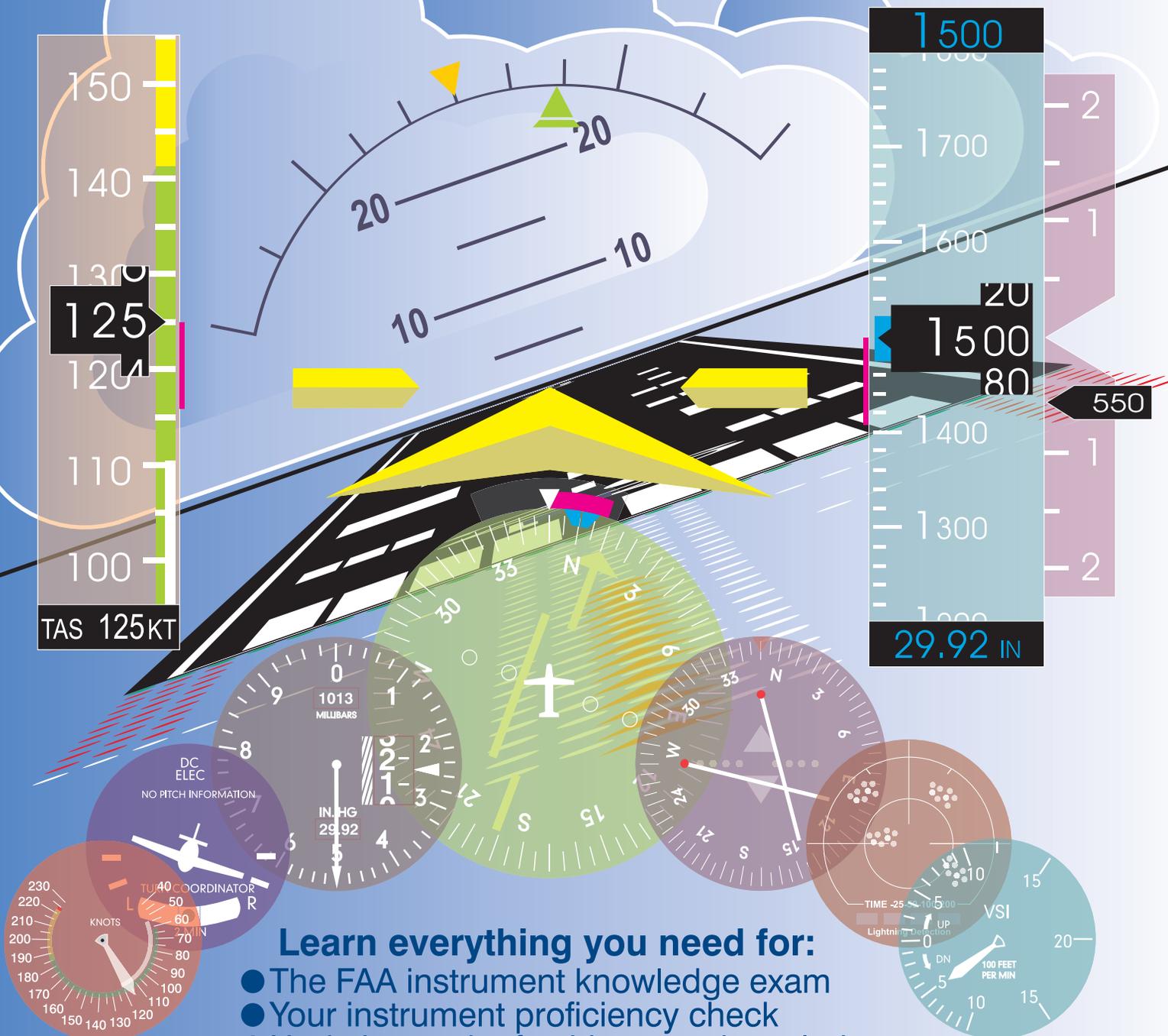


Rod Machado's Instrument Pilot's Handbook



Learn everything you need for:

- The FAA instrument knowledge exam
- Your instrument proficiency check
- Updating and refreshing your knowledge

Rod Machado has taught millions the basics of flying through flight lessons, simulation, and training materials.

Rod Machado's Instrument Pilot's Handbook

Rod Machado's Instrument Pilot's eHandbook

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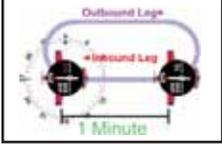
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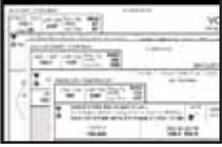
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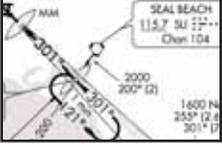
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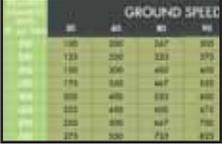
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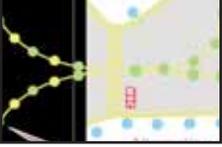
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INTRODUCTION

What the instrument rating is to a pilot, the black belt is to a martial artist. Let me elaborate.

Both the martial artist and instrument pilot are trained to handle challenging situations with skill and poise. It's their defensive skills that allow them to do the right thing if and when their environment turns bad. When the martial artist is asked whether or not he's ever had to use his training, he will often reply, "I use it every day." His training teaches him discipline and confidence, which is something he uses in all aspects of his life, not just in self-defense situations.

The instrument rating does something very similar in the life of a pilot, even when he's not flying instruments. How? His instrument training teaches him to fly precisely and to make maximum and optimal use of the ATC system. For this, and many other reasons, he's a far more capable pilot even when he's not flying in actual IFR conditions.

There's another parallel to consider, too. Both the instrument pilot and the martial artist learn to avoid whenever possible those situations where their defensive skills (avoiding blows from a fist or from a thunderstorm) might actually be needed. That's why I consider the instrument rating to be the martial arts equivalent of a first-degree black belt. I'm not pulling any punches when I tell you that to get the most out of your airplane, to fly it safely, to fly it confidently, you'll want to earn your instrument rating. Period.

I'm guessing you're already sold on that concept. If so, then this book provides the information you need to take the first step, which is passing the FAA instrument knowledge exam. But the goal is not just "minimally competent to pass the test." The goal is "maximally competent to fly the airplane," which is why you will find far more than the minimum information presented in these pages. You will emerge from the final page with not just answers to test questions, but the knowledge behind each answer.

For instance, good instrument pilots know how to gauge the thunderstorm potential of a cumulus cloud by estimating its rainfall rate. They understand how to scan their instruments in a way that provides maximum performance with minimum effort. They know that keeping the needle centered during an ILS or an approach to LPV minimums is best done by using the sky pointer on the attitude indicator instead of staring at the heading indicator.

Whether you're an IFR-rating-seeker in training, or already rated and looking for a review of those instrument concepts you might have forgotten over the years, this book is for you.

Ultimately, by reading this book, you'll know what I know about instrument flying.

That's what I want for you. So have fun, learn and fly.

Rod Machado

Chapter 1

Starting Your Instrument Training

An Instrument Rating? Why Me?

There are a lot of things you really don't need as a pilot. I hate to disappoint you, but a big watch is one of them. Sorry, but someone had to tell you this.

On the other hand, one thing I absolutely know you can use is an instrument rating. It's a combination passport, insurance policy, and bragging-rights card, all rolled into one. It will enable you to leap tall buildings at a single bound, travel almost as fast as a speeding bullet, and do it all in conditions that appear to require X-ray vision. People will ask, "Who was that hooded pilot?" and others will say, "I don't know, but he had an instrument rating." That makes it worth the effort.

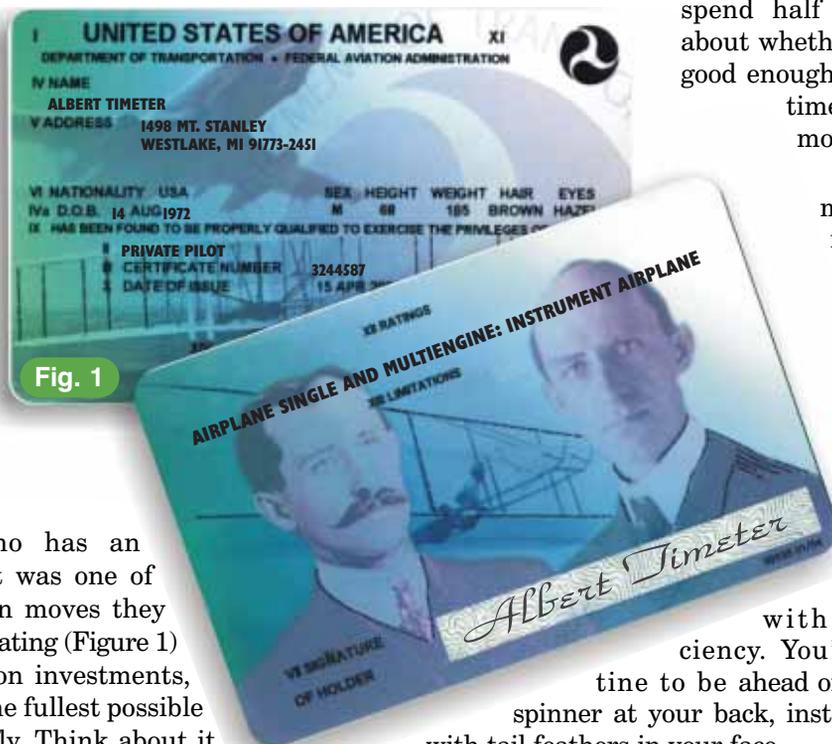
Everyone I know who has an instrument rating feels it was one of the most valuable aviation moves they ever made. An instrument rating (Figure 1) is one of your best aviation investments, because it lets you make the fullest possible use of your capability to fly. Think about it for a second. As a VFR-only pilot, you are not using the full potential of most airplanes, which are typically IFR capable. You pay the full rent (if a renter) or the full expenses (if an owner), but you can use only part of the possibilities! The only way to be PICE (pilot-in-command of everything) is to get your instrument rating.

Without an instrument rating, even relatively small weather hiccups can keep you ground-bound, where you'll miss business appointments, work, and/or fun (and sometimes all three!). It only takes being weathered in by fog for one or two nights at a motel named *The Nine One One* to provide all the motivation you'll need to pursue that rating.

Another and less obvious benefit of an instrument rating is the newfound confidence you will have in your ability to fly the airplane. You will learn to fly more capably, more competently, and more smoothly. You will navigate with more precision, and fly with the confidence that comes from knowing that if the weather is a bit less than perfect, you are not putting yourself and your passengers at risk. And on those weekend trips, you don't have to spend half your time worrying about whether the weather will be good enough to get home again in time for work on Monday morning.

The fact is that instrument training also makes you a better VFR pilot. Perhaps the biggest difference you'll notice is that you will fly with much greater VFR precision. You'll maintain altitude, hold headings and generally maneuver the airplane with much greater proficiency. You'll soon find it routine to be ahead of the airplane with the spinner at your back, instead of being behind it with tail feathers in your face.

Please don't let me (or anyone else) mislead you. The instrument rating will not be your unlimited license to fly fearlessly into raging hurricanes, towering thunderstorms, and not-so-heavenly hail. A big part of getting an IFR rating is learning when to say "No." In fact, having the instrument rating may make the go/no-go decision harder because you have more options from which to





Technically advanced aircraft (TAAs) are the newer generation of glass cockpit airplanes that are becoming very popular for instrument training.

choose. Certain weather phenomena like thunderstorms and icing keep even the most experienced instrument rated pilots on the ground. Even big pilots in really BIG airplanes avoid, rather than challenge, the worst of the weather. The instrument rating extends, by a considerable number, your options to fly when the weather won't allow VFR operations. But it is not an unlimited extension. Knowing where to draw the line in the runway is one of the brain skills you will be acquiring.

I'm happy to play a part in helping you better understand what's required to obtain this rating. I know it will make you a better pilot if you are willing to work hard to gain this credential. In short, it makes you an overall better pilot even if you don't wear overalls when you fly.

Let's take a closer look at what you'll be doing to become an instrument rated pilot.

What It Takes to Obtain an Instrument Rating—Part 61

You can start working on your instrument rating as soon as you've earned your private pilot certificate. Yes, five minutes later is fine, and many people jump into formal instrument training immediately after passing the private checkride. There was a time when applicants for the instrument rating needed a certain minimum flight time (125 hours, for example) before they were eligible to take the instrument rating practical (flight) test. Not any more. The FAA, with help from the researchers in the aviation industry, finally concluded that minimum flight time wasn't a strong predictor of a person's readiness to be a good instrument pilot.

It goes without saying that you'll also need at least a third class medical certificate (Figure 3). Just thought I'd mention this in case you were under the impression that the medical standards, such as eyesight, cardiovascular health, and normal brain function, are suddenly suspended when you enter a cloud and no one can see you.

