HAND OUT

Constant Speed Propeller

CONSTANT SPEED PROPELLER

This article is excerpted from Rod Machado's Private Pilot Handbook, a complete information manual by Rod Machado, one of aviation's best-known -- and funniest -- teachers. Rod's Handbook contains all of the information you need to pass the FAA knowledge test for the private pilot certificate, and it's a great reference for updating and refreshing your knowledge of aerodynamics, aircraft systems, navigation, weather, and other topics. To find out more about Rod, his books, audiotapes, and other products, visit www.rodmachado.com.

CONSTANT SPEED PROPELLER

Propellers come in all sizes and colours, but they are of two basic types: fixed pitch and constant speed. In an aeroplane with a fixed pitch prop, one lever – the throttle – controls both power and propeller blade RPM (revolutions per minute). In a constant speed prop, there are separate controls for power and RPM.

When you start your flight training, you'll probably fly an aeroplane with a fixed pitch propeller. Fixed pitch propellers have their pitch (angle of attack) fixed during the forging process. The angle is set in stone (actually, aluminium). This pitch can't be changed except by replacing the propeller, which pretty much prevents you from changing the propeller's pitch in flight.

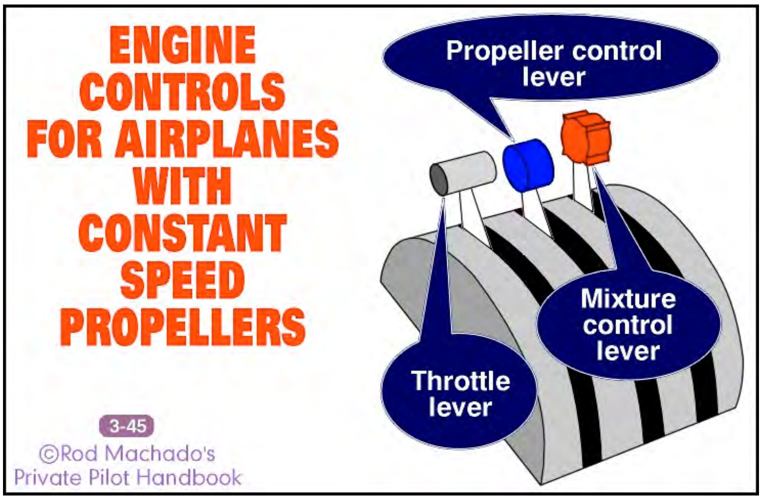
Fixed pitch props are not ideal for any one thing, yet they're in many ways best for everything. They represent a compromise between the best angle of attack for climb and the best angle for cruise. They are simple to operate, and easier (thus less expensive) to maintain.

On fixed pitch propeller aeroplanes, engine power and engine RPM are both controlled by the throttle. One lever does it all, power equals RPM, and that's the end.

CONSTANT SPEED PROPELLER

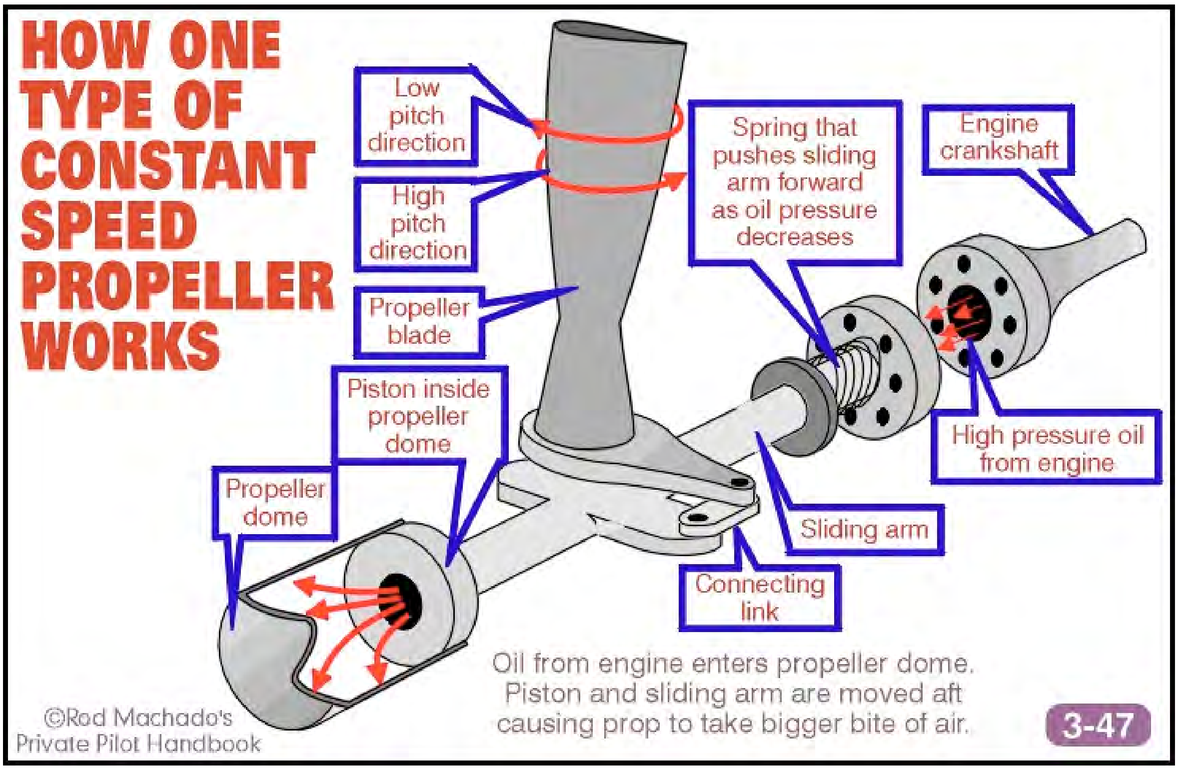
As you move up into higher performance aeroplanes, however, you'll soon encounter constant speed (controllable pitch) propellers.

Aeroplanes with these propellers usually have both a throttle and a propeller control, so you manage engine power and propeller RPM separately (*Fig. 3-45*).



On aeroplanes with constant speed propellers, movement of the throttle determines the amount of fuel and air reaching the cylinders. Simply stated, the throttle determines how much power the engine can develop.

Movement of the propeller control changes the propeller's pitch (it´s angle of attack). This directly controls how fast the propeller rotates (its speed or RPM) as shown in Figure 3-47.



