air or Caravan parked on the ramp and you'll see this clearly. But having the prop on a piston engine go into feather at shutdown would be very tough on the engine at the next startup. There would be so much air resistance with the blades feathered that it would be difficult to keep the engine running until enough oil pressure built up to bring the prop back out of feather. It would probably be hard on the engine, too, for it would have to develop considerably more power while still cold, before there is sufficient lubrication for the bearings. This would cause a lot more metal-to-metal contact before the oil starts circulating.

Consequently, the full-feathering props used on piston twins and certain turboprops are designed with a system of centrifugal latches and pins that lock the blades in a medium-pitch position when the RPM drops below 600 or so, preventing them from going into feather at shutdown. In the event of an in-flight loss of oil pressure, however, windmilling action keeps the prop RPM high enough that the centrifugal latches don't come into play and the prop fails in the feathered position. Pretty clever.

Take a walk on any general aviation ramp, and look at the constant speed props. You will generally see the singles sitting at rest with a very flat pitch (usually around 15 degrees), the piston twins with a very coarse pitch (usually around 30 degrees), and most of the turboprops in full feather.

"What's up, Guv?"

To this point, all we have are variations on a common theme, and some mechanical descriptions of how to change the pitch of a prop. Now we come to the clever device that makes it easier for the pilot (remember, the whining increases, though) and allows him to simply select a desired RPM. This device is the prop governor, and here's a very simple "concept schematic" of one type of this hard-working device.



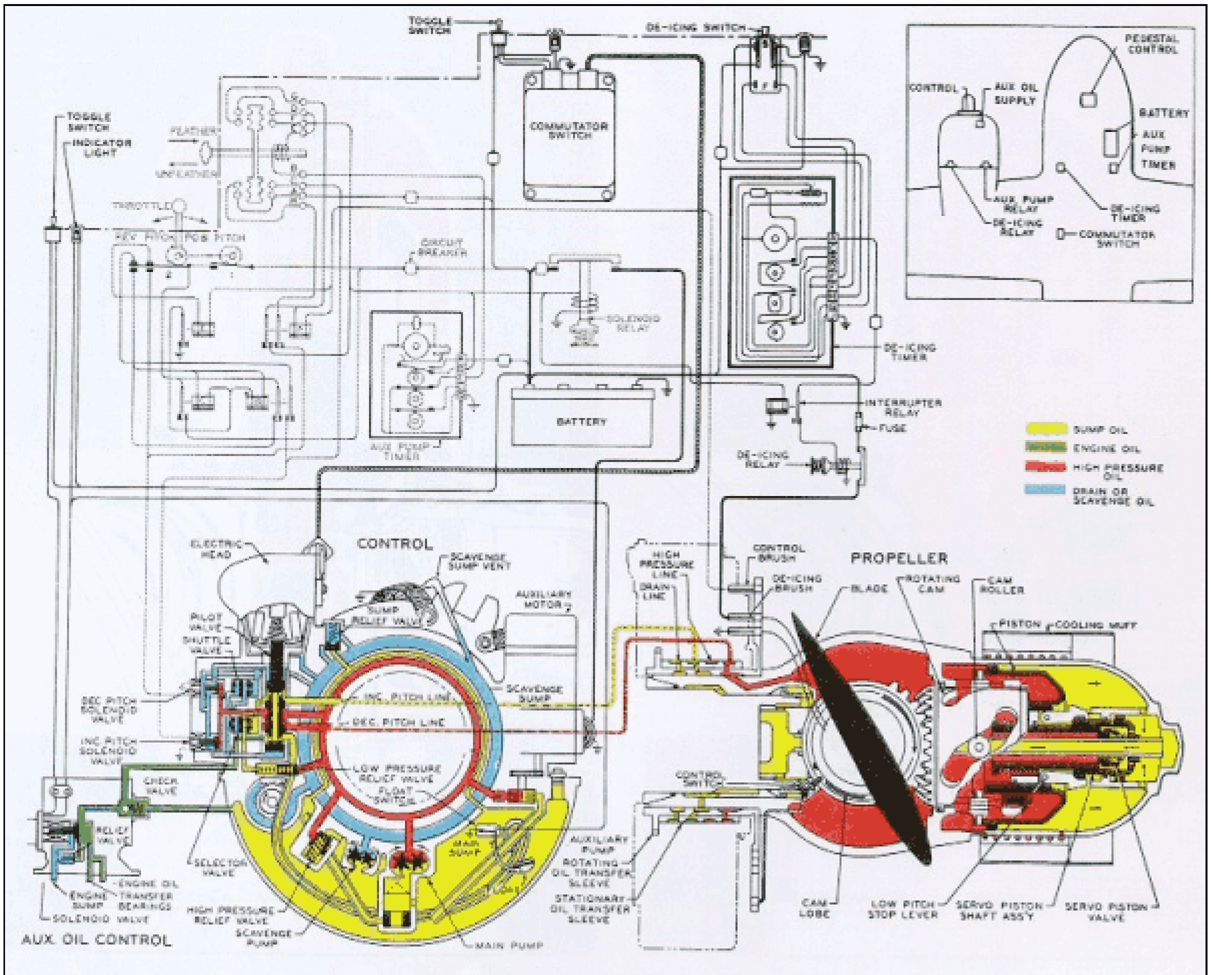
Prop governors are gear-driven by the engine, so the faster the engine turns, the faster the governor turns. Flyweights work against a spring, and the prop control in the cockpit adjusts the loading on that "speeder" spring. If the engine is turning faster than the desired RPM, centrifugal force flings the flyweights out against the spring pressure, which moves a valve that allows oil to flow in the proper direction to move the prop blades to a greater pitch. If the RPM drops below that desired, the flyweights move in towards the center, moving the oil valve that allows oil to flow as needed to decrease the blade angle, increasing RPM. When the RPM exactly matches the setting by the pilot, the flyweights exactly balance the spring pressure, and shuts off all oil flow to the prop.

