POWER MANAGEMENT

Prop throttle throttle prop (and don't you forget it, except. . .)

BY BARRY SCHIFF

Flying an airplane depends on understanding numerous important relationships. Lift and drag, roll and yaw, weather and water vapor are but a few examples. The relationship between engine manifold pressure and propeller rpm is equally significant but is not well understood, especially by pilots transitioning for the first time to complex airplanes.

First, what is a manifold? It is no more than a system of ducts and plumbing that guides a fluid (such as air) from one place to another. Figure 1 shows an induction manifold, which directs air from outside the aircraft to the engine cylinders for combustion. (An exhaust manifold guides the refuse of combustion from the cylinders to outside the aircraft.)

The figure also shows a throttle valve (or butterfly valve, as it is sometimes called), which is used to control the amount of air allowed to enter the cylinders. This valve is an integral part of the carburetor or fuel-injector servo. The amount of air passing the throttle valve is important because it determines how much fuel can be burned and, therefore, how much power can be developed.

Technically, fuel flow and engine power depend on the weight of air entering the cylinder. One way to measure engine power, therefore, is to measure the density of air downstream of the throttle valve, something more difficult in practice than in principle. Much simpler and almost as effective is measuring the pressure of the air (or fuel/air mixture) as it enters the cylinders. This is called manifold pressure or, to be accurate, manifold absolute pressure (MAP), which is measured in inches of mercury by an instrument similar to a crude altimeter.

Notice in the figure that the throttle valve is closed. Very little air (and fuel)

