There's more to proper care than checking for nicks and cracks

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Know Your Propeller

■■ When a pilot yells "Clear!" before starting the engine, how much does he need to know about that whirling airfoil other than the fact it was smooth enough when he ran his hand along its leading edge a few minutes before and that it is operating properly?

Obviously there is not much required knowledge on the subject of propellers since it is rare to find a question about them on FAA exams. However, a working familiarity with that often-ignored essential item for powered flight will enhance your pilot skills and help you reduce maintenance and repair bills.

Figure 1 illustrates a typical, fixed-pitch, one-piece metal propeller as viewed both from the cockpit and from in front of the airplane, along with the terminology we will be using in this discussion. Note that, while the black-painted side of the propeller blade that is seen from the cockpit would logically seem to be the back, it is instead referred to as the "face" of the blade; the other side which you would see when standing in front of the airplane is called the back, or camber, side. Since the blade is airfoil-shaped it works just like a wing, except in the direction of its effect; the propeller's lift pulls the aircraft forward whereas the wing lift holds it up.

The heaviest structural area of the propeller is the hub, where the propeller is attached to the crankshaft. Propeller pitch is the blade angle relative to a line perpendicular to the hub axis (see blade angle sketch in Figure 1). In actual practice the blade angle on a fixed-pitch propeller will vary somewhat from hub to tip. For checking purposes, the pitch angle for which the propeller is rated is measured at a specific station on the blade which is measured outward from the center of the hub. Sometimes this station will be identified on the face with a small painted rectangle.

The propeller blade is an airfoil section and this also may vary in type from hub to tip. Figure 2 depicts several airfoil sections, shown radically different from one another for comparative purposes. Most propeller airfoil sections are similar in appearance to the 2412 (A). There probably still are some propellers built with negative camber faces as shown under B in Figure 2.

The speed at which the propeller revolves has a direct bearing on both its efficiency and the noise produced. Keep in mind that, even though the blade tips are revolving the same number of revolutions per minute (rpm's) as the hub, they travel through the air at a much greater speed because of the larger circle they scribe. The noise produced by some aircraft under takeoff conditions is due largely to the near sonic speeds approached by the blade tips.

Noise is not the only undesirable factor of high tip speed. Such speeds can induce structually damaging blade tip flutter as well. Fortunately, these hazards are not approached when the propeller is fitted to the engine for which it was designed and operated within its specified speed ranges. The variations in blade pitch and airfoil

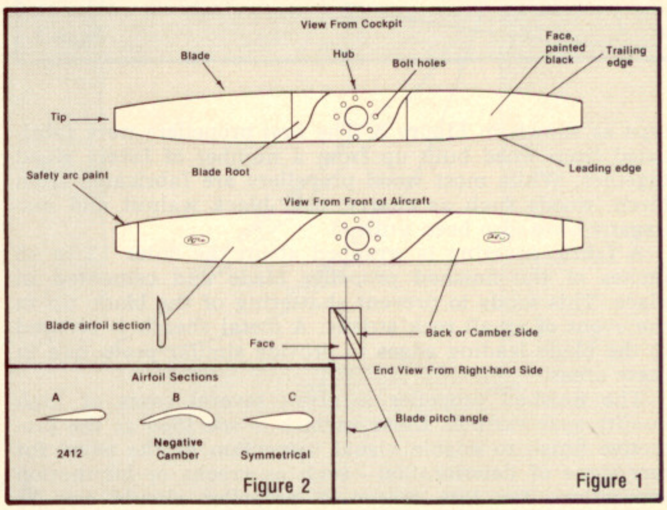

Figure 2

Figure 1

shape from blade root to tip are compensating factors resulting from the variations in blade airspeed from root to tip.

Still another factor that enters the picture is the centrifugal force acting upon the propeller during rotation. The faster the propeller revolves, the greater becomes the centrifugal force pulling outward upon the blades. At takeoff and normal cruise speeds this force reaches a magnitude of many tons. Here again, all of these forces are within the boundaries of safe limits when application and operation are also.

