Rod Machado's Private Pilot Handbook

Second Edition

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Updating and refreshing your knowledge

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More than 1,100 original color illustrations and photos

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ward acting forces. (If you're having trouble with vectors, see the accompanying sidebar at the bottom of page B3.)

Here's what you've been waiting for: The upward push of the road on the car (arrow A) is equal to the car's weight on the road (arrow C). In other words, lift still equals weight, even in a climb. Part of the weight, however, now acts like drag (arrow D), which really *is* a drag, because it gets added to the wind resistance. As we've already learned, thrust is the force that overcomes drag.

The forces acting on an airplane during a climb are similar to those of the car (Figure 5), the only major difference being that you (the pilot) choose the slope of the hill you climb. This is done using the elevator control in the cockpit (more on the elevator control later).

As you can see, it's excess thrust, not lift, that allows an airplane to climb. Given this very important bit of knowledge, you'll now understand why smaller airplanes with limited power can't climb at steep angles like the Blue Angels do at airshows.

AN AIRPLANE'S FOUR FORCES IN A CLIMB

Similar to the automobile, it is engine thrust (F), not extra lift (A) from the wings, that pulls an airplane up its "pilot-made" hill. The steeper the angle of climb (the hill) the more the force of weight (B) acts aft (D). That portion of the weight (D), acting in the direction of drag (E), pulls the airplane aft and acts just like drag. Lift (A) still acts opposite the portion of weight (C) that acts 90 degrees to the flight path (which is also the relative wind).

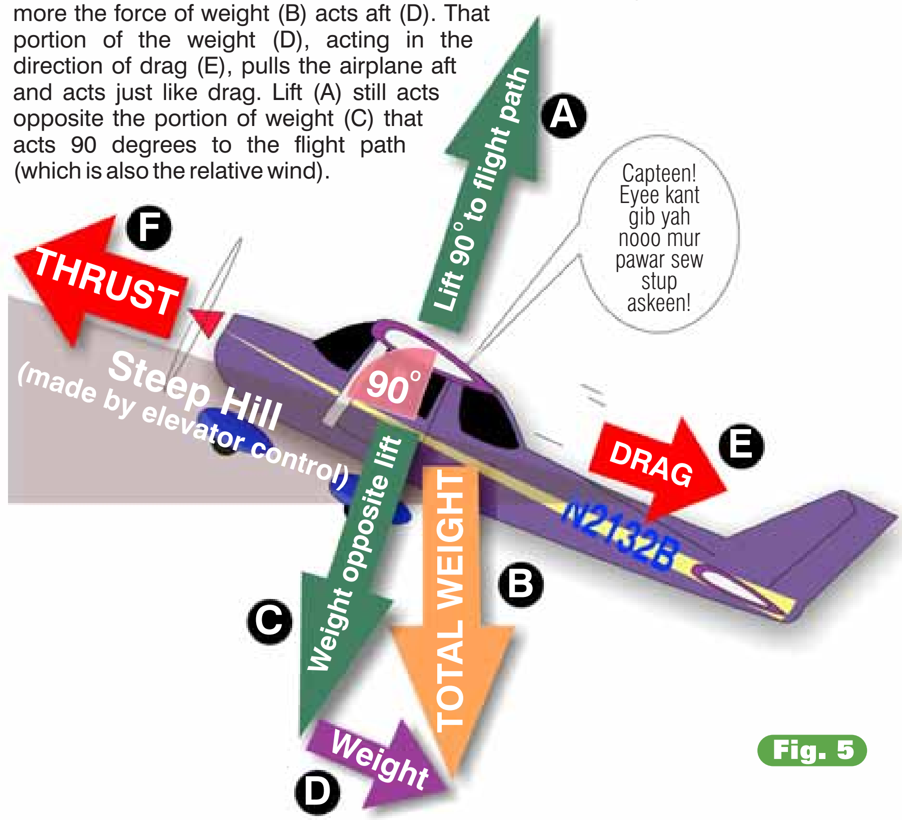


Fig. 5

Let's go back to the automobile and climb a steep hill (Figure 6). The maximum forward speed of our car on a level road with full power is 65 mph (Car A). As we move up a hill (Car B) our speed drops to 50 mph. An even steeper hill slows the car to 40 mph (Car C). The limited horsepower of the car's engine simply can't match the drag caused by wind resistance plus rearward-acting weight as the hill steepens, so the car slows. A bigger engine or redesign of the car to produce less wind resistance are the only options that will help.

POWER AND CLIMB ANGLE

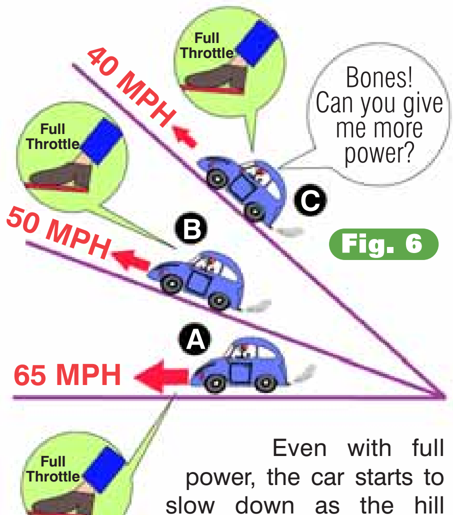


Fig. 6

Even with full power, the car starts to slow down as the hill steepens. Eventually the car will come to a stop if the hill becomes too steep. In an airplane, you don't try to climb too steep a hill or you might slow down to the point where your wings can't develop the necessary lift to remain in flight.

The same analysis works, up to a point, for an airplane attempting to climb a hill in the air (Figure 7). Let's say your airplane has a maximum speed of 120 mph in straight and level flight with full throttle (Airplane A). (Airplane throttles are similar to automobile throttles except that they're hand operated. You push in for more power and pull out for less.) Applying slight back pressure on the elevator control points the airplane's nose upward (Airplane B). This causes the airplane to climb a shallow hill. The speed decreases to 80 mph just as it did in the car. Attempting to climb a steeper hill (Airplane C) slows our speed down to 70 mph. We can't climb the hill we just selected faster than 70 mph because we don't have the extra horsepower (thrust) to do so.

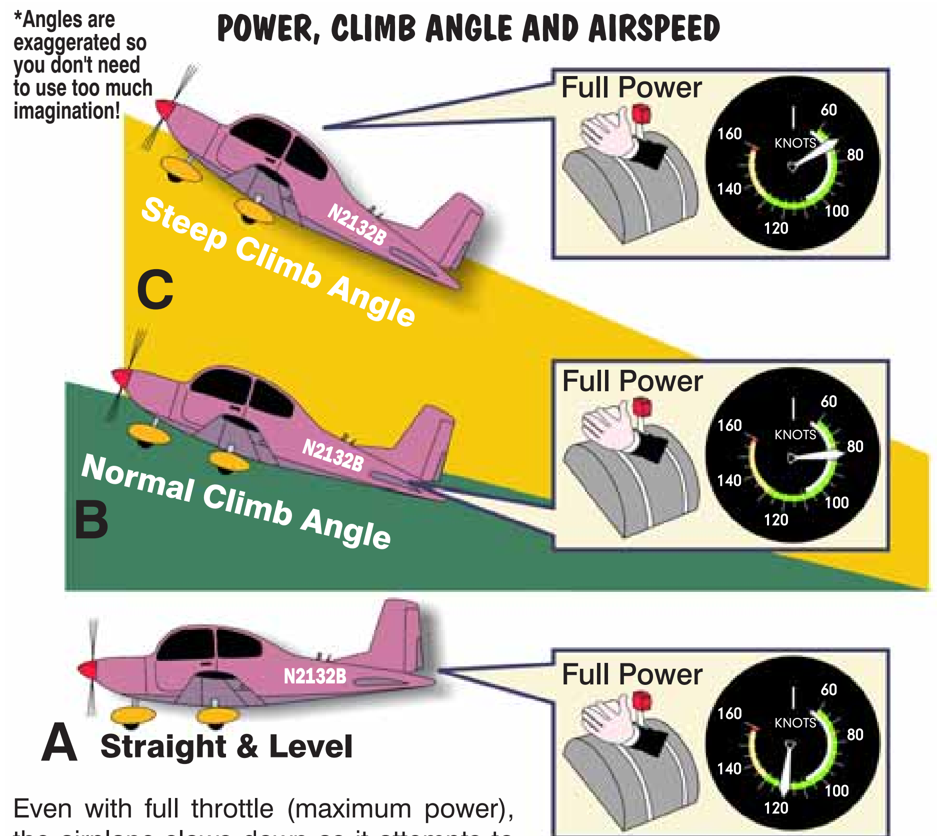
As we continue to steepen the angle of climb, our airspeed decreases further, just like the car's speed did. Here, however, is where the airplane goes its own way. Airplanes need to maintain a minimum forward speed for their wings to produce the lift required to stay airborne. Ever wonder why airplanes need runways? Same reason long jumpers do. Airplanes (and long jumpers) must attain a certain speed before they can take flight.

This minimum forward speed is called the *stall speed* of the airplane. It's a very important speed that changes with variations in weight, flap setting, power setting and angle of bank. It also varies among airplanes (no need to worry because later I'll show you how to recognize when you're near a stall). As long as the airplane stays above its stall speed, enough lift is produced to counter the airplane's weight and the airplane will fly.

If the stall speed of Airplane C (Figure 7) is 60 mph, then climbing at a slightly steeper angle will result in insufficient lift for flight. We call this condition a *stall*. Done unintentionally, it leads to such primitive linguistic sounds as "Uh-oh," "yipes," "ahhhhh," as well as "I think I need to have my chakras balanced." Needless to say, these sounds make passengers reluctant to ever fly with you again. This is why some of your time as a student pilot will be spent finding out about stalls, and doing them (intentionally, that is). Instructors have special biological filters installed that keep them from making these sounds on those rare occasions when you unintentionally stall the airplane. That's why they are sometimes referred to as *certified* flight instructors.

What you need to know is that airplanes with a lot of power (like jet fighters) can climb at steep angles; those with limited power, however, must climb at less steep angles.

Knowing it's extra thrust and not extra lift from the wings that is responsible for the climb allows you to draw some interesting conclusions. For instance, anything that causes the engine to produce less power prevents you from achieving your maximum rate of climb. Among the things resulting in less power production are high altitudes and high temperatures. More on these factors a bit later.



Even with full throttle (maximum power), the airplane slows down as it attempts to ascend a steeper hill. Pilots adjust their climb angle (hill size) by selecting an attitude that gives them a specific climb airspeed.

Fig. 7

At this point you should be asking an important question. I certainly don't mean questions of the "Zen-Koan" type, such as "What is the sound of one cylinder firing?" or "If an airplane lands hard in the forest and nobody is there to hear it, does it really make a sound?" A good question for you to ask is, "How can I determine the proper size hill for my airplane to climb?" Let's find out.

Airplanes have a specific climb attitude (steepness of hill) that offers the best of all worlds—optimum climb performance while keeping the airplane safely above its stall speed. You can determine the proper climb attitude for your airplane by referring to its airspeed indicator.

With climb power applied (usually full throttle in smaller airplanes) the pitch attitude is adjusted until the airspeed indicates one of two commonly used climb speeds. These speeds are known as the *best angle of climb* and the *best rate of climb* airspeed. The best *angle* of climb provides the greatest vertical gain in height per unit of forward travel; the best *rate* of climb provides the greatest vertical travel per unit of time. You select best angle when you need to get up in the shortest possible distance, usually to clear an obstacle. You choose best rate of climb to gain the most altitude per minute. Let's put this in concrete terms. Say there's a concrete tower 750 feet high half a mile off the end of the runway. You definitely want to be above 750 feet at one-half mile out, and you

During a descent, your job is to maintain stable cylinder head temperatures (CHT) and oil temperatures (i.e., keep their temperature indications in the green). On some airplanes, gear extension or even partial flap extension at high speeds can be used in lieu of large power reductions to start a descent (check your POH). While momentary power reductions aren't as harmful if the power is immediately restored, large ones over long periods can be damaging. Try planning your descents so engine temperatures change slowly from their previous cruise values.

The Propeller

Propellers come in all sizes and colors, but they are of two basic types: *fixed pitch* and *constant speed*. In an airplane 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 airplane 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, aluminum). 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.

THE CONSTANT SPEED PROPELLER

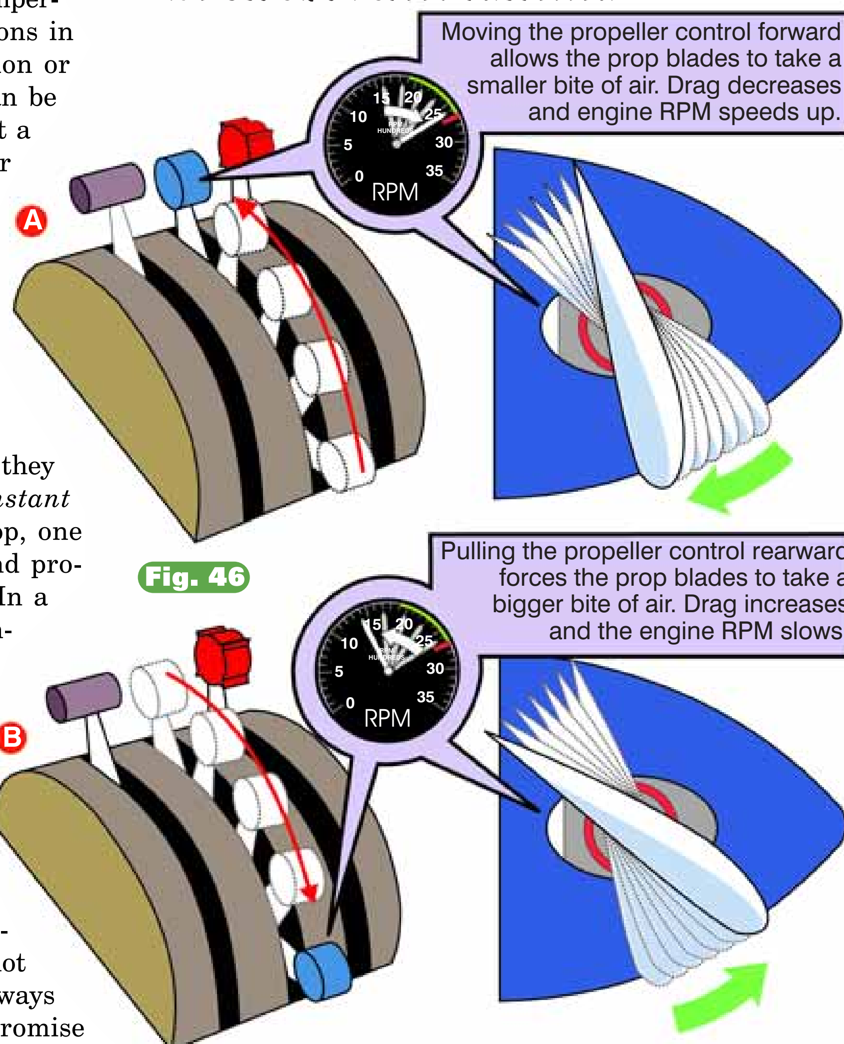


Fig. 46

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

As you move up into higher performance airplanes, you'll soon encounter *constant speed (controllable pitch)* propellers. Airplanes with these propellers usually have both a throttle and a propeller control, so you manage engine power and propeller RPM separately (Figure 45).