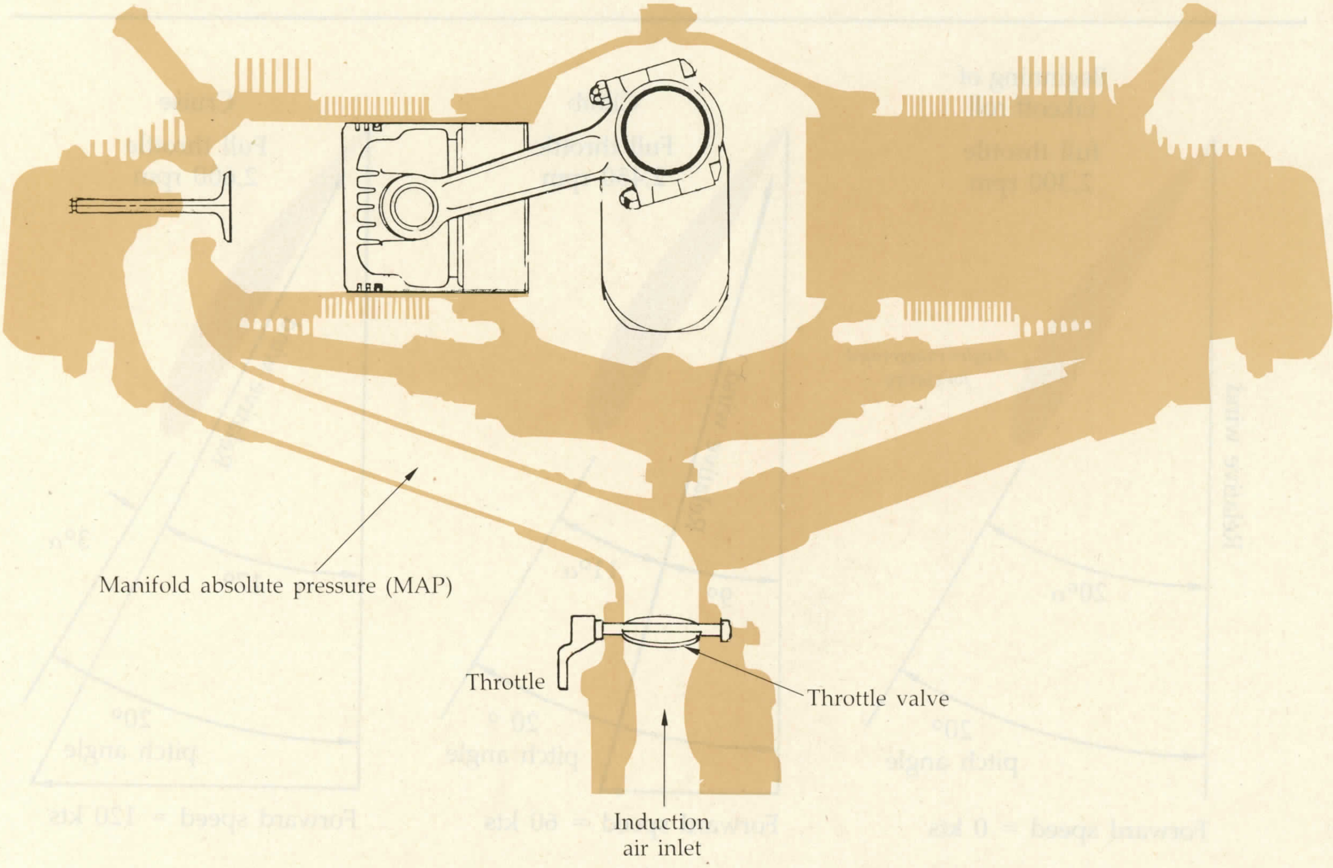

Figure 1. Manifold absolute pressure (MAP) is the pressure at which the fuel-air mixture enters the cylinders. In a normally aspirated engine, the maximum available manifold pressure decreases steadily with altitude.

is being processed by the engine, which is idling. In the meantime, the pistons—acting like large vacuum pumps—attempt to suck in much more air than the throttle allows. As a result, manifold pressure is quite low (typically nine to 11 inches when the engine is idling). Since the air pressure on the upstream side of the throttle is approximately 30 inches (sea level barometric pressure), only one-third of atmospheric pressure can get to the engine. No wonder that a "throttled" engine develops so little power.

As the throttle valve is opened, increasingly more atmospheric pressure is allowed to enter the low-pressure region downstream of the valve. Finally, when the throttle is wide open, all atmospheric pressure is allowed to fill the induction manifold. Manifold pressure increases to approximately 30 inches (at sea level) and the engine develops maximum power.

In reality, MAP rarely equals atmospheric pressure because some pressure is lost as the air makes its way through the manifold. Losses of one to two inches are typical. MAP and atmospheric pressure are equal in nonturbocharged engines only when the engine is not running.

FIGURE 2
FULL THROTTLE HORSEPOWER AND MANIFOLD PRESSURE AT ALTITUDE
(for naturally aspirated engines)

Altitude (feet)	Percent of Sea-level Horsepower	Manifold Pressure (typical, inches of mercury)
Sea Level	100.0	28.7
1,000	96.8	27.7
2,000	93.6	26.6
3,000	90.5	25.6
4,000	87.5	24.6
5,000	84.6	23.7
6,000	81.7	22.8
7,000	78.9	21.9
8,000	76.2	21.0
9,000	73.5	20.2
10,000	70.8	19.4
11,000	68.3	18.6
12,000	65.8	17.8
13,000	63.4	17.1
14,000	61.0	16.4
15,000	58.7	15.7
16,000	56.5	15.0
17,000	54.3	14.4
18,000	52.1	13.7
19,000	50.0	13.1
20,000	48.0	12.6
21,000	46.0	12.0
22,000	44.0	11.4
23,000	42.2	10.9
24,000	40.3	10.4
25,000	38.5	9.9

(Mooney has devised an interesting method of recovering some induction loss. When the aircraft is at an altitude where the air is relatively clean, the pilot pulls a knob that allows ambient air to bypass the air filter and go straight to the throttle valve. This, plus the effect of ram-air pressure entering the bypass, increases manifold pressure by at least an inch.)

As an airplane climbs into steadily decreasing atmospheric pressure, maximum-available manifold pressure (in nonturbocharged engines) also decreases because there is less air available to enter the induction manifold. The table in Figure 2 shows the maximum power and manifold pressure available up to 25,000 feet.

Some engines have turbochargers, devices that compress induction air and increase manifold pressure, thereby increasing available power at altitude. But even turbochargers will run out of steam. The critical altitude is the highest altitude at which the maximum-allowable manifold pressure can be maintained in a turbocharged engine.