Most governors also contain a high-pressure oil pump to boost engine oil pressure (which is typically around 50 PSI) up to the levels needed to control the prop (often around 200 PSI).

In reality, the flyweights are constantly making tiny movements to keep the RPM at the desired value, either pumping little squirts of oil to the dome, or letting a little oil out. Once again, there are many variations here. Some systems will pump oil to drive the blades one way, or allow that oil to dump into the crankcase, allowing the spring to push the piston the other way.

For general aviation singles and twins, the very least you should know is what will happen with a failure. For singles, the prop will generally go flat. For twins, it will probably feather. Check your POH, and ask your mechanic about the details for the airplane you fly. You can't know too much about props!

For big radials, there are a number of additional sub-systems and failure modes. If there is sufficient interest, I might do a future column on them, but I doubt there are more than a few people reading this with any interest in these "dinosaurs." Just for fun, here's what one looks like. This is a Hamilton-Standard, Constant-Speed, Full-Feathering, Reversing, Auto-Feather, Step-Head Motor Controlled, Heated prop, as found on the Martin 404, an early-fifties airliner operated mostly by TWA and Eastern. The governor is similar to the one I've described, but instead of being controlled by a push-pull cable, there is an electric motor on top of the governor that sets the speeder spring compression, and this motor is toggled with switches in the cockpit. As you might imagine, this adds considerably to the failure modes, since an electrical failure deprives the crew of all prop control, it will simply try and maintain the last RPM requested. This system takes up major portion of the ground school I teach on this airplane!



Reversing Propeller Operating Diagram — Underspeed Condition

Bringing it all together

The airplane you fly is probably sitting on the ground somewhere as you read this, at rest, with the prop control lever fully forward. What would you expect to see? If it's a single, the prop should be in full flat pitch (spring-driven). We might say, "It's on the low-pitch mechanical stops." If it's a twin, the spring will be pushing the prop toward high ("coarse") pitch, but the little mechanical pins will be engaged, preventing the prop from feathering. This may or may not coincide with the prop pitch setting when the governor commands "full high pitch" (as opposed to "feather," which is even higher pitch). In these full-feathering props used on twins, there is no mechanical high-pitch stop. Most props will be at about 15 to 20 degrees at "Low Pitch", and about 30 degrees at "High Pitch." This difference can be seen clearly just in looking at the prop.

If the prop lever is fully forward on either the single or twin, it is "requesting" full takeoff RPM from the governor, probably something between 2,400 and 2,700 RPM. This prop control setting fully compresses the speeder spring, and since there is no centrifugal force holding the flyweights out with the engine at rest, they will be fully "in," porting oil as necessary to flatten the pitch and increase RPM. Of course, without oil pressure, nothing is happening, but the governor is trying!

Startup

Now, ladies, start the engine and bring it up to about 1,000 RPM.