ENGINE CONTROLS FOR AIRPLANES WITH CONSTANT SPEED PROPELLERS

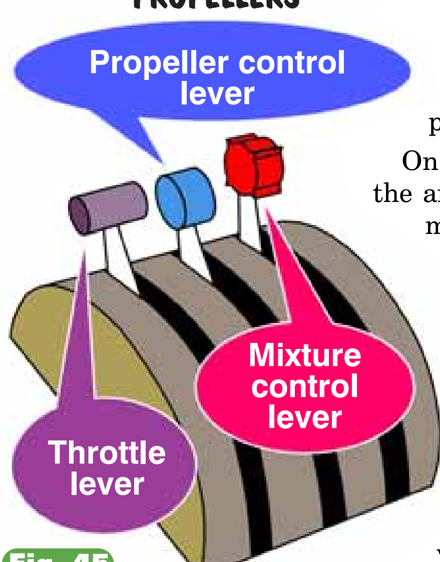
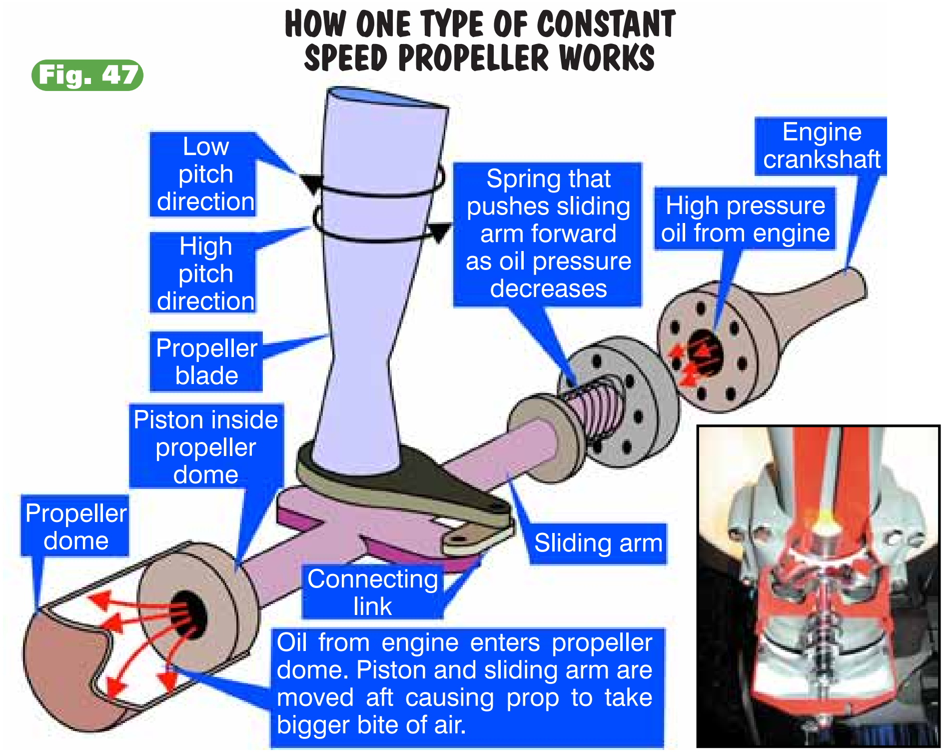


Fig. 45

On airplanes 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 (its angle of attack). This directly controls how fast the propeller rotates (its speed or RPM) as shown in Figure 46. 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 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

Fig. 47



Keeping Up To (Constant) Speed

Figure 47 shows how the constant speed propeller system works on a typical single engine airplane. Oil pressure from the engine provides the hydraulic force used to increase the propeller's pitch. Moving the propeller control aft sends high pressure engine oil to a piston/cylinder arrangement within the propeller hub. This hydraulically pushes the propeller toward a high pitch position. Moving the propeller control forward reduces oil pressure within this piston/cylinder arrangement allowing centrifugal force to return the propeller blades to their low pitch (high RPM) position. We *cycle* the propeller during our runup (change the pitch from low to high and back again a few times) to make sure the system is working as well as to purge cold oil from the propeller's hydraulic system.

RPM. 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 46B.

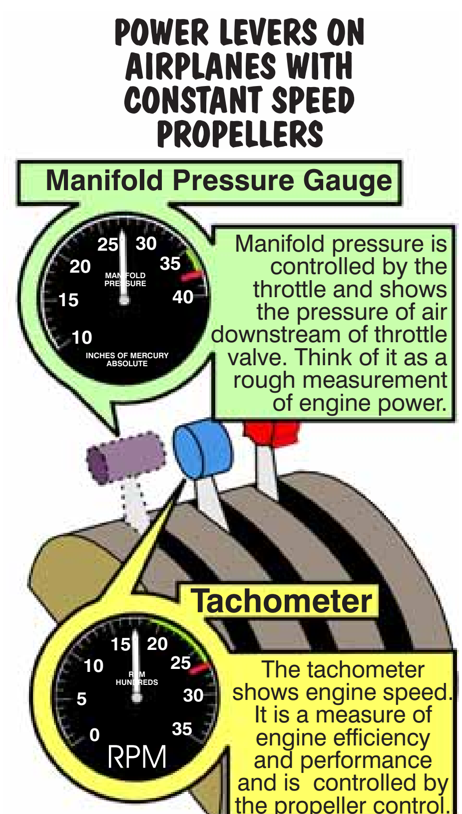


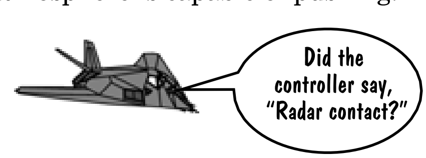
Fig. 48

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 (Figure 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 (Figure 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 that we'll discuss in Chapter 5).

Manifold pressure is measured downstream of the throttle valve, as shown in Figure 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 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 (Figure 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.



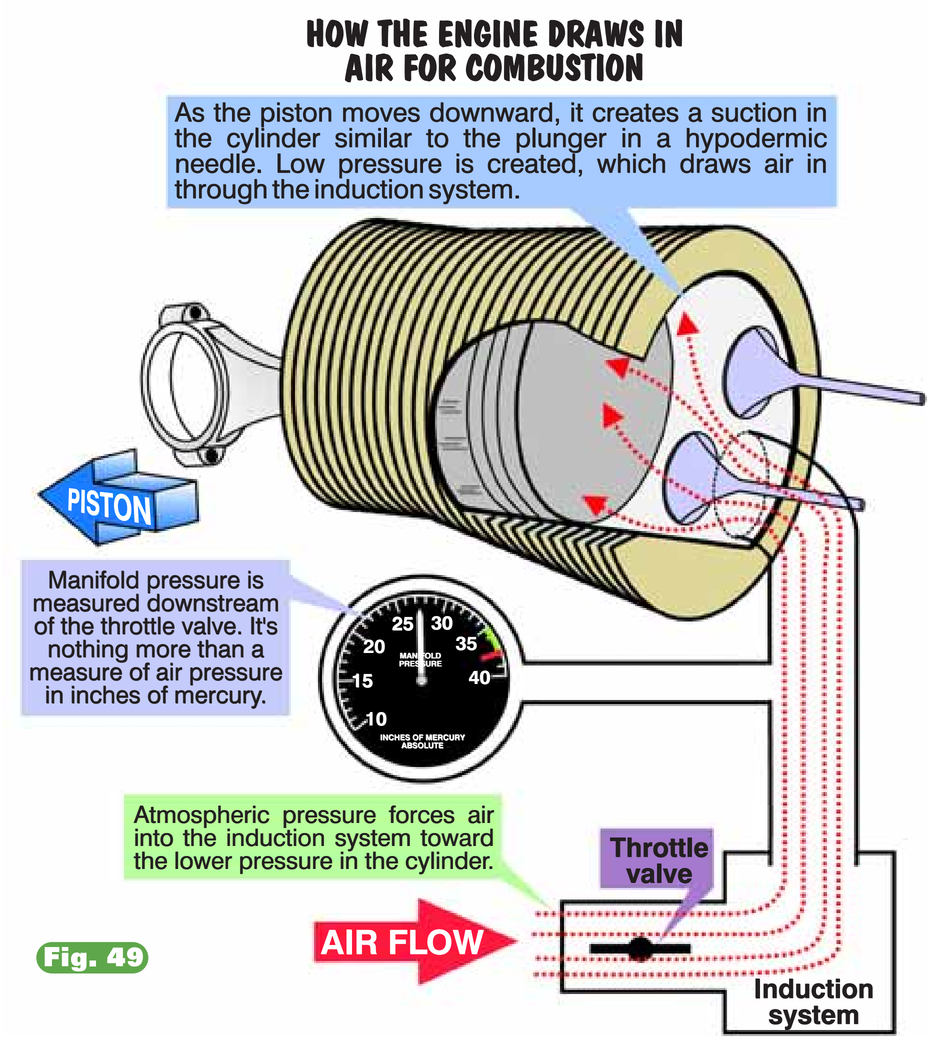
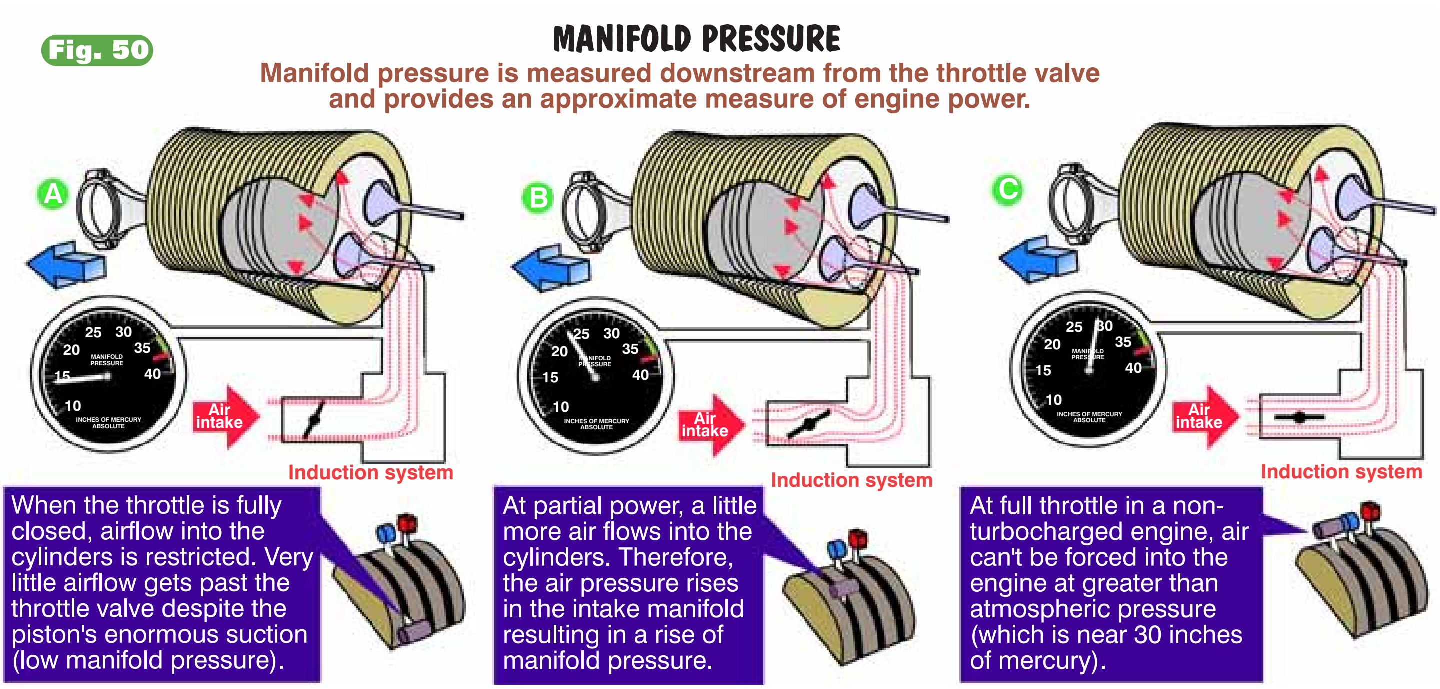


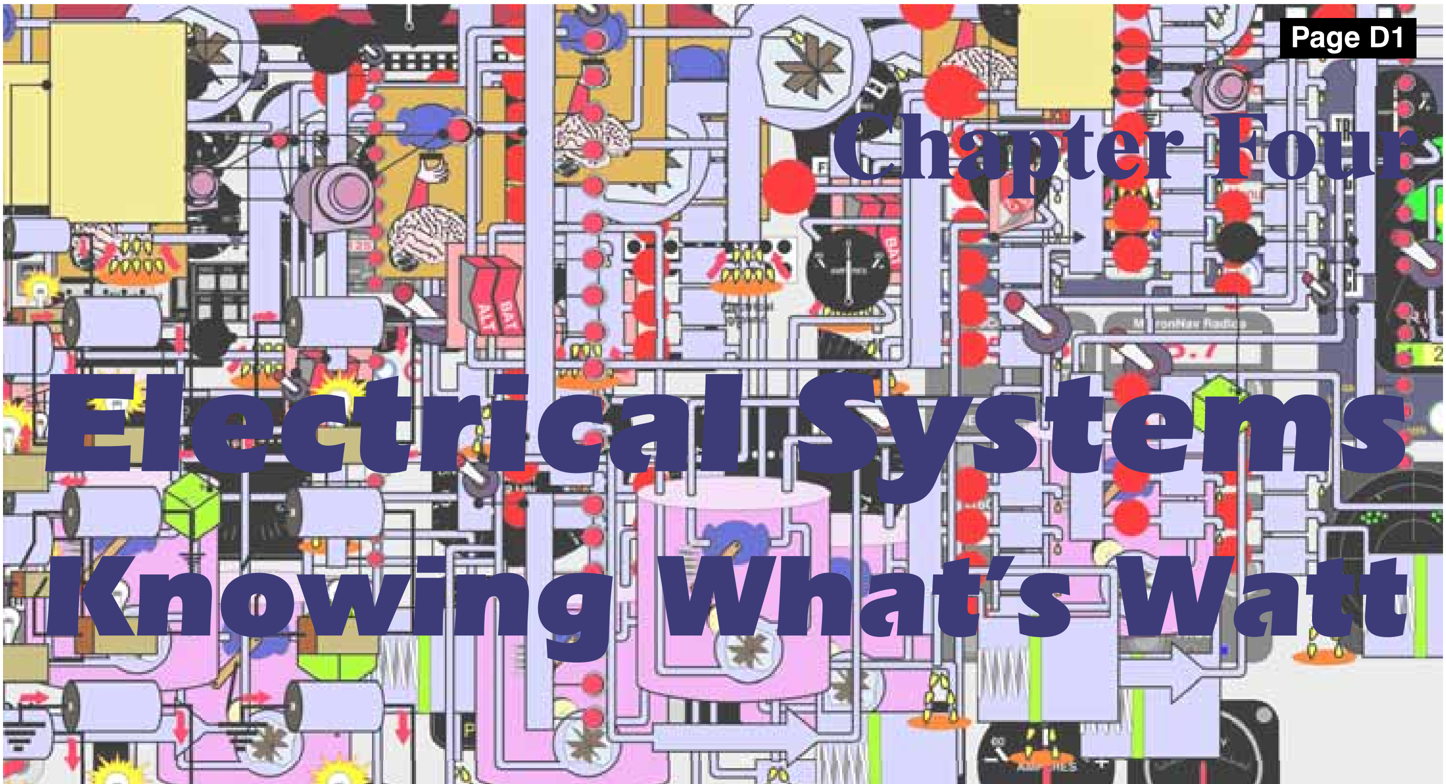
Fig. 49

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. At sea level, atmospheric pressure weighs enough to push a column of mercury 30 inches into a glass tube containing a vacuum (see Chapter 5 for more details on barometric pressure). 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, manifold pressures 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 airplane 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

Fig. 50





Chapter Four

Electrical Systems
Knowing What's Watt

A Simplified Approach for Those With Little or No Understanding of Electricity

Welcome to Volts for Dolts, the Machado QuickCourse for those afraid of electricity.