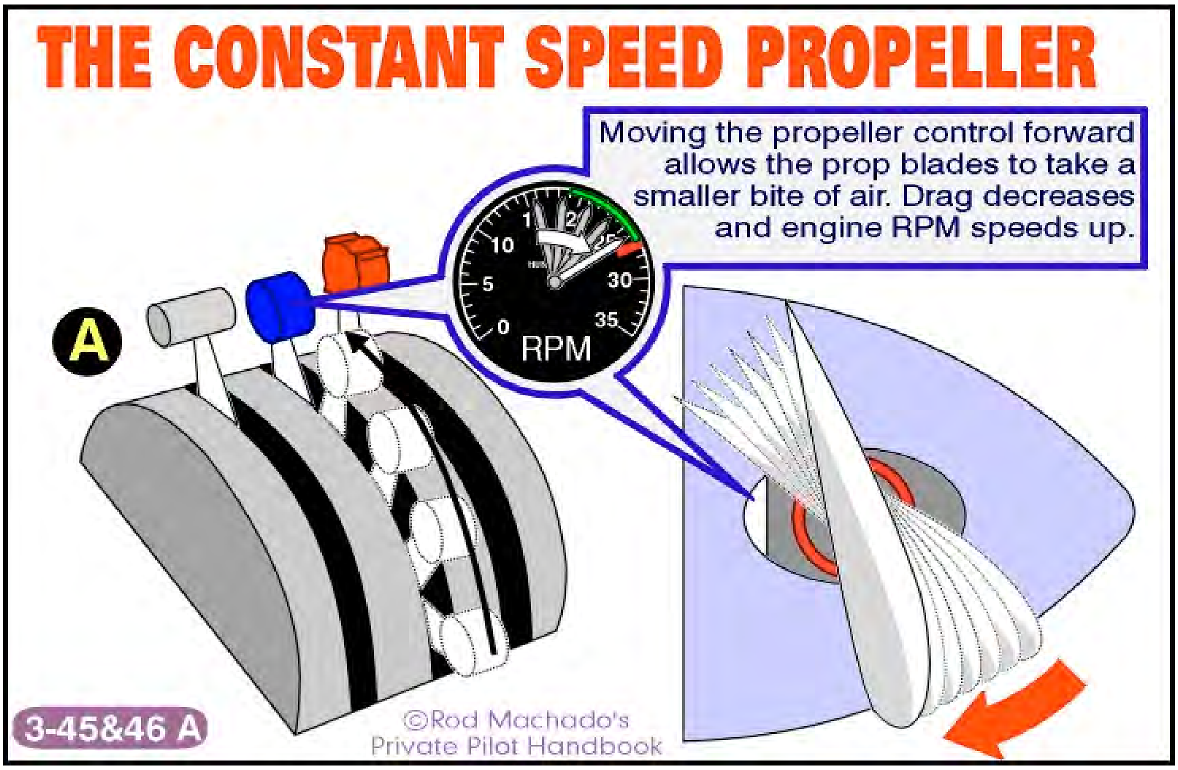
CONSTANT SPEED PROPELLER

While throttle determines engine power, propeller pitch determines how efficiently that power is used.

Let's examine how the controllable propeller works. Then we'll examine why changing the propeller's pitch is useful.

Forward movement of the propeller control causes both halves of the propeller to rotate about their axes and attack the wind at a smaller angle (i.e., take a smaller bite of air) as shown in Figure 3-45&46A.

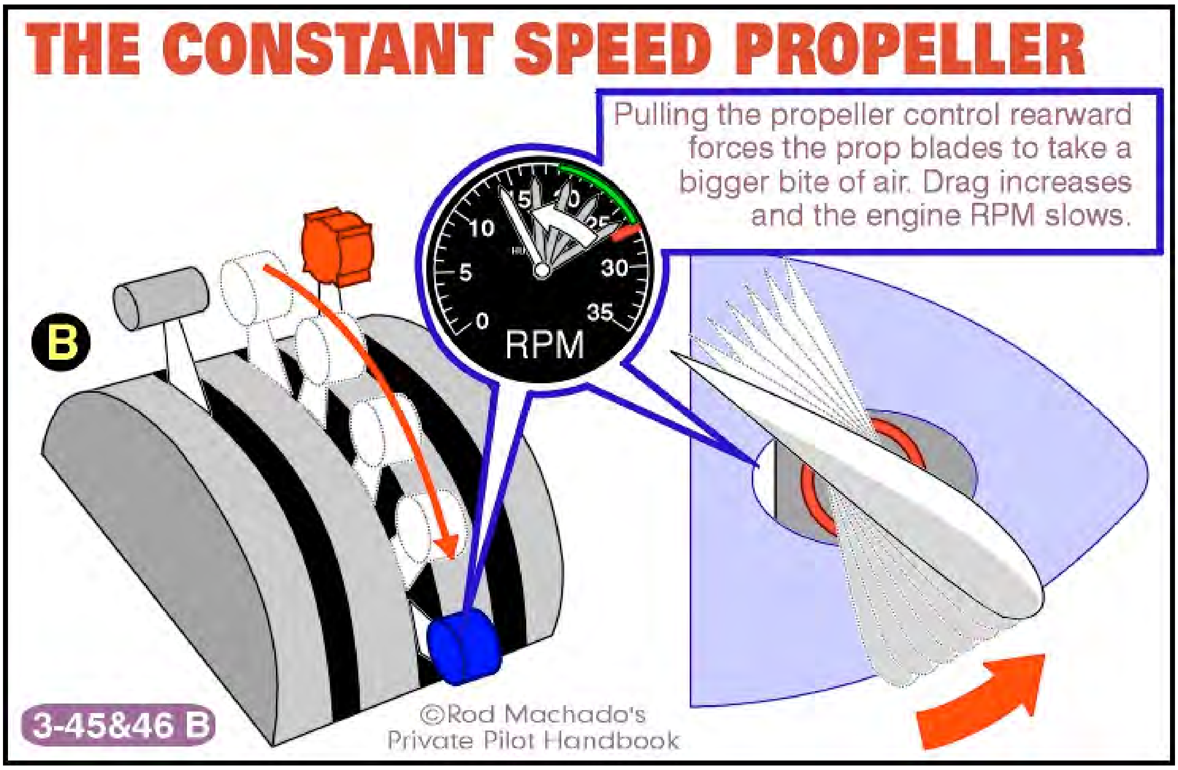
From aerodynamics, you know that a smaller angle of attack means less drag and less resistance to forward motion. Therefore, moving the propeller control forward increases propeller RPM.