A side note on one of my pet peeves here, if I may? If there is anything that reveals a rookie to me, it's the pilot who starts any recip and lets the RPM go roaring to some high figure. I see and hear some of these airplanes started, and it sounds like the engine instantly goes to 1,800 RPM and then it stays there for a time. The parts are cold, the bearing surfaces have hardly any oil film to keep them apart, there is no oil pressure at first, and you're destroying an engine.

Some powerplant experts suggest that 90% of all piston engine wear takes place during that initial few seconds of engine run, and that's when it's properly done. Once the oil is warm, and at full pressure, there should be virtually no metal-to-metal contact anywhere in the engine. Some ground-bound recips that run continuously -- the ones that operate "walking beam" pumps in oilfields, for example -- have run for years without stopping, yet show very little wear when torn down. Starting is hard on engines, especially when cold. You need about 800 to 1,000 RPM to get the oil pressure up and to provide some "splash" lubrication on those engines with wet sumps, but please keep the RPM down to about 1,000 until the engine has a chance to get the oil circulating. NEVER start a recip with the oil temperature below about 40°F.

I'd also like to point out that almost every time I see one of these rookies do the high-RPM start trick, there is almost always someone on the receiving end of their prop blast, and not very happy about it. THINK about your prop blast, and minimize it, when you're on the ground! Think where the dust cloud will go, too.

[Flame off.]

Okay, we've started the engine, and the oil pressure comes up. In the single, the oil doesn't do anything at all for the prop yet, because with the prop lever fully forward, it's calling for full RPM, and the prop is already as flat as it ever gets. In the twin, the oil pressure will drive the prop blades off those latch pins to full low pitch (flat). Once oil pressure is up in both the single and the twin, the prop blades will be on the low-pitch mechanical stops. RPM is, of course, controlled directly by power, since there is no airflow on the ground to "windmill" the props.

Runup

Most Continental direct-drive engines are run up at 1,700 RPM, and most Lycomings specify runup at 2,000 RPM. There is no magic about 1,700 or 2,000 -- it's more tradition than anything else -- but such mid-range RPM settings do provide a little room to exercise the prop, and also provide a modicum of power to check out the ignition system. The tests and checks will be just as good at 1,500, 1,800 or 2,100, so there is no real need to be precise in setting exactly 1,700 or 2,000 for the runup.

At runup RPM, the prop lever is still fully forward, the prop governor is still calling for redline (2,400 to 2,700 in most cases), and the prop blades will still be on their low-pitch mechanical stops. Now, we pull the prop lever back. It doesn't really matter how quickly or how slowly you do that, but for our purposes here, let's say you do it very slowly, perhaps an inch at a time, stopping along the way to see the results. The first inch will reduce the speeder spring pressure, and perhaps it will call for 2300 RPM. Since runup RPM is lower than this, the flyweights are still fully "in" and the system is still trying to increase the RPM by driving the prop blades "flat." The blades are still on the low-pitch mechanical stops, and the governor still sees an "underspeed" condition.

Pull the lever back some more, to the point that might call for exactly runup RPM (1,700 or 2,000). Now, at last, "something happens." Moving the prop lever that far will reduce the speeder spring pressure enough that the centrifugal force on the flyweights is "enough" to move them "out" to the "balance point," where the centrifugal force on the flyweights is exactly balanced by the speeder spring pressure. Still, nothing happens at the prop, because the governor is calling for 1,700 (or 2,000), and we've got 1,700 (or 2,000). The blades will still be on the mechanical low-pitch stops, but barely so.

Finally, pull the lever all the way back. This further loosens the pressure on the speeder spring and runup RPM is now more than enough to make the flyweights open out. We call this an "overspeed condition," as the prop is (momentarily) turning faster than the governor wants it to. The flyweights open up, porting high-pressure oil into the the prop dome (or for twins, letting oil flow out of the dome), and at last, the prop blades come off the low-pitch mechanical stops and move towards the "coarse" position. Since we have changed nothing but the prop control, this will reduce the RPM, proving the system works as advertised. Many POHs will specify what the lowest RPM should be on runup, and this is important, as it shows "full range." If your POH doesn't list this figure, check it out for yourself, and note it for future runups. The prop does not necessarily go all the way to the high pitch stops, it only goes far enough to satisfy the governor.