Attention, class. This is going to be easy.

Watt? Easy? Yes, because we're going to learn what electricity does, rather than split atoms over what it is.

Let's be practical. You don't know, and don't much care, about the difference between jewels and joules. You do want and need to know how to detect and direct electrons in your airplane and put them to work for you. You also need to know when the electrical system is threatening to roll over and play dead, and what can be done about it.

Read on. Fear not. Think volt, not bolt.

Electricity and Water

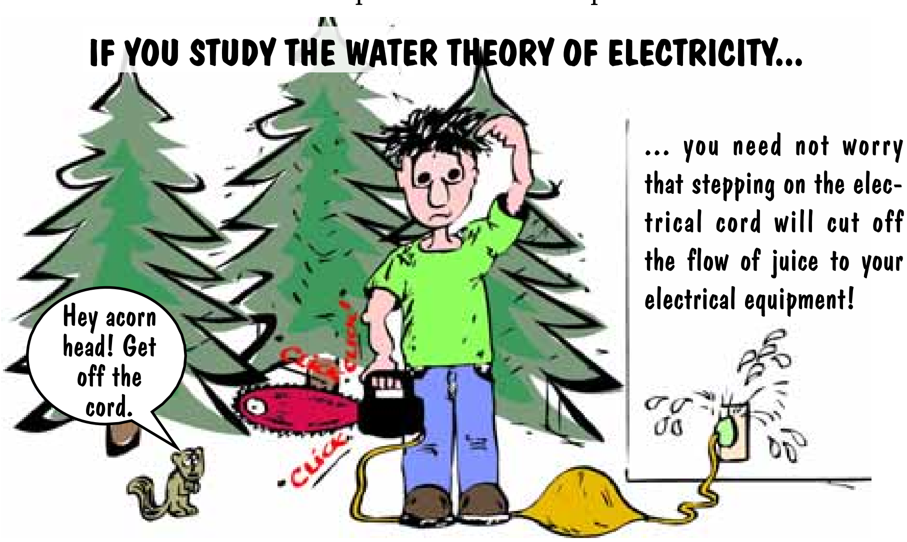
Albert Einstein once said, "Make everything as simple as possible, but not simpler." For instance, Einstein's concept of time distortion is often discussed from a mathematical perspective. For most of us, this is like listening to a lecture delivered in Martian. Actually, Southern Martian. On the other hand, suppose someone said that the length of one minute depends on which side of the bathroom door you're on. Now we're communicating.

Unfortunately, the philosophy of simplicity has not been applied to understanding the airplane's electrical system—until now.

We're going to approach this like a plumber, by thinking about electricity as though it were water. This may be the only chance you will ever have to mix electricity and water safely, so pay attention.

A water model of electricity uses basic plumbing language to explain how electrons flow in a circuit. The only problem with the model is that you can't use it to build a computer. The model's language isn't precise enough to describe the intricate electrical nuances necessary to accurately convey the point (besides, what would you do if water suddenly shot out of your hard drive?). You can, however, use the water model to describe—accurately enough to suit any normal private pilot—how an airplane's electrical system works.

I caution you not to take this model literally, and if you actually are knowledgeable about things electrical, I also urge you not to take offense. The model is only used to help clarify certain cause and effect relationships.



The Charge-Discharge Ammeter

Between the positive terminal of the battery and the primary bus is another version of an ammeter found on some airplanes (Figure 12). Ammeters of this variety are often called *charge-discharge* ammeters. Figure 13 shows a charge-discharge ammeter. As the name implies, the charge-discharge ammeter tells you if electrical current is flowing into or out of the battery. This directly informs you about your electrical system's state of health. Whether you have a load meter or a charge-discharge ammeter depends on the specific make and model of your airplane. Most airplanes have one or the other but seldom both.

Current flow from the primary bus into the battery is indicated by a positive needle deflection (Figure 14). Think of water (electrical current) pushing the needle toward the (+) or (-) side of the ammeter as it enters or leaves the battery. A positive deflection usually implies that the battery is being charged (water is moving into the battery). A negative needle deflection indicates that the battery is supplying the primary bus with electrical current (water is moving out of the battery).

Normally, the needle should be resting near the zero or center mark. This implies that the battery is neither being charged nor discharged (a good sign). Continuous needle deflections too far from center, however, are cause for concern. There are circumstances where the needle will indicate a large deflection from the center position for short periods.

Starter motors demand large amounts of electrical current for their operation. After startup, the battery is sure to be slightly drained. Expect to see a positive (+) needle deflection of five, maybe six or seven needle widths on the ammeter right after engine start. This means that the alternator is replenishing battery energy consumed by the current-hungry starter. Expect a similar ammeter indication if the radios were

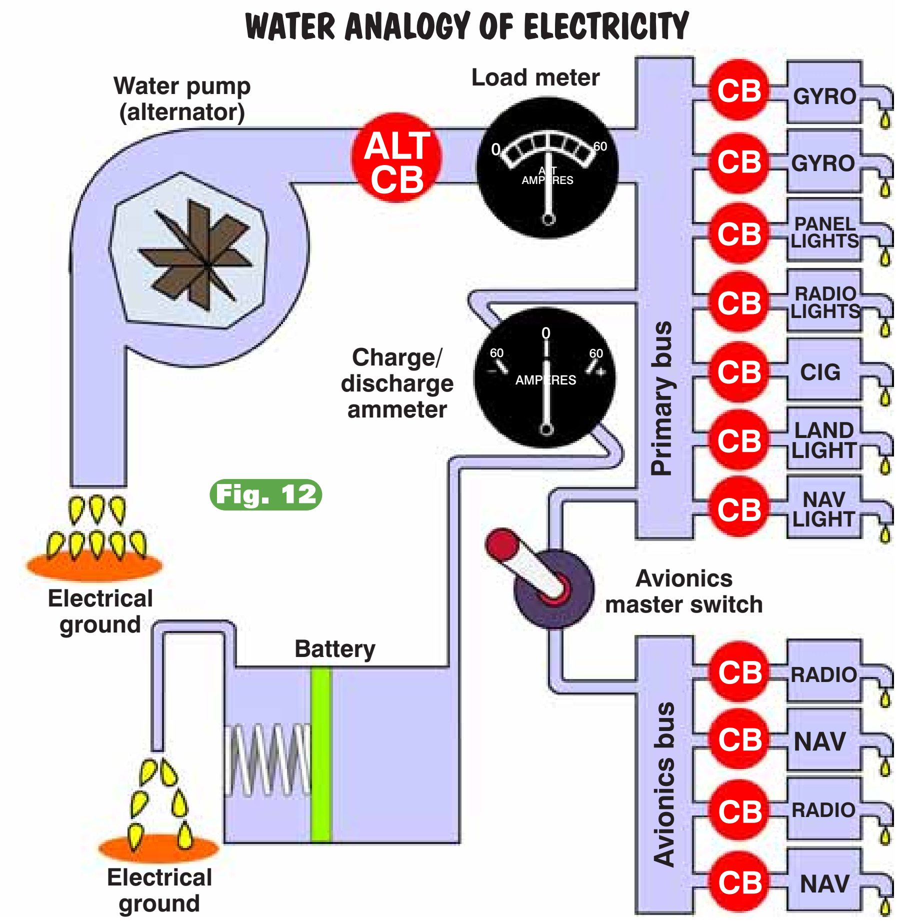


Fig. 12

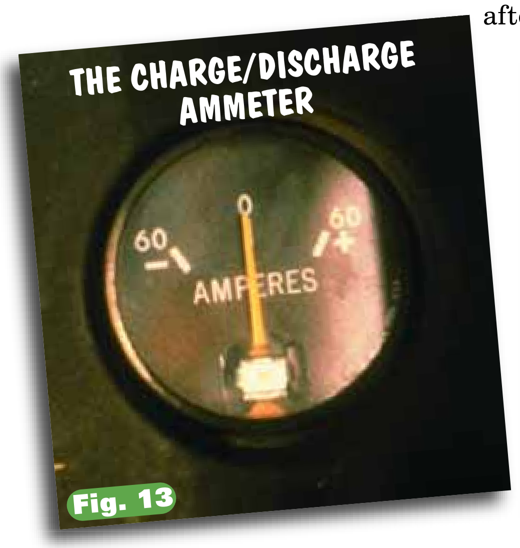


Fig. 13

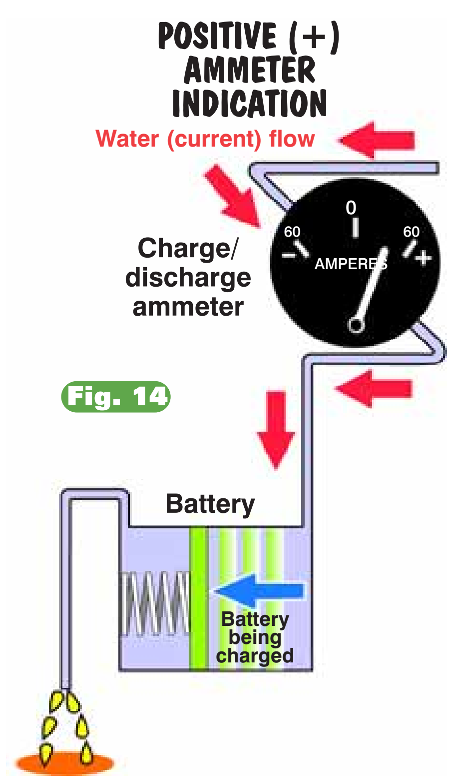


Fig. 14

used extensively prior to engine start. But beware! Too much charge is not a good thing—for batteries or credit cards!

Most airplane operation manuals suggest that after approximately 30 minutes of cruising flight, the ammeter needle should return to within a two-needle-width deflection from center on the positive (+) or charging side. A larger (positive) needle deflection suggests problems with the battery or the alternator. A runaway (unregulated) alternator can provide too much current and overcharge the battery. This is usually indicated by a large positive needle deflection (more than one or two needle widths).The excess voltage can boil off battery fluid (electrolyte), damaging the battery and possibly causing a battery fire.

A needle deflection on the negative (-) side means current is flowing out of the battery onto the primary bus (Figure 15). It also means the alternator isn't providing the necessary voltage to keep the battery charged. This situation is similar to a flight instructor's bank account, where more is going out than is coming in. Chances are the alternator has failed, has been automatically disconnected from the system, or is being improperly regulated. Any way you look at it, you have a problem. The battery will eventually lose its charge.

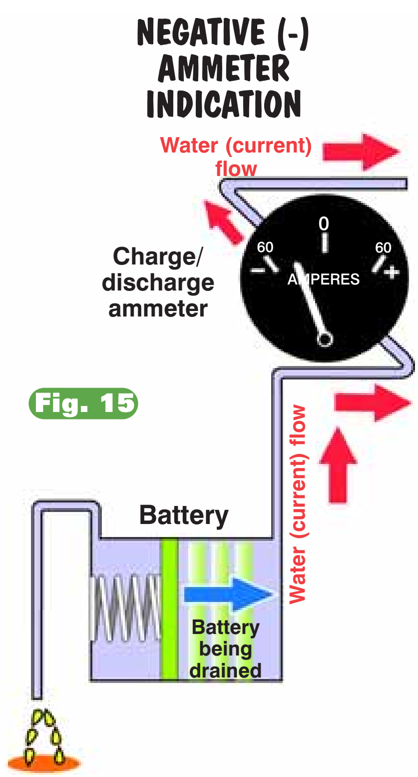


Fig. 15

Airplanes With Volt and Ammeters

The voltmeter gives you more direct information about the alternator's output or, if the alternator isn't on line, about the energy available in the battery. Unlike the ammeter, the voltmeter can tell you the condition of your battery before the engine is started.

An excessive system-voltage reading probably indicates voltage regulator trouble that can lead to battery overcharge and electrical equipment damage. Insufficient voltage indicates that the battery isn't being charged properly. Remember, system voltage must be higher than battery voltage for the battery to charge.

This situation is best handled by conserving battery energy (turning off everything you don't need) and, if necessary, landing at the nearest airport. Remember, you may need battery power to lower landing gear or flaps, or power the landing lights if flying at night. This is why good pilots carry flashlights (and bad pilots use flashlights to carry their dead batteries). A nearly centered charge-discharge ammeter needle usually means an electrical system that knows what's watt and is taking care of business.

In the early 1980's I had the pleasure of checking out an airline captain in a Cessna 152. We had a wonderful time learning the systems and flying the aircraft. He did quite well except for one thing. On every final approach he would call the tower and say, "Ahhh, John Wayne Tower, this is United heavy, we're on a long final approach for 1-9-Left." The controller thought this was really funny. The pilots of the little planes on short final for runway 19 Left didn't. The thought of an enormous metallic Pac Man gaining on them was downright scary! Attempting to understand the electrical system is somewhat like being the guy on short final for 19L. It's scary at first, but when you get a good, clear look at the threat, it's not so bad after all. Hopefully, you haven't been scared by the electrical system so far. Let's return to our discussion on load meters and discuss them in relation to the airplane's battery.

Load Meters

There are benefits and disadvantages to almost everything you do. For instance, whenever I travel to a location for a speech, I always get the most economical airfare for the client. However, economy is not without its disadvantages. On my last flight to Nome, Alaska I had four plane changes. Unfortunately, two were in flight. Load meters in lieu of charge-discharge ammeters have their benefits and disadvantages. Essentially, both kinds of meters provide pilots with the same type of information, but in a slightly different format.

Load meters provide important indications about the health of the airplane's electrical system. Unlike charge-discharge ammeters, they are calibrated to reflect the actual ampere load placed on the alternator. Both varieties of ammeter are shown in Figure 16. Remember, most airplanes will have either one variety of ammeter or the other.

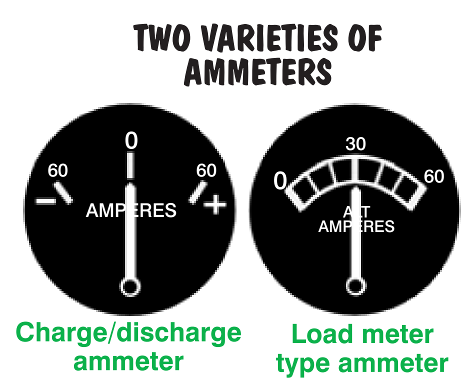


Fig. 16

Load meters with a zero or full-left deflection indicate the alternator isn't providing current to the primary bus. Any electrical equipment that's in use must be receiving its electrical energy from the battery. A full left deflection of a load meter needle is similar to a charge-discharge ammeter reading pointing to the negative (-) side of its scale.

Load meter needle deflections to the right of the zero index represent the electrical current drain on the alternator. Another way of saying this is that a right needle deflection represents the alternator's output. If you add all the electrical current used by the active electrical equipment, this sum should be equal to the amount the needle's deflected. After all, the alternator should be producing what the system demands, otherwise battery energy is being drained.