Propellers come in a variety of sizes, shapes and types. The simplest of all is the one-piece, two-bladed, fixed-pitch

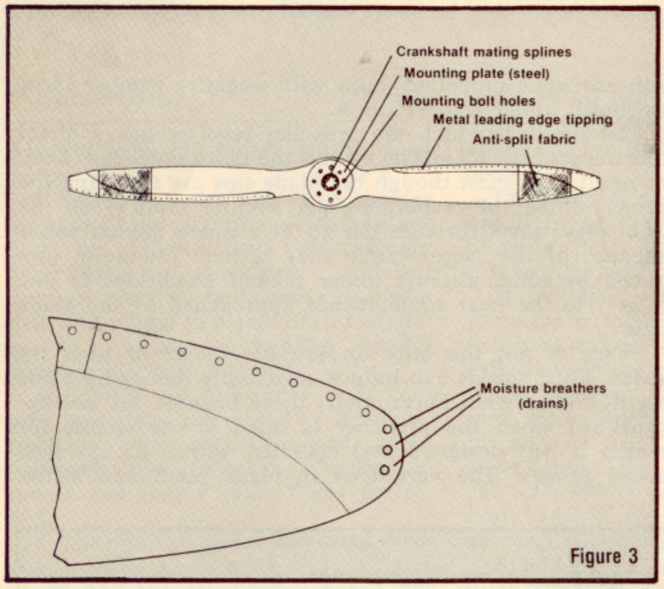

Figure 3

type as shown in Figure 3. The first propellers were fabricated from wood built up from a number of layers glued together. While most wood propellers are fabricated from birch, woods such as cherry, oak, black walnut and mahogany have also been utilized.

A fabric covering is wrapped about the outer 12 to 15 inches of the finished propeller blade and cemented in place. This tends to prevent shattering of the blade tip in the event of small rock strikes. A metal sheath is secured to the blade leading edges to provide similar protection in these areas.

The finished propeller is given several coats of high quality spar varnish. Clear varnish is specified as the protective finish to enable visual inspection of the wood for any signs of deterioration—such as cracks or lamination separation; for this reason a propeller should not be painted. Some wood propellers have been plastic encased; however, such treatment must be approved and then conducted by only those persons and/or agencies so qualified. Wood propellers have "moisture breather," or drain holes, located at the tips (Figure 3); these openings permit condensed moisture between the metal tipping and wood to escape. These holes must be kept clear. To insure proper drainage a wood propeller should always be rotated to a horizontal position after engine shutdown.

Wooden propellers are usually restricted to engines of 200 hp or less; however, fighter planes such as the British WW-II Spitfire and several German fighters have on occasion sported wooden propellers.

Today a wooden propeller costs more to make than one from metal and it is nearly always a total loss in prop strike situations, whereas a metal propeller can be straightened and repaired. But in their day wooden propellers did a commendable job and certainly are more beautiful to behold than any metal propeller.

The fixed-pitch metal propeller is virtually the same as the wood model it replaced, except that it is more durable, more repairable, more efficient, and requires very little maintenance. It is made in various diameters and pitches. A new airplane delivered from the factory with a fixed-pitch propeller will usually have the blades pitched for some desirable compromise between maximum cruising speed and a reasonable rate of climb. Such a propeller is usually defined as a cruise prop because of its greater pitch in the interest of cruising speed. A lesser degree of pitch that would provide a shorter takeoff run and a faster rate of climb is generally considered a climb, or sometimes aerobatic, prop.

The next propeller development after the all-metal one was introduced, was the ground-adjustable type. This consisted of a hub assembly made in two halves which were joined together over a retaining ring at the base of each of the individual propeller blades. When the two hub halves were securely drawn together, they would retain the blades as well as hold them to the pitch established during assembly. To change blade pitch one merely loosened the hub halves until the blades could be twisted, reset the blades to the new pitch desired, and then retightened the hub assembly.

Ground-adjustable propellers were frequently employed for early military fighters and aerobatic craft. In fighters, the blades could be set for fast cruise speeds while the fighters were being ferried to the battle area. Once in the forward area, the blades were reset to a lower pitch for snappy fighter performance. It is not uncommon to see a ground-adjustable propeller on various restored antique airplanes.

Next came the controllable-pitch propeller, sometimes called a two-position propeller. This was essentially a version of the ground-adjustable propeller, the difference being that it could be controlled from the cockpit. When placed in the takeoff and climb position, the blades were moved to a low-pitch position sufficient to permit maximum rated engine rpm. This arrangement allowed the engine to deliver its full rated power output for takeoff and subsequent climb. When leveling off at cruise altitude, the control was actuated to move the propeller to a greater pitch setting which would provide a higher cruising speed. Normally the propeller remained in the cruise pitch setting through cruise, descent and landing.

The effect of the propeller on engine speed is often quite confusing to the fledgling pilot. The propeller converts engine horsepower into forward thrust. The greater the propeller-blade pitch, the farther the propeller tries to travel forward per revolution and, consequently, the more work it can do each time it turns. Of course, the propeller doesn't actually do any work. The engine does the work and the propeller is the loading device.