For many twins, moving the prop lever fully aft not only reduces the "desired" RPM, but will cause the prop to move towards feather. This should also be checked (very briefly), in accordance with the POH. In most cases, you should avoid allowing the RPM to decrease below 1,200 or so to prevent the anti-feather latch pins from wearing out.

(Note that pulling the prop lever back in "steps" is only for the purpose of this discussion. In practice, it's one smooth motion.)

How many times should you cycle the prop? If the RPM drops smoothly and properly, once is enough. The fresh oil will probably cause the piston to move a good deal and when it comes back to the low pitch stops, most of the "old" oil will be pushed out. If you really want to feel good, do it twice, to get even more of that "old" oil out of there. Three times is gross overkill, in my opinion, but a lot of people do three times, or more. In reality, there are tiny bleed holes that allow a constant flow of warm oil to both sides of the prop piston, so even if you take off with cold oil in there, it will quickly be replaced with nice slippery warm stuff. On some of the big old props on the radials, in extreme Arctic conditions, the oil would congeal faster than the bleed ports could replace it, but I doubt you'll find any modern props with this problem. I should note for completeness that many of the props on the big radials might require many more cycles to achieve a smooth RPM drop when cold. In freezing temperatures, it may take up to ten cycles. There's a lot more to the mechanism, and a lot more oil involved.

Takeoff

Runup complete, we clear the area, taxi onto the runway, set full power, and go. You should, by habit, check the RPM, manifold pressure, and fuel flow (if available) on the roll. A glance at the rest of the engine indications is a good idea too, but these three are primary. If you've read my previous column you should know what is "normal" for manifold pressure on any takeoff. On most of the big-bore flat engines by TCM and Lycoming, it is vital to see full redline fuel flow at full power at sea level. A hair over is better than a hair under. (I plan to cover this and other mixture-related stuff in my next column.)

What about RPM on takeoff? At some point, you must see full redline RPM, plus or minus very little, perhaps 50 RPM or so (check your manual). You may see this early in the takeoff roll, or it may take some speed to bring it up. On my airplane, full power, sea level, holding the brakes (bad idea, this is a test only), I'll see about 2,600 normally, and this will build quickly after brake release to about 2,740, a bit over redline. (I'll adjust this at the next opportunity.) I have the Horizon electronic tach -- which is extremely accurate -- so I'm confident in those numbers.

Incidentally, normal mechanical tachs are much less reliable and far less accurate. When they get out of calibration, the errors always tend to be on the downside, which means that the engine is turning higher RPM than you think it is. If your airplane has a mechanical tach and it's not making redline RPM on takeoff, be sure your mechanic checks the tachometer calibration with an electronic tach checker before making any adjustment to the high-RPM stop on the prop governor. There's a good chance that your prop is making redline after all, but your mechanical tach is simply reading low.

Returning to our takeoff, you should now be starting to understand what is happening here. At full power, brakes locked, the prop is fully flat, and the governor is calling for "more," or 2,740 (speeder spring is fully compressed, flyweights "in".) As the speed increases after brake release, the "load" on the prop decreases ("windmill effect"), and the RPM kicks up to 2,740. At this point, the flyweights move out to the neutral position, and everything is "in balance." As the speed continues to build, the RPM will rise slightly above 2,740, but the flyweights will "open up" a tiny bit, and allow oil to flow to the prop hub to twist the blades off the low-pitch stops, cutting the RPM back to 2,740. Repeating this process, it should keep the RPM right at 2,740 until otherwise set.

Immediately after liftoff, gear coming up, altitude and airspeed increasing, I'll reach over and pull the prop back a bit, perhaps two turns on the vernier control. This loosens up the pressure on the speeder spring, which allows the flyweights to move "out" (overspeed condition), porting oil to "coarsen" the blade pitch, reducing the RPM. As the actual RPM matches the "requested" RPM, the flyweights move back to neutral, returning to the "on-speed" condition.

If the airspeed continues to increase and we change nothing else, the "load" on the prop becomes a tiny bit less, the prop tends to overspeed, the flyweights correct, and the RPM returns to the RPM set.

Hitting The Stops

You will recall that when I described the "controllable" prop above, I said "the pilot sets the pitch angle of the blades directly." Contrast this with the "constant speed" prop, where the pilot sets a desired RPM, and the governor takes care of the blade angle as necessary to attain and maintain that RPM.

But there are limits. If the prop blades come to rest on either the low-pitch or the high-pitch stops in flight, the governor can do no more, and the RPM will then be controlled directly by power and airspeed once again. In effect, once the prop blades "hit the stops," what you have is just an old-fashioned fixed-pitch prop.