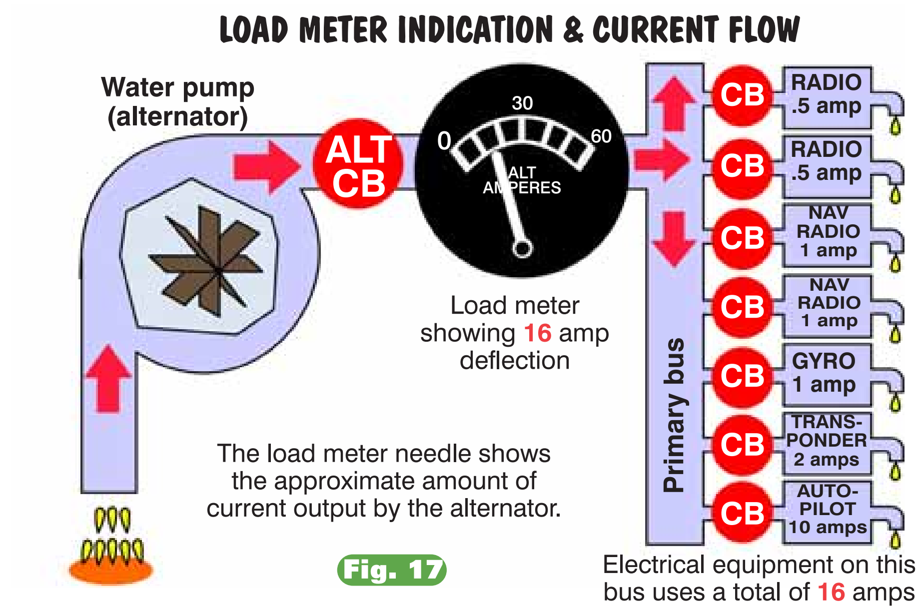
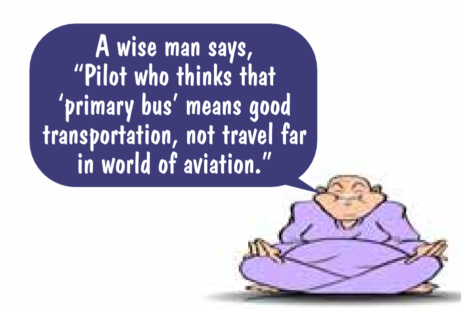


Fig. 17



Electrical Drain

If you're piloting an airplane equipped with a load meter, you need to know how much electrical current each piece of electrical equipment consumes. Think of each piece of electrical equipment as having a minimum thirst level. Some equipment needs more water (current) to operate than others. *Amperes* are a measure of the amount of electrical current (gallons of water per hour) consumed by each of the airplane's electrical items. Understanding how thirsty each electrical item is, is the key to understanding if your alternator is working properly.

Radios typically consume one-half amp of current while receiving and about 5 amps while transmitting. Nav radios and gyros require about 1 amp, transponders about 2 amps, autopilots about 10 amps. Full deice equipment (this is special equipment for advanced airplanes) might gulp as much as 70 amps for continued operation.

With two receiving radios, two nav radios, one electric gyro, a transponder and an autopilot in use, a 16 amp deflection should be shown on the load meter (Figure 17). A needle deflection less than 16 amps implies that the alternator isn't providing enough current to run the equipment. Where is the extra electrical energy coming from? Need a hint? There's only one place: the battery. Needle deflections less than the summed amperage of active and properly working electrical equipment imply that the battery will eventually be drained. That's why it's absolutely necessary that you know how much current each piece of electrical equipment draws.

Suppose the load meter's needle deflection is greater than the needs of the electrical equipment, as shown in Figure 18. This is similar to a charge-discharge ammeter indicating a large, positive (+) needle deflection. In either case, such indications suggest that the alternator isn't working properly or that there is a leak in the electrical plumbing (otherwise known as a short). Soon, we'll discuss how the alternator is regulated and why it may develop problems.

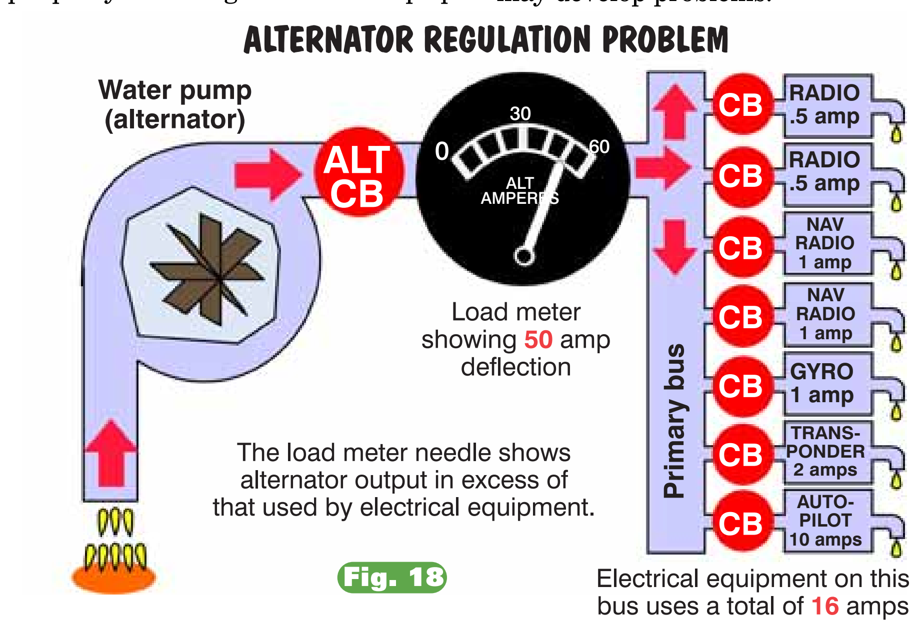


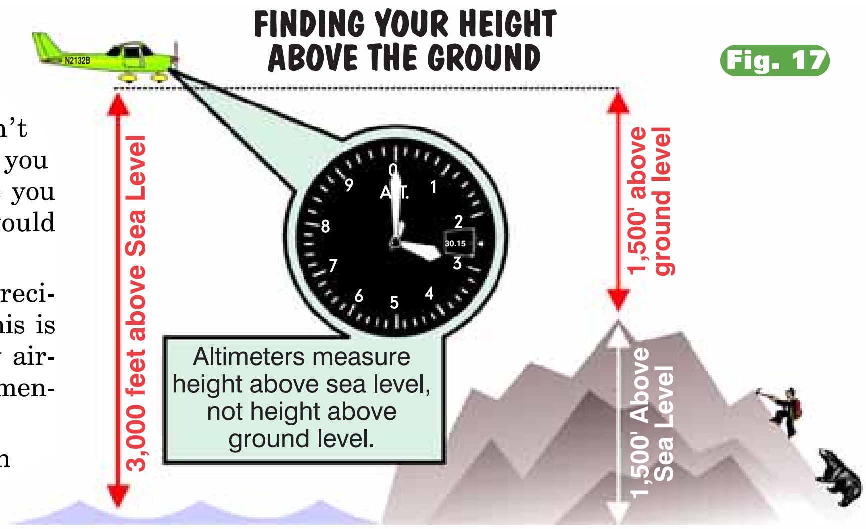
Fig. 18

The Altimeter

Welcome to the third dimension. One of the things that makes aviation unique is your ability to operate in 3D. No, you won't need any of those funny-colored glasses, but you will need some assistance figuring out where you are in the third dimension. This is why I would now like to introduce you to your *altimeter*.

Airplanes move left or right with great precision, flying specific headings and airways. This is two-dimensional navigation. Altimeters allow airplanes to fly at specific altitudes—a third dimension—with equal precision.

There are lots of ways to get high in aviation (all perfectly legal and honest, honest!). In the next few minutes, you will discover that there's altitude and then there's *altitude*. Knowing one from the other is crucial to your success as a pilot, not to mention your longevity as a person.



Finding your height above the ground requires that you subtract the ground's height (its MSL value is found on sectional charts—see Chapter 10) from your height above sea level (which is shown on your altimeter).

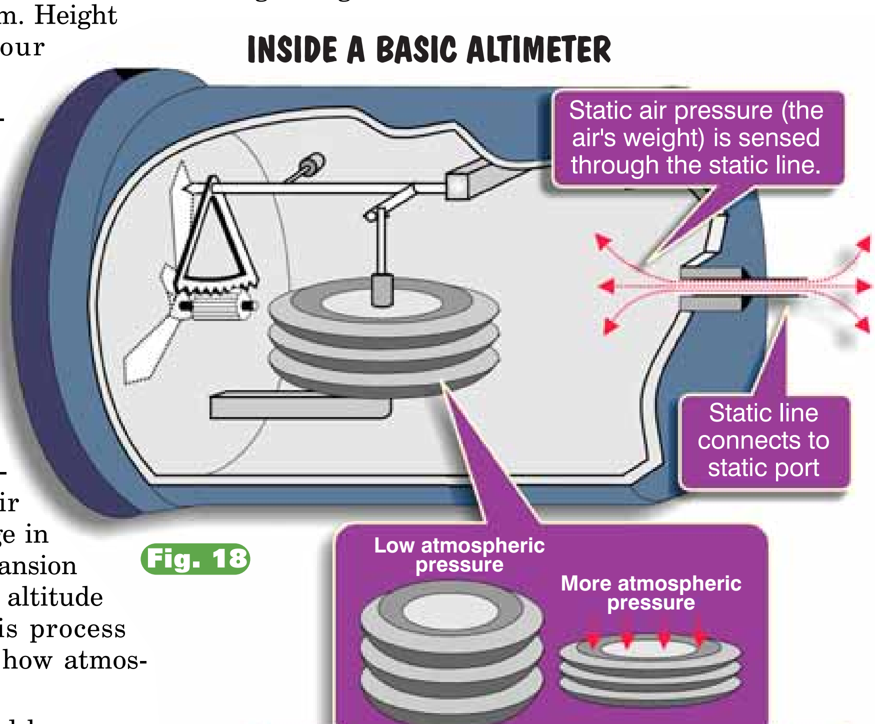
An altimeter (Figure 17) provides you with your height above sea level—otherwise known as your *true altitude*. Sea level is a worldwide standard; therefore, it's a consistent reference for altimeter measurement.

Altimeters do not directly tell you your height above the ground. Why? The ground isn't a consistent reference. Ground height varies dramatically. If, however, you know how high you are above sea level, and you also know the ground's height above sea level (this is found on navigational charts), then finding your height above the ground is simply a "take-away" math problem. Height above ground is technically known as your *absolute altitude*.

An altimeter works by measuring the difference between sea level pressure and pressure at the airplane's present altitude. Figure 18 shows how this is accomplished. Inside the altimeter is a small, expandable capsule somewhat similar to a metal-skinned balloon (they're actually called *aneroid wafers*). The expansion or contraction of the capsule is mechanically converted into a movement of altimeter hands, resulting in an altitude readout.

Notice that the altimeter's case is connected to the static port. This allows static air pressure to surround the capsule. Any change in static air pressure is then reflected by an expansion or contraction of the capsule, providing the altitude reading. To understand precisely how this process works, we need a clearer understanding of how atmospheric pressure changes with height.

Atmospheric pressure used to be measured by a mercury barometer. A tube of the heavy liquid metal mercury is filled and placed upside down in a vat of mercury (Figure 19A). The weight of the mercury inside the inverted tube creates a small vacuum as the column attempts to sink out of the tube and into the vat. It's the vacuum that prevents the mercury from entirely sinking into the reservoir. The column finally stabilizes at a certain height (Figure 19B). Let's say the height is 30 inches of mercury (sometimes abbreviated *Hg*, which is the chemists' symbol for the element mercury). Decreasing the atmosphere's pressure on the reservoir surrounding the tube allows the column to decrease in height. Increasing atmospheric pressure pushes on the reservoir, moving the column upward into the tube and increasing its height (Figure 19C).



The altimeter's capsules expand or contract based on the pressure of the atmosphere. This movement is mechanically converted into an altitude reading.

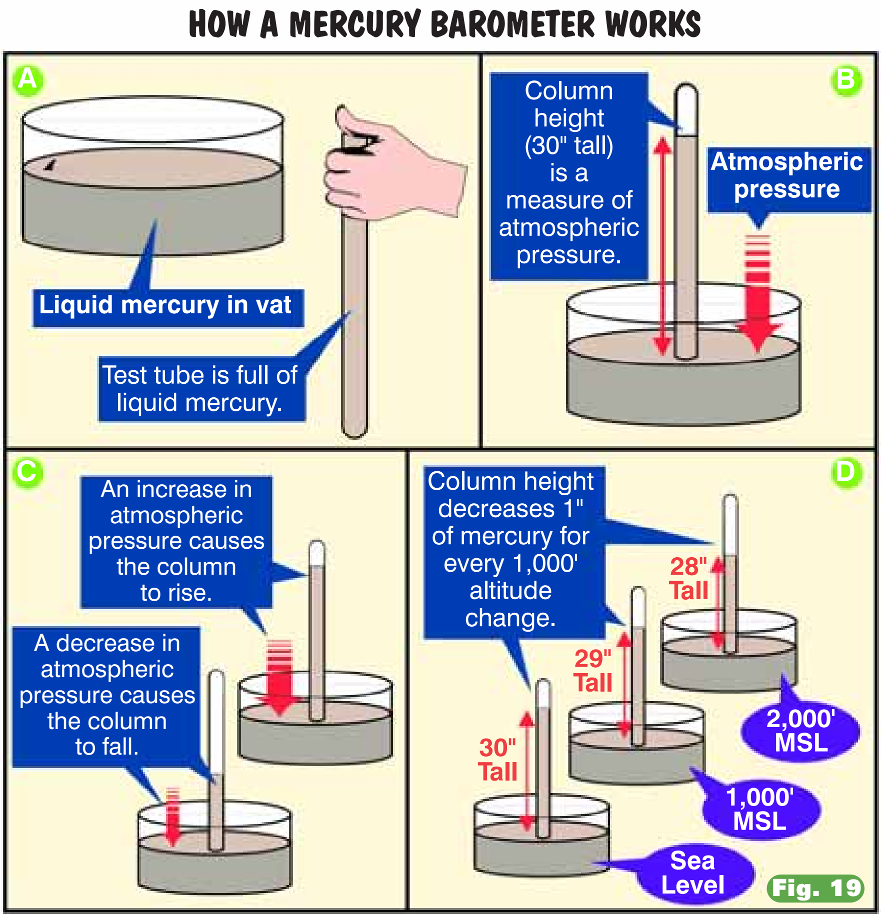


Fig. 19

Let's say that at sea level, under typical pressure conditions, our mercury column stands 30 inches tall. We say the atmospheric pressure is *30 inches of mercury*. At 1,000 feet MSL (mean sea level), the pressure decreases and the mercury column falls approximately one inch. It now stands 29 inches tall. The atmospheric pressure at 1,000 feet MSL is properly stated as *29 inches of mercury*. Altitude measurement is based on the consistency of this known pressure change.

Aircraft altimeters don't use mercury barometers. If they did, there would be a big, three-foot long tube protruding from the instrument panel (Not a pretty sight. Besides, it would keep poking you in the eye). Instead, the small expandable capsule's expansion or contraction is calibrated in inches of mercury. In other words, taken from sea level to 1,000 feet MSL, the capsule expands a small but predictable amount. Altimeter designers calibrate this change as equaling one inch on the mercury barometer.

Now you are ready to understand how altimeters can determine your airplane's height above sea level.

The changing height of the mercury column represents atmospheric pressure in much the same way your tongue might represent the pressure of someone standing on your chest. A tongue sticking way out of your mouth would represent a lot of pressure on your chest. When the person stepped off your chest, your tongue would (we hope) recede into your mouth. One might be able to calculate the person's weight by measuring the exact amount of tongue protrusion. One might say that 200 pounds is worth 6 inches of tongue. Of course, I say this tongue in cheek since it's not all that accurate; after all, it's only a rule of tongue, and calibration would always be a challenge.