Full open throttle doesn't always produce full rated horsepower; to do that the engine must be able to turn its full rated rpm as well as develop full manifold pressure. Thus, as engine speed is increased so will be its power output. But, if the work load on the engine increases at a rate faster than horsepower is increasing, the power output will stop increasing at the point where work load equals power developed.

The selection of a propeller and its pitch limits are predicated on maximum-rated engine power. For instance, an engine developing 250 hp at 2,600 rpm will have a propeller with the amount of blade pitch necessary to absorb 250 hp at 2,600 propeller rpm (it will require exactly 250 hp to drive that propeller at 2,600 rpm).

If we reduce that propeller's blade-pitch angle, it would take less than 250 hp to reach 2,600 rpm and the propeller would overspeed the engine until it reached the rpm where its increasing load equaled engine power output. Of course, engine power output also increases with rpm; therefore, when that propeller reaches an rpm requiring 250 hp the engine speed, by exceeding 2,600 rpm, may result in a power output of 260 hp or more; here a very dangerous overspeed (not runaway) condition could exist. If we increased the propeller's pitch angle to where it required 260 hp to drive it at 2,600 rpm, it would simply load the engine too much and neither engine nor propeller would ever reach 2,600 rpm. At some point prior to 2,600 rpm propeller load would overtake the acceleration of power development and at that particular rpm the engine would cease to accelerate any further.

The two graphs in Figure 4 show how this situation would look if plotted as such. In Graph A the propeller blades are pitched too much, causing the propeller loading to prematurely catch up with power development, at 2,300

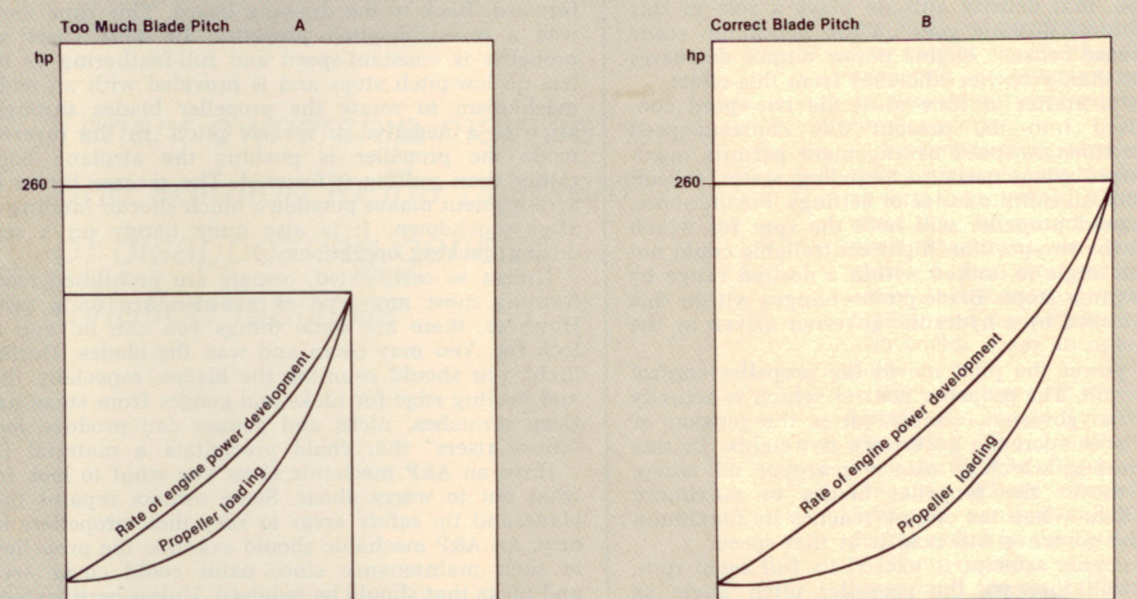

Figure 4

rpm. Power and load are equal, so the engine has nothing left with which to further accelerate. In Graph B the loading doesn't equal power developed until a speed of 2,600 rpm is reached. The propeller blades are pitched to a lesser degree, allowing power development to increase at a rate ahead of propeller loading until 2,600 rpm is reached. At this speed the loading catches up to power and they equalize at the desired engine speed.