So, are you qualified to obtain an instrument rating? That depends. Can you read, speak, write, and understand English? You must at least be able to do this. Pig Latin and baby babble don't count. If you've gotten this far, you're probably qualified in the language department.

| Date of Birth | Height | Weight | Hair | Eyes | Sex |
|---------------|--------|--------|-------|-------|------|
| 08/20/1956 | 69" | 162 | Brown | Hazel | Male |

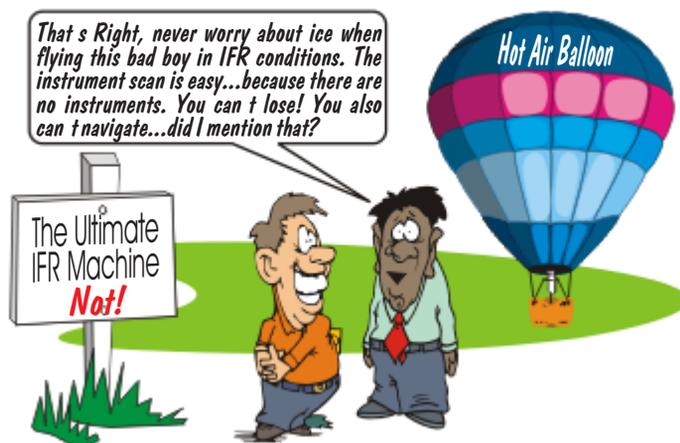
Examined by: *Marvin R. Shapiro, MD*
 Typed Name: Marvin R. Shapiro, MD
 AIRMAN'S SIGNATURE: *Landi Tu Lhong*

Fig. 3

You'll need to pass a knowledge test for the instrument rating, and that's part of what this book is all about. In addition to providing you with the information necessary to pass the test, I'll also be discussing and dissecting much more material that's useful and practical for the instrument pilot in training. When we're finished, you will thoroughly understand the physical and mental skills involved in instrument flying.

The instrument knowledge exam consists of 60 multiple-choice questions. You're given 2 hours and 30 minutes to answer them, and you must obtain at least a 70% score to pass. Where can you take the test? Denny's? Sorry, but you'll have to visit one of the many FAA-approved test centers around the country. Don't worry. There's almost certainly one nearby. Ask your instructor. He or she will know. If not, you can fly to the nearest center with your instructor and log the time toward your rating!

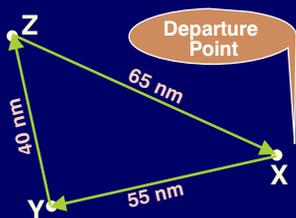
In terms of aeronautical experience, you'll need at least 50 hours of cross-country flight time as pilot in command (PIC). At least 10 hours of this must be in an airplane. Of course, I'm assuming that you're working toward the airplane instrument rating here. Sorry, there is no instrument rating for hot air balloon pilots (but if there were, you certainly wouldn't have to worry about airframe icing, right?).



Meeting The Instrument Cross Country Requirement

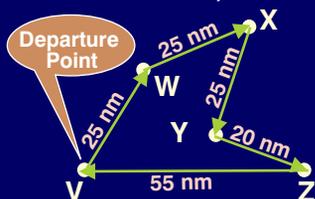
Example A

This cross country flight has 3 stops (the departure airport is considered one of the stops). Two segments (X to Y) and (Z to X) being more than 50 nautical miles from the original point of departure. It meets the XC requirements for the instrument rating.



Example B

This cross country flight has 5 stops and one segment (Z to V, the last segment of the flight) is more than 50 nautical miles from the original point of departure. It meets the XC flight requirements for the instrument rating (the direct distance from V to X is less than 50 nautical miles).



Example C

This flight has 4 stops but there is no segment with a landing that is more than 50 nautical miles from the original point of departure. The time acquired on this flight can't be used to meet the cross country flight time requirement for the instrument rating.

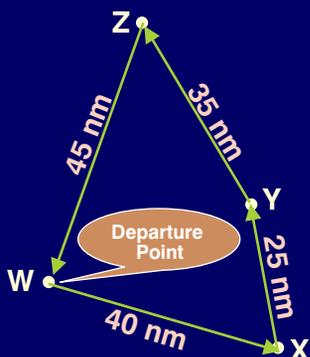


Fig. 4

In certain parts of the country (Southern California, for instance), early morning and late evening stratus clouds make it easy for instrument students to obtain actual instrument experience.



Fig. 5

To count as a cross-country flight, you must make a landing more than 50 nautical miles from the original point of departure as shown in Figure 4. Fortunately, the cross-country flights you made as a student pilot can be used to at least partially meet this requirement. Just to make things clear on the cross country issue, you can land at as many airports as you like on a cross-country flight. To count as a cross-country flight toward the instrument rating, one of the airports you land at must be a straight line distance of more than 50 nautical miles from the original point of departure. Suppose you land at an airport that's 40 miles from the original point of departure, and then proceed to another that's 51 miles from the original point of departure. Does this count toward the instrument rating? You bet it does.

Granted, most applicants working on the instrument rating soon after obtaining their private pilot certificate will have to work hard to acquire the minimum cross-country flight time. Here's an idea that may help you clear this hurdle.

When you and your instructor begin the approach phase of your instrument training, you'll probably make instrument approaches to different airports. If so, elect to make some of these approaches to airports that are more than 50 nautical miles away. If your wheels touch down at those airports (you can do touch-and-goes, that's OK), then the entire flight counts toward the requirement for 50 hours of cross-country time as PIC. The reason you can do this is that it's legal to log PIC time as that time during which you're the sole manipulator of the controls of an aircraft for which you are rated. If you received your private pilot certificate in a single-engine land airplane, then you're rated to fly a single-engine land airplane. If you're taking your instrument training in a Cessna 172, for instance, then you're allowed to log the time as PIC when you are the sole manipulator of the controls, even if your instructor is on board. This doesn't necessarily make you the legal PIC, but it does allow you to log the time as PIC. You were the sole manipulator of the controls during the flight, weren't you?

Regarding the instrument training time, you'll need a minimum of 40 hours of actual or simulated instrument time. Let me explain what *instrument time* is for purposes of meeting this requirement. Whenever you are flying solely by reference to the instruments—in other words, without reference to the horizon outside—you are accumulating loggable instrument flight time.

Now, it would be great if nice, mild, real instrument conditions were always available close to the airport whenever you wanted to train (Figure 5). You'd get all the *actual* instrument conditions you could possibly desire. Very realistic. But not a very realistic possibility in some parts of the country, like Palm Springs, California, unless you want to spend about 40 years getting your 40 hours (but mostly getting a sunburn).

Conveniently, there is an alternative available. *Simulated* instrument time is logged whenever you are flying entirely by reference to the instruments with your

Why Have the IFR Rating? Stuck On Top, Perhaps?

In the aviation equivalent of painting oneself into a corner, this pilot left himself no way out. The decision to stay out of the clouds must be made early, while there are still viable options available.

The FSS said that there was a large band of rain showers and thunderstorms blocking my route. I called back an hour or more later and [FSS] said that the area of rain had passed and that I shouldn't have any trouble going VFR. Initially I was at 5,500 feet, but then I climbed to 7,500 feet to clear the hills and clouds. The farther north I went, the more marginal the weather became. I climbed again trying to maintain VMC. I was talking with several controllers advising them of my problem and requesting higher altitudes to clear the clouds. Eventually I was at 18,300 feet. A controller advised me that I had less than 15 minutes of consciousness at that altitude. I was aware of my bad situation, but I felt that I could not descend into the clouds as I did not have an artificial horizon and I am not instrument rated. I knew that an instrument rating is required at 18,000 feet and above, but I couldn't descend into instrument conditions. The plane got out of control twice and into a spin, but I was able to spot a cloud base for reference and recover.

NASA Callback Report

view of the outer world blocked by an elongated visor (generically referred to as a *hood*), glasses that are opaque on the top part (*Foggles* is one popular brand), or a Klingon force field. Devices like these (shown in Figure 6) are designed by people who specialize in evading all provisions of the Geneva Conventions, and you will develop a deep and meaningful love/hate relationship with all forms of view-limiting devices as your training progresses. Using these contraptions will make you wish you had your head in the clouds.

Out of the 40 hours total instrument time required, a minimum of 15 hours must be given by an *instrument flight instructor*. Yes, there are certified flight instructors who only teach others to fly airplanes (called CFI-A, the *A* stands for *airplane*) and certified flight instructors who only teach instrument flying (CFI-I, the *I* stands for *instruments*). Of course, many instructors elect to obtain both ratings. We unofficially represent these ratings by the designation CFI-AI. You'll need to find at least a CFI-I (usually spoken as "C-F-double-I") to give you a minimum of 15 hours of flight training in preparation for the instrument rating. In all likelihood, you'll just train from beginning to end with an instrument flight instructor.

It's also likely that the 40 hours of minimum time will all be spent with the instructor, despite the regulations allowing you to acquire as many as 25 hours of instrument time alone. No, I don't mean flying solo while wearing some type of view limiting device! Anyone who'd even try such a thing should sign up to be the world's first living brain donor, because it's obvious that their brain isn't being used at all.

So how would you acquire instrument time while flying without an instructor? By having someone who is appropriately rated in the airplane sit in the right seat as a safety pilot, while you fly with a view limiting device (Figure 6). This is perfectly legal, and is, in fact, how many instrument-rated pilots meet their instrument currency requirements and keep their skills sharp. The simulated instrument flight time acquired while doing this counts toward the 40-hour minimum for the instrument rating.

If you decide to acquire instrument time with a safety pilot on board, you'll certainly want to discuss this plan with

your prospective instrument flight instructor first. Don't, however, count on any instructor being too enthusiastic about your scheme if you intend to try to use it as a way of cutting the amount of time you'll spend with the instructor.

The fact is that most IFR students need *at least* 40 hours of dual instrument instruction to gain the required level of competence, and sometimes much more, particularly in major urban areas where the airspace is complex and congested. One study found that the national average was closer to 55 hours.

Like fine wine, there can be no instrument pilot before its time. Getting it right is a lot more important than getting it quickly. Take the long view, and be patient. An instrument rating will last a lifetime, so a few hours beyond the bare minimum shouldn't be viewed as a burden or imposition, but rather as an opportunity to hone your skills and elevate your confidence as well as your airplane.

In addition to the other requirements, you will need to make a long instrument cross-country flight with your instrument flight instructor. The FAA defines "long" as being a minimum of 250 nautical miles along airways or



Fig. 6

This is a personal view limiting device made from protective eyewear and black electrician's tape. Total cost? About \$3.



Fig. 7A



Fig. 7B



Fig. 7C

Flight training devices (FTDs) are often full motion devices that come very close to simulating reality (Figure 7A). In fact, it's possible to obtain a type rating for some airplanes by using these devices and never once having to fly the real airplane. Frasca's Piper Seminole FTD (Figure 7B) is a smaller version of these devices. Aviation Training Devices (ATDs) are often smaller desktop units, such as the one in Figure 7C, which is a sub-category of ATDs known as a *basic ATD* or *BATD*.

via an ATC-directed routing, with at least one landing at an airport more than 50 nautical miles from the original point of departure. The purpose of this flight is to give you experience flying IFR over long distances. It's also helpful in getting you away from your home area, where you feel most comfortable because you have everything memorized. Part of IFR flying is being capable of coping with sudden changes and unfamiliar circumstances without getting rattled.

You'll be required to make an instrument approach at each airport on your long cross country, and to make at least three different kinds of instrument approaches (either a GPS, VOR, Localizer, LDA, SDF, NDB and/or an ILS approach. Don't worry. You'll learn about these abbreviations later). You aren't required to make approaches to three different airports (although this is certainly a good thing to do for the experience it offers). If you think about it, you must make approaches to a minimum of two airports, one of which may be your home airport. Getting an IFR rating is costly in both time and money, but invaluable in terms of what it gives you for the rest of your piloting life. And there is a way to help reduce the cost of this training and make it more effective in the process. This involves using something known as a simulator or a flight training device.

Aviation Training Devices (ATDs) & Flight Training Devices (FTDs)

The regulations allow you to obtain a maximum of 20 of the required hours "flying" in one of two devices—a flight training device (FTD), or an aviation training device (ATD)—to meet the 40 hour minimum instrument time requirement.

FTDs tend to be highly sophisticated units that simulate the cockpit environment (Figure 7A). These devices are often full-size aircraft cockpit mockups of specific aircraft. They often have three degrees of motion and use a visual presentation to provide a simulation that's almost like the real thing. So real and life-like is it that most airlines use them to train the pilots that carry passengers around the world. In fact, they're so real that pilots have actually had heart attacks in them during exhaustive training sessions. I guess you could also call them heart attack simulators, too (although I don't think the instructor's objective is to stop an engine and the pilot's heart at the same time).

The Frasca Piper Seminole simulator (Figure 7B) is a flight training device (FTD). No an FTD is not a machine that gives you flowers when you push its buttons (that device is known as a *husband*). These machines are full size replicas of the instruments, equipment, panels, and controls of an aircraft, or set of aircraft, in an open flight deck area or in an enclosed cockpit, including the hardware and software for the systems installed, that is necessary to simulate the aircraft in ground and flight operations. It does not need to have a visual system or have any degree of motion (although on one occasion, I heard that a pilot leaned on the fixed box containing the panel mockup and tipped it over, thus simulating a hard landing on a wing).