Even if we calculated tongue protrusion for a given amount of weight, this information is totally useless (but high in entertainment value, nevertheless). There is, however, great value in calculating the height, in inches, that a column of mercury will change if it's moved vertically. Since the weight of the atmosphere changes with height, this pressure change should be reflected by a lengthening or shortening of the mercury column. Indeed, this is exactly what happens. A column of mercury changes about one inch in height per thousand feet of altitude change, and this is the standard used to calibrate altimeters (Figure 19D).

Figure 20A shows an altimeter resting at sea level, where the pressure is 30″ Hg. This is the pressure sensed through the airplane's static port; therefore, the pressure surrounding the expandable capsule is also 30″ Hg. Let's say the pressure inside the capsule is also at 30″ Hg. What's going to happen to the capsule? Will it expand? No. The pressure inside the capsule is the same as the pressure outside the capsule. Without any pressure difference, the capsule doesn't expand and the altimeter reads an altitude of zero feet.

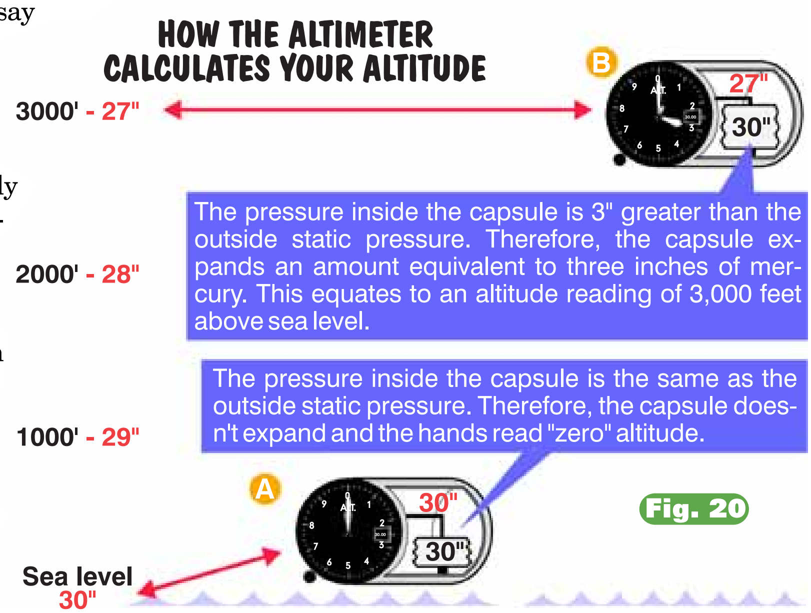
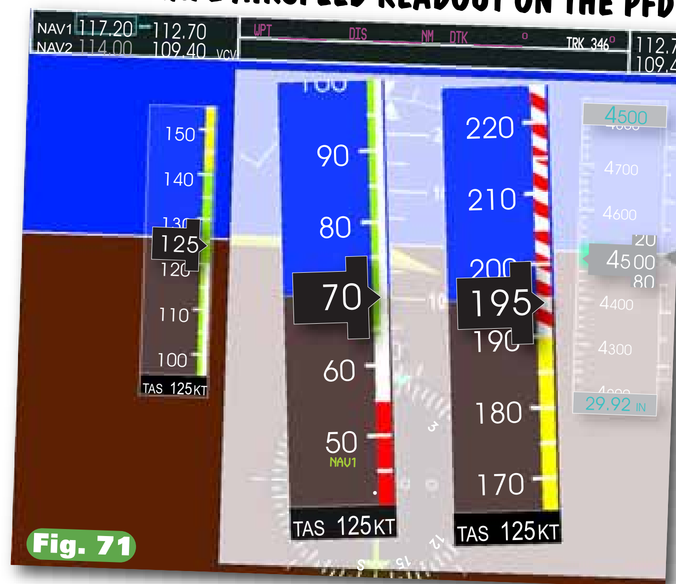


Fig. 20

INDIVIDUAL INSTRUMENTS OF THE PFD

Airspeed and altimeter information are presented as a moveable digital-tape strips while the entire background of the PFD presents attitude information.

DIGITAL-TAPE AIRSPEED READOUT ON THE PFD



Airspeed information is presented in moveable tape format with the airplane's present airspeed shown digitally.

cator, with the white horizon line stretching from side-to-side on the instrument. At the top is the inclinometer-bank angle indicator. The altitude is also read from a tape-type indicator, and the vertical speed indicator is presented to the right of the altimeter tape. The heading indicator is similar in shape to an HSI.

Sure, it looks spooky, but it's only instrumentation. PFDs still use gyros as well as static and dynamic air pressure inputs to their air data computers to generate the information shown on their displays. We'll discuss this in detail, soon. First, let's examine each of the PFD's instruments in detail.

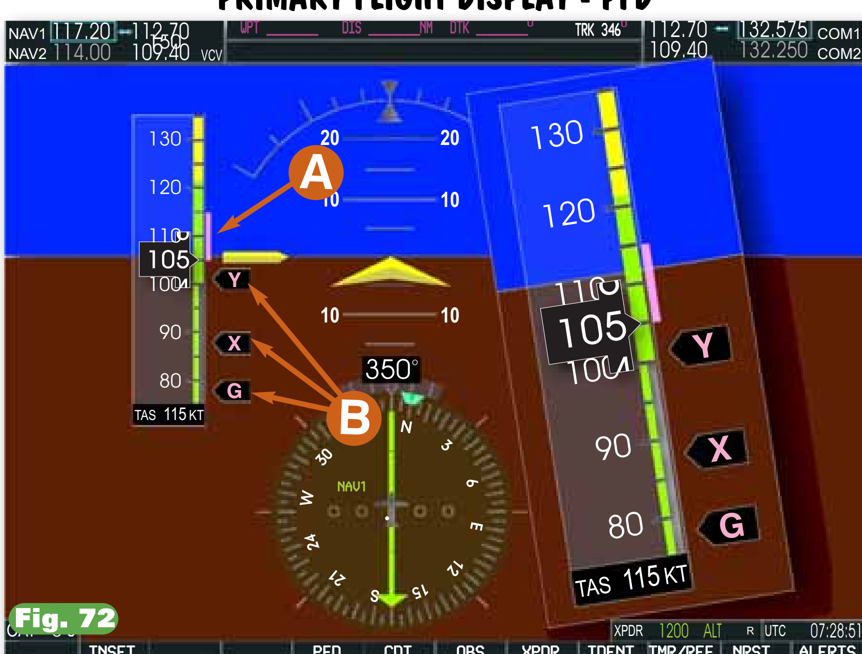
Digital Airspeed Readouts on PFDs

Primary flight displays provide digital airspeed readouts (Figure 71). The numerical airspeed tape moves vertically with airspeed change. The airplane's present airspeed is shown in the white-on-black box in the center of the tape. Notice that the yellow, green and white color codes correspond to the same color codes shown in Figure 8 of this chapter. On this primary flight display, the never-exceed speed region is indicated with a red striped line, and the stall speed region is marked with a solid red color. PFD manufacturers may vary the color coding used for these airspeed regions.

Some PFDs provide you with an automatic calculation of true airspeed, as seen at the bottom of the airspeed tape in Figure 71. The airplane's air data computer calculates the TAS based on the calibrated airspeed, pressure altitude, and outside air temperature (OAT). Isn't that nice? Now, if you could just use an English accent and say, "Earl Grey tea, hot" into the PFD and get your drink. Someday, perhaps. But not quit yet.

Some PFDs provide you with trend lines (the magenta line, Figure 72, position A) that show where your airspeed will be in six seconds (more on this in a minute). Best rate, angle and best glide speeds may also be shown by thumbnail identifiers (position B).

PRIMARY FLIGHT DISPLAY - PFD



The magenta trend line (position A) tells you what your airspeed will be in six seconds at the airplane's present pitch and power setting. Best rate, best angle and best glide speed are identified by the Y, X and G tabs, respectively.

THE PRIMARY FLIGHT DISPLAY'S TREND LINES

One of the very unique features of the primary flight display is the trend line. This is the magenta line in positions A, B, C and D that show where a particular airspeed and altitude value will be in the next six seconds based on the airplane's present pitch and power condition. For instance, the nose up attitude on the left PFD shows a decreasing airspeed and increasing altitude. The airspeed trend line in position A indicates that the airspeed and altitude will be at 107 knots and 4,630 feet in six seconds. The pitch down attitude shown on the PFD to the right has trend lines indicating that the airspeed and vertical speed will be 182 knots (position C) and 3,710 feet (position D) in six seconds. The wonderful thing about trend lines is that they help you anticipate airspeed and altitude targets. Anticipating trends with round-dial instruments was more a matter of feel and it took some time to develop this skill.

Trend Lines

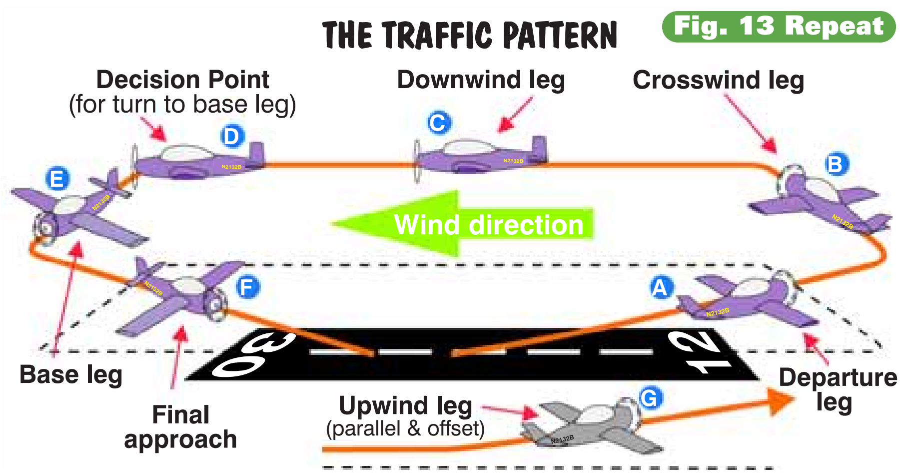
Trend lines aren't proof that the PFD is reading your mind. The projection is based on the airplane's present pitch and power condition. For instance, the nose up attitude on the left PFD (Figure 73) shows a decreasing airspeed and increasing altitude. The airspeed trend line in position A shows that the airspeed and altitude will be at 107 knots and 4,630 feet in six seconds. The pitch-down attitude shown on the PFD to the right has trend lines showing that the airspeed and vertical speed will be 182 knots (Figure 74, position C) and 3,710 feet (position D) in six seconds. The wonderful thing about trend lines is that they help you anticipate airspeed and altitude targets. Anticipating trends with traditional analog flight instruments is more a matter of feel and it takes some time to develop this skill.

Digital Altitude Readouts

Primary flight displays use a tape display of altitudes (Figure 75). As altitude changes, the numerical display tape of altitude moves up and down in the display window, while the number values in the white-on-black window in the center of the display (Figure 75, position A) change to reflect the airplane's current altitude. Figure 75, position B represents the target altitude you may (or may not) have previously selected in the PFD. Figure 75, position C represents the latest barometer setting you've dialed into the altimeter.

PRIMARY FLIGHT DISPLAY - PFD

On the PFD, altitude is read on a similar moving tape. The airplane's present altitude is shown digitally (position A), the target altitude (selected previously by the pilot) is read at position B and the current altimeter setting is read at position C.



Left Wing Pilots

Traffic patterns are, unless posted otherwise, made with a series of left turns. This is referred to as flying *left traffic.*

Given a choice, pilots generally favor left turns because their visibility is better when the airplane is tilted toward the side they're sitting on. This is another example of a way in which flying is completely unlike driving. In a car, no matter which way you turn, your visibility from the driver's seat is pretty much the same. An airplane, however, operates in three dimensions. All things being equal, a pilot would rather have things rolling his or her way when it comes to turns.

Let's take a closer look at the airport traffic pattern, and what you will do once you're in one.

Traffic Pattern Components

Traffic patterns are rectangular in shape and consist of six segments: *departure leg, crosswind leg, downwind leg, base leg, final approach* and *upwind leg* (Figure 13).

Airplane takeoffs are made into the wind, and the takeoff flight path is thus called the *departure leg* (point A). After takeoff, you have two major choices—you can either depart the airport traffic area, or you can *remain in the pattern,* which means you will fly a prescribed path, come around, and land on the runway you just departed from. This is done by pilots who enjoy very short flights, as well as by pilots who are practicing landings. From time to time, we pilots remain in the traffic pattern in order to polish our skills and minimize the explanations to passengers for our occasional bad landings.

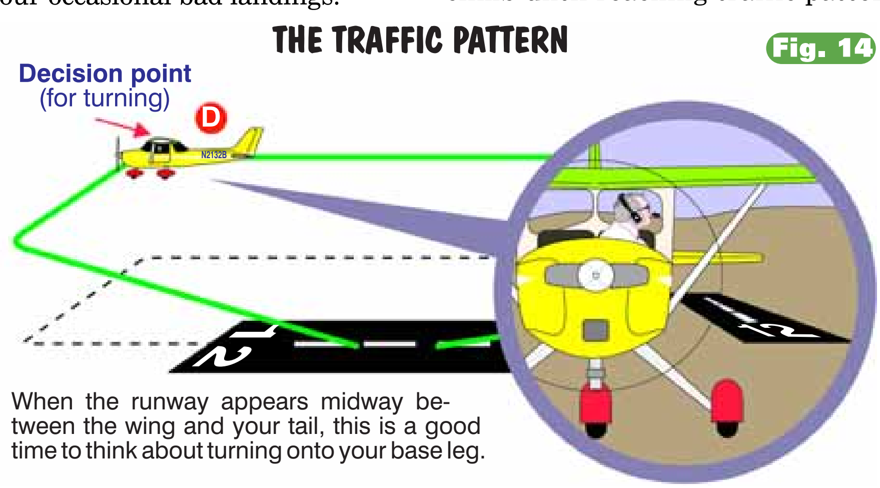
If you're remaining in the pattern, a turn (generally a left turn) to the *crosswind leg* (point B) will be made when the airplane is beyond the departure end of the runway and within 300 feet of the traffic pattern altitude. This portion of the pattern is called the crosswind leg because the flight path is perpendicular to the runway and generally crosswise to the wind direction (one time I asked a student what leg he was on in the traffic pattern. He replied, "I'm on my right leg, but plan on using my left leg once the right one gets tired" (I, of course, immediately asked if anyone had delivered him a sandwich lately).

As the airplane continues its climb, another 90 degree turn is made. This places the airplane parallel to the runway and traveling opposite to the direction of landing. This is called the *downwind leg* (point C) because your direction is with the wind. Throughout the upwind, crosswind and even a part of the downwind leg, the airplane continues to climb until reaching traffic pattern altitude. This altitude varies from one airport to the next because of terrain, obstruction and noise concerns. Expect traffic pattern altitudes to range from 600 to 1,500 feet above the airport elevation, typically averaging about 1,000 feet AGL. The downwind leg is flown approximately 1/2 to one mile out from the landing runway. This keeps you comfortably close to the runway. In the event of an engine problem, you can glide to a safe landing.

