Propeller primer

It's easy and inexpensive to re-angle fixed-pitch propellers

BY STEVEN W. ELLS

The Wright brothers thought that building a propeller would be a cinch. What could be hard about it? They soon found that there's more to a propeller than meets the eye.

Propellers convert the rotating motion from the engine crankshaft into thrust, act as a flywheel for the engine reciprocating parts, and make noise.

The fixed-pitch propeller

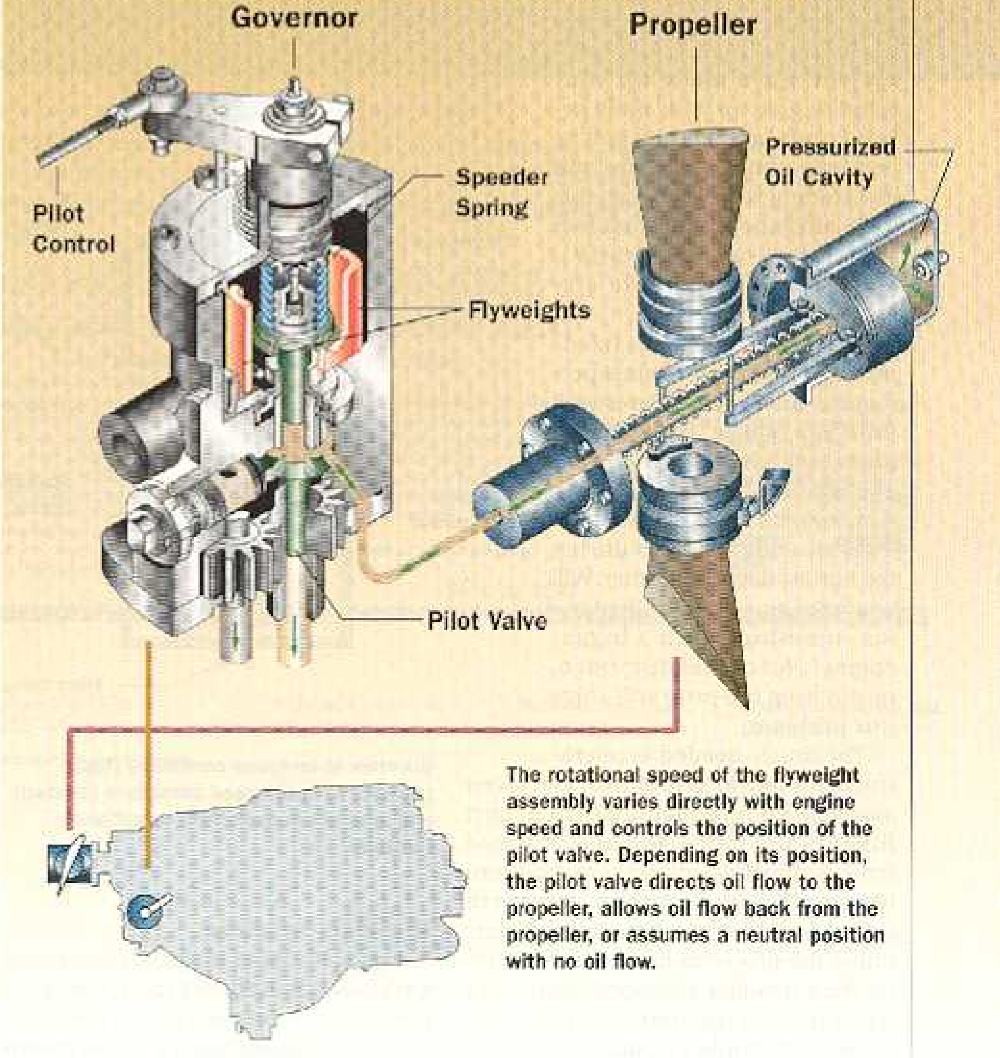
Fixed-pitch propellers are a compromise where performance is concerned and a boon when economics are important. These seemingly prosaic propellers are sized by length (in inches) and angle, which is termed *pitch*. The angle is measured relative to the propeller plane of rotation at a specific distance from the rotational center of the propeller. For instance, the owner's manual for Cessna 172A through -H models (a Continental six-cylinder 145-horsepower O-300 engine) specifies a McCauley propeller with a 76-inch diameter and a 53-degree pitch. In 1968 the 172 got a new engine when Cessna installed a Lycoming four-cylinder 150-hp O-320. The propeller was changed to a McCauley propeller that is one inch shorter, yet has the same 53-degree pitch (DTM7553). Sensenich, another fixed-pitch propeller manufacturer, specifies a 74-inch propeller with a 56-degree pitch for the same airplane-engine combination.