3-45&46 A

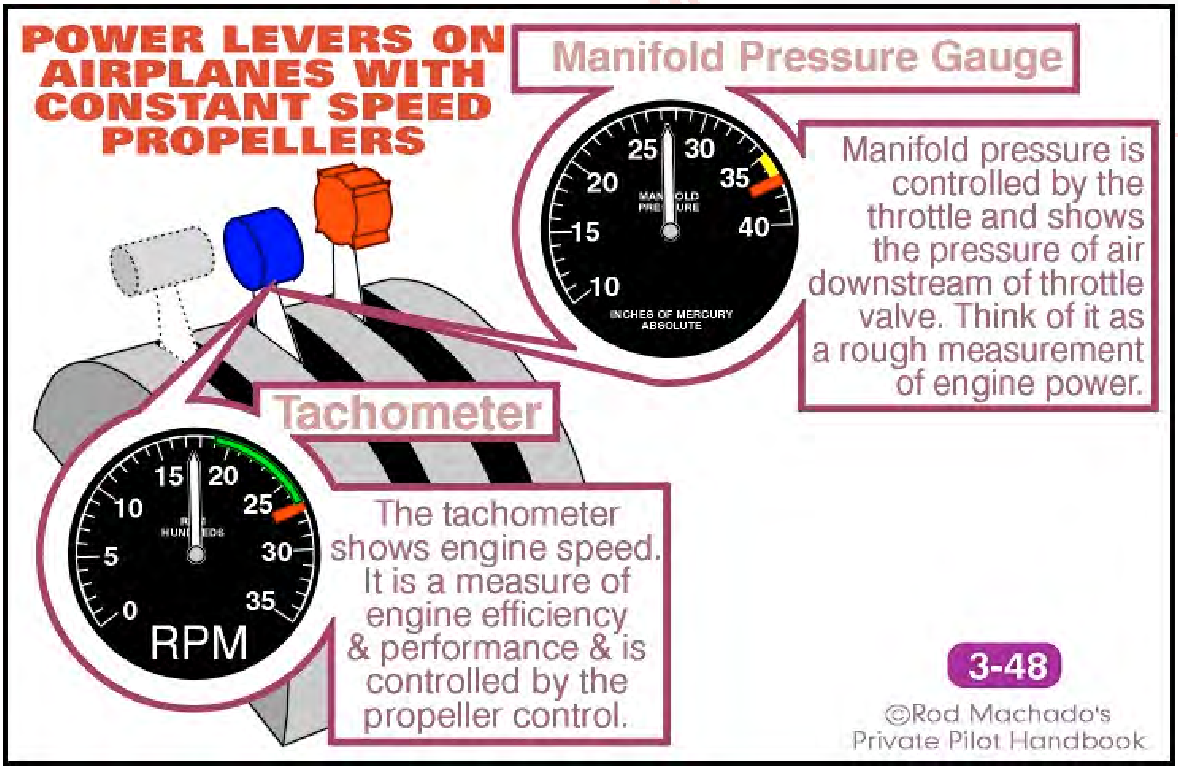
CONSTANT SPEED PROPELLER

Pulling the propeller control rearward causes the propeller to attack the wind at a larger angle of attack (i.e., take a larger bite of air). Propeller drag increases and engine RPM slows as shown in Figure 3-45&46B.

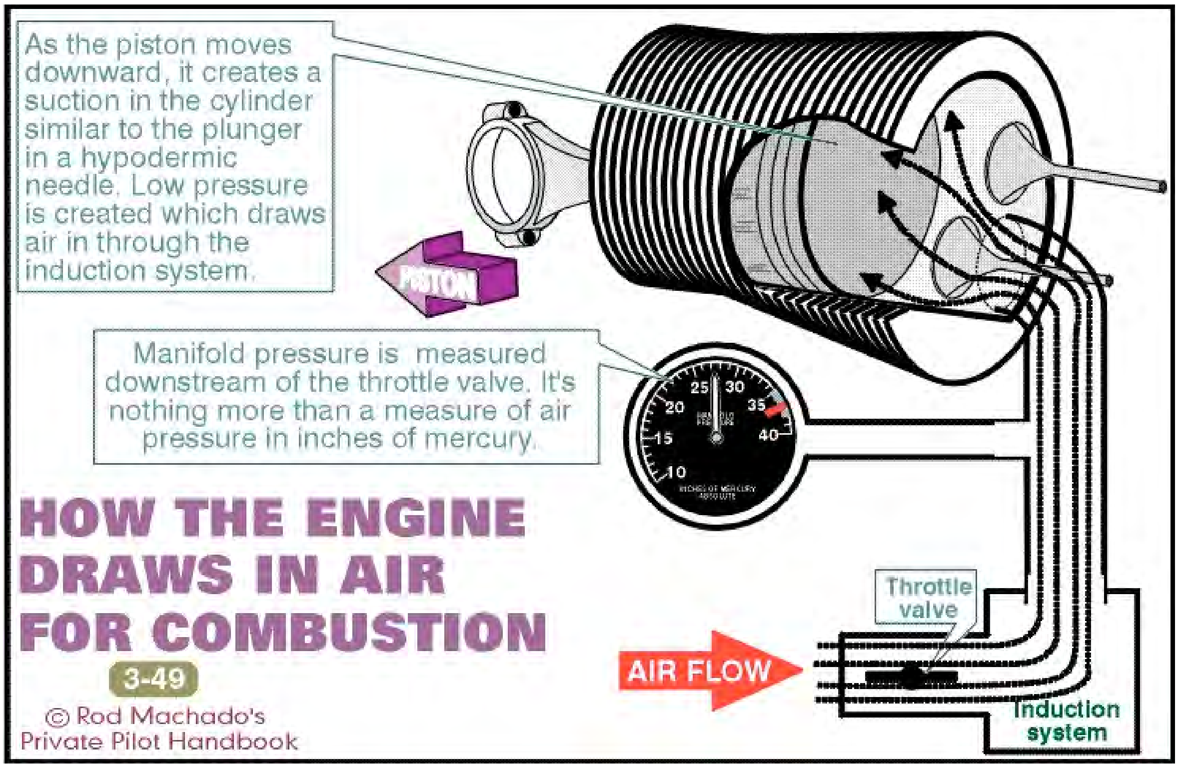


Since the tachometer tells you how fast the propeller spins (its RPM), is there a gauge to tell you how much throttle is applied?

Yes. It's called a manifold pressure gauge and it gives you an approximate measure of engine power. (*Fig. 3-48*).



At the beginning of this chapter we said a vacuum is created in the induction system as a result of pistons descending on their intake strokes (*Fig. 3-49*).



With the throttle closed, the throttle valve in the induction system prevents air (thus fuel) from rushing into the cylinders and powering the engine.

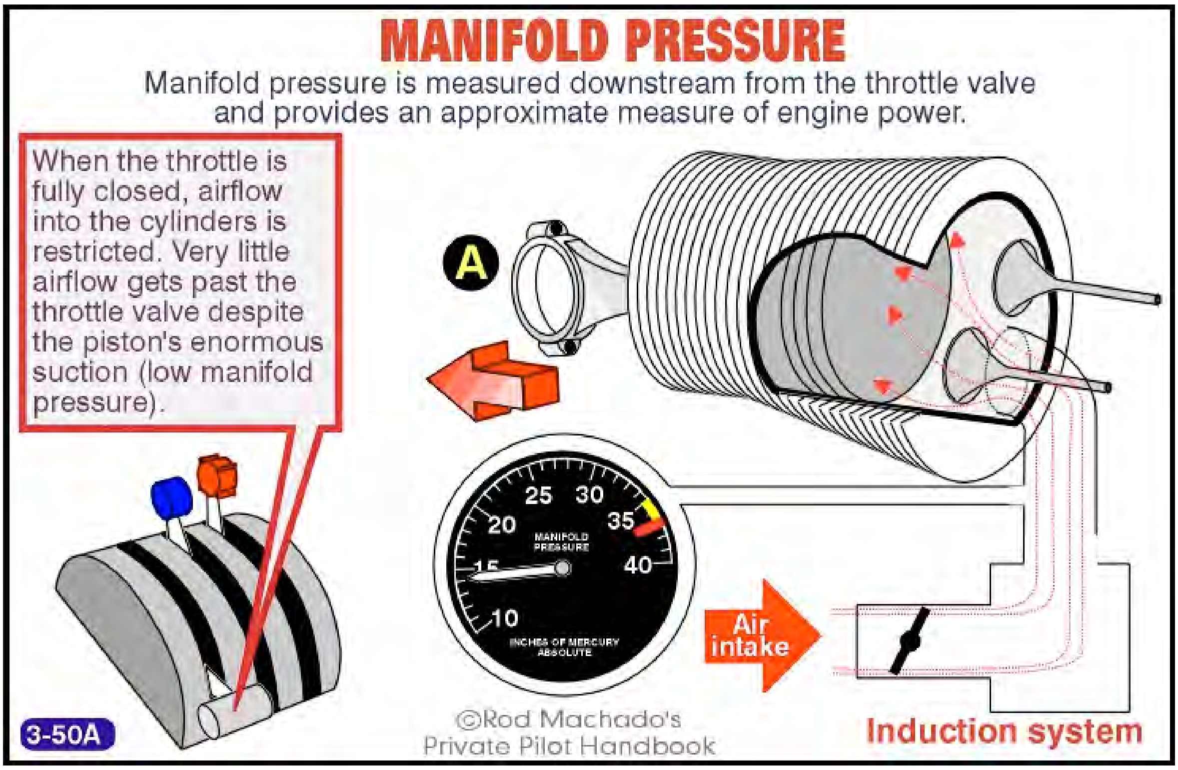
But what is it that forces air into the induction system in the first place?