It's possible that your flight school will have a FTD or ATD available for training purposes. What if they don't? You might consider purchasing your own Basic ATD to help you train at home.

The FAA's Ruling on the Long "250 Nautical Mile" Instrument Cross Country Flight

QUESTION: Do the approaches required under § 61.65(d)(2)(iii)(C) need to be completed at three different airports?

ANSWER: Ref. § 61.65(d)(2)(iii); No. Under § 61.65(d)(2)(iii), a pilot seeking an instrument-airplane rating must perform three different kinds of approaches with the use of navigation systems, but the approaches may be performed at one or more airports. In addition, in order to meet the aeronautical experience requirements under § 61.65(d)(2)(iii), the pilot also must (1) land at one or more airport(s), other than the airport of original departure, using an instrument approach; (2) return to the airport of original departure using an instrument approach; (3) travel a total distance of 250 nautical miles or greater along airways or ATC-directed routing; and (4) choose an airport for landing that is separated by a minimum straight line distance of more than 50 nautical miles from the airport of original departure (see § 61.1(b)(3)(ii)(B)). Given the requirement that the pilot land at a minimum of one airport other than the airport he or she originated from, it is most efficient if a different approach is used for each landing so the requirements under § 61.65(d)(2)(iii)(C) partially are met.

Maneuvering Speed Truth

As you know by now, an airplane flown at or below its maneuvering speed in turbulence, will stall before exceeding its limit load factor (if you don't know this then please read Postflight Briefing #2-5 in *Rod Machado's Private Pilot Handbook* for a comprehensive and very different look at maneuvering speed). As a result, the airplane doesn't suffer structural damage. Yes, it may momentarily stall, but you probably never have to use standard stall recovery procedures as a result. You can't say the same about doing something as positive when a wing comes off. In strong turbulence, the only way to ensure that you won't exceed the airplane's structural limit is to fly a little below maneuvering speed, perhaps by 10-15 knots. Since maneuvering speed is an indicated airspeed, the horizontal component of a gust (which can cause a 10-25 knot airspeed change in moderate turbulence according to one British study) can temporarily increase your indicated airspeed many knots over V_a .

speed below the colored minimum. (For your information, the color coded stall speed can also be the minimum steady speed at which the airplane is controllable. Either definition is correct).

Moving in a clockwise direction and following the white arc, we come to its high-speed end. This represents the maximum airspeed at which you may fully extend the flaps or fly with them fully extended. Called V_{fe} or velocity (V) of flaps (f) extended (e), flaps (unless approved by the POH) may not be used above this speed for fear of structural damage (and the prime directive of any pilot is to avoid bending any or all parts of the airplane).

Most things that are green are good (especially vegetables, although my little nephew considers asparagus to be nothing more than spinach legs). That's why the green arc represents the normal operating range of the airplane. The beginning of the green arc represents the power-off stall speed or minimum steady flight speed in a specified configuration. For the airplanes we typically fly, this configuration occurs when the plane is at its maximum take-off weight and the flaps and gear (if retractable) are up. This is called V_{s1} or velocity (V) of stall (s) with everything inside (1)—think of the 1 as the letter *i* representing gear and flaps up or *inside*. With flaps up, gear up, and power at idle, the beginning of the green arc in Figure 15 suggests this airplane needs a minimum of 64 knots of wind flowing over its wings before it starts flying. If you're flying an airplane with a primary flight display, Figure 16 shows how these airspeeds might be portrayed on these instruments (the display may vary between manufacturers).

Additionally, maneuvering speed is determined in a power-off condition by the manufacturer. Since you use power when you fly airplanes (you do, don't you?), the result is that the airplane stalls at a slightly slower speed. Why? Because some of that power is applied vertically, in the direction of lift, thus reducing the total amount of lift the wings need to produce for flight. Thus, the wings can fly at a slightly lower angle of attack for a given power condition. In cruise flight your wings are now slightly farther away from the angle of attack at which they will stall when a strong vertical gust is encountered. Those wings can now develop slightly more lift (perhaps more than they, or the airplane's fixed weight components, can withstand) before they stall if and when they encounter a strong enough vertical gust.

The high speed end of the green arc is called V_{no} or the maximum structural cruising speed. Since the green arc is the airplane's normal operating range, think of the top of the green arc as the velocity (V) of normal (n) operation (o). At and below V_{no} , airplanes (certified on or after September 14, 1969) are certified to withstand substantial sharp-edge vertical gusts of 50 feet per second without experiencing structural damage (or sharp edge vertical gusts of 30 feet per second if the airplane was certified

All this adds up to one important point. It's safer to fly a little less than the manufacturer's posted maneuvering speed for your airplane when in strong turbulence.

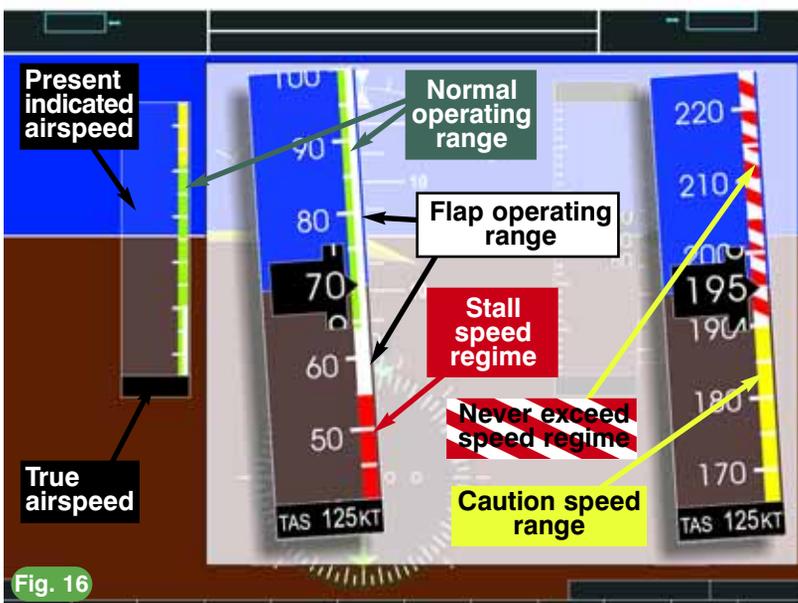


Fig. 16

Digital Airspeed Readouts on PFDs

Primary flight displays provide digital airspeed readouts, as shown in Figure 16. 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 have the same meaning as the color codes shown in Figure 15. On this primary flight display, however, the never-exceed speed region, is shown by a red striped line and the stall speed region is shown by a solid red color. PFD manufacturers may vary the color coding used for these airspeed regions.

Some PFDs provide you with trend lines (the magenta line, Figure 17, position Z) that show where your airspeed will be in six seconds. Best rate, angle and glide speeds may also be shown by thumbnail identifiers (position X).

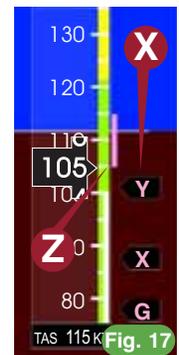


Fig. 17

How Strong Are Those Wings?

Looking at the Mooney airplane to the right, you're only seeing a portion of the force the wings on most small general aviation airplanes are safely capable of handling. As a matter of fact, it's rare for a wing to fail because it's overstressed by turbulence. Most wing failures occur because the pilot was flying in or near IMC and lost control of the airplane, resulting in a dramatic increase in airspeed. Too much speed increases the likelihood of damage by flutter or excess stress caused by the pilot pulling too hard during a 200-300 mph recovery. Take comfort in knowing that you'll be lucky to find a single case of a wing breaking off an airplane flown at or below its V_o/V_a .



Courtesy Mooney Aircraft Co.

before September 14, 1969). Operations above V_{no} within the yellow arc are allowed only in smooth air (and this means smooth air, not air that's less than the 30 or 50 FPS limit values, either). To learn more about these vertical gust values and how they may affect your airplane, you might want to read the sidebar on page 2-11 and/or Chapter 21 of my *Instrument Pilot's Survival Manual* that covers this topic in much greater detail.

Your airplane has one speed that should never be exceeded. Coincidentally, it's called V_{ne} or velocity (V) that you never (n) exceed (e). This is the red line on the airspeed indicator. It's also the maximum speed at which the airplane can be operated in smooth air and going above it means all bets are off, and if you go past it you're a bit off, too. Exceeding V_{ne} can cause aerodynamic flutter, which, coincidentally, is something your heart valves also do if you experience flutter. Aerodynamic flutter is often an uncontrollable and destructive vibration of certain airfoil surfaces.

Dynamic divergence and *aileron reversal* are a couple of the other bad boys associated with exceeding V_{ne} . Don't go there. Many unprepared pilots have lost control of their airplane in IMC (instrument meteorological conditions) and reached, then exceeded, V_{ne} . Many have paid a hefty price for this error. Don't exceed this speed. Period. No exceptions and no excuses, unless you're a test pilot and getting test pilot pay, a bonus, and a free chocolate treat for bringing the plane back undamaged. Consider this your Surgeon General's warning to avoid flying above the airspeed indicator's redline.

V_{ne} is 90% of the speed at which flutter occurs. Granted, V_{ne} has a slight, built-in safety factor but who wants to count on that? General aviation flying isn't the test pilot business. If you're looking for thrills, try tightrope walking during bee season. Leave exploring the

far reaches of the airplane's envelope to folks who wear parachutes and are trained to do such things.

Three important speeds are *not* shown on the airspeed indicator: V_a , V_{lo} and V_{le} . The first speed is called *maneuvering speed* or V_a , otherwise remembered as velocity (V) of acceleration (a). In turbulence, you should be at or below maneuvering speed. (my preference in serious turbulence is to be below maneuvering speed, perhaps by 10-15 knots, since this is an indicated airspeed and a gust can increase your indicated airspeed many knots over V_a).

Maneuvering speed is found well below V_{no} . Your Pilot's Operating Handbook or posted placards provide you with the airplane's maneuvering speed. Since V_a is

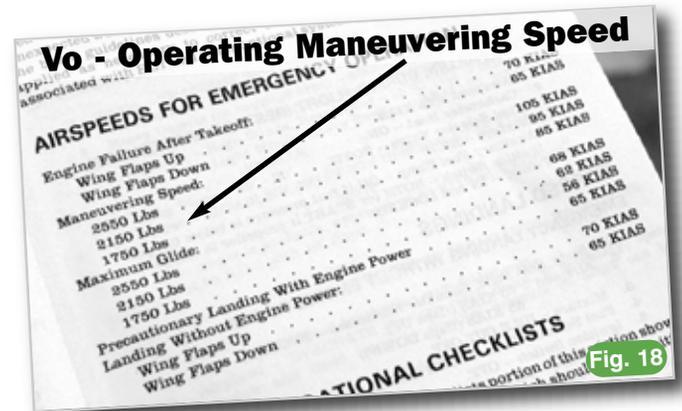
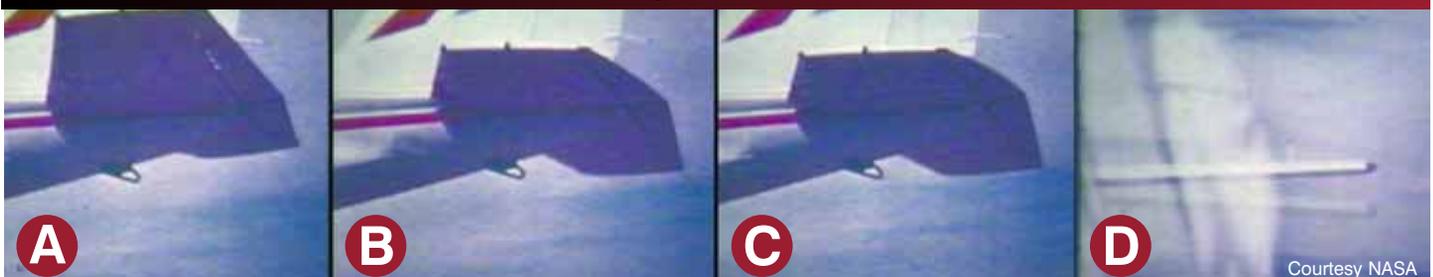


Fig. 18

technically defined at the airplane's maximum design weight and since maneuvering speed decreases with a decrease in weight, the FAA has added a new term referencing the maneuvering speeds associated with lighter weights. This term is called V_o or *operating maneuvering speed*. Some manufacturers provide one or more V_o 's for weights less than max gross, as shown in Figure 18.

Divergent Flutter



Courtesy NASA

The following video frame sequence (A to B to C) represents approximately one-fifth of a second in which the horizontal stabilizer and the elevator are in the throes of divergent flutter. The test pilot on this Twin Comanche induced flutter at high speed by pulsing the control wheel with his hand then, when flutter occurred, he immediately reduced power and applied some back pressure on the elevator to stop it. Frame D shows the range of surface movement as captured by a camera inside the cockpit.