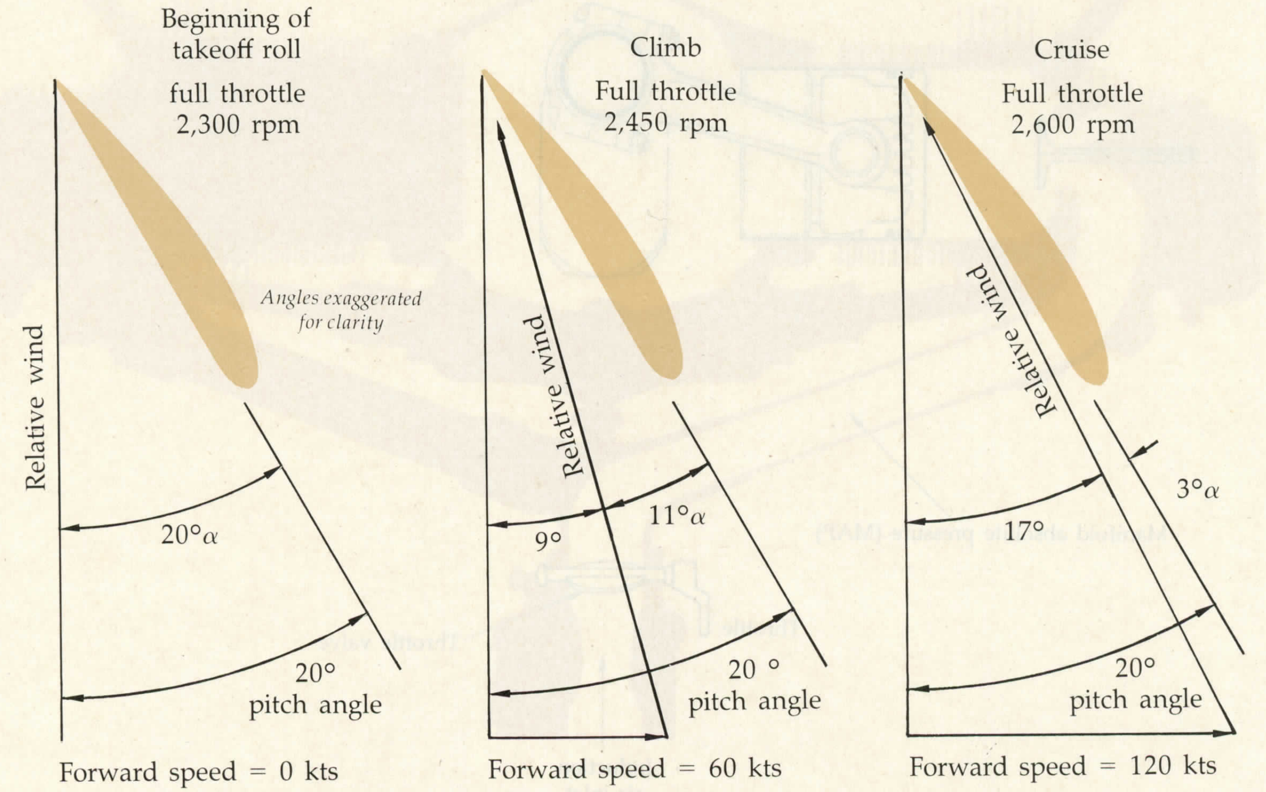

Figure 3. The angle of attack (designated by the Greek letter alpha, α)varies from quite large at the beginning of the takeoff roll to quite small in high-speed cruise flight.