Yes, it's the pressure of the surrounding atmosphere.

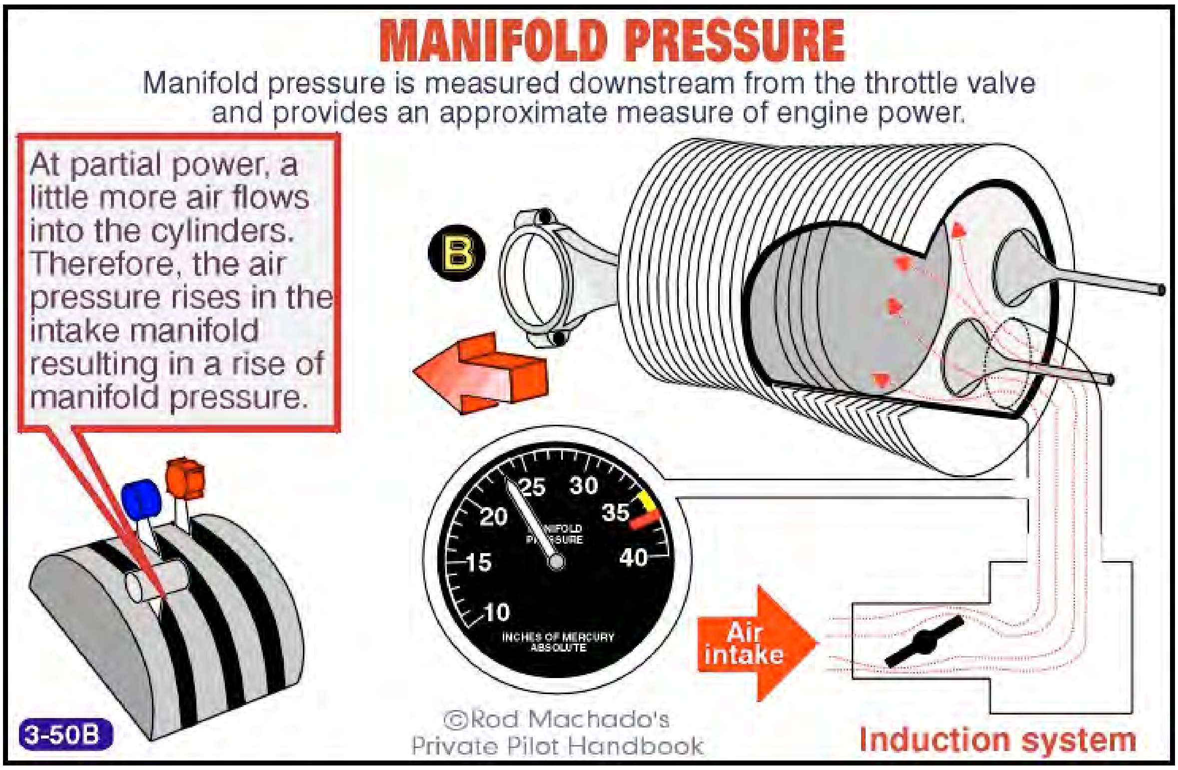
Because atmospheric pressure is higher than the pressure within the induction system, air flows into the cylinders. Simply stated, the atmosphere wants to push air into the induction system (toward the suction created by the downward moving pistons). The amount of this push is measured by the manifold pressure gauge (the gauge is nothing more than a barometric measuring device calibrated to read pressure in inches of mercury--just like altimeters).

Manifold pressure is measured downstream of the throttle valve as shown in Figure 3-49. When the throttle is closed, air outside the engine (under higher atmospheric pressure) can't flow into the induction system, despite the vacuum on the engine side of the throttle valve.

Figure 3-50A shows a manifold pressure of 14 inches of mercury with a closed throttle. The engine is sucking as hard as it can but the outside air can't get past the closed throttle valve.



Opening the throttle slightly causes an increase in manifold pressure as shown in Figure 50B. More air and fuel are drawn inside the engine, and power increases.

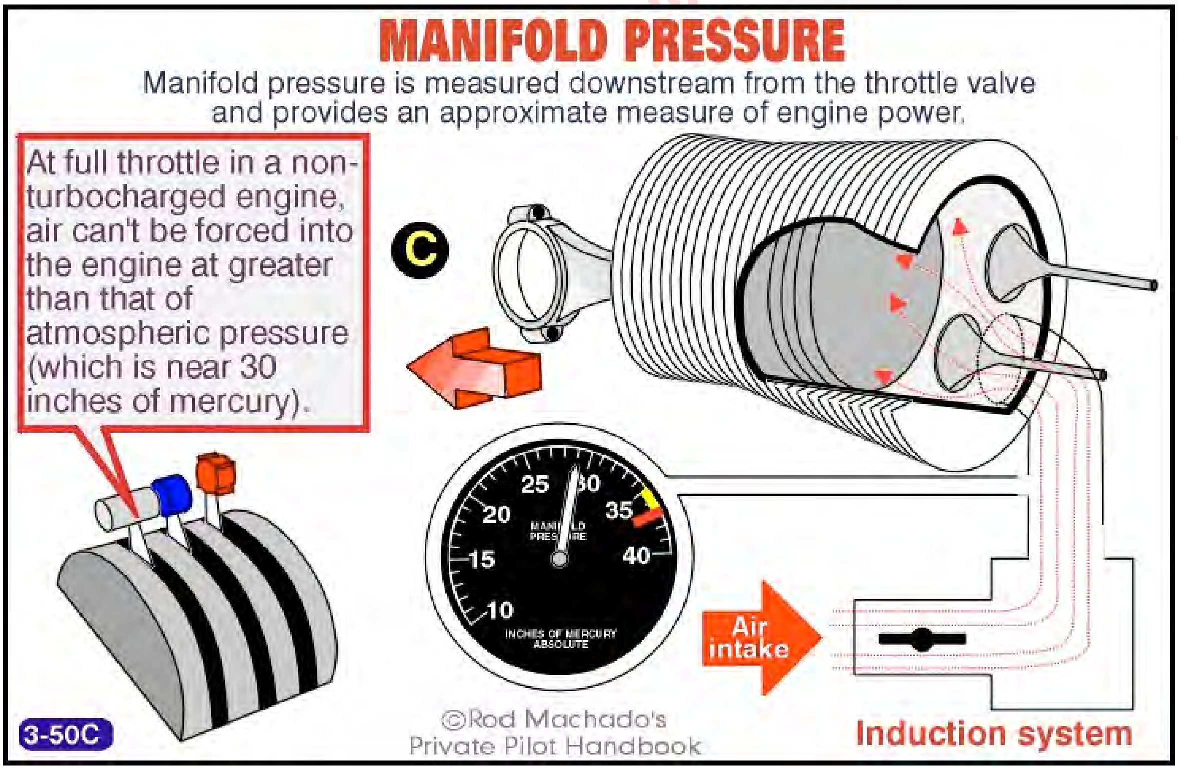


Eventually, as the throttle is fully opened (*Fig. 3-50C*), the pressure downstream of the throttle valve approaches that of the atmosphere.