When might this happen? Low power plus low airspeed will do it, such as when you pull the throttle way back on short final. If the engine doesn't produce enough power to maintain the desired RPM and there isn't enough windmill effect to drive the prop, the prop blades will eventually reach the low-pitch stop while trying to maintain the desired RPM, and thereafter, RPM will drop.

Another common scenario I see is letting down at high speed from high altitude, with airspeed edging up into the yellow arc. The windmill effect will "unload" the prop, tending to increase the RPM, and the prop blades will twist to a "coarser" pitch to maintain the set RPM (I usually set 1,800 in this case). When the prop blades hit the high pitch stops, they can go no further, and the RPM will rise. Again, your constant-speed prop becomes a fixed-pitch prop. There's no harm, but it can cause concern to the unwary because it will appear the prop governor has failed. Pulling the prop all the way back, even to the full high-pitch (low RPM) position will have no effect at all because the prop is at the highest pitch it can achieve and the governor has no way of increasing the pitch further. Only a decrease in airspeed or power will bring the RPM back down to whatever is set by the prop control. At some very high airspeed, even idle power would not be enough to overcome the windmilling effect, and the prop would overspeed no matter what you did. I prefer not to investigate that, thank you very much.

A most interesting scenario is the twin with an engine failure. The classic demonstration is to set up a cruise speed, with a fairly low RPM on both engines, and cut one mixture or turn off the mags. The beginning multiengine student will assume the RPM will drop, but he'll be quite surprised to see the RPM on the failed engine remain the same as the running engine! In general, a failed engine will show no immediate changes whatsoever on any engine instrument. After some seconds, the cylinder head temperature will start down, but in most cases, the manifold pressure, the RPM, oil pressure, temperature, and other parameters will be unchanged, not helping to identify which engine has failed. Of course, if there is a fuel flow indicator, and the mixture is cut, or the fuel turned off, that will show, but the nasty old instructor will probably cover that up.

What's happening here? Well, when the power is lost, the RPM starts dropping. But the flyweights instantly move "in" (underspeed), and port oil to decrease the blade angle, towards "low pitch" or flat. Given enough airspeed, and cruise is almost always enough, the windmill effect will continue to drive the prop at full RPM, and the governor may even have to keep it from going all the way to low pitch. The prop governor has no knowledge of "power" -- it senses only actual RPM, and tries to correct to "desired" RPM, but it can only do that within the limits of prop blade travel.

(Incidentally, I lied to you above. There is one engine instrument that will always give an immediate indication of an engine failure. That instrument is the EGT gauge. Extra credit if you caught this.)

Cruisin' along

How do we set cruise RPM, and what are we trying to accomplish? Remember when talking about wings and airspeeds for "max range" or "max glide" or "minimum sink." What we are trying to do with the wing is change the efficiency by varying the angle of attack. We can go real fast, and run the parasite drag up, or we can slow down to minimize it. At some point, we will be making the "Max L/D" or the most lift we can get relative to the drag, or even slower to find the absolute maximum lift the wing will produce.

By changing cruise RPM, we are doing the same thing. A high RPM may produce the maximum power, but at a cost in drag (and fuel). Just like any airfoil, the prop has its optimum angles, too, but data on these are not readily available to the pilot, and they are often overridden by the need for the most efficient airspeeds of the airplane. But generally speaking, for any given power, the lowest possible RPM will reduce friction within the engine, and this may be the most important parameter. Some props are probably more efficient at a specific RPM.

A final thought experiment. Let us start with a feathered prop, in flight. Assume we have feathered it as a training exercise -- preferably in a twin -- and now it's time to restart the engine. We have enough power on the other engine to just maintain altitude and airspeed.

Feathered, the blades are edge-on to the airflow, so there is minimum drag on the airplane, and there is nothing make the prop turn. Let us fantasize a bit here, and say that we can control the pitch directly, holding it exactly where we want. (This is possible with the old Curtiss Electric props, by the way.) Now we move the prop blades just a tiny bit out of the full-feather position, just barely enough to make the prop start to rotate -- maybe one revolution per hour. Think about what's happening here: The blades act just as any airfoil, with speed, and a small angle of attack. They produce just a tiny bit of lift, and almost all of it is in the direction of rotation, so there is little added drag. The prop is moving forward at the aircraft's speed in full feather, and to this speed, we must add the speed of rotation.