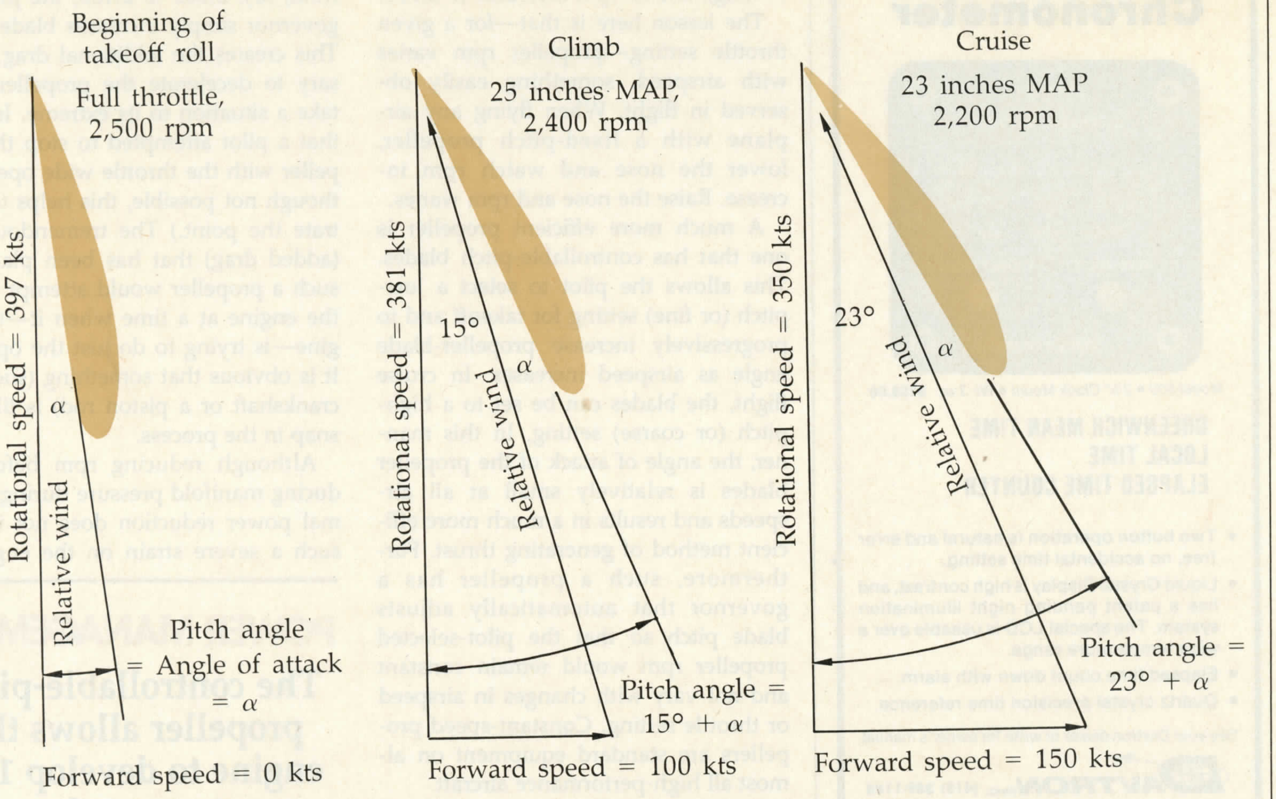

Figure 4. *The blades of a constant-speed propeller have a relatively constant and efficient angle of attack throughout all regimes of flight.*

Although manifold pressure is the primary indication of the weight of air entering the cylinders and often is regarded as a power gauge, it alone does not measure power output. Power is the rate at which work is performed. So if the engine is not moving something, it is not developing power. Manifold pressure can be compared to the legs of a bicyclist. No matter how much muscle is applied, power is not developed unless those legs are used to turn the wheels. Loosely stated, manifold pressure is a form of muscle—energy—a force that can be harnessed to perform a task.

An aircraft engine performs work by turning a propeller. To determine power ouput, therefore, it is necessary to know how much muscle (manifold pressure) is being applied and how much work (rpm) is being done with that muscle. Consequently, it is the combination of MAP and rpm that determines power output. This is why the pilot's operating handbook for a given airplane specifies that rated engine power is available only when the throttle is wide open (an implied condition for naturally aspirated engines), standard conditions exist at sea level and the propeller is turning at the maximum-allowable (redline) rpm.

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Manifold pressure is a form of energy that can be harnessed to perform the work of turning the propeller.

It is impossible, however, for the fixed-pitch propeller of a lightplane to achieve redline rpm when the aircraft is motionless on the ground. For example, the engine of a Cessna 152 develops only 2,280 rpm during a full-throttle, static runup, even though its redline rpm is 2,550. This means that the 152's engine cannot develop rated horsepower during the takeoff roll and partially explains why aircraft fitted with fixed-pitch propellers have relatively lethargic takeoff performance.