Gear Operating Speeds

| SECTION 2 LIMITATIONS | | PIPER AIRCRAFT CORPORATION PA-28RT-201T, TURBO ARROW IV | |
|--|-------|--|------|
| | SPEED | KIAS | KCAS |
| Maximum Flaps Extended Speed (VFE) - Do not exceed this speed with the flaps extended. | | 108 | 104 |
| Maximum Landing Gear Extension Speed - Do not exceed this speed when extending the landing gear. | | 133 | 130 |
| Maximum Landing Gear Retraction Speed - Do not exceed this speed when retracting the landing gear. | | 111 | 109 |
| Maximum Landing Gear Extended Speed (VLE) - Do not exceed this speed with the landing gear extended. | | 133 | 130 |

Fig. 19

The other two speeds not shown on the airspeed indicator are V_{lo} and V_{le} . These speeds refer to operations of the airplane's retractable landing gear (if equipped with retractable gear, of course; please don't make yours retractable if it wasn't built that way). The velocity (V) of landing gear (l) operation (o) (V_{lo}) is the maximum speed at which the gear may be raised or lowered. The velocity (V) with the landing gear (l) extended (e) (V_{le}) is

the maximum speed at which the airplane can be flown with the gear down.

When the gear is in transition, it's often more vulnerable to the effects of speed (often because of exposed and relatively delicate gear doors or the forces placed on the mechanisms used to extend or retract the gear). Once down and locked into position, the gear is able to resist a larger wind force. This is why V_{lo} is sometimes less than V_{le} rather than equal to it. Look in your Pilot's Operating Handbook or on the airplane's placards to find information on these speeds (Figure 19).

As a passing point, if you ever manage to extend your gear beyond V_{lo} or fly gear down beyond V_{le} , don't raise the gear again. Leave it down until you have a chance to check the gear doors for damage. Some gear doors can warp, bend, twist or even depart the airplane if excessive speeds are encountered. Don't be like the Air Force colonel departing in a T-28 with a young lieutenant in the rear seat. The colonel lifted off prematurely, retracted the gear, and the airplane began settling back to the runway. The prop dug out a few hundred chunks of asphalt from the landing surface before the airplane was once again airborne. The colonel continued flying, paying no attention to the matter. The lieutenant said, "Sir, shouldn't we return to land and check for damage?"

The colonel replies in a gruff voice, "Naw, let 'em check their own dang runway."

Should Turbulence Scare You? A Case for a G-Meter

I constantly marvel at the human reaction to in-flight turbulence on airliners. People scream, people cry, people pray. And that's just in the cockpit. Simply stated, we don't like turbulence because it's unpredictable. Many years ago, I sent a student pilot on a solo cross county flight to Palm Springs, CA. Several large mountains—aviation's biggest troublemakers—form the perimeter of the route to this desert airport. Given enough wind, these mountains often produce sheets of churning, bubbling air.

That day was forecast clear and smooth (ha!). My student departed, only to return four hours later, his face flushed free of all blood, color, and apparent life. He waved me over and told his tale. "It was the worst turbulence I've ever seen," he blurted. "It was so bad I thought I saw the Buddha."

Since he was in a Cessna 150 Aerobat (it had a G meter), I walked him over to the cockpit. We looked inside at the G meter (which stays pegged at the highest G-force encountered, until reset). I pointed to the instrument. It read 1.7 G's. I said, "You only pulled .7 more G's than you feel in straight-and-level, unaccelerated flight. In fact, you experience more G's (2 to be exact) in a 60 degree steep bank turn."

He looked puzzled, liked a baker who had never heard of yeast. I was waiting for him to admit that he really saw his friend Bubba, not the Buddha. In the end, he was simply amazed that the shelling he took never exceeded even one-third of the airplane's limit load factor (aerobatic aircraft have a limit load factor of 6 G's positive). In other words, he was in a 6G airplane with a 1.7G triggered imagination. If anything, this should reinforce the point that it's not the G force that scares pilots, it's the unpredictability of the event. This is, however a good reason to install a G-meter in your airplane to help calibrate your "seat of the pants" reaction to turbulence.

On the other hand, how likely is the average airplane to reach or exceed this G force limit? On a rare occasion, it happens. When and where it happens is no real surprise.

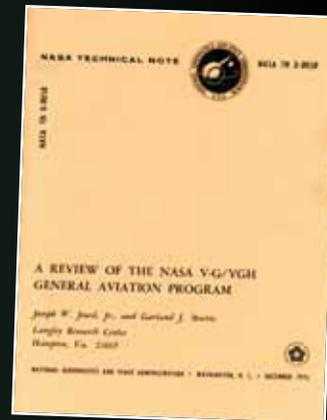
A Typical G-Meter



A NASA study on gusts and maneuvering loads found that exceeding an airplane's limit load factor as a result of pilot-applied control inputs was primarily the province of aerobatic flight, aerial applications and instructional operations.

It's no surprise that an aerobatic pilot, confined to a designated cube of airspace, might yank and bank to keep the airplane within that cube. Aerial applicators are similarly self-restricted by the size of the field they're dusting. Both operations can lead to high load factors as pilots maneuver to remain within these self-imposed zones.

Students are no less likely to be rough on the flight controls, which is the primary reason instructional flights experience excessive load factors. This same NASA study concluded that commercial survey operations (e.g., forest and pipeline patrol airplanes) were most likely to experience turbulence or gust-induced forces outside the design flight envelope. This isn't surprising, because these folks constantly fly from 50 to 1,500 feet above the surface where mechanical turbulence is greatest.



Understanding the Airplane's Gust/Stress Envelope

The stress envelope, sometimes known as the v-g (velocity-load factor) diagram provides you with a picture of an airplane's stress limits. Figure 20A shows the stress limits for a typical general aviation airplane. The borders of the stress envelope (the red dashed line) identify the operating limits of this airplane. The left upper border of the normal flight (green) envelope is the airplane's stall speed in the clean configuration (V_{s1}). The upward and downward curving lines represent the accelerated stall speed for a specific positive or negative load factor (remember, as the load factor increases [or decreases in the negative direction] the stall speed increases and this line represents that increase in stall speed). V_a represents the airplane's maneuvering speed at the airplane's max certified gross weight. The far right vertical border of the caution range (yellow) envelope is the airplane's maximum allowable cruising speed (also known as V_{ne} —never exceed velocity). V_d is the airplane's design dive speed. Beyond V_d the airplane may experience flutter and a bunch of other bad things I'd rather not talk about. V_{ne} is designed to be no more than 90% of V_d . The top and bottom parts of the normal and caution regions represent the limit load factors for the airplane. In this instance, the airplane shown is certified as a normal category airplane (+3.8 G's, -1.52 G's).

The airplane's gust envelope in Figure 20B represents the gust limits of a typical general aviation airplane certified under the newer FAR Part 23 regulations (effective September 14, 1969).

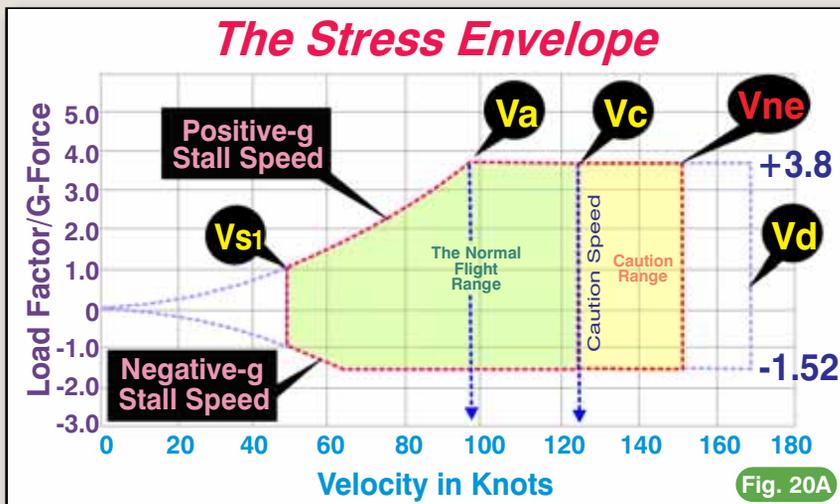
These regulations require that an airplane be capable of withstanding a 50 FPS sharp-edge gust at V_c (the beginning of the yellow arc on most airspeed indicators) without exceeding its limit load factor. These regulations also require an airplane to withstand 25 FPS sharp-edge gusts at its design dive speed (V_d).

Looking at Figure 20B, the blue diagonal lines represent the effect of a 50 FPS sharp edge gust on the airplane. It's clear that a gust of this magnitude (or less) would not stress the airplane beyond its design limits (this envelope and all the others shown in this book are based on the airplane operating at maximum gross weight).

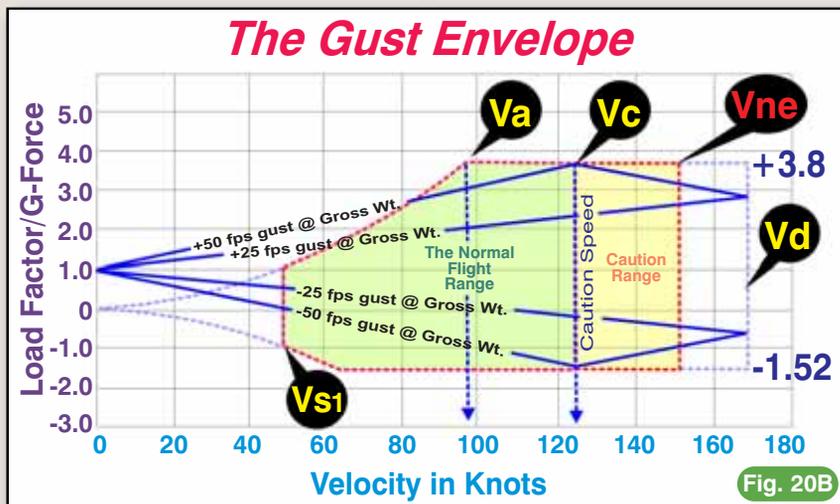
Airplanes certified under the older Civil Air Regulations (CAR 3.201, pre-September 14, 1969) are only required to withstand 30 FPS and 15 FPS sharp-edge gusts, respectively, without exceeding their stress limits (Figure 20C). Beechcraft Bonanzas, for example, were certified under the older FAR Part 23.

As a point of curiosity, a sharp-edge gust is one that is expected to occur instantaneously instead of coming on slowly and peaking in intensity. Since most gusts aren't the theoretical sharp-edge type, it certainly works in your favor to expose the airplane to a little less overall stress.

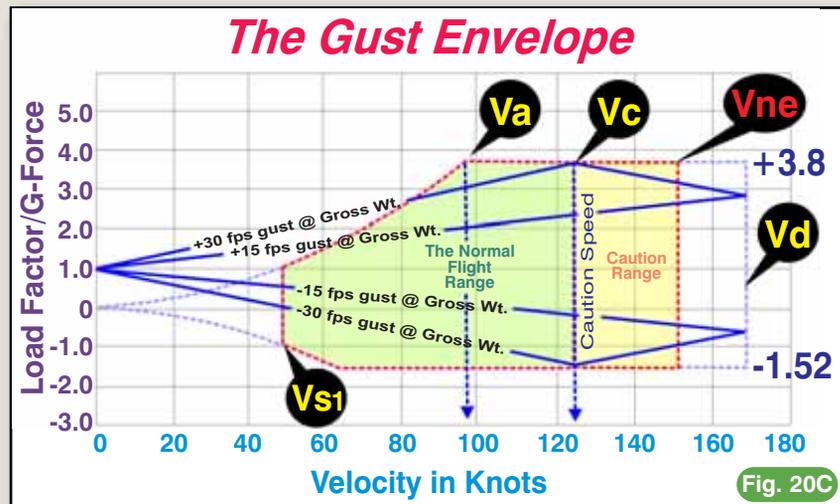
If you'd like to learn more about how turbulence can affect your airplane, please read Postflight Briefing #9-3 on Page 9-64.



The borders of the airplane's stress envelope are established by the physical limits of the airplane's accelerated stall speed (both in the positive-g and negative-g condition), by the limit load factor (both in the positive-g and negative-g condition), by the stall speed (V_{s1}), and design dive speed (V_d).



Airplane certificated on or after September 14th, 1969 were required to meet the stress standards of a design envelope based on a maximum sharp-edge gust of 50 feet per second.



Airplane certificated prior to September 14th, 1969 were required to meet the stress standards of a design envelope based on a maximum sharp-edge gust of 30 feet per second.

Now it's time to nudge your noodle a bit. Suppose we wanted to **change airspeed** while we were in level flight or in a turn. Which instruments are primary and supporting in these two conditions?

The primary and supporting pitch and bank instruments don't change for either of these conditions, but the power instruments do (Figure 20). When changing airspeed, the RPM/MP gauge becomes temporarily significant, thus it becomes primary, with the airspeed indicator a supporting instrument. After all, we may look at the RPM/MP gauge as we set the power value (Figure 20, position A) used to give us the target airspeed (approach airspeed, for instance). Once the desired airspeed is reached, the airspeed indicator becomes primary for power and the RPM/MP gauge becomes a supporting power instrument (Figure 20, position B). As a general rule, any time the throttle is being moved to a specific setting, the RPM/MP gauge becomes the primary power instrument.