Pilots flying airplanes with fixed-pitch propellers often ask why engine rpm doesn't reach redline at full throttle on the ground. The answer is simply because the blade angle for most fixed-pitch installations is a compromise between takeoff and climb performance and cruise performance.

Each engine data plate lists the rated hp at a given rpm. Many Lycoming O-320 engines are rated at 150 hp at 2,700 rpm. If the blades were pitched flat enough to allow full rpm during the takeoff and climb portions of flight, the angle numbers would be down in the high 40s or low 50s. An airplane with such a propeller would be slow in cruise but would accelerate and climb with gusto when compared to one with the compromise 56-degree-angle propeller.

Pilots of Piper Super Cubs, the pickup trucks of Alaska, often remove their McCauley 74-inch-by-56-degree propellers and install special STCed McCauley 82-inch-by-41-degree propellers—the STCed version is 8 inches longer and has 15 degrees less angle.

Full-feathering constant-speed governor system



The rotational speed of the flyweight assembly varies directly with engine speed and controls the position of the pilot valve. Depending on its position, the pilot valve directs oil flow to the propeller, allows oil flow back from the propeller, or assumes a neutral position with no oil flow.

ILLUSTRATIONS BY STEVE KARP

These Super Cub pilots are willing to forego cruise speed in order to obtain fantastic acceleration and climb performance. Since there are only a few STCed replacement propellers for lower-horsepower airplanes, most owners have little choice except to live with their existing compromise propellers. Yet it's an easy and inexpensive task to re-pitch (re-angle) fixed-pitch propellers. Unfortunately, this propeller fine-tuning solution isn't available on all airplanes.

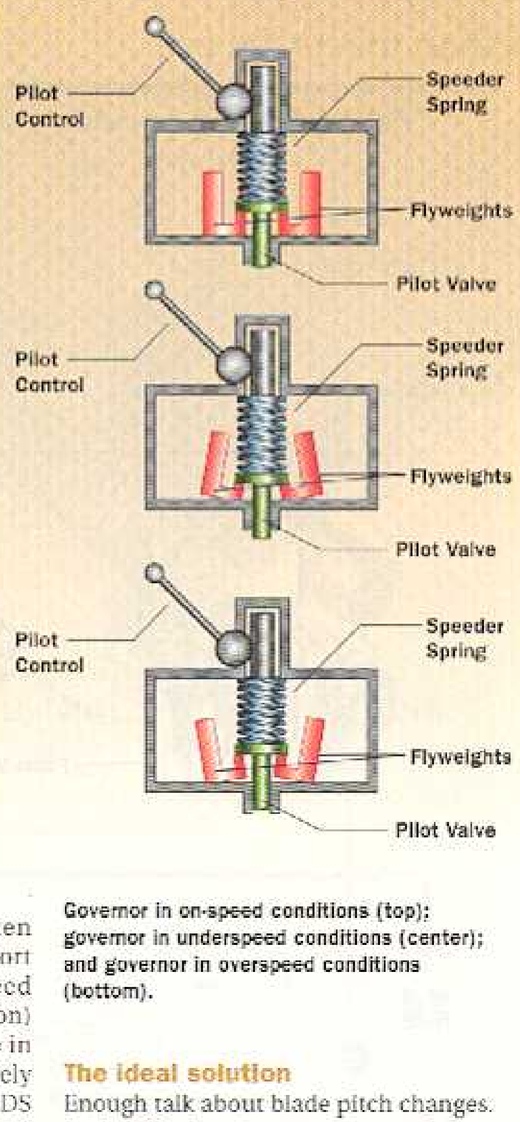
Not all airplane specifications listed in the type certificate data sheets (TCDS) allow the owner to change the blade angle to better fit the pilot's most common mission. Let's say you have made up your mind to give up your daily urban commute. Instead you've decided to buy a little farm, put in a landing strip, buy a capable little airplane (many cost less than a well-outfitted SUV), and commute into the city by airplane.