In other words, the air is being forced into the induction system at the maximum pressure the atmosphere is capable of pushing.

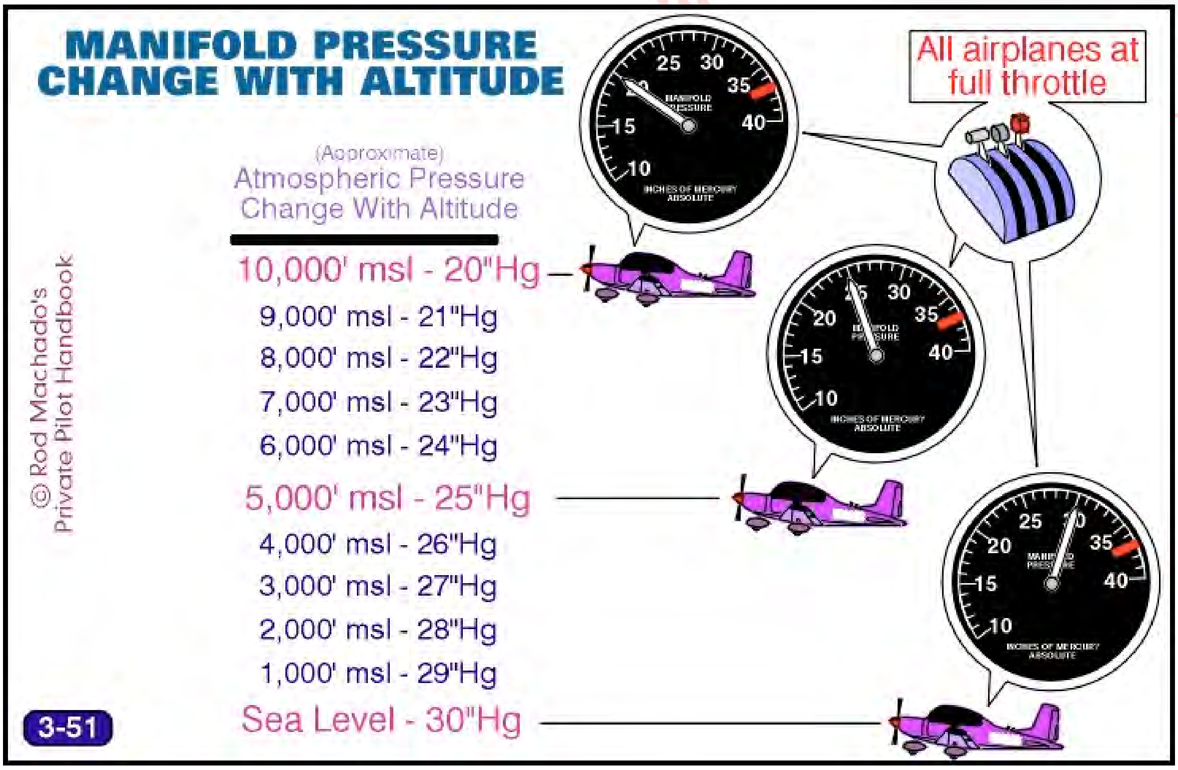
Under normal conditions, the engine's manifold pressure can't rise above atmospheric pressure. Why? The atmosphere can only push an amount equal to how much it weighs.

CONSTANT SPEED PROPELLER



At sea level, atmospheric pressure weighs enough to push a column of mercury 30 inches into a glass tube containing a vacuum. As a measurement of the atmosphere's weight, we say that the outside air pressure is 30 inches of mercury. Therefore, the engine's manifold pressure at full throttle is a little less than 30 inches (it's a little less because of air friction and intake restrictions within the induction system). Clearly, then, a manifold pressure near 30 inches of mercury signifies more power is being developed by the engine. On the other hand, low manifold pressures (say 15 inches or so) indicate less fuel and air is entering the cylinders and less power is being produced.

As the aeroplane climbs, you'll notice the manifold pressure decreases even though the throttle is fully opened. Why? Atmospheric pressure decreases as you ascend. It decreases approximately one inch of mercury for every thousand feet of altitude gain (and increases approximately one inch of mercury for every thousand feet of altitude loss). At sea level you can develop approximately 30 inches of manifold pressure with full throttle. At 5,000 MSL, however, your manifold pressure will be approximately 25 inches with full throttle (Figure 3-51).



Remember, under normal conditions the atmosphere can't force air into the induction system at more than its own pressure (its own weight).

I mentioned that the throttle controls engine power. That's basically true. But engine power can also be varied slightly by the RPM you've selected. In other words, the total power produced by the engine is really a combination of both manifold pressure and engine RPM. Think of it this way: you're on a 2000-calorie diet. You can eat 1500 calories for breakfast, 500 for lunch and skip dinner, 1000 for breakfast, and 500 each for lunch and dinner, etc. There are lots of combinations that will yield 2000 calories.

The same is true on a constant speed prop plane. Different combinations of manifold pressure and engine (prop blade) RPM can be used to attain a given power setting. Any of the manifold pressure and engine RPM combinations listed in the a Pilot's Operating Handbook can be selected to obtain the desired engine power output in cruise flight.

The throttle selects the desired manifold pressure and the propeller control selects engine RPM.

CONSTANT SPEED PROPELLER

Why would you want so many combinations of manifold pressure and RPM?

The reason is that fuel consumption, airspeed and the percent of power produced all vary based on different combinations of manifold pressure and RPM. Noise levels and smoothness of engine operation also vary based on RPM. Even some of your airborne electronic equipment can be affected by engine speed. At least you have a choice among different combinations for power selection.

The big question is, "Why have a propeller that can change its pitch in flight in the first place?" After all, this is just another aeroplane knob you have to contend with, isn't it? Yes it is. But it's worth the trouble.

Aeroplanes having constant speed propellers are much more versatile in their operation. For instance, fixed pitch propeller aeroplanes have their propellers permanently configured (pitched) for either a fast cruise, a fast climb, or somewhere in between. You can't change their pitch in flight.