In the practice of making this work on the airplane we run into another problem. If we pitched the propeller blades so that the 250 hp engine could attain 2,600 rpm while sitting still on the ground (static), the engine would begin to overspeed in the takeoff roll and more so in cruise flight. Now what went wrong? When the propeller begins to move forward through the air, its efficiency begins to increase and, therefore, less horsepower is necessary to drive the propeller at a given rpm in flight as opposed to that same rpm under static conditions. We can use the graphs in Figure 4 to illustrate this point as well. Consider Graph A a static runup condition with full-open throttle; we can only get a maximum engine speed of 2,300 rpm. Now consider Graph B as full-open throttle only under cruise flight conditions and you get full rpm because of the increased propeller efficiency. This describes exactly the behavior of a fixed-pitch propeller and explains why the engine will not reach full rated rpm at full throttle under static, takeoff and climb conditions. Remember, too, that density altitude plays a role in this picture. As density altitude goes up the maximum static rpm will decrease because engine power output decreases at a faster rate than propeller efficiency from this effect.

It was only a matter of time until the two-speed controllable evolved into the present day constant-speed propeller. The constant-speed arrangement permits maximum engine rpm when needed (including static, takeoff and climb), plus an infinite range of settings. Furthermore, the constant-speed propeller will hold the rpm for which it is set which the two-position flight controllable could not do. Blade pitch angle is limited within a desired range by high- and low-pitch stops. Blade-pitch changes within this range are controlled by a hydraulic governor driven by the engine.

For takeoff power the pilot moves the propeller control to full engine rpm. The propeller control, which is actually connected to the governor, simply varies the tension of a spring that acts upon the governor's flyweights. In this mode the governor, which is also a gear-type oil pump, hydraulically moves the propeller blades to maximum low-pitch position. When the engine reaches its maximum rated speed, the governor will hold it at that speed.

Should the engine attempt to exceed its full rated rpm, the governor will increase the propeller pitch angle as necessary, thereby loading the engine enough to prevent it from accelerating beyond maximum rated rpm. The governor has an adjustable stop that limits maximum engine speed. When the pilot moves the propeller control to decrease engine speed, the governor responds by increasing blade pitch. This action overloads the engine, causing it to slow down. Of course, the propeller slows down as well and in doing so reduces engine loading.

Engine speed will stabilize at that point where power output equals propeller loading. Thus the pilot regulates engine speed by varying propeller pitch, which in turn varies engine loading. Once the desired engine speed is set, the governor will maintain it by variations in propeller pitch as necessary. While with the fixed-pitch propeller any increase in power will likewise require an increase in engine speed, with a constant-speed propeller, the pilot can increase power while maintaining a desired rpm.

There are various types of constant-speed propellers. Some employ blade counterweights to move the blades to high pitch and governor oil pressure for actuation to low pitch. Others use governor oil pressure for high pitch and the natural force of centrifugal twisting moment (CTM) for low pitch. Whatever the type, the constant-speed propeller is one of the foremost advances in aviation.

In the advent of an engine-out on a multi-engine airplane, dragging the dead propeller through the air will cause it to "windmill" the inoperative engine. Such windmilling and its subsequent drag could be prevented by having the dead propeller's blades assume a streamlined position in which their leading and trailing edges would face fore and aft. Consequently the constant-speed propeller was redesigned to incorporate this ability; the new feature was called "feathering."

It would seem that a full feathering, constant-speed propeller would be all one could wish. But, some people are never satisfied. Some wanted to back up as well as go forward. Back to the drawing board. This time the result was a reversible-pitch propeller. In most cases such a propeller is constant-speed and full-feathering as well. It has no low-pitch stops and is provided with an additional mechanism to rotate the propeller blades through zero pitch to a negative or reverse pitch. In the reverse-pitch mode the propeller is pushing the airplane backward rather than pulling it forward. The reverse thrust of this arrangement makes possible a much shorter landing rollout after touchdown. It is also quite handy on a seaplane during docking operations.

Unless so certificated, owners are prohibited from performing most any type of maintenance on a propeller. However, there are some things you can do and should look for. You may clean and wax the blades. During preflight you should examine the blades, especially the face and leading edge for nicks and gouges from stone damage. Deep scratches, nicks and gouges can produce localized "stress risers" that could precipitate a material failure.

Have an A&P mechanic show you what to look for and what not to worry about. Some owners repaint the face blade and tip safety areas to keep their propellers looking new. An A&P mechanic should examine the propeller prior to such maintenance since paint could cover scratches and nicks that should be removed. Unless certificated as an A&P mechanic, the owner should not attempt removal and replacement of a propeller. Such practice is illegal and could result in serious consequences if improperly accomplished. Perhaps the best maintenance the owner can provide the propeller is to avoid operating in areas abounding in loose surface and tall grass or weeds. □