Figure 3 helps to demonstrate why a fixed-pitch propeller is rpm-limited at low airspeeds and lays a foundation for understanding the operating principles of the constant-speed propeller. The fixed-pitch propeller shown in the figure has a 20-degree pitch angle (as measured at a point three-fourths of the way from the center of the propeller hub to the tip). At full throttle and with no forward speed, the propeller can achieve only 2,300 rpm. The large, 20-degree "angle of bite" combines with the relative wind (caused by propeller rotation) to produce a 20-degree angle of attack. This angle is quite large and since the blade section is rotating at 364 knots, the resultant drag is quite high. The propeller is said to be heavily loaded (with drag) and the engine simply does not have sufficient power to turn the propeller faster.

When the aircraft is at 60 knots, however, the propeller blade encounters a relative wind that is a result of its rotation (380 knots) and its forward speed (60 knots). As can be seen, the angle of attack now is only 11 degrees. Since this smaller angle of attack results in less drag, engine and propeller rpm increase to 2,450. Finally, at a forward speed of 120 knots, the propeller blade's angle of attack is only three degrees. At such a small angle of attack, the propeller is unloaded (with respect to drag), and its rpm increases to 2,600.

The lesson here is that—for a given throttle setting—propeller rpm varies with airspeed, something easily observed in flight. When flying any airplane with a fixed-pitch propeller, lower the nose and watch rpm increase. Raise the nose and rpm wanes.

A much more efficient propeller is one that has controllable-pitch blades. This allows the pilot to select a low-pitch (or fine) setting for takeoff and to progressively increase propeller-blade angle as airspeed increases. In cruise flight, the blades can be set to a high-pitch (or coarse) setting. In this manner, the angle of attack of the propeller blades is relatively small at all airspeeds and results in a much more efficient method of generating thrust. Furthermore, such a propeller has a governor that automatically adjusts blade pitch so that the pilot-selected propeller rpm would remain constant and not vary with changes in airspeed or throttle setting. Constant-speed propellers are standard equipment on almost all high-performance aircraft.

Figure 4 helps to explain both the theoretical and operational aspects of a constant-speed propeller.

During takeoff, the propeller blades are set to low pitch using a control adjacent to the throttle. Since a small pitch angle results in relatively little drag, the propeller can accelerate to high (redline) rpm as the throttle is advanced and manifold pressure is increased. During standard conditions, this allows the engine to develop 100-percent power and maximize takeoff performance.

As the aircraft accelerates, however, forward speed unloads the propeller, which tends to exceed redline rpm. The propeller governor senses this overspeeding tendency and increases the blade angles ever so slightly. The added drag on the blades prevents overspeeding and allows the propeller to maintain redline, which, in this case, is 2,500 rpm.

Once the aircraft is climbing at a safe altitude, the pilot can reduce power to that recommended for climb, which, in this case, is 25 inches MAP and 2,400 rpm. It is important that the pilot make such a power reduction by first reducing manifold pressure and then by reducing rpm.

Reducing rpm first can place excessive strain on the engine. When the propeller control is used to reduce rpm from, say, 2,500 to 2,400, the propeller governor simply increases blade angle. This creates the additional drag necessary to decelerate the propeller. Now take a situation to its extreme. Imagine that a pilot attempted to stop the propeller with the throttle wide open. (Although not possible, this helps to illustrate the point.) The tremendous load (added drag) that has been placed on such a propeller would attempt to stop the engine at a time when it—the engine—is trying to do just the opposite. It is obvious that something (such as a crankshaft or a piston rod) is likely to snap in the process.

Although reducing rpm before reducing manifold pressure during a normal power reduction does not impose such a severe strain on the engine, it nevertheless does increase internal engine stresses.

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The controllable-pitch propeller allows the engine to develop 100-percent power, boosting takeoff performance.

For the same reason, power increases should be made by first increasing rpm and then increasing manifold pressure. (When the rpm of a naturally aspirated engine is increased, manifold pressure drops slightly. This is because the added rpm causes the pumping rate of the pistons to increase, thereby causing a slight pressure reduction in the intake manifold downstream of the throttle valve. Conversely, decreasing rpm reduces this pumping action and causes manifold pressure to increase.)