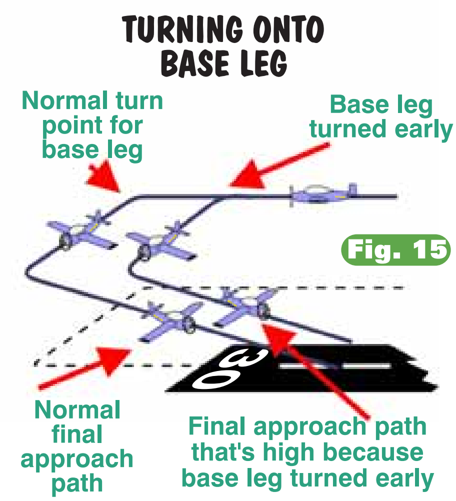
You continue downwind until passing a point abeam the beginning of the landing threshold of the runway. Then it's another 90 degree turn and you're on *base leg* (point E). From here you make one more 90 degree turn, onto *final approach* (point F). The *upwind leg* (point G) is flown parallel to the runway in the direction of landing. It's often used during go-arounds or overflights to avoid departing traffic.

Assuming traffic isn't a factor, it's convenient and practical to start your turn onto base leg when the landing threshold appears 45° between the wing and the tail of your airplane. In other words, as you look out the left window (Figure 14, point D), the threshold appears to be at a 45° angle to the left of the wing (or midway between the wing and the tail). This provides you with a symmetrical, rectangular-type pattern and gives you enough distance from the runway to make a comfortable approach.

Aviation is one place where it is not good to become a homeboy or homegirl. Some student pilots fudge by using familiar landmarks on the ground to tell them when to make



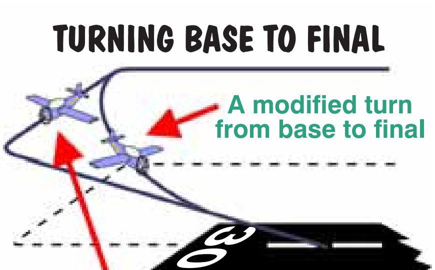
When the runway appears midway between the wing and your tail, this is a good time to think about turning onto your base leg.



their turns. This is bad because it leads to a lack of flexibility. If you need the local Burger Boy restaurant to land, what will you do when you go to a new airport? There's nothing more pitiful than a pilot who can only fly to and from his or her home airport comfortably!

I've seen student pilots come absolutely unglued when they weren't allowed to turn base at "their" landmark. You will *not* always be able to turn base or final at an ideal time, and the ability to make adjustments is crucial. When traffic is heavy, you may have to fly the downwind leg for some distance past the airport before turning base leg. In fact, I was once in a traffic pattern with 19 other airplanes. One pilot was so far downwind that the controller called and asked, "45 Charlie, what time zone are you in now?"

Base leg is a point of transition for landing. It's the place where important adjustments are made in the airplane's speed and landing configuration. This is why, even when there is little or no traffic, you should avoid turning base too early, as shown in Figure 15. Things happen mighty fast as you approach the runway. You want to give yourself enough time to adjust your airspeed, flaps, and glidepath. The descent for landing is normally started on base leg and continues throughout the final approach.



A square turn (90°) from base to final gives you time to assess your glide path and the effects of any crosswind.

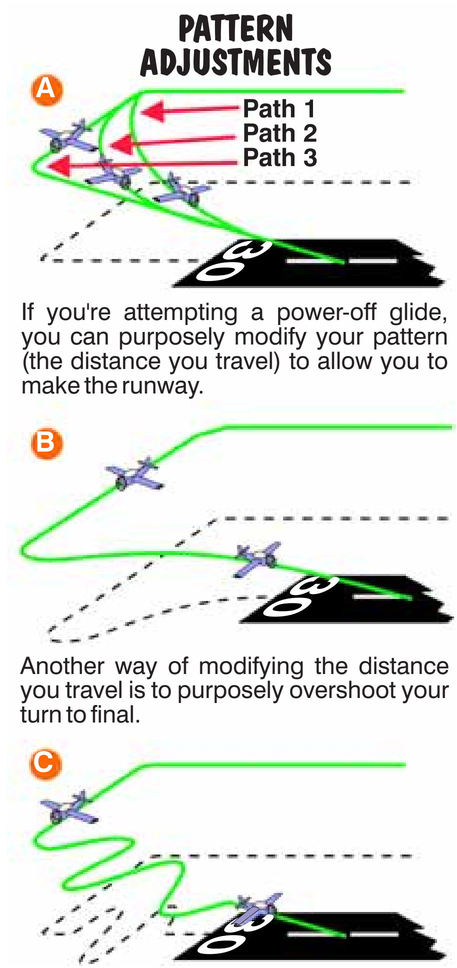
Fig. 16

The *final approach* (sometimes just called *final*) is a critical part of the landing sequence. Generally, a square turn from base onto final approach is best (Figure 16). This provides you with enough time to observe your airplane's descent path and alignment with the runway. You can observe and correct for the effect of crosswinds on the airplane if you give yourself a reasonably long final approach. During the final approach, the airplane's glide path can be adjusted (using flaps, slips, or S-turns), making it easier for you to land on any selected runway spot.

When turning from base leg onto final approach, you have an additional opportunity to correct your glidepath (Figure 17). Let's assume that you are making a power-off approach from the base leg. After turning base, you retard the power and commence a descent. Your objective is to land on the runway numbers (the ones at the beginning, not the end of the runway—unless you want a sandwich!). If you're too low, you can cut short the turn from the base leg to final approach as shown in Figure 17A. Flying path 1 allows you to fly less distance during the descent, thus increasing your chances of making the runway numbers. Path 2 is longer, and path 3 is a nice square turn onto final.

If you're too high, you can deliberately overshoot the turn onto final approach giving you more distance to cover during your descent as shown in Figure 17B. Another option is to S-turn on final as shown in Figure 17C. S-turns are simply a series of alternating turns left and right of the direct glide path. Since the shortest distance between any two points is a straight line, anything you do to fly *other* than a straight line lengthens the trip. Assuming a constant rate of descent, taking the long way home will allow you to lose more altitude.

S-turns, coupled with forward slips and use of flaps, provide you with several ways of adjusting your glidepath. This knowledge becomes especially important when a precision landing is necessary, such as on a short field or in the event of an engine failure when you generally get only one opportunity to hit the safe landing spot you've chosen. With a little practice you will be able to put the airplane down in the precise place you want. (We won't discuss forward or side slips in this book. Any good aviation procedures book should have information on this.)



A: If you're attempting a power-off glide, you can purposely modify your pattern (the distance you travel) to allow you to make the runway.

B: Another way of modifying the distance you travel is to purposely overshoot your turn to final.

C: Another very effective way to modify your pattern is to make S-turns while on final approach. This is also very effective if you're following slower traffic ahead.

Fig. 17

CLASS E AIRSPACE AT 700' AGL

Within the borders of the magenta faded area surrounding an airport, Class E (controlled) airspace starts at 700 feet above ground level (AGL) instead of the normal 1,200 feet AGL. The lower base of Class E airspace (i.e., 700' AGL), keeps airplanes flying instrument approaches in controlled airspace as they descend to the airport.

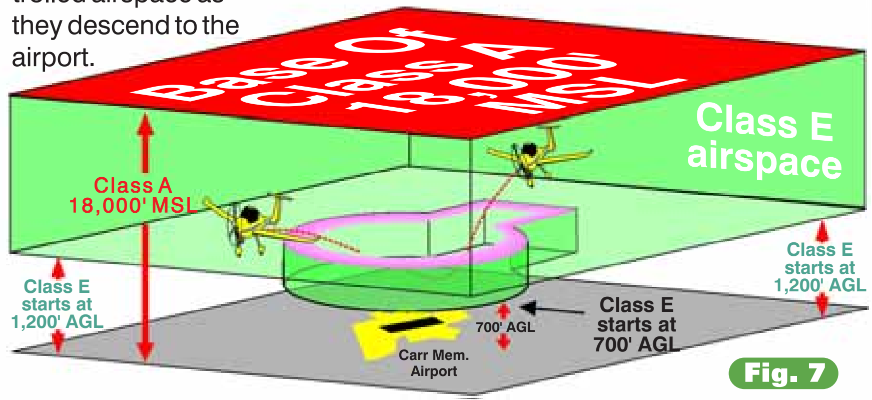


Fig. 7

Carr airport as shown on an aeronautical sectional chart.

Fig. 8

Class E Airspace Starting At 700 Feet AGL

When Class E airspace starts at 700 above ground level, it will be surrounded by a magenta faded line, as shown in Figure 7. Anywhere within this magenta faded area, controlled airspace starts at 700 feet AGL. An aeronautical sectional chart shows this magenta faded border quite clearly in Figure 8, position 1. Outside the border of the magenta fade, controlled airspace starts at 1,200 feet AGL.

Within the borders of the magenta fade, at and above 700 feet AGL, Rod Machado's Airspace Simplification Rule #2 applies. In other words, you need a minimum of 3V/152 for VFR flight.

Why would an airspace designer want to lower Class E airspace to 700 feet AGL around or near an airport? To keep VFR pilots from bumping into IFR pilots who are making instrument approaches.

The keyhole type extensions of Class E airspace starting at 700 feet AGL in Figure 8 identify descent paths followed by IFR airplanes during their instrument approaches. The keyhole slot is shown on the aeronautical sectional chart excerpt in Figure 8, position 1. IFR pilots on an instrument approach typically descend to altitudes of 700 feet AGL (and lower). They remain in Class E airspace during most of their IFR approach. If they see the airport, they land; if they don't see it, they fly off to another airport (hopefully one that has fewer clouds and better visibility).

Remember that in Class E airspace *below* 10,000 feet MSL, VFR pilots should be flying with no less than 3V/152. This means if an IFR pilot pops out of the clouds, there should be ample time for the VFR and IFR pilots to see and avoid each other (IFR pilots are equally responsible to see and avoid whenever they are not in instrument meteorological conditions).

Some airports have instrument approaches that bring IFR pilots down closer than 700 feet AGL, as shown in Figure 9. There are airports allowing IFR pilots to come within 200 feet AGL or less while still in the clouds. Since controlled airspace

CLASS E AIRSPACE AT THE SURFACE

Within the borders of the magenta (red) dashed line, Class E airspace descends all the way to the surface surrounding McComb-Pike airport. Since some instrument approaches bring pilots real close to the surface of an airport, this lower Class E surface area keeps them in controlled airspace during their descent.

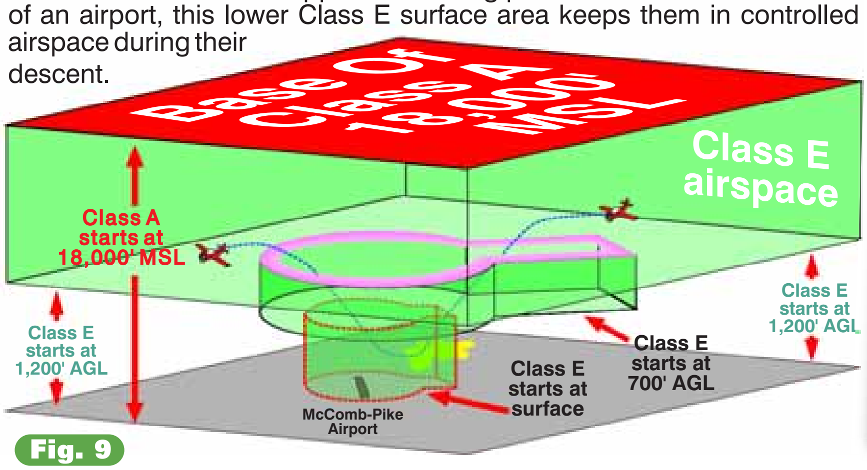


Fig. 9

Fig. 10

helps VFR pilots see and avoid other pilots, these airports have Class E airspace lowered all the way to the surface. (There are other reasons why controlled airspace is lowered, but these are beyond the scope of this book.)

Figure 10 shows how surface-based Class E airspace is shown on an aeronautical sectional chart. A dotted magenta line defines the lateral boundaries of the controlled airspace surrounding McComb-Pike County airport (position 1). Airports without air traffic control towers use a magenta dashed line to represent this surface-based Class E airspace. (Airports with established control towers, as you'll see a little later, use blue-dashed lines to represent controlled airspace in contact with the surface around that airport.)

What does this surface-based Class E airspace mean to you as a VFR pilot approaching and departing McComb-Pike airport? It means Rod Machado's Airspace Simplification Rule #2 applies all the way to the surface within the boundaries of the magenta-dashed line. The only thing different here is that the controlled airspace normally existing at 700 feet or 1,200 feet AGL drops to the surface within the boundaries of the magenta dashed line.

WHY 1,000 FEET WAS CHOSEN AS THE MINIMUM CEILING

If you think like a flight instructor (we're attracted to bright, shiny objects and trinkets that rattle), then you're probably wondering why 1,000 feet was chosen as the minimum ceiling for basic VFR within any surface-based controlled airspace. Well, as famed undersea explorer Jacques Cousteau says, "We do not know, but we shall soon find out." (Although, come to think of it, I've never actually seen him go into the water).

In Class E airspace, less than 10,000 feet MSL, you need to remain at least 500 feet below any cloud formation. Regulations also require that you remain at least 500 feet above the surface over a noncongested area. For the sake of rulemaking, the airport is assumed to be built around a noncongested area (you and I know that this isn't always true, but it's general enough to make this point). Adding the 500 foot minimum altitude requirement to the 500 foot minimum clearance beneath a cloud gives you a minimum ceiling height of 1,000 feet. These values are shown in Figure 11.

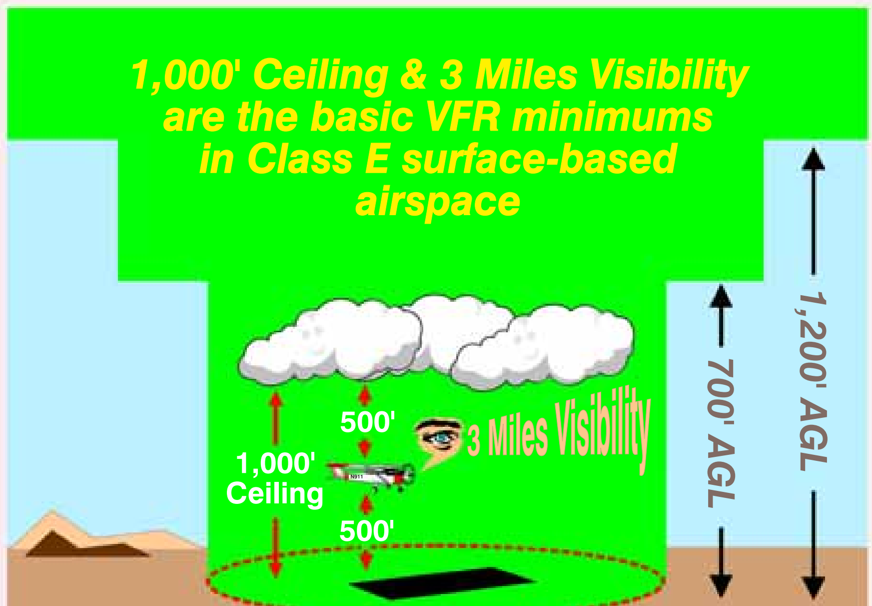


Fig. 11

Additional Requirements In Surface-Based Controlled Airspace

There are two additional requirements when operating at an airport having *any* type of surface-based controlled airspace established for it (Class E in the case of McComb-Pike):

1. The reported ground visibility at the airport must be at least three statute miles. If the ground visibility isn't reported, then the flight visibility during takeoff, landing or when operating in the traffic pattern must be at least three statute miles. (The *flight visibility* is always determined by the pilot on the honor system.)