Light airplanes with fixed-pitch propellers are almost perfect for this task. All goes well until you realize that your airplane, which performed well enough in the spring and early summer, has some real problems clearing the trees during the hottest days of summer. Will you have to sell your airplane for something with a bigger engine? Not necessarily; often, re-pitching the prop will solve this problem.

The much-needed acceleration and better climb rate are often available for less than $200. On a short flight to the office, the loss of speed (and slightly higher fuel consumption) is a good trade-off for the increase in safety. Specification data immediately under the propeller listing in the TCDS for the Lycoming-equipped Cessna 172 has a line saying that the static rpm must be no higher than 2,370 and no lower than 2,270. Static rpm is the maximum rpm the engine will produce with the aircraft brakes locked.

Does this mean that a prop shop can bend the blade enough to reduce the angle as necessary as long as the static rpm is no higher than 2,370? Sometimes, but not on this particular Cessna. In this case, Cessna listed the pitch (blade angle) setting in the prop-blade model in the TCDS. If a blade angle is listed, that's the only angle that's legal. If the TCDS lists only a blade model and length, and gives a static rpm range, the blade angle can be reset as long as the static rpm is within the specified range. For your airplane's TCDS listing, visit the FAA Web site (www.faa.gov/certification/aircraft).

Governor systems



Governor in on-speed conditions (top); governor in underspeed conditions (center); and governor in overspeed conditions (bottom).

The ideal solution

Enough talk about blade pitch changes. Let's talk about constant-speed propellers. Since we need all the power we can get at takeoff, and want high speeds in cruise, why doesn't someone create a propeller that is like the transmission of a car—low gears for accelerating and high gears for cruisin'? It has been done—we call it a *constant-speed prop*. The constant-speed propeller (in combination with a *propeller governor*) automatically adjusts the propeller blade angle to maintain the rpm selected by the pilot. Constant-speed propellers are more versatile, more expensive, require more maintenance, must be matched with the correct governor, and are a lot heavier. But once a pilot has experienced the advantages of a constant-speed propeller, it's hard to go back to a one-speed airplane.

Before we talk about automatic propellers, it should be mentioned that many general aviation airplanes have controllable pitch propellers that aren't automatic. Pilots of Bellanca 14-13-2 airplanes could change the pitch of the blades via a handcrank-driven linkage.

Early Beechcraft Bonanza owners had the ability to change propeller-blade angle by using a simple panel-mounted toggle switch that sent electrical power to a two-direction all-electric motor connected to a pitch-angle change mechanism.

These systems were a step up from fixed-pitch propellers but lacked a compensation mechanism for the varying engine loads that occur with climbs, descents, or engine power changes. Automatic propellers utilize a mechanical device (the propeller governor) that adjusts the angle of attack of the propeller blades as necessary to maintain the propeller rpm, regardless of the varying loads applied.

The forces at work

In the FAA's *Airframe and Powerplant Mechanic's Powerplant Handbook* a propeller blade is described as "a twisted airfoil of irregular planform."