Primary/Supporting Power Instruments For Airspeed Change in Level Flight

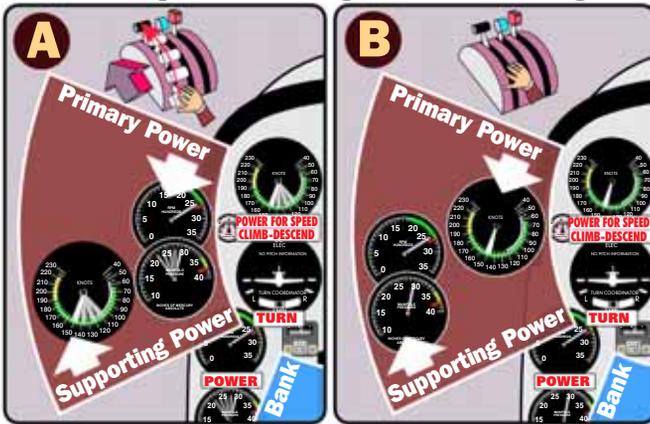


Fig. 20

What we haven't talked about yet is **transitioning between different attitudes**. This is where the attitude indicator plays a very big part in attitude instrument flying. As a general rule, whenever you're transitioning between attitudes (i.e., making a major attitude change), the attitude indicator becomes primary for either pitch and/or bank during the transition. This is why the word **START** is found under the attitude indicator. All major attitude changes should start with a look at this instrument. Major attitude changes include rolling into or out of a turn, pitching up or down to climb or descend, or any combination of these. All these attitude changes are initially made by focusing on the attitude indicator until the transition is complete. This is a very important point for you to understand.

For instance, if you're transitioning from straight and level flight to a constant-air-speed climb, the attitude indicator is the primary pitch instrument during the transition. The airspeed indicator and vertical speed indicator become the supporting pitch instruments as shown in Figure 21. Once you're *established* in the correct attitude, the airspeed indicator becomes primary for pitch and the

attitude indicator and vertical speed indicator become the supporting pitch instruments (as we've previously shown in Figure 18).

Here's another example. Suppose you're transitioning from straight and level flight into a level, standard rate turn at a specific airspeed. You'll enter the turn using the attitude indicator, so you'll start your scan there. During the transition, as you're rolling into the turn, the attitude indicator is primary for bank, the altimeter is primary for pitch, and the airspeed indicator is primary for power as shown in Figure 22. The turn coordinator is supporting for bank, the attitude indicator and vertical speed indicator are supporting for pitch, and the RPM/MP is supporting for power. Once the turn is established, the primary and supporting instruments are the same as those previously shown in Figure 17.

Of course, there are many subtleties that we'll cover regarding what to do in correcting for small altitude and heading variations. These aren't too important right now. I'm more interested in putting your knowledge of primary and supporting instruments to work in that three-step scan procedure I talked about earlier. We've put in a lot of effort figuring out how to decide which instruments are primary and secondary. Besides the fact that it's on the FAA knowledge exam, why do you care? Because this information is going to determine how you scan the instruments at any moment, and scanning the instruments is the core skill of instrument flying.

Instrument Scanning: Doing the Three-Step

All knowledge begins with definition. No, I didn't make that up. It sounds too good. Besides, it's true. Before I can show you how to scan instruments, I want to be sure you understand what I mean by the term *instrument scan*.

When I speak of instrument scan, I'm talking about how you will check the primary and supporting instruments, interpret them, then use them to ensure that the airplane is being controlled properly. All of this can be packaged into a three-step scan procedure that you'll use every time you make a **major attitude change**. These three-steps will now be officially called our *instrument scan procedure*.

Primary/Supporting Instruments Entering a Climb from S&L Flight

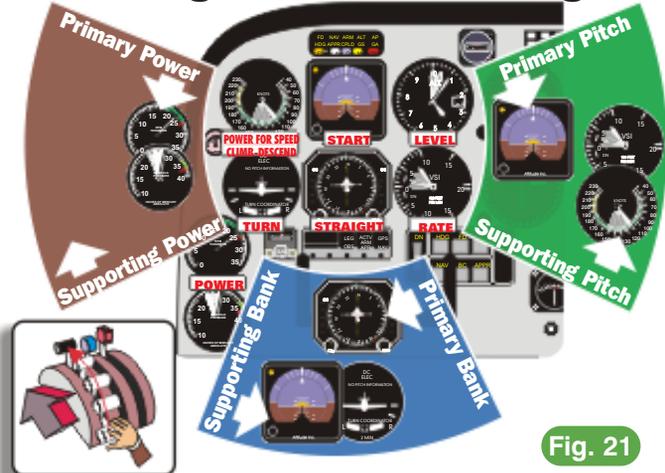


Fig. 21

Primary/Supporting Instruments Entering a Level Turn from S&L



Fig. 22

The Scan Starts with The AI



Fig. 24

Think about it this way. If you want to enter a climb, a descent, a turn, or any other maneuver that instrument pilots make, you'll simply run through the three steps that I'll give you. You *don't* need to memorize a specific scan pattern for each maneuver you want to accomplish. Imagine having to say to yourself, "OK, I'm going to enter a climb so what's the specific scan pattern required to do this?" or "I'm returning to straight and level flight from a climbing turn so what's the scan pattern for this maneuver?" This would be cruel, like using turtles for speed bumps. I wouldn't want to punish that three pound brain of yours with an exercise that requires as many scan patterns as there are basic flight maneuvers (and there are quite a few, too).

Instead, you only need to remember three steps along with the instrument labeling system I showed you in Figure 13. You'll do the three steps in order every time you

want to make a *major attitude change* (i.e., climb, descend, turn, enter a climb from a turn, enter straight and level flight from a climb and so on). All three steps together should take approximately 10 to 15 seconds to complete. Figure 23 shows the three steps and the order in which to do them.

I'll speak only of primary instruments in the three-step instrument scan procedure. Any pitch, bank or power instrument that isn't primary becomes a supporting pitch, bank, and power instrument by default.

Here's the big picture of the three steps in action:

Begin any major attitude change by placing the airplane in the new attitude, adjust the power and trim if necessary, all the while checking that no instrument has failed or is reading erroneously.

Radial cross-check the primary instruments, making small corrections on the attitude indicator if necessary.

Make a final trim adjustment, and then monitor all six flight instruments to maintain the new attitude.

The specific details and reasons for each of the three steps follow.

Step 1 of the Three-Step Scan

The first step in the three-step scan is to select the *attitude*, *power*, and *trim* conditions for the new flight attitude and confirm the correct operation of the attitude indicator. This first step is executed by focusing *solely* on the attitude indicator. That's why it's labeled START as shown in Figure 24 (hopefully, someone won't try and start the engine by tapping on this instrument). Select the attitude that your experience says will provide the flight conditions you're after. You don't have to be perfect, just reasonably close.

The big question here is whether it's reasonable to focus your attention on only the attitude indicator when changing attitudes. After all, the attitude indicator could fail and lead you astray (like scanning

The Three-Step Instrument Scan

Fig. 23

| Steps | |
|---|--|
| <p>1. Select attitude, power and trim.</p> | |
| <p>2. Radial cross-check the primary instruments.</p> | |
| <p>3. Make final trim adjustments and rectangular cross-check the Big-6 instruments.</p> | |

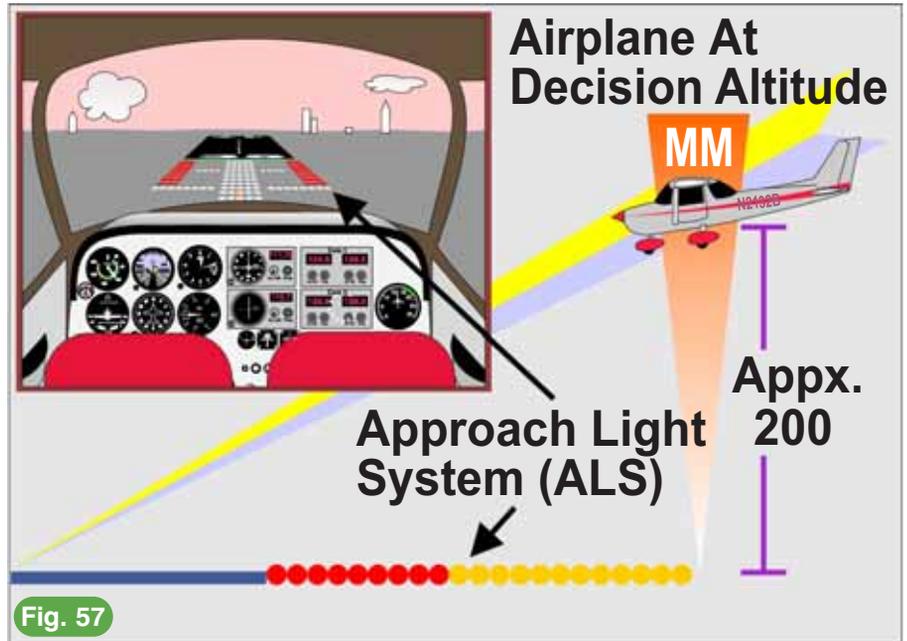
Light Up My Life: The Approach Lighting System (ALS)

Finally, we arrive at the last part of the ILS, the *approach lighting system* (ALS). Sherlock Holmes apprentice that you are, you've probably noticed that the ILS brings you to within approximately 3,500 feet of the runway threshold at a vertical height of 200 feet (Figure 57). That's an awfully thrilling place to leave a pilot hanging, especially when most of the ILS approaches we fly (known as Category I ILSs) require only a half mile visibility and no minimum ceiling height for landing. This is precisely why the approach lighting system was developed. Keep in mind that when all the fancy electronic stuff is done, you still have to make the last bit of the approach visually. From DA (Decision Altitude, sometimes referred to as DH or Decision Height), it's "no see, no go." The ALS is there to help pilots flying on instruments transition to visual flight for landing.

The folks who developed the ALS should be named Einstein for their sheer brilliance in designing such a system of lights. Relatively speaking, of course. When you are at or near DA on an ILS, you don't have a lot of time to identify the ALS. That's why there are two basic light systems: precision and nonprecision instrument runway approach lighting (Figure 58). (See page 17-1 for a definition of *precision instrument runway*.)

Two common precision instrument runway ALSs are named ALSF-1 and ALSF-2. The ALSF 1 and II systems are often 2,400 to 3,000 feet in length and