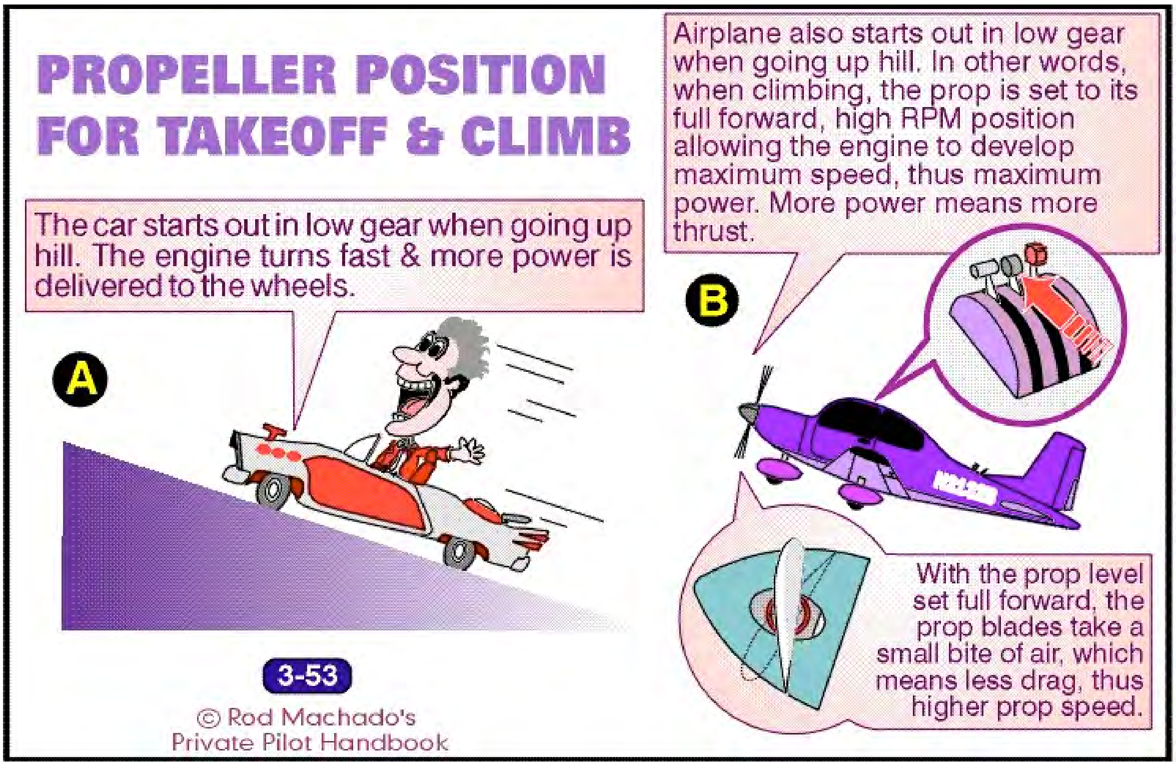
Aeroplanes with controllable pitch propellers, however, can essentially reshape the prop, by changing its pitch, from within. The optimum angle of attack can be used for climb and cruise.

Let's take a look at how a different pitch may result in increased performance.

Low Pitch And High RPM´s

When climbing a very steep hill in a car, you want your automobile's engine to develop nearly 100% of its maximum power. That's why you start off in low gear.

Low gear results in high engine RPM, thus more engine power being transferred to the wheels (Figure 3-53).



As a result, your car is less likely to bog down during the climb. Pay attention the next time you walk up a steep hill. You'll find yourself using lots of short steps (high RPM) instead of the long strides you'll use on the flatlands.

The same philosophy applies to aeroplanes.

During a climb, we want the aeroplane’s engine to develop maximum power. This allows maximum thrust to be produced (remember, it's excess thrust that allows an aeroplane to climb).

Engine power is dependent on its RPM. For an engine to develop its maximum power, it must be operated at its highest allowable RPM. At any lower RPM the engine develops only a fraction of its total horsepower.

CONSTANT SPEED PROPELLER

That's why on takeoff we want the propeller set to its lowest pitch (highest RPM) position (full forward on the prop lever). In this position the prop experiences less wind resistance, resulting in less drag and higher engine RPMs (Figure 3-53B). Under these conditions the engine develops maximum power, thus maximum thrust for climbing and accelerating.

You may be thinking, "How can the propeller deliver maximum thrust if it doesn't take a big bite of air?"

Think of it this way: If the propeller does take a big bite of air (a large angle of attack), it will surely develop more thrust – but only if the propeller continues to turn over at a high speed.

That's the problem! Taking such a large bite of air increases the propeller's drag (just like a wing at a large angle of attack).

This decreases the propeller's speed and prevents the engine from developing its maximum horsepower (it bogs it down, like the car). The final result is that the propeller produces less thrust than it's capable of producing.

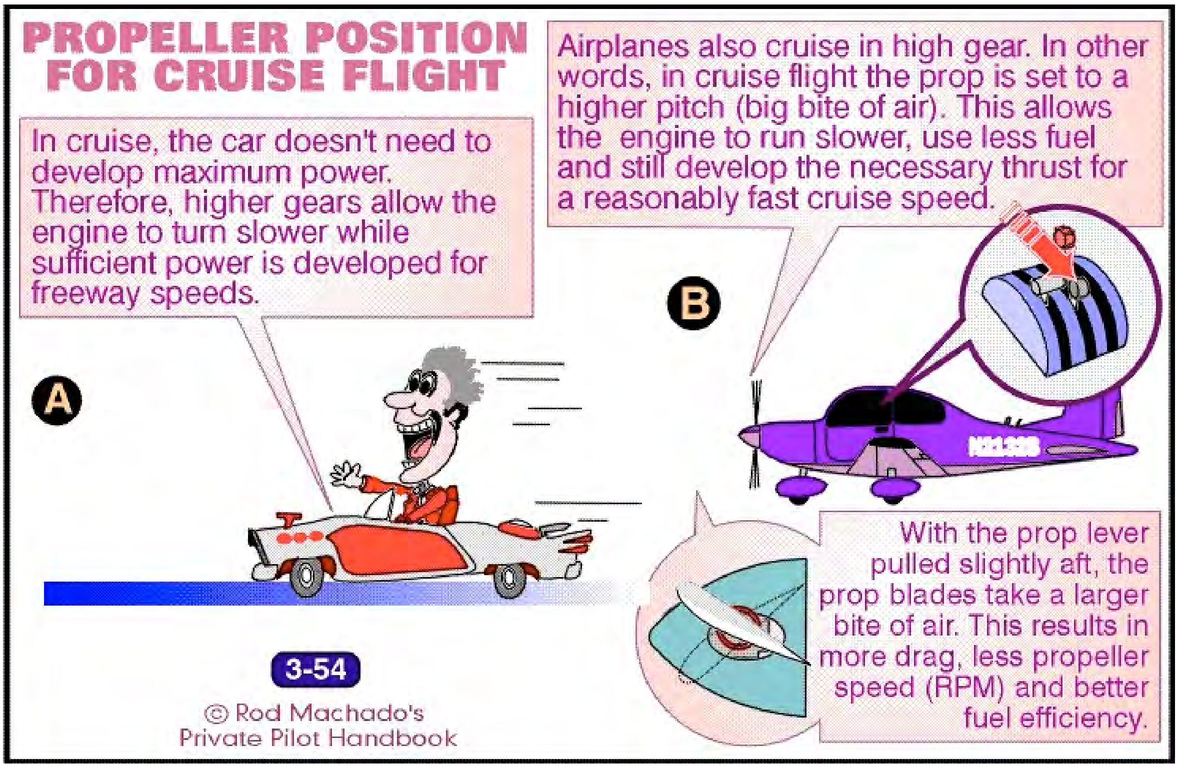
One last way of conceptualising this is to think about a blender (if you don't have one, simply send out a few wedding invitations). If hard vegetable fibre is dropped in before the blades have a chance to spin up, the machine bogs down (RPMs stay low). Nothing gets chopped because the motor has less spinning force or torque at slower speeds. However, once the blender's blades spin to a fast speed, nothing seems to resist the spinning force of the blades. High motor RPMs mean maximum power is developed and the blender's blades resist slowing when they encounter thick vegetable fibre.