As the aircraft climbs, manifold pressure decreases because of the reduction in atmospheric pressure. If operating at less than full throttle, the throttle can be opened farther to compensate for this power loss. Eventually, however, the manifold pressure recommended for climb requires a wide-open throttle. Above this altitude, the manifold pressure and power output of a nonturbocharged engine decrease as shown in Figure 2.

Upon reaching cruise altitude, and after accelerating to the appropriate speed, the throttle and propeller control—in that order—are used to establish the recommended cruise power.

There are two rules of thumb pilots use to set cruise power on a naturally aspirated engine. The first suggests using 23 inches MAP and 2,300 rpm, a procedure popularly called "23 square." Although such a power setting can be used in most cases, it is the sign of a pilot too lazy to use available power charts. There is a variety of recommended power settings, and a pilot should use the one appropriate to his mission if he wants to get the most out of his aircraft.

The second rule claims that manifold pressure should not exceed rpm (in hundreds). When using 2,400 rpm, for example, manifold pressure should not exceed 24 inches. While such a conservative technique might have been appropriate when engines were no more reliable than a politician's promise, it has no place in the operation of modern powerplants. As a matter of fact, this rule is violated during every takeoff from a low-elevation airport where manifold pressure is close to 30 inches and rpm is as much as "five" less than 30 (even less for geared engines). So much for that rule of thumb.

A pilot can opt to use any combination of MAP and rpm specified in the power charts for his engine. When operating a Lycoming O-540-B, 235-hp engine at 65-percent power, for example, he can use extremes of 2,575 rpm and 21 inches MAP, or any of several in-between combinations. Using reduced rpm and high manifold pressure within approved limits usually is the most advantageous. For one thing, low propeller rpm reduces noise. For another, fuel savings can be significant. When operating the O-540-B at 2,575 rpm and 21 inches MAP at sea level, for example, fuel consumption is 13.8 gph. But when pulling the same power with 1,875 rpm and 25.2 inches MAP, fuel consumption is only 12.1 gph. This represents a 13-percent fuel-flow reduction without affecting power output. (Slow-turning engines are most efficient because they generate less internal friction.)

As a general rule, manifold pressure in cruise flight can exceed rpm by "four," but this should be confirmed with appropriate power charts.

To those accustomed to fixed-pitch propellers, the constant-speed propeller is a joy to operate. It is similar to making the transition from a car with a single-gear transmission to one with multiple gears. In a way, the constant-speed propeller and automotive transmissions are analagous; each is used to convert engine muscle into locomotion.

The constant-speed propeller not only is more efficient than a fixed-pitch propeller, it also is easier to use. Once the desired rpm is established in cruise flight, for example, it does not have to be adjusted in any way for the duration of cruise flight. Should airspeed vary for any reason, the propeller governor automatically adjusts the pitch of the blades to maintain the selected rpm. Blade angle is increased to prevent an rpm increase and vice-versa. Propeller rpm does not vary with minor throttle adjustments, either. If manifold pressure is reduced, the governor decreases blade pitch to maintain a constant rpm; conversely, a power increase causes blade pitch to increase.

Descending with a constant-speed propeller generally requires little attention. Just leave the propeller set to cruise rpm and it takes care of itself. One word of caution, however: Descending rapidly with cruise rpm and very low manifold pressure can cause piston rings to flutter, which eventually can cause them to break. If very-low-power descents are necessary, prevent the possibility of ring flutter by adjusting propeller rpm to the lower possible cruise setting. Prior to reapplying power, however, increase propeller rpm to its cruise or climb setting, whichever is appropriate.

There is no need to adjust propeller rpm on an approach, either. But prior to descending through approximately 500 feet agl, increase propeller rpm to the maximum in preparation for a possible go-around. In this way, maximum power will be available as soon as the throttle is put to the fire wall. (Modern noise abatement recommendations are to avoid maximum rpm during approach unless a missed approach or go-around are initiated.)

Constant-speed propellers are so much more efficient than fixed-pitch models that it causes one to wonder why all aircraft are not equipped with them. The answer consists of two words: weight and price, factors that generally make constant-speed propellers impractical for most aircraft with less than 180-hp engines. ☐

Barry Schiff, AOPA 110803, is an airline captain and an FAA-designated examiner. He has all seven flight instructor ratings and has flown more than 200 types of aircraft.