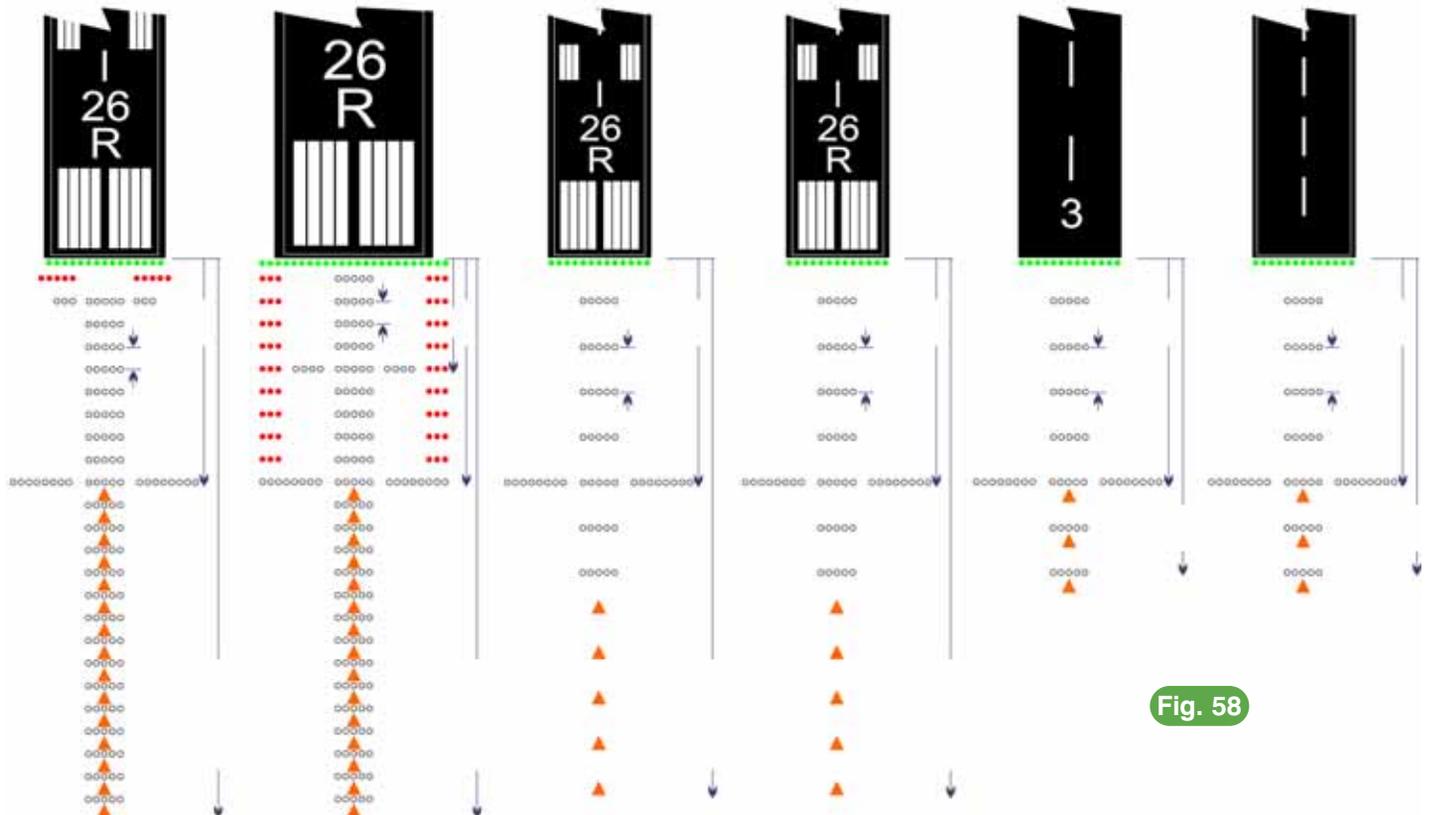
Decision Altitude and the Middle Marker



Common Varieties of Approach Lighting

Precision Instrument Runway Approach Lighting

Nonprecision Instrument Runway Approach Lighting



stop at the runway threshold. The “F” in the ALSF designation stands for sequenced flashing lights (brilliant white bursts of light appearing as a ball of light moving toward the runway). Where possible, sequenced flashing lights are built into the approach lighting system and stop at the approach light’s decision bar, which is located 1,000 feet from the runway threshold (Figure 59). Because they appear to run quickly as they flash in sequence, the sequenced flashing lights are sometimes called “the rabbit.” So don’t call the animal protection squad if you hear a pilot ask the controller to “Kill the rabbit.” They’re not cooking up a hasenpfeffer dinner date. It’s simply a request to turn off the sequenced flasher, which some pilots find so intense it makes them tense (and makes it difficult for them to make the instrument to visual transition for landing, too). As a general rule, any ALS system that’s 2,400 to 3,000 feet in length is usually associated with a precision instrument runway as shown in Figure 60 B and D.

Nonprecision instrument runway ALSs are typically (but not always) 1,400 feet in length as shown in Figure 60, A, C and E. Here are examples of the five additional categories of approach light systems:

1. Figure 60A shows a typical MALS or *medium intensity approach light system*, consisting of seven white light bars separated by 200 feet in length for a total length of 1,400 feet.

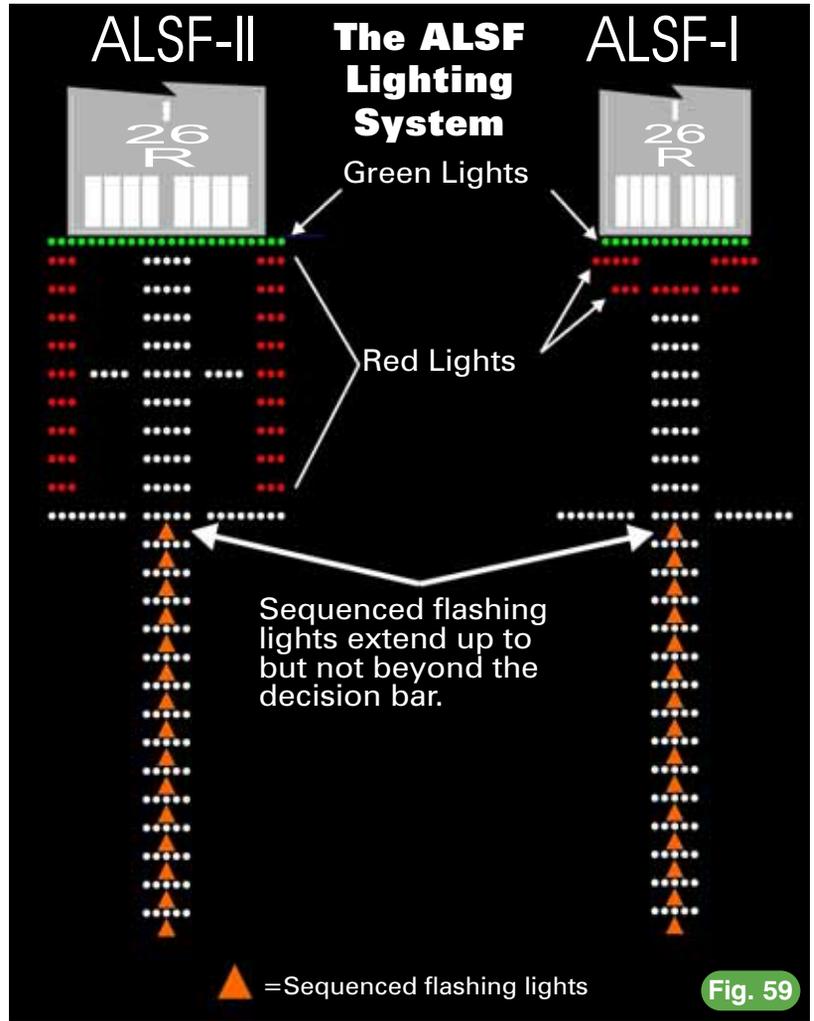


Fig. 59

Precision and Nonprecision Instrument Runway Approach Lighting

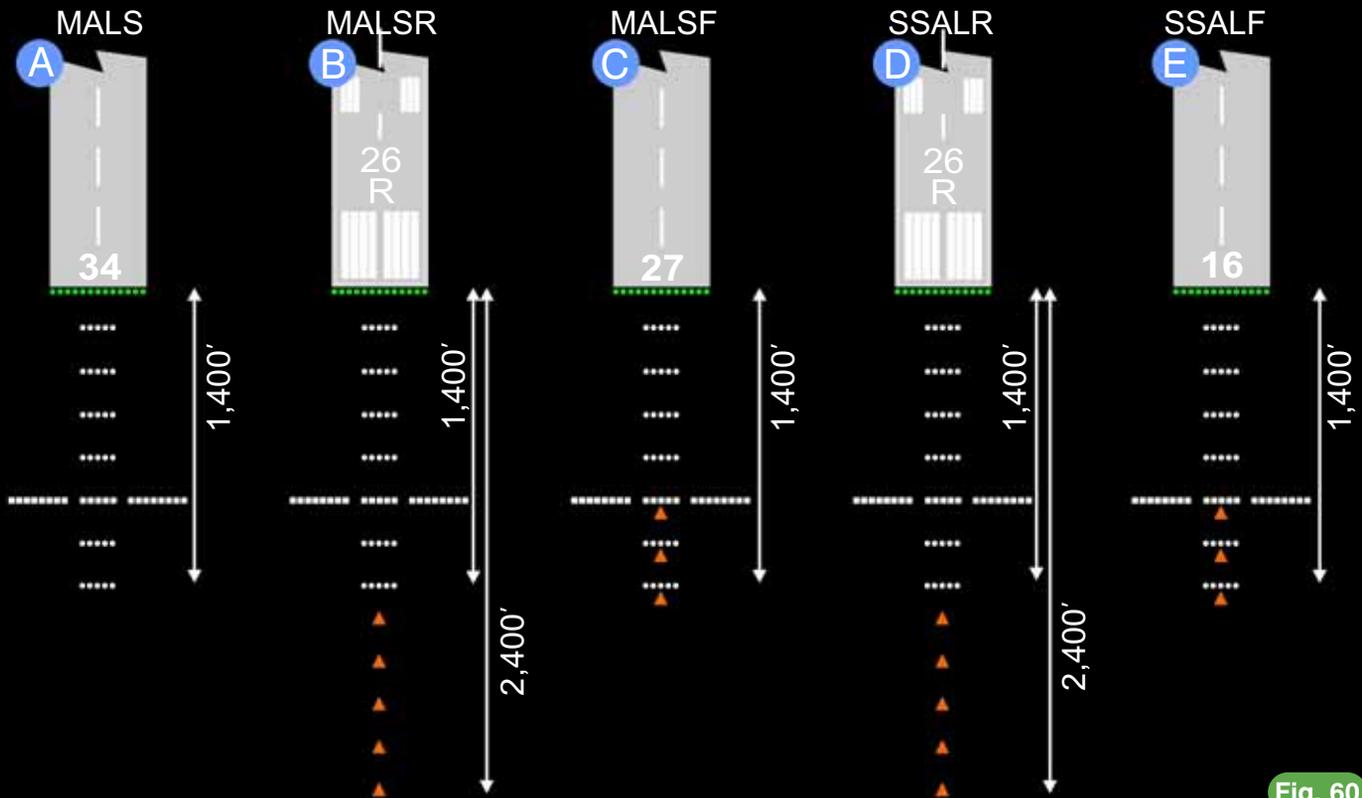
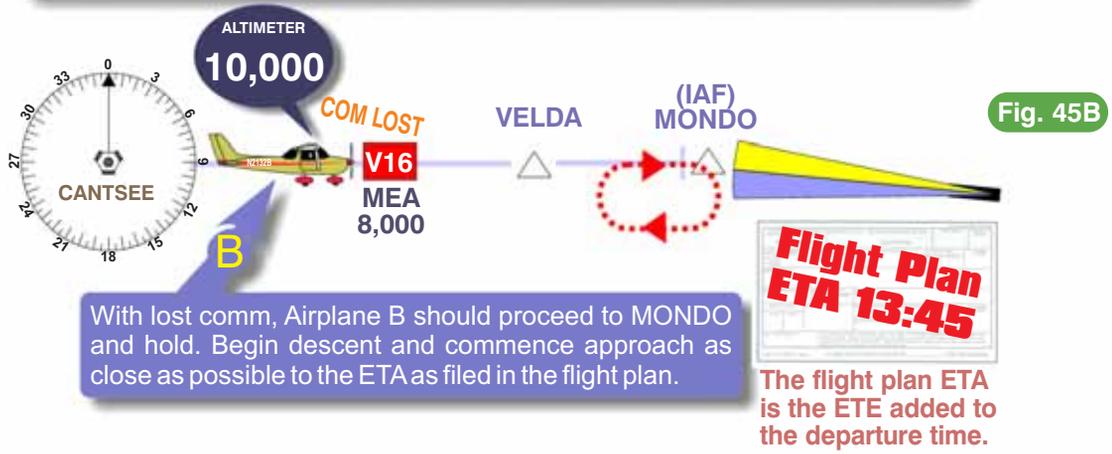


Fig. 60

Lost Comm: When Should You Fly the Approach? Scenario 2

“2132 Bravo, is cleared to MONDO intersection via V16 direct MONDO. (Note: no EFC time given by controller in this clearance.)



why you should always advise ATC when your ETE changes significantly, and give them an update on your new ETE. Remember, ATC is counting on this estimate to determine when you'll leave the IAF and begin your descent for the approach under lost comm conditions. This is why, when filing an IFR flight plan, you want to file your ETE to the IAF along the route you plan to use and not file the ETE to the destination airport itself. Keep in mind that some IAFs can be as far as 50 nautical miles from the destination airport.

3. The controller gives you a clearance limit that's a fix short of the IAF and also gave you a time to expect further clearance.

Here, the controller clears you to a fix that is short of where the approach officially begins (i.e., the IAF) as shown in Figure 45C. Your clearance might read:

2132 Bravo is cleared to VELDA intersection, expect further clearance at 1330.

In this example, leave your clearance limit at the EFC and proceed to the IAF via the route shown in your clearance (Figure 45C, Airplane C). If you arrive at the IAF earlier than your flight planned ETA (i.e., dept. time + ETE = ETA) (or as amended with ATC), hold in a standard holding pattern (or the published holding pattern). Leave the holding pattern, descend, and fly the approach when reaching the ETA (if you arrive at the IAF after your ETA is passed, then descend and fly the approach. No delay is necessary). Does this make sense to you? If not, think about it this way. When ATC issues this clearance limit and you subsequently lose comm, the only means the controller has of determining when you'll begin your descent and start flying the approach is when your ETA is reached. Sure, the

Lost Comm: When Should You Fly the Approach? Scenario 3

“2132 Bravo, is cleared to VELDA intersection via V16 direct VELDA, expect further clearance at 13:30, time now, 1305.