The net result of higher engine RPMs for the aeroplane is that maximum engine thrust is produced when the propeller spins faster, even though the blades are at a lower pitch.

High Pitch and Low RPMs

Are there times when you don't need to develop maximum engine power?

Yes. For example, if you're on the freeway, your automobile only needs enough power to keep it moving at a reasonable speed-perhaps only 55% to 65% of its maximum power (if it's a VW Beetle). Anything more than that and it's red-light-in-the-back-window time. High gear (low engine RPM) is selected to maintain freeway speeds (*Fig. 3-54*).



High gear means the engine turns over at a lower RPM, thus producing only the horsepower needed to keep the car moving along at an acceptable pace. This is achieved with less fuel consumption than if the car were running flat out.

Aeroplanes are operated in a similar manner during cruise flight (Figure 3-54B). There is no need to develop maximum horsepower during cruise flight. Our concern is to obtain a reasonably fast airspeed while keeping the fuel consumption low. After all, we could operate our aeroplane in cruise flight at full throttle – but why? The larger drag associated with higher speeds would consume enormous amounts of fuel and not allow us to move all that much faster anyway (remember, total drag increases dramatically at higher airspeeds).

CONSTANT SPEED PROPELLER

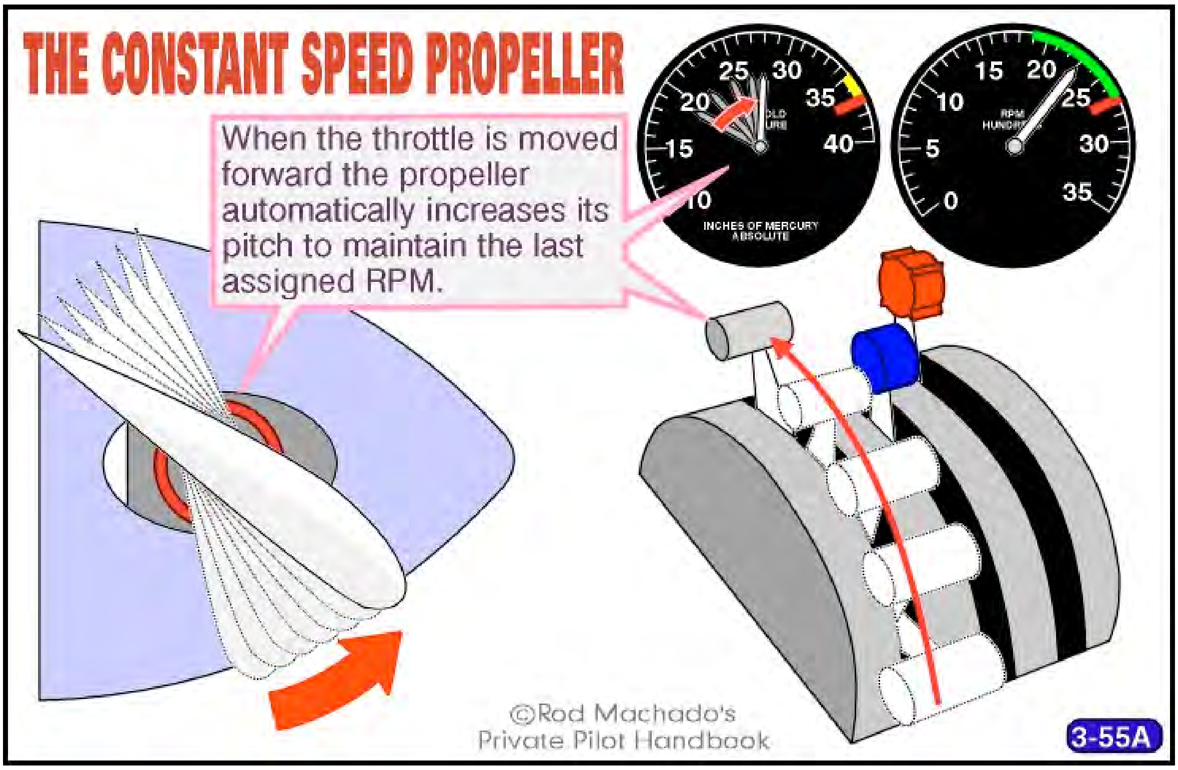
Therefore, cruise flight is a trade-off between high airspeed and low fuel consumption.

With the proper combination of manifold pressure and engine RPM, you can obtain a reasonably fast airspeed for a given rate of fuel consumption.

In cruise flight we select the desired manifold pressure with the throttle, and engine RPM with the propeller control. Now the propeller produces a specific amount of lift (thrust) for a given (lower) fuel consumption.

Why Constant Speed Propellers?

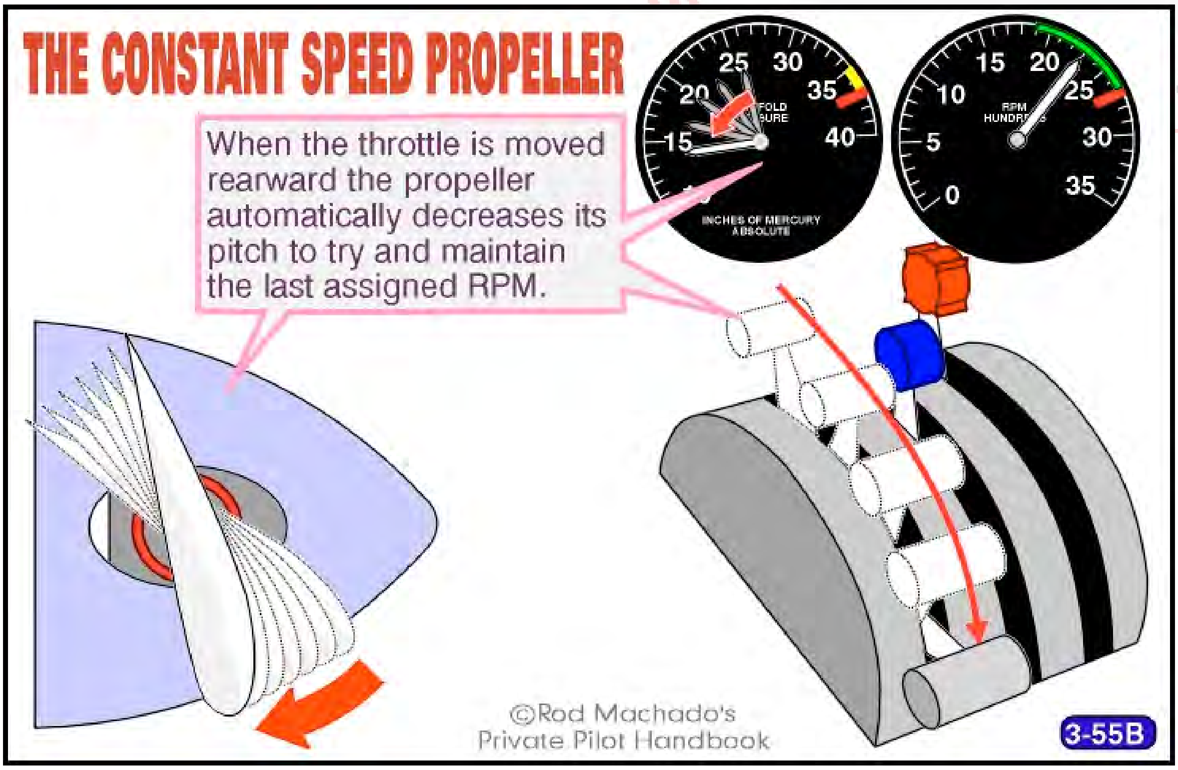
Controllable pitch propellers on general aviation aeroplanes are of the constant speed variety. Once the RPM is established, changes in manifold pressure (by moving the throttle) won't affect engine speed (*Fig. 3-55A&B*).