2. If a ceiling exists at that airport, it can be no lower than 1,000 feet AGL if you desire to operate beneath it. If you want to take off, land or operate in the traffic pattern, the ceiling (if one exists) must be at least 1,000 feet AGL or more.

A *ceiling* is defined as the height above the earth's surface of the lowest layer of clouds reported as *broken* or *overcast*, or any reported *vertical visibility* into obscuring phenomena. We'll be talking more about these terms in Chapter 13. For the moment, consider a ceiling as being anything in the sky you can't readily see through (like clouds for instance).

To summarize these requirements, remember this. To operate to, from, or at an airport within the boundaries of any surface-based controlled airspace, you need a minimum of three miles reported visibility (flight visibility if none reported) and no less than a 1,000 foot ceiling (if a ceiling exists). Let's symbolize these basic VFR requirements as *3V/1C*. (As you'll soon see, in addition to Class E, there are three other types of controlled airspace that can surround an airport at the surface: Class D, C and B.)

Here's Rod Machado's Airspace Simplification Rule #3: Taking off, landing, or operating in the traffic pattern of an airport having *any* type of surface-based controlled airspace requires basic VFR minimums of at least three miles visibility and, if a ceiling exists at that airport, it can be no lower than 1,000 feet. We'll symbolize this rule as 3V/1C.

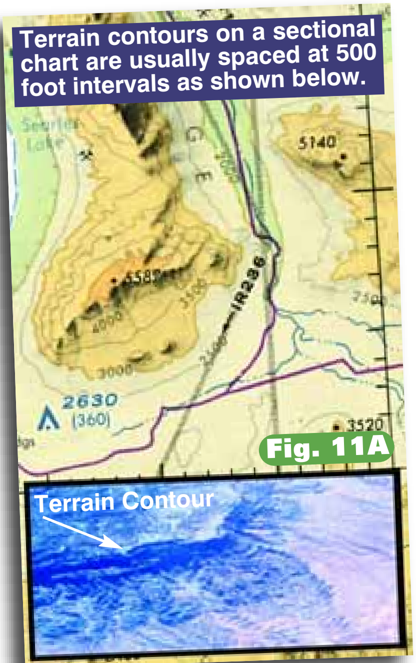


Fig. 11A

Fig. 11B

On a sectional chart, contour lines are spaced at 500 foot intervals, as shown in Figures 11A and 11B. Occasionally, contours may be shown at 250 foot, 100 foot or even 50 foot levels in areas of relatively low relief (slope). You can tell a lot about the slope of the terrain by examining the spacing between the contour lines in Figure 11A. Closely-spaced contour levels indicate rapidly rising terrain, while contours spaced farther apart indicate less precipitous terrain.

Color – An additional aid in determining the height and slope of terrain is color. Every sectional chart has a terrain color bar on its front side (see Figure 12). The color bar shows a specific color representing the maximum and minimum elevations of terrain. These colors range from light green for the lowest elevation to dark brown for higher elevations. For instance, the dark yellowish-color shown at position A in Figure 12 represents terrain rising between 5,000 and 7,000 feet above sea level. Remember, a specific color doesn't precisely indicate the height of terrain, it indicates a range of altitudes (i.e., 5,000′ to 7,000′) through which terrain can be found in those areas. More precise indications of terrain are identified by something known as *spot elevations*.

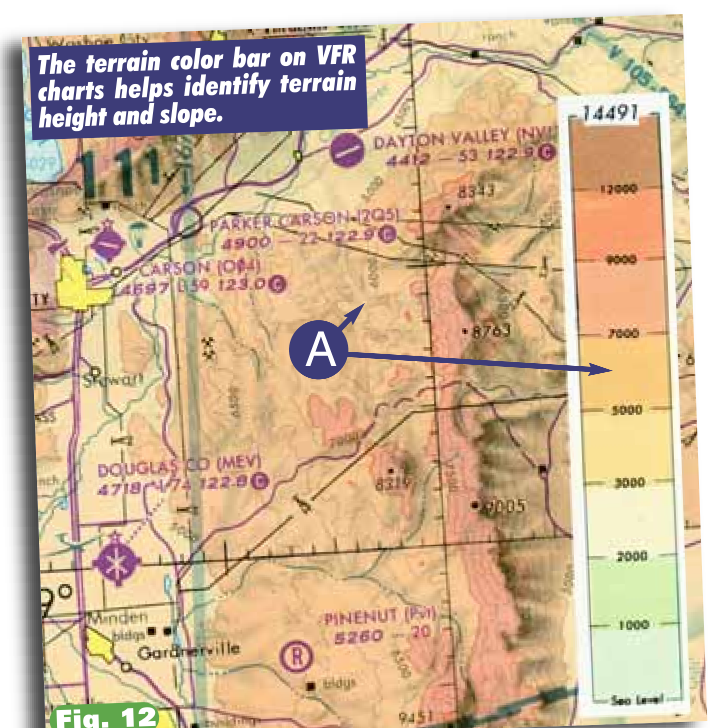


Fig. 12

Spot Elevation Symbols – Figure 13A shows a spot elevation used on VFR charts (Figure 13B shows the actual terrain features from the air). Normally, spot elevations (shown as *small* black dots) are chosen by mapmakers to indicate the high point on a particular mountain range or ridge. Next to the small black dot is the elevation of that spot above sea level. Remember, there can be several spot elevations in a local area. These spot elevations show heights of local peaks and don't necessarily represent the highest terrain in that area. The highest terrain located within an area bordered by lines of latitude and longitude (known as a *quadrangle*) is identified by a slightly *larger* black dot.

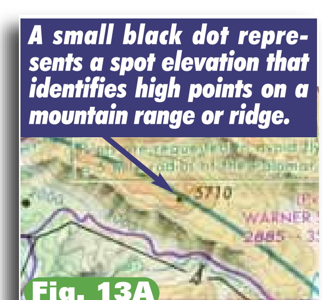


Fig. 13A

Fig. 13B

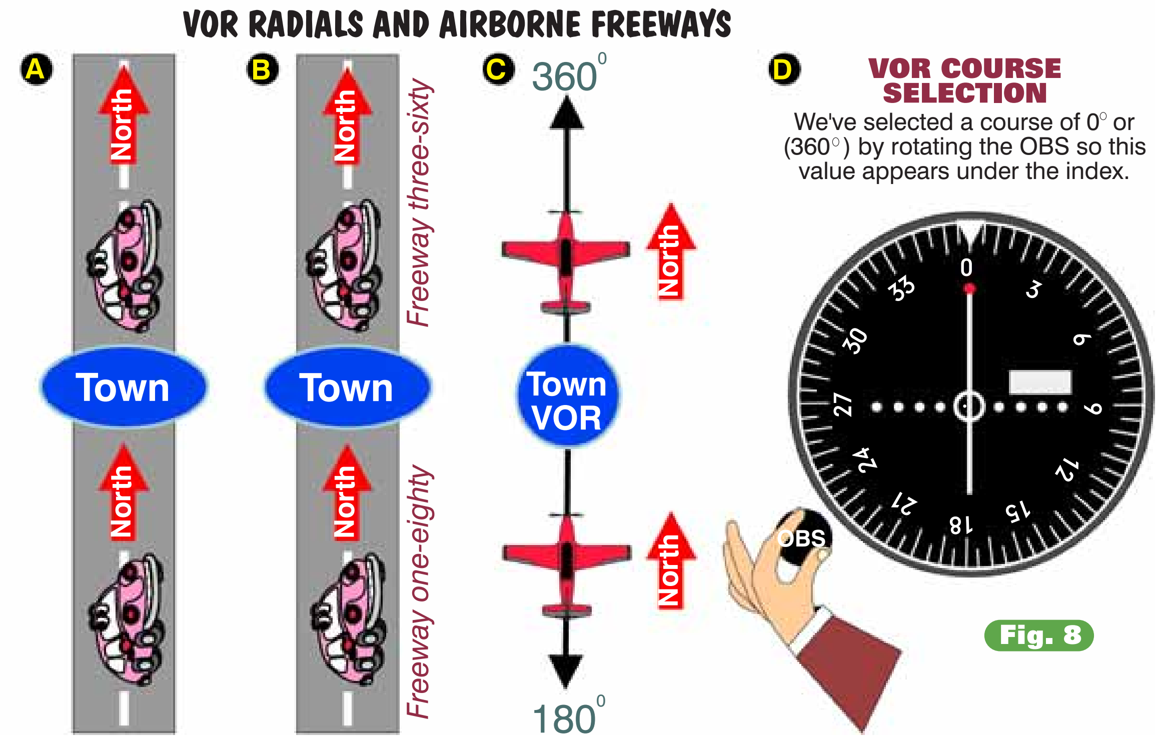


Fig. 8

The freeway at position (A) takes the car into and out of town. The car's direction is due north (or 360 degrees) on its journey through town. If we give the freeways entering and leaving town separate names as in position (B), the car still heads due north on its passage through town. We can say that we went into town on *freeway one-eighty* and out of town on *freeway three-sixty*. Regardless of what we name the freeways, the car still heads 360 degrees as it passes through town. If we're tracking to and from the VOR as shown in position (C), we track inbound on the 180 degree radial and outbound on the 360 degree radial. Either way our airborne freeway points in a direction of 360 degrees (just like our car). For convenience, we'll refer to the direction our airborne freeway points as its *course*. The airplane's VOR equipment (D) can be set to any one of 360 different courses.

pointed due north as it passed straight through town as shown in Figure 8, position A. While entering and leaving town, your car pointed north (360 degrees), in the same direction as the freeway. If the portion of the freeway exiting the town had a different name than the portion entering the town, would this affect the direction your car pointed while passing through town? Of course not. Let's call the portion of the freeway exiting the town to the south, *Freeway 180* and the portion exiting to the north, *Freeway 360* (position B). Now we can say that we went to town on *Freeway 180* and exited on *Freeway 360*. Our direction never changed despite giving the freeway different names.

Navigation by VOR is basically the same, as shown by position C. If we're headed northbound to the Town VOR, we travel inbound on the 180 degree radial and outbound on the 360 degree radial. Either way, our airborne freeway points in a direction of 360 degrees, just like the ground freeway. Referring to a single freeway by radials going to and from a VOR station is sometimes awkward. So let's refer to our freeways as *courses*. The course is simply the direction our airborne freeway points.

OK, now you're ready to see how we can select and fly any one of 360 individual courses (airborne freeways) by using our VOR equipment.

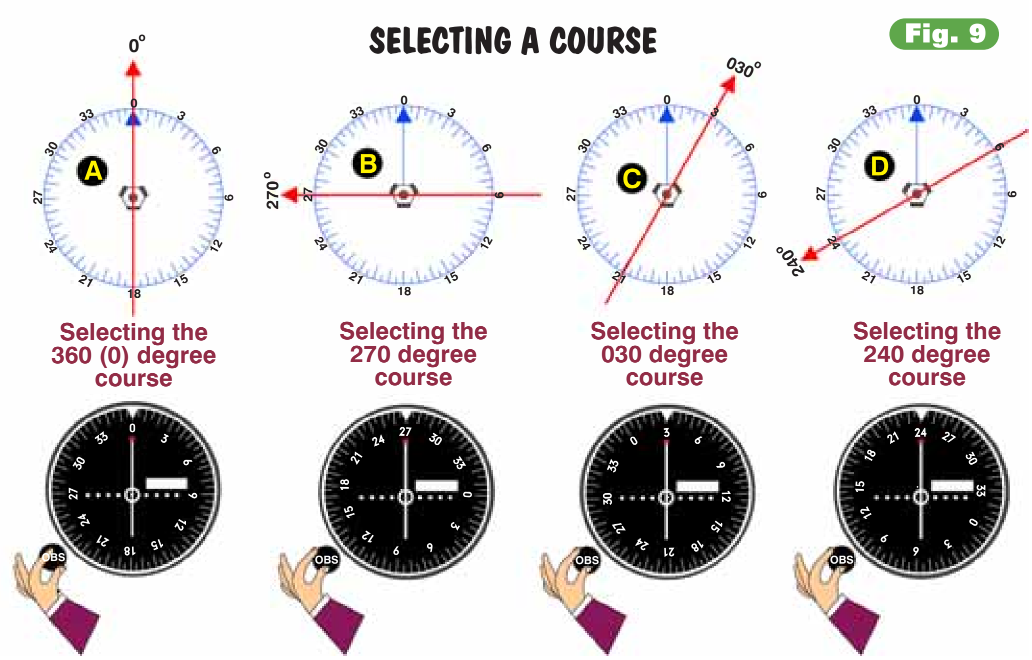
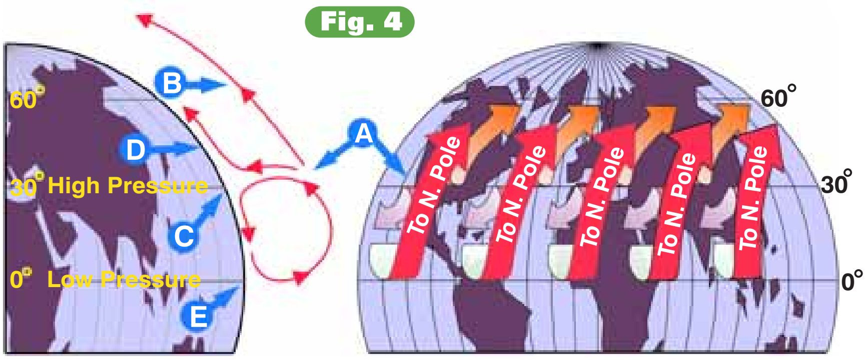


Fig. 9

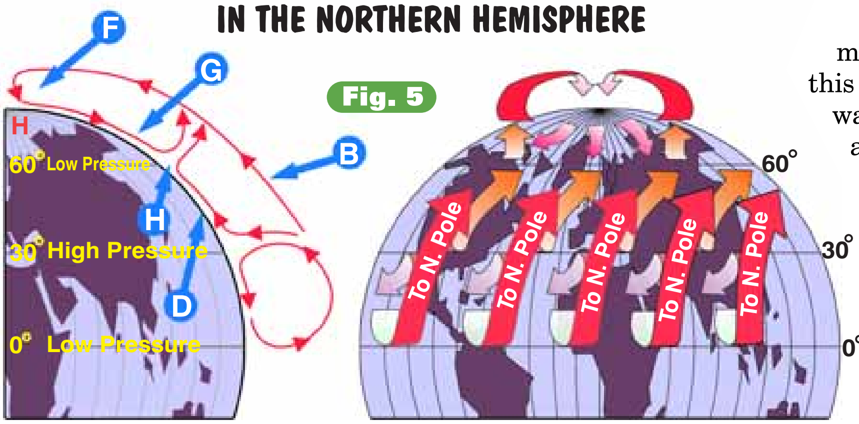
Rotating the OBS to a specific course number, orients your airborne VOR equipment to tell you where you are in relation to that course. You may chose any one of 360 different courses using the OBS.

CIRCULATION OF AIR AT 30 DEGREES NORTH LATITUDE



High altitude, northeasterly flowing air bunches up at 30° north latitude (position A). Some of this high altitude air continues northward (position B), while some of it falls, creating a permanent band of high pressure air around the globe at approximately 30 degrees of latitude (position C). The air at this latitude splits, some moving north (position D) and some moving south, back to the equator (position E).