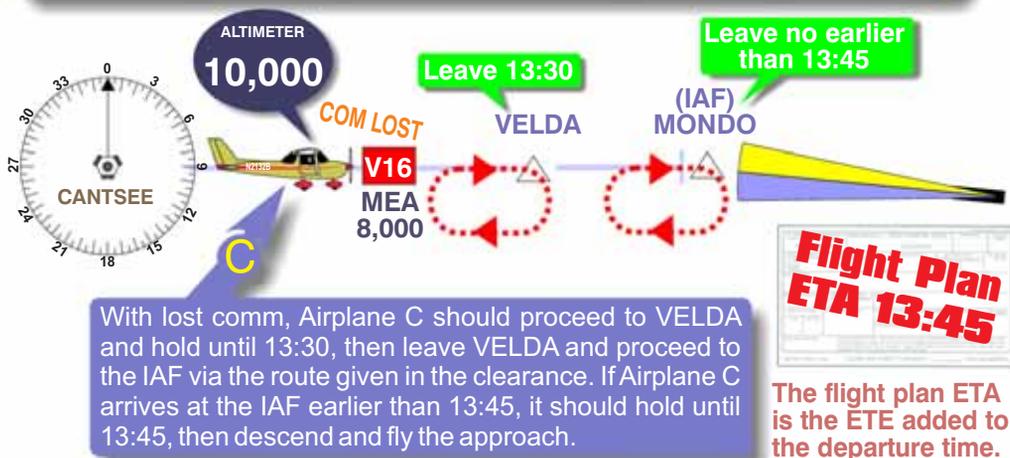


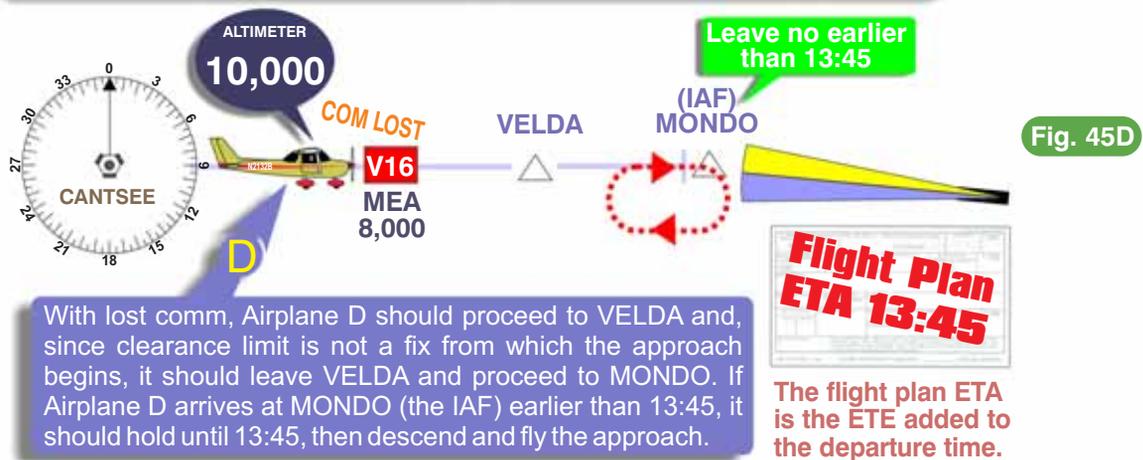
Fig. 45C

Rod Machado's Instrument Pilot's Handbook

Lost Comm: When Should You Fly the Approach?

Scenario 4

"2132 Bravo, is cleared to VELDA intersection via V16 direct VELDA. (Note: no EFC time given by controller in this clearance.)"



controller might have radar and can see your altitude readout, but this is real time. Estimating when (ETA) and where (IAF) you'll leave your altitude and fly the approach is based on the controller having an idea of your ETA.

As a second part of this example, suppose your clearance limit is short of the IAF and you didn't receive an EFC by the time you arrived at this point. Your clearance might read:

2132 Bravo is cleared to VELDA intersection.

In that situation, fly past the clearance limit and proceed to the IAF (Figure 45, Airplane D). From there you'd hold until the ETA as filed (or amended) in your flight plan expired, then complete the approach. If you arrive over the IAF and the ETA has already passed, keep on going. Leave your altitude and complete the approach.

So, is that what pilots do when flying IFR in the real world? The fact is that many pilots fly their given clearance directly to the airport and land because they don't remember the lost comm rules (but this doesn't make their actions right). Fortunately, given that most areas have radar coverage nowadays, controllers are very adept at getting other folks out of your way. Nevertheless, you can't go wrong by following the lost communication rules. So know them well because you need to know them and you'll most certainly be tested on them in the FAA knowledge exam and on the practical test.

FAR 91.187—Operation Under IFR in Controlled Airspace: Malfunction Reports

"Houston, we have a problem!" Hopefully, yours won't be as severe as the one that afflicted Apollo 13. As pilot in command of an airplane being operated IFR in controlled airspace, you are required to report as soon as practical to ATC any malfunctions of navigational, approach, or communication equipment occurring in flight (Figure 46). While you might think, "Hey, guys, you'll never guess what my altimeter is doing" makes for interesting conversation, what the controller really wants from you (because that's what the rules say he wants) is:

- (1) Aircraft identification;
- (2) Equipment affected;
- (3) Degree to which the capability of the pilot to operate under IFR in the ATC system is impaired; and
- (4) The nature-extent of assistance needed from ATC.

Radio Insurance

One of the best insurance policies against IFR lost communication is to the purchase of a portable VHF radio. Kept in the flight case, you're sure to find the investment worthwhile if your radios stop working. And, you can listen to ATC at home all the while learning to better interpret what fast talking controllers are really saying.



Malfunction Reports

Report malfunction of navigation or communication equipment to ATC and state:

1. Aircraft Identification,
2. Equipment affected,
3. Degree to which capability of the pilot to operate IFR is impaired,
4. The nature and extend of assistance needed.



this category. This doesn't mean, however, that airplanes in the pre-'69 category can't withstand vertical gusts of greater intensity. This was just the minimum vertical gust requirement necessary according to the regulations at the time.

Now let's talk about water.

As you've already learned, to keep large volumes of water suspended in the atmosphere it takes a lifting force, otherwise known as *updrafts*. The more water suspended within a cloud the greater the lifting force or updraft that's required to keep it there. When the amount of water suspended exceeds the lifting force that suspends it, the water falls. We call this rain and measure the amount in *inches per hour*.

It doesn't have to rain, however, for us to measure the amount of water suspended inside the cloud. We can merely identify the amount of water in a cloud using radar and say that if it did rain, then the rainfall rate would be a specific amount, calibrated in inches per hour.

Given this observation, it's logical to say that a cloud with a rainfall rate (or potential rainfall rate) of .5 inches per hour has less updraft action than a cloud with a rainfall rate of 2 inches per hour. We can conclude that the larger the rainfall rate (or potential rainfall rate), the stronger the updrafts found inside a cloud.

As you undoubtedly know, radar energy is reflected by solid objects, not clouds themselves. The water suspended in a cloud is a solid object, but the cloud itself isn't. The more water suspended within the cloud, the greater the ratio of radar energy returned for a given amount sent out by the radar unit. The amount of this reflected radar energy, referred to as *reflectivity* or *Z*, is calibrated in the form of a quantity known as *dBZ* or *decibels of Z*.

Now things are about to get really interesting.

Years ago Project Rough Rider (and subsequent government studies) established a correlation between the amount of water suspended in a cloud and the vertical gusts found within that cloud (measured in feet per second) as shown in Figure 113. If we can equate rainfall rates with radar reflectivity or dBZs, we can make some interesting assumptions using the results of the Rough Rider study.

It turns out that rainfall rates producing radar reflectivity ranging from 16 to 29 dBZs (known as a *Level 1* radar return) generate a 100% probability of light turbulence and a 10% chance of moderate turbulence. Light turbulence is defined as vertical gusts from 0-19 FPS and moderate turbulence is defined as vertical gusts from 20 to 34 FPS.

Rainfall rates producing radar reflectivity ranging from 30 to 39 dBZs (known as a *Level 2* radar return) generate a 100% probability of light turbulence, a 40% chance of moderate turbulence, and a 2% chance of severe turbulence. Severe turbulence is defined as vertical gusts from 35 to 49 FPS.

Rainfall rates producing radar reflectivity ranging from 40 to 49 dBZs (known as a *Level 3 and 4* radar return) generate a 100% probability of light turbulence, a 90% chance of moderate turbulence, a 10% chance of severe turbulence, and a 3% chance of destructive turbulence. Destructive turbulence is defined as vertical gusts of 50 FPS and higher.

Now you know the answer to the question, "What criterion distinguishes a convectively harmless cumulus cloud from one that can damage an airplane?" The answer is: *Any convective cloud with a radar reflectivity of 40 dBZs (a Level 3 radar return) or higher needs to be avoided and treated as an immediate threat to your safety aloft.*

Turbulence Probability

The turbulence probability chart provides you with a statistical means of estimating the probability of turbulence based on the amount of water in a cloud.

For instance, if a cloud has sufficient water to reflect radar energy to a value of 40 to 49 dBZs, then there is a 3% chance of destructive turbulence (at the higher 49 dBZ value), a 10% chance of severe turbulence (at the higher 49 dBZ value), and a 100% chance of light turbulence in that cloud.

Because of this potential for severe and destructive turbulence, pilots always avoid cloud areas/masses containing 40 dBZ and higher.

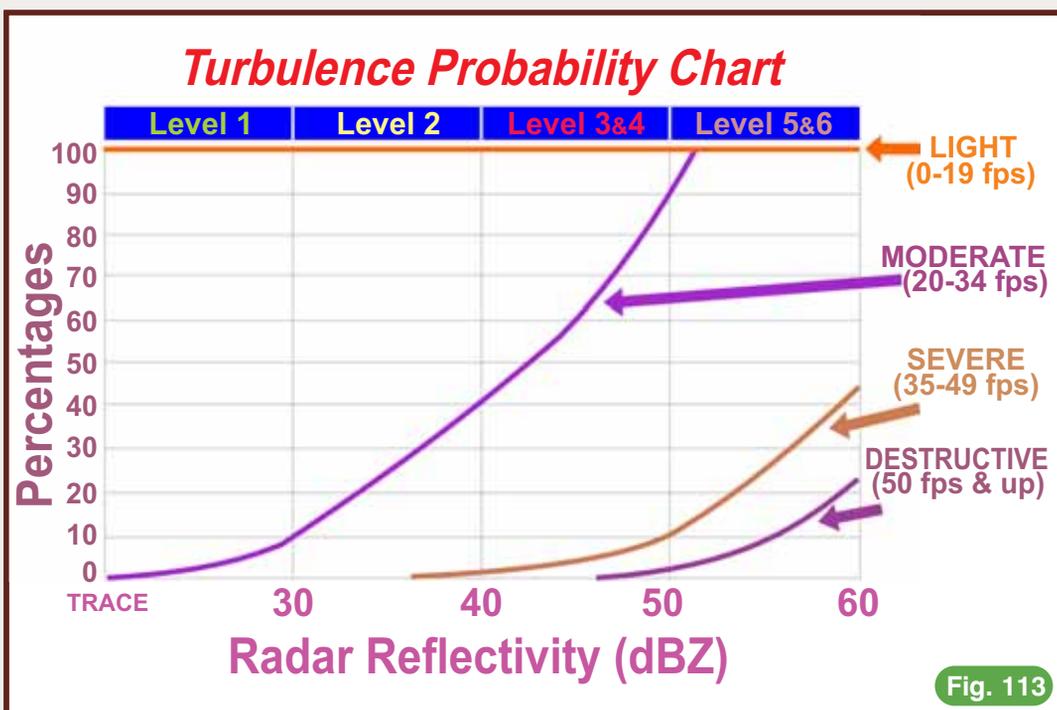


Fig. 113

| Airborne Weather Radar Display Levels | | | |
|---------------------------------------|--|-----------|-----------------|
| Airborne Display Level/Color | Display Level | VIP Level | dBz Appx. |
| 5-6 Magenta | Extreme | Level 6 | 50 to 59 dBZ |
| | | Level 5 | |
| 3-4 Red | Heavy | Level 4 | 40 to 49 dBZ |
| | | Level 3 | |
| 2 Yellow | Moderate | Level 2 | 30 to 39 dBZ |
| 1 Green | Light | Level 1 | 16 to 29 dBZ |
| 0 Black | These display descriptions are for airborne radar and differ from the NWS, Center and Approach Control screen weather display. | | |

Fig. 114

The National Weather Service has established six storm levels. Airborne radar manufacturers adopted these levels along with the color codes shown above. These are the colors seen on modern airborne radar displays.

The 3% chance of destructive turbulence is simply too significant to ignore. While the chances are small, the outcome is eternal. Figure 114 shows how different dBZs of reflectivity are color coded on airborne radars. It is any wonder that the Level 3 radar return is identified as red as shown in Figure 115? Red means danger, right? Airline pilots avoid all areas having red on their radars and so should you.

Sharp pilot that you are, I'm sure you're wondering why I would not suggest the mandatory avoidance of a Level 2 radar return when flying a pre 1969-certificated airplane. After all, a Level 2 return has a 40% chance of 20

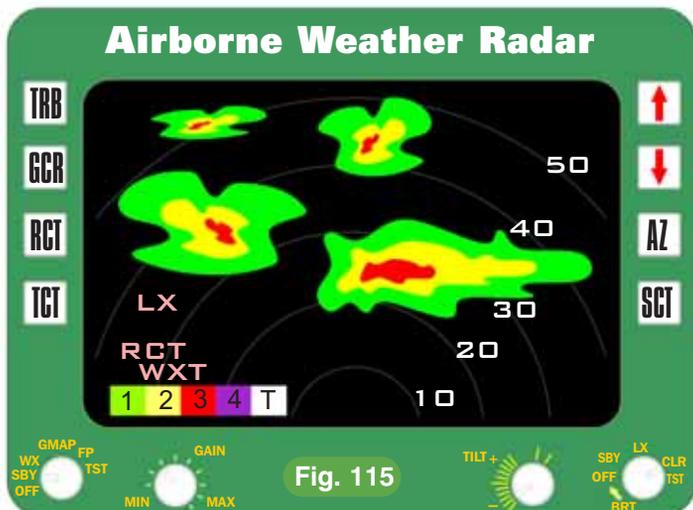


Fig. 115

Because the areas shown in red on an airborne radar represent Level 3 storm returns, all pilots should avoid these areas. Because the highest level of turbulence probability also applies to lesser storm levels, the yellow and green areas surrounding the red areas should also be avoided by thunderstorm distance recommendations.

to 34 FPS gusts, which can exceed the certificated stress limit of this airplane when it is flown at Vc (the top of the green arc or Vno). Consider the following idea.