In other words, opening or closing the throttle (or changing the aeroplane's attitude) doesn't vary the engine's RPM. This is why these controllable propellers are given the name constant-speed propellers. (Of course, if you pull the throttle all the way back, there's simply no power available to keep the propeller spinning. The engine's RPM has no choice but to drop.)

The reason constant speed propellers are put on an aeroplane is to reduce a pilot's workload. Instead of having to readjust the RPM with every change in power, you simply set the RPM and it stays where it's put--just like your home thermostat keeps the temperature constant.

CONSTANT SPEED PROPELLER



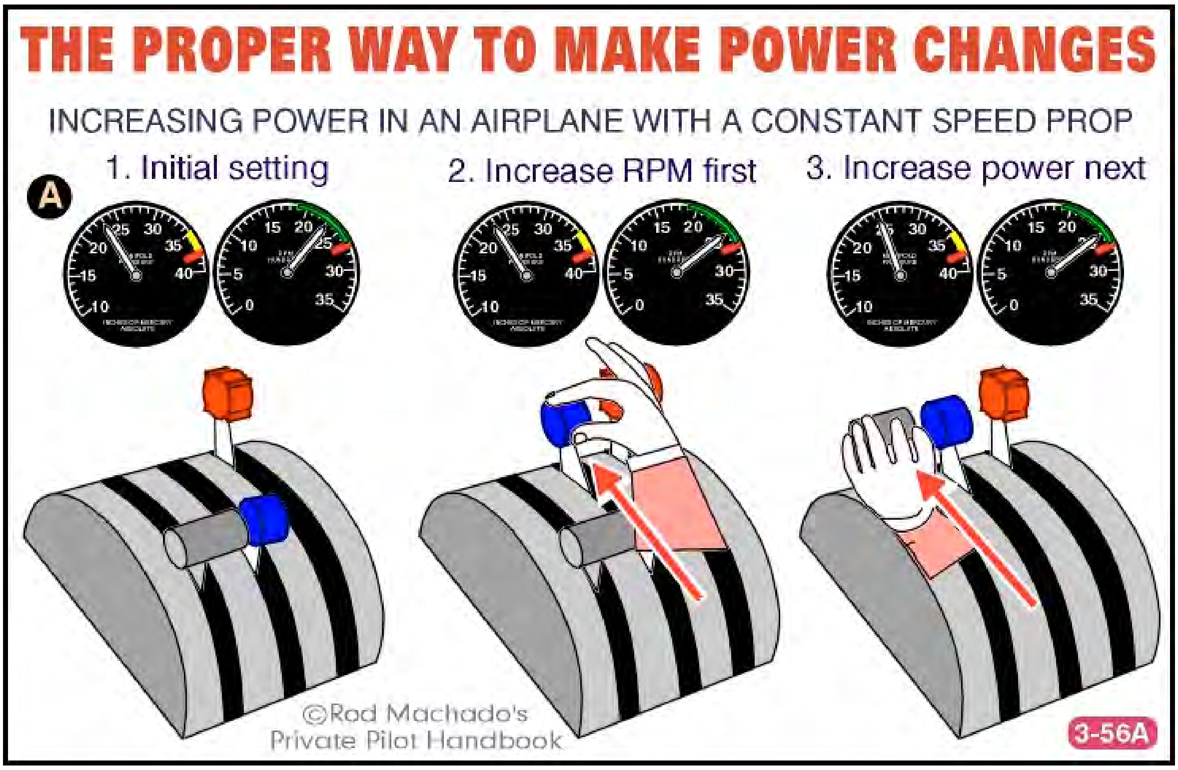
What is the value of having a propeller that maintains a pre-set (constant) speed?

It provides you with one less item to readjust while managing power.

Let's suppose your Pilot's Operating Handbook suggests the most efficient use of engine power during climb occurs at 25 inches of manifold pressure and 2,500 RPM. As you climb, the manifold pressure decreases approximately one inch per thousand feet (because the outside air pressure decreases one inch for every thousand feet altitude gain). Since you have a constant speed propeller, the RPM automatically stays set at 2,500, despite variations in manifold pressure (or throttle positions). All you need to do is keep adding throttle to maintain the desired manifold pressure during the climb; the RPM needs no adjusting.

How to Make Power Changes

With the ability to vary propeller pitch you need to understand a few very important principles about power management. It's relatively easy to over-stress an engine if the throttle and propeller controls aren't used in the proper order during power changes. For instance, suppose your manifold pressure and RPM are set at 23 inches and 2,300 RPM (*Fig. 3-56A-1*).



You want to increase the manifold pressure and RPM to 25 inches and 2,500 RPM.

If you increase the manifold pressure to 25 inches first, it will increase the combustible mixture flowing to the cylinders. This would normally spin the propeller faster. Yet this doesn't happen, since the propeller takes a bigger bite of air to absorb the increase in power.

Cylinder stress increases as the propeller keeps the RPM from increasing (i.e., the expanding gases push harder, yet are unable to move the pistons faster). Given enough cylinder stress, you could damage the engine.

When you want to increase both the manifold pressure and RPM, change the RPM first, then increase the manifold pressure. In other words, move the propeller control forward first, the throttle next, as shown in Figure 56A-2+3.

CONSTANT SPEED PROPELLER

Follow the same philosophy when decreasing manifold pressure and RPM.

Pull the throttle back first, followed by the propeller control.

Another way of thinking about this is to keep the propeller control lever physically ahead of the throttle during all manifold pressure and RPM changes.

A memory aid for this is to keep the prop on top (or always in front of the throttle).

Propeller Tips and Ideas

Be aware that the propeller governor starts working only when the engine is operating above a specific RPM and not below.

In other words, moving the throttle will change the RPM until the propeller reaches its minimum governing RPM.

This is why the magneto check we discussed earlier is performed below this minimum governing RPM.

Remember, we're interested in seeing how much of an RPM drop occurs on each mag and well as between the mags.

Magneto checks done at higher RPMs wouldn't show any mag drops on the tachometer since the propeller would vary its pitch to maintain a specific RPM.

On complex, high performance aeroplanes (those with retractable landing gear and constant speed propellers) we use a verbal checklist while on final approach to land. It's the acronym GUMP.

It stands for Gas (fuel pump on), Undercarriage (gear down), Mixture (full in) and Prop (propeller control full forward).

Why is the propeller control put in the full-forward (low pitch--high RPM) position just before landing?

We do so in the unlikely event there's a need to go-around.

A go around is an aborted landing; you apply full power, climb out, and go around for another attempt at landing. In this situation, it's important that the engine develop full power--just like on takeoff.

That's why the propeller control is moved to the full-forward position – exactly where it is during takeoff.