Since a propeller blade is an airfoil there are forces (one force is called the *centrifugal twisting moment* or CTM) generated during rotation that tend to drive the blade to low blade angles. Low blade angles are also called *flat pitch* or *high rpm*.

Propeller manufacturers use one of two methods to change prop pitch. Feathering propellers are designed to automatically move the propeller blades to a position that's beyond the highest normal operating blade angle—a position in which the blade chord is aligned with the slipstream. This position is called *feather*, and it's accomplished by using blade-changing forces such as a compressed air charge in the prop dome, a spring, and counterweights. These forces always overcome the CTM forces in a feathering propeller.

This built-in disposition to automatically feather the prop blades is a safety feature—if the engine or governor fails, the propeller will automatically go into feather, reducing propeller drag. The method used for nonfeathering propellers is to allow the propeller blades to move toward flat pitch using the CTM force already mentioned. This movement is often assisted by an internal spring.

The propeller governor is the engine accessory that controls propeller rpm. It's bolted onto a mounting pad on the side or rear of the engine and engages a drive gear that turns the internal parts. These parts include a small gear-type oil pump that boosts oil pressure (used to change blade angles) to approximately 1,290 psi, an engine rpm monitoring mechanism, and an oil control valve that directs oil to or from the propeller-blade change mechanism.

The speeder spring

When the pilot moves the propeller control lever (which could more accurately be called the *engine speed control*) he is, through a rack-and-pinion mechanism on the governor, changing the length of the *speeder spring*, which is inside the governor. This spring bears on the top of the *pilot valve*, which looks like a tube with a series of drilled passages, and supplies a force that pushes the valve down toward the engine end of the governor.

A beveled gear on the engine end of the governor meshes with an engine gear directly linked to crankshaft speed. Engine rotation causes governor rotation, which drives a set of matched flyweights—as the rpm of the engine increases, centrifugal force causes the flyweights to get "heavier." The flyweights are connected to the pilot valve and, as engine speed increases, they apply an upward force that opposes the speeder spring's downward force. When the downward force of the speeder spring is equal to the upward force of the flyweights the pilot valve is in a neutral position and the propeller is "on speed." All oil passages in the pilot valve are blocked and no oil flows to or returns from the blade-change mechanism in the propeller hub.

Overspeed and underspeed

If the pilot decides to climb without touching the throttle or prop controls, there will be an increase in the load on the engine. Since the pilot hasn't increased engine power, the engine will not be able to keep up with the increased load and will start to slow down. When the rpm decreases, centrifugal force on the flyweight lessens. Then the balance between the speeder spring's downward force and the flyweight's upward force will be lost and the speeder spring will push the pilot valve down.

When the pilot valve is moved away from the neutral position, passages in the pilot valve release oil from one side of a piston in the prop dome or direct pressurized oil from the governor pump to one side of a piston in the prop dome, depending on whether the propeller is feathering or nonfeathering. The point is to move the blades. The result is the same—during an underspeed condition the blades will automatically be moved to a higher-rpm (less blade angle) position, there will be less load on the propeller so the crankshaft rpm will increase, the flyweights will "become heavier," and a state of equilibrium will be reached, with the flyweights and speeder-spring forces in balance.

The same forces are at work during an overspeed except that the flyweights' increased lifting force will overcome the speeder spring's downward pressure and move the pilot valve up and out of the balanced neutral position. Oil will be released or directed to the propeller and the piston in the dome will be moved in such a way that the blades will move to a lower-rpm position. The engine will slow down since there's a greater load on the engine, the flyweights will lessen their upward force on the pilot valve, and equilibrium will be restored. And it all happens so fast we never even notice it.

Pilot's responsibilities

Both McCauley (www.mccauley.textron.com) and Hartzell (www.hartzellprop.com) have information on the care and feeding of their propellers—and most of it's free for the asking. Hartzell Senior Test Engineer John Hartman recommends checking the airplane tachometer for inaccuracies. "If the tachometer is inaccurate, a pilot may unintentionally be operating in a restricted operating range, which will increase the blade stresses," says Hartman. Inaccuracies of up to 200 rpm are common in older mechanical-style tachometers.