For you math buffs, by the following formula:

$$\mathbf{PropTipSpeed = Sqrt(Radius^2\ X\ AngularVelocity^2 + TAS^2)}$$

where:

Angular Velocity in radians per second

TAS in feet per second

Radius in feet

PropTipSpeed will come out in feet per second

One prop I'm accustomed to is 15 feet in diameter (C-46), and is driven by a 2:1 reduction gearbox. Here are some of the numbers for the prop tip at an airplane TAS of 120 knots:

Engine RPM	Prop Tip TAS (knots)	Remarks
10	120	At 10 RPM, negligible additional speed at prop tip.
50	122	At 50, we pick up two knots at the tip
100	128	

200	148	
300	177	
400	211	
500	248	At 500 prop RPM (1,000 engine RPM), we've doubled the TAS at the tip
600	287	
700	327	
800	368	
900	409	
1000	451	
1100	493	
1200	535	
1350	599	At 1,350 prop RPM (2,700 engine RPM), the prop tip is moving five times faster than the airplane!

You will not see prop tips moving much faster than 600 knots, as this is getting too close to the speed of sound, and all sorts of nasty aerodynamic things start to happen in the vicinity of the prop tips. The noise alone is bad enough!

This, by the way, is the reason for using a reduction gearbox between the engine crankshaft and the propeller. Engines are most efficient when they turn fairly fast, while props do best when they turn fairly slowly. Direct-drive engines operate at a compromise between the two. Geared engines permits both the engine and prop to operate more efficiently, but with penalties in weight, complexity, cost, and sometimes TBO.

Windmilling

But back to our thought experiment, where we can control prop pitch directly. Remember, the engine is being turned by the prop, it is not yet developing any power, we've still got the mags and fuel turned off for this experiment. (This is not the correct way to restart an engine, we're just playing here!)

In the chart above, note that at a prop RPM of about 500 (engine 1,000), half the tip speed is coming from the forward speed of the airplane, and half is coming from the rotation of the prop. I don't know the blade angle, but in order to develop the "lift" to rotate the prop that fast, there must be a considerable angle. Just as a wing at a high angle of attack produces a drag component, the prop is now producing a "lift" component that is turning the prop, and a drag component that is acting to the rear, slowing the airplane. The normal range of movement of this prop is between 10 and 42 degrees blade angle, so you can see that if it's developing enough "lift" to windmill the prop and the engine that fast, it must be producing an awesome amount of drag on the airplane. It does!

Continuing our thought experiment one step further, let's assume we can set the blades to "totally flat." Without the engine running, the prop will slow down again, and come to a stop, this time pushing the blades through the air at 90 degrees. Draggier than when in feather, sure, but not anywhere near as much drag as when the prop blades were acting as airfoils.

From this, we can see that a windmilling prop is similar to an airplane gliding, without power. A stopped prop is similar to an airplane falling flat, with no forward speed. Which do you think will produce more "lift" and less vertical velocity?

This is why a windmilling prop has the highest performance penalty on the airplane, why a stopped prop is "better," and why a feathered prop is the best of all (if the engine isn't running).

With the 15-foot prop above, with the prop lever full forward (a bad thing), at 138 knots airplane TAS, this prop will windmill the engine at the full 2,700 RPM, with a prop tip speed of about 603 knots without the engine running! If we increase the airplane TAS, the governor will kick in (assuming there is oil pressure) and increase the blade pitch, maintaining the RPM at 2,700. If we decrease the TAS, the blades cannot move beyond the flattest pitch, and the RPM will drop.

In summary, the governor will do a fine job of maintaining the RPM set by the pilot, so long as other conditions do not place the prop blades on the mechanical limits. Once those limits are reached, the prop is essentially a fixed-pitch prop until conditions change and return the system to conditions of airspeed and power that will permit the governor to resume control.

Be careful, up there!

...John Deakin

John Deakin is a 33,000-hour pilot who worked his way up the aviation food chain via charter, corporate, and cargo flying; spent five years in Southeast Asia with Air America; and joined Japan Airlines 31 years ago, where he is a 747 captain. He also flies his own V35 Bonanza (N1BE) and is very active in the warbird and vintage aircraft scene, serving as an instructor in several aircraft and as an FAA Examiner on the Curtiss-Wright C-46, the DC-3 and on the Martin 404.

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