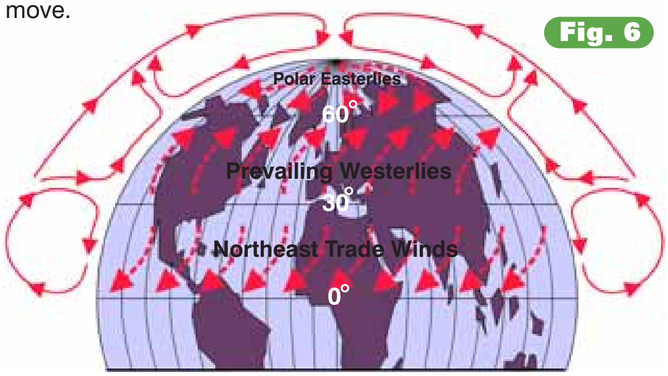
MULTI CELL CIRCULATION OF AIR IN THE NORTHERN HEMISPHERE



As high altitude air (position B) flows north, it finally reaches the North Pole (position F) where it cools, falls and flows southward (position G). The cold polar air flowing southward (position G) eventually makes contact with the warmer air flowing northward (position D). This warmer air flows up and over the cooler air, forming the polar front (position H). Three individual circulation cells are now apparent in both the northern and southern hemispheres (not shown here).

WIND BELTS OF THE NORTHERN HEMISPHERE

Surface winds, resulting from three individual circulating cells in the atmosphere, form three permanent wind bands across the northern hemisphere. Effects of the Coriolis force cause these winds to curve to their right in the direction in which they move.



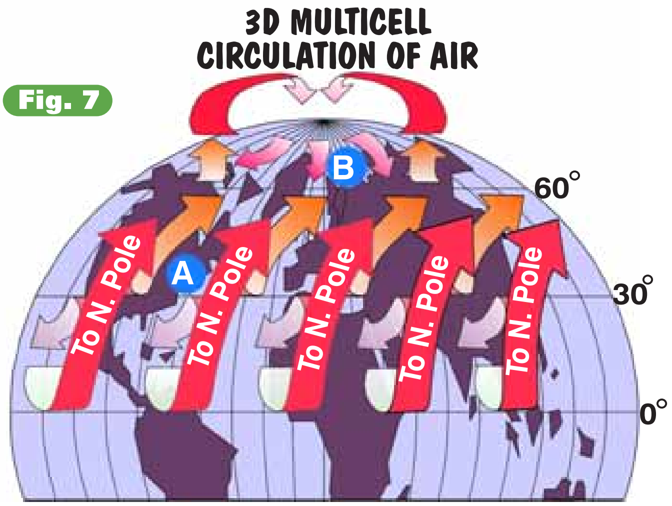
Both bunching up and cooling cause some (not all) of this air to slowly descend at the 30 degree north latitude location, shown in Figure 4, position A. Bunching up increases the air mass above and thus causes a higher surface pressure at the 30 degree latitude position. As the air descends toward the surface it warms, causing clear skies (usually) and warm surface temperatures. Some of this high pressure air flows southward toward lower pressure at the equator (position E). The rest of this warm, low altitude air at position D moves northward.

Some of the high altitude air that didn’t descend at 30 degrees latitude continues to move northward toward the pole, as shown by position B in Figure 5. As it continues to cool, it falls, and travels southward from the north pole (position F). At approximately the 60 degree north latitude (position G), this southward-moving colder air meets the northward moving warmer air (position D). These two air masses have different temperatures, and thus different densities. We know that things with different densities tend not to mix. For example, crude oil and water have different densities and certainly don’t mix (that’s why California, with all its oil spills, now has three different types of beaches—regular, super and unleaded).

When very cold polar air bumps into cool tropical air, the result is a transition zone, shown at position H. This zone is known as the *polar front* (a front is simply a zone where air masses with different densities meet). Some of the northward-moving, cool air flows upward over the colder (denser) polar air (position H). This ascending air is carried northward, toward the pole, with the rest of the high altitude winds. Three separate cells of circulation are now evident. In a while, we’ll discuss fronts and their movement. Right now, just notice how winds in these three cells are affected by the Coriolis force.

Figure 6 depicts a profile of these three individual circulation cells. Between 0 and 30 degrees latitude, the northeast tradewinds blow. From 30 to 60 degrees, the prevailing winds are westerlies, and from 60 to 90 degrees the winds are the polar easterlies.

Notice that meteorologists always talk about winds in terms of the direction they blow *from,* not to! Meteorologists do this because winds, like people, are better understood when you know their origins. If winds come from the north, they’re likely to be cold; from the south, they’re likely to be warm. If a mean looking guy comes from a bad neighborhood, you know a lot about him. If he said he not only grew up on the wrong side of the



Three wind belts are seen from above in 3-D perspective. Notice how warmer, northward moving air from 30° latitude (position A) confronts colder, southward moving air from the north polar region (position B). This confrontation is the source of much of the nasty weather we experience in the United States.

tracks, but grew up underneath them, you know he was a bad dude. Figure 7 depicts this circulation on a multidimensional level.

While the issue of air is weighing on your mind, let's see how it weighs on the earth.

Air Pressure and Vertical Air Movement

Air has weight. This weight exerts a pressure on the earth's surface in much the same way a professional wrestler exerts pressure on your body by standing on your chest (I hope this doesn't happen to you a lot). Changing the air's temperature, however, changes its density and the pressure it exerts on the earth's surface.

For example, along the equator there exist areas of warmer (less dense) rising air, as shown in Figure 8, position 1. Rising air certainly wouldn't create as much pressure on the surface as descending air. After all, one moves upward while the other pushes downward. Warmer (less dense) rising air provides less push or pressure on the surface. We call large areas of warm rising air *low pressure centers*. Near the equator, it's quite common to find permanent belts of low pressure air wrapped around the earth.

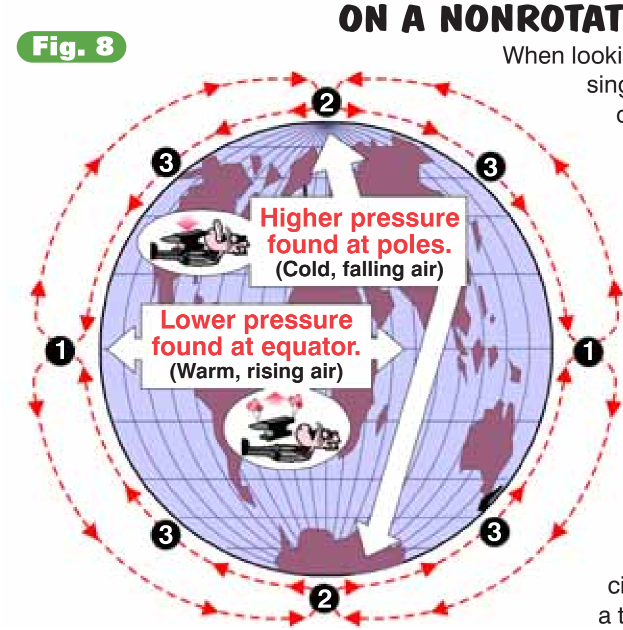
Conversely, permanent high pressure areas exists at the poles (Figure 8, position 2). Colder (more dense) air descends, creating more pressure on the earth's surface. Now you know why cold air falls on your toes during those nocturnal refrigerator raids. Think of cold air as an anvil resting on your chest, as shown in Figure 9. Gravity pulls the anvil downward as it does with cold air, increasing the pressure on your body. Let's attach helium balloons to the anvil, making it lighter. Now the anvil moves upward (off your chest), in the same manner as rising warmer air moves upward off the earth's surface. Pressure at the surface decreases as warm air rises. Of course, as warm air rises, cold air moves in underneath to replace it. Thus, atmospheric circulation consists of high pressure air moving toward lower pressure air (Figure 8, position 3). This simple air circulation model is a fundamental key to understanding weather.

Now that you understand major wind patterns, it's time to examine exactly what makes the wind blow.

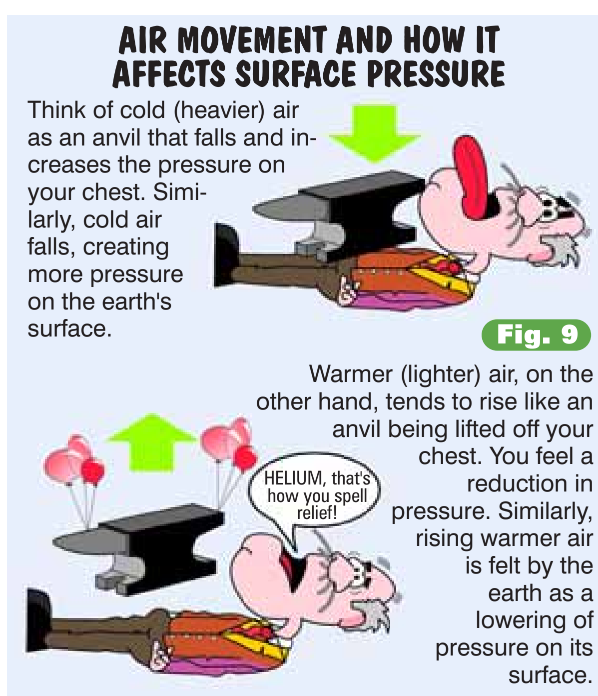
Getting Water in the Air

Weather (meaning clouds, rain, thunderstorms, etc.) wouldn't exist if there wasn't a means of putting water into the air. Television meteorologists would be forced to entertain their flock with hand-puppet shadows and benign patter. Nearly half of all pilot fatalities would disappear, and any remaining Flight Service Stations could be retrofitted as bowling alleys.

HIGH AND LOW PRESSURE CENTERS ON A NONROTATING EARTH



When looking at a simplified, single-cell circulation of the atmosphere we see that the cold air descending at the poles (#2) creates higher pressure on the surface. This air (#3) moves toward the equator to fill in the lower pressure created by the rising, warmer air (#1). Of course, as the earth rotates, the circulation become a tad more complex as you've already seen.



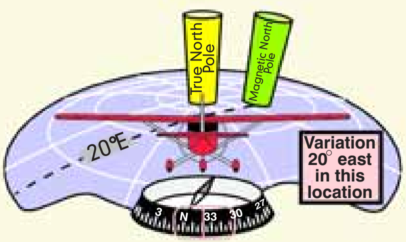
Home Plate

Never leave your flashlight (with its magnetic clip) lying on the dash, next to the compass. Word has it that entire platoons of soldiers went the wrong direction in Vietnam when they held their compasses up next to their steel helmets to take a directional reading. Anything magnetic (and many steels) can affect the compass; keep such items away from wherever the compass is mounted.

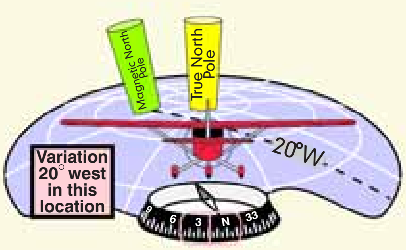
A friend had a student who was worried that an anatomical problem might affect his navigation. He had a metal plate in his head (I think he installed it himself). I'm not sure if this would be harmful in terms of navigational accuracy, but it sure would keep him from losing his flashlight!

Another Way Of Looking at It

WHY WE SUBTRACT EASTERLY VARIATION AND ADD WESTERLY VARIATION



Our airplane is headed directly toward the true north pole. Its true course is 360 degrees. Its magnetic compass, however, says it's flying 340 degrees (it's flying at a 340 degree angle to the magnetic north pole). Thus, when we know our true course and we want to find our magnetic course (or heading), we subtract easterly variation from the true course. Subtracting 20 degrees of easterly variation from a true course of 360 degrees gives us our magnetic course of 340 degrees (the angle our airplane makes with the magnetic north pole).



In an area where the westerly variation is 20 degrees, our airplane makes a 0 degree angle (same as 360 degrees) with the true north pole, yet it makes a 20 degree angle with the magnetic north pole. Therefore, to find our magnetic course (or heading) when we are given westerly variation, we need to add this to the true course. Twenty degrees of westerly variation added to a true course of zero degrees give us a magnetic course of 020 degrees.

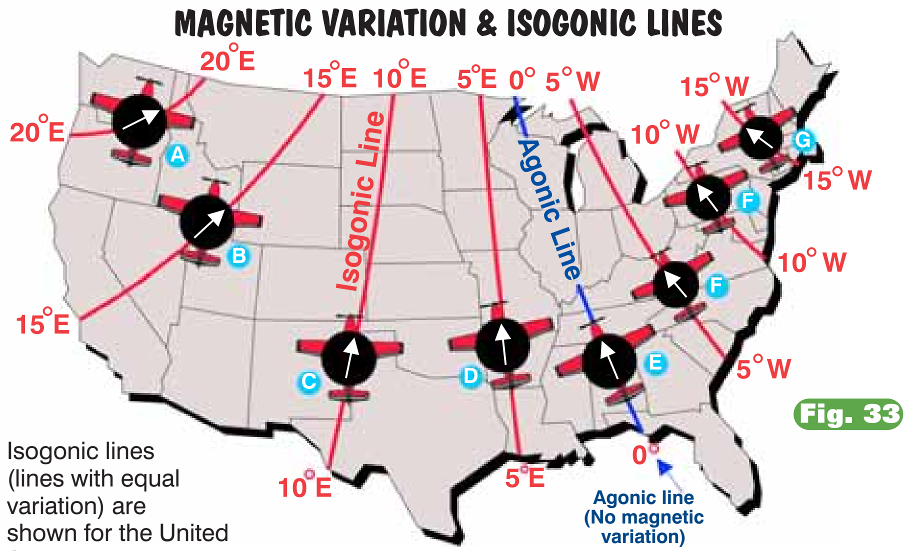


Fig. 33

Isogonic lines (lines with equal variation) are shown for the United States. Anywhere along the depicted line the angular variation between the true north pole and the magnetic north pole is the same (thus the prefix *iso* which means *the same as*). As you can see above, all the airplanes are headed toward the true north pole while their white compass needles are deflected an amount equal to the magnetic variation for that location.

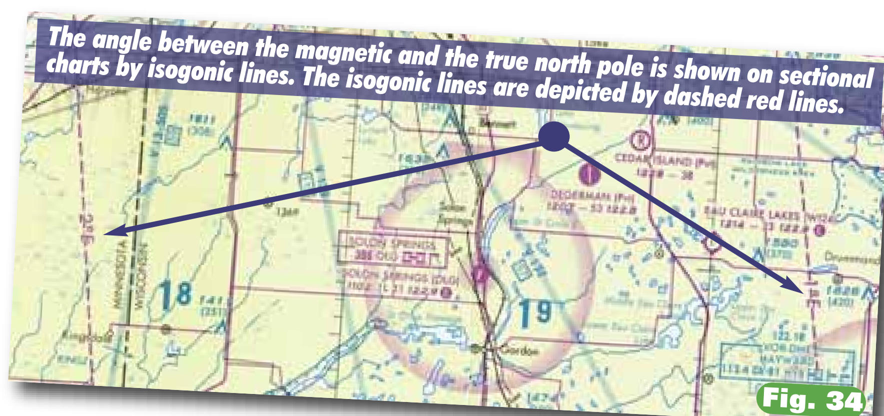


Fig. 34

variation shown on sectional charts are known as *isogonic lines* and are shown in Figure 34. They are spaced at increments of one degree and are marked for either east or west variation with an E or W respectively. *Iso,* like isobar, means *the same as*. *Gonic* is a Greek derivative meaning *angles*. Anywhere along an isogonic line, the angular variation between the poles is the same.

To the northwest of Florida, Airplane E (Figure 33), is on an *agonic line*. The prefix *a* means *no*. Along the agonic line there is no angular variation between the poles. Standing along this line, the true and magnetic north poles would be aligned with one another and no variation exists in this location. The isogonic lines aren't straight because of the many slight variations in the

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