James Dean, chief inspector for American Propeller in Redding, California, suggests that sticking to the manufacturer's maintenance schedule gives the best results and is cheaper in the long run. "If pilots bring their two-bladed McCauley prop in every five years, we can usually send it back out, fully serviced, for $1,100 to $1,200. If they wait until the propeller starts acting up, often the hub and blades are full of corrosion and they'll end up buying a new prop, which will cost from $5,500 to $8,500."

Dean cites lack of maintenance as a problem in fixed-pitch propellers. "As long as the propeller doesn't hit something, people think they can keep on running them."

Keeping propellers clean and conducting thorough preflight inspections are the first steps in achieving propeller safety. A light application of a corrosion-inhibiting lubricant such as LPS 1, LPS 2, or Corrosion X keeps corrosion at bay between flights.

A qualified mechanic should always be consulted whenever damage or leaks are found during preflight. Rock damage to a propeller leading edge is nothing to fool with—even what appears to be slight propeller-blade damage has a high potential for disastrous consequences.

Since propellers are subject to tremendous forces during flight, even the slightest vibration is important. Don't ignore unusual or new vibrations. Generally speaking, a vibration caused by a propeller will be through the entire rpm range—if the vibration is only at one particular rpm or within a limited rpm range, the problem is a poor propeller/engine match. Get vibrations checked out by qualified personnel before further flight.

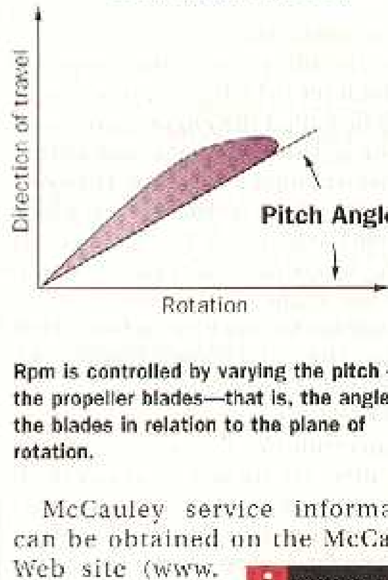
One propeller vibration troubleshooting test that pilots can do is prop-tracking. The most common (and safest) method of prop tracking is to first remove the top spark plugs, which permits easy propeller rotation by hand. Position some solid object (a ladder, work stand, or block of wood) so that it is just touching the front or the back of the tip of one propeller blade. Then rotate the other propeller blade into the same position and measure the distance it is from the ladder or block.

The track should be within one-sixteenth of an inch.

Hartzell's *Propeller Owner's Manual* recommends dynamic prop balancing to 0.2 IPS. A lower reading is desirable, and if the prop cannot be balanced to the 0.2 IPS level, it must be removed to have the static balance checked. Balancing adjusts the center of balance of the rotating prop with the true center point of the propeller.

These simple tips should help you get the best performance out of your propeller. For further information on Hartzell propellers, contact Hartzell Propeller Inc., telephone 937/778-4200; or visit the Web site (www.hartzellprop.com) to get your copy of *Propeller Care and Maintenance for Pilots* or *Propeller Care and Maintenance for Professionals.*

Full feathering vs. constant speed



Rpm is controlled by varying the pitch of the propeller blades—that is, the angle of the blades in relation to the plane of rotation.

McCauley service information can be obtained on the McCauley Web site (www.mccauley.textron.com) or at McCauley Propeller Systems telephone 937/890-5246 or 800/821-7767.

Sensenich Propeller Manufacturing Company can be contacted at telephone 717/569-0435; or visit the Web site (www.sensenich.com).

> Links to additional information about propellers may be found on AOPA Online (www.aopa.org/pilot/links.shtml).

E-mail the author at steve.ells@aopa.org