Airplanes typically cruise at high altitudes which means that the higher they fly, the lower their IAS. In my A36 Bonanza, at lower altitudes I can cruise at more than 170 knots indicated (about 5 knots over Vc). At 10,000 feet, I'm indicating about 145 knots in cruise (which is about 5 knots above the "gross weight" maneuvering speed). When cruising at higher altitudes, the A36 should be able to withstand sharp edge gusts a little greater than 30 FPS without experiencing any problems (not that I look forward to or even desire to experience this, of course). What about the 2% chance of severe turbulence? Well, this also implies that there is a 98% chance of not experiencing severe turbulence. We have to choose our risks and this one doesn't disturb me that much given the following preference.

Whenever possible, I always try to avoid flying in or near Level 2 radar returns, regardless of when the airplane was certificated. If you're flying IFR and you want to obtain full utility from your airplane, you may often fly in or near areas containing Level 2 returns. I wouldn't, however, enter a Level 2 return if I thought there was any chance of it evolving into a Level 3 or greater return. How would I make this assessment? There are many clues. One of the best is the presence of any Level 3 or greater returns within the same airmass. If these exist, it's reasonable to assume that the airmass is unstable enough to hatch Level 3 and greater convective weather.

There's a very important point to be made here that is subtle but significant. If red (Level 3) exists anywhere in a mass or area of clouds, then the statistical turbulence associated with that Level 3 area applies to all the lesser levels, too. In other words, just avoiding the red area in a radar return and flying through the yellow or green area of that return isn't safe. Project Rough Rider established that the lesser levels will also have the same probability of turbulence associated with the highest level of return in that mass or areas of cells.

At this point I know you're wondering if it's possible for you to identify the strength of radar returns when you don't have radar. There are several ways to do this, all of which require that you use OPR's (*Other People's Radar*).

It's perfectly acceptable for you to ask the controller to solicit a pilot report for you from another radar-equipped airplane under his or her control. You can simply ask if there is anyone with radar showing a Level 3 or higher radar return headed in your direction of flight. There is, however, a better way to obtain this information thanks to modern technology.

For instance, it's now quite common for airplanes to have uplinked, real time NEXRAD radar available in the cockpit (Figure 116). Though it's sometimes called "real time," this is a misnomer. NEXRAD radar updates can be five to six minutes old when received in the cockpit. In a sense, the NEXRAD information you see in the cockpit

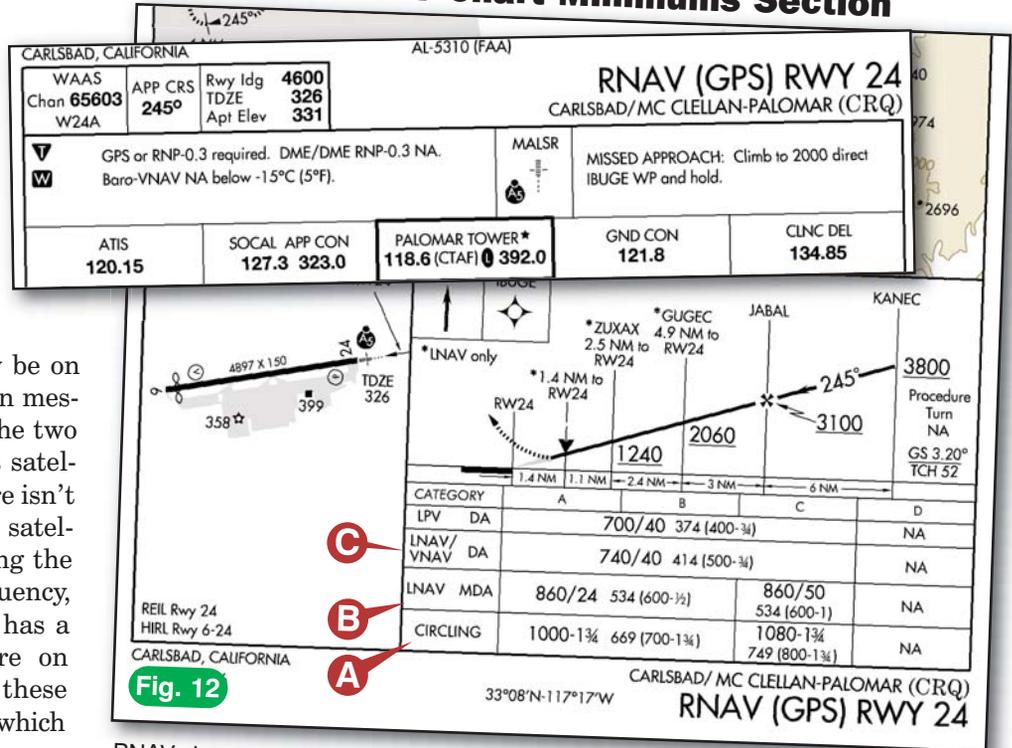
corrections are applied to determine the GPS error for a particular part of the country. Yep, different parts of the country might have different GPS errors. After all, the satellites have different positions when seen from different parts of the country, to say nothing of variable atmospheric conditions at different places across the U.S. or electromagnetic interference from who knows what may be on the ground nearby. The correction message is then uplinked to one of the two geosynchronous communications satellites (GEO). We have to hope there isn't a busy signal, because the GEO satellite is responsible for broadcasting the correction on a specific GPS frequency, to be picked up by anyone who has a WAAS-capable receiver. If you're on approach and have one of these receivers, then this would be you, which is really the most important point.

How do you benefit from all these calculational shenanigans? Your WAAS receiver can, with correction, be accurate to within a few meters vertically and horizontally. Of course, WAAS doesn't do you any good if you didn't purchase a WAAS-capable GPS receiver (don't fret over what WAAS, but what can be on your next purchase). Fortunately, WAAS-capable receivers are available for IFR use. There are even handheld GPS units having WAAS capability to assist you in VFR flying. (Remember, there are no IFR certified handheld GPS receivers, WAAS or not, on the market and probably won't be in the future. These units are simply not likely to ever meet the installation standards of Technical Standard Orders C129a, governing IFR certified GPS installations or TSO C146a, governing GPS units augmented by WAAS.)

Without WAAS, you can still fly GPS approaches on your IFR certified GPS. When you do, you're using what is properly called *lateral navigation (LNAV)*. This is what you've been doing when you've flown regular RNAV (GPS) approaches. With a WAAS-capable IFR certified GPS receiver, you now have the capability of generating a glideslope. This allows you to do something called LNAV/VNAV (sometimes referred to as L/VNAV) approaches which are approaches that use both lateral and vertical navigation. You can also fly something called APV (Approaches with Vertical guidance) approaches. These are approaches that provide horizontal and vertical guidance (through a software generated glideslope) as accurate as any ILS. They can provide decision altitudes as low as 200 feet with touchdown and visibility minimums of 1/2 mile.

Now that you understand the basics, let's take a look at the minimums section of an RNAV approach chart. This is

The RNAV Chart Minimums Section



RNAV charts can have four different rows of minimums. LPV with a decision altitude, LNAV/VNAV with a decision altitude, and LNAV with an MDA and a circling MDA.

how we determine where the rubber meets (or at least approaches) the runway.

The RNAV Chart Minimums Section

Figure 12 shows the minimums section for the NACO RNAV (GPS) Runway 24 approach to Carlsbad, California. At first glance, the horizontal minimums equipment section on the left is a little different from the standard format to which you've become accustomed. Let's start at the bottom and work our way up.

The last line (position A) shows the circling minimums for this approach. There's nothing new in this section. The MDAs and required visibilities make their appearance here. You are already familiar with these items.

The next line up lists the LNAV MDA (position B). This is the MDA for lateral navigation. In other words, these are the minimums for flying an ordinary non-precision GPS approach. If you were cleared for the approach and crossed JABAL at 3,100 feet, then you could descend to 2,060 until reaching GUGEC, 1,240 feet until reaching ZUXAX, then 860 feet to the missed approach point (intersections are named after the aliens that crashed at Roswell).

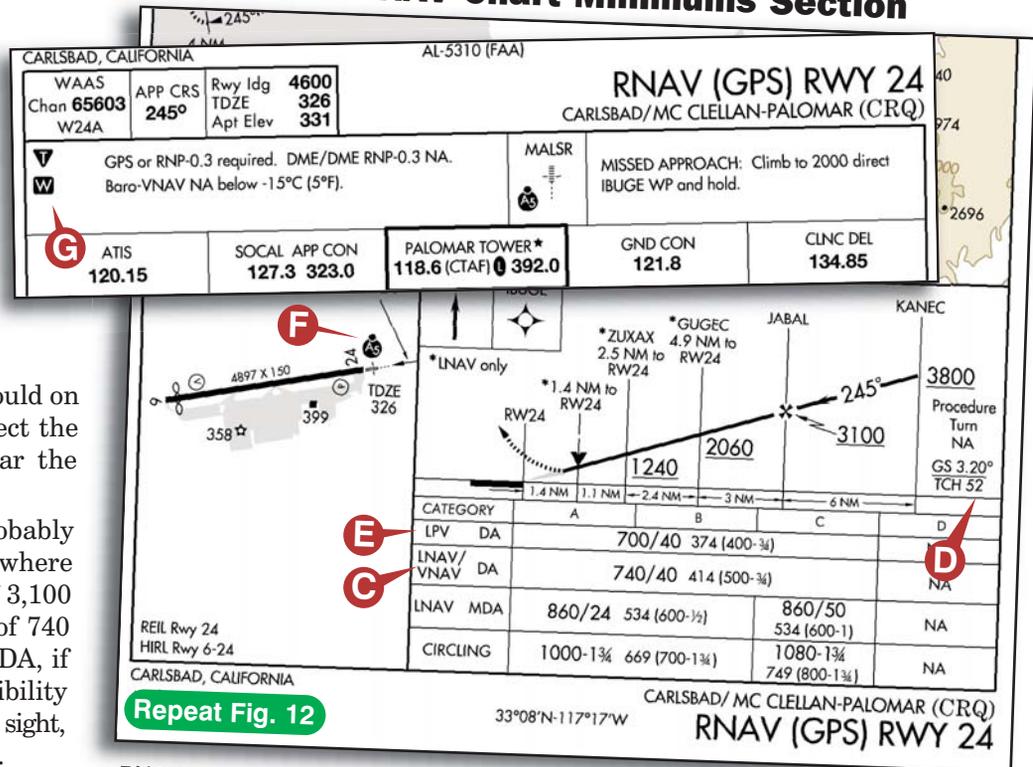
If, on the other hand, you happen to have a WAAS-capable, IFR-certified GPS receiver, you have the option of flying an *approach with vertical guidance (APV)* to this runway (these approaches have decision altitudes but are not technically considered to be precision approaches). APV minima are found in the next two lines up, starting with the letters LNAV/VNAV (Figure 12, position C). If you flew to the LNAV/VNAV minimums your decision altitude (DA) would be 1,000 feet and the required visibility would be 1/4 miles. The slope of the descent path would be

3.20 degrees, as shown in the profile view above the threshold crossing height (TCH) of 52 feet (Figure 12, position D). In short (or in pants), you'd fly a glideslope just as you would on an ILS, except this glideslope is generated by your WAAS-capable, IFR certified GPS receiver. Since your CDI display (your VOR or HSI display) is slaved to your GPS, you'd fly the glideslope down to DA as you would on any ILS approach. You can expect the glideslope to become active near the intermediate fix (IF).

In this instance, you'd probably intersect the glideslope somewhere before JABAL at a minimum of 3,100 feet and fly it down to the DA of 740 feet (Figure 12, position C). At DA, if you didn't have the required visibility and the runway environment in sight, you'd execute the missed approach.

Keep in mind that, when flying to LNAV/VNAV minimums, you may not level off at the DA and continue to the end of the runway in level flight. The DA is the point where you must make a decision to land or execute the missed approach, perhaps while singing the line from a 1960s hit, "Did you ever have to finally decide?" As with all approaches having a decision altitude, you're brought in low and dropped off a slight distance from the threshold. If you're on glidepath at DA, you're in a very good configuration for landing. There is usually little or no reconfiguration needed until touchdown. On the other hand, the LNAV/VNAV DA is 140 feet higher than the LNAV MDA here? Isn't a precision approach supposed to get you down lower and put you in a position for landing? What gives?

The RNAV Chart Minimums Section



RNAV charts can have four different rows of minimums. LPV with a decision altitude, LNAV/VNAV with a decision altitude, and LNAV with an MDA and a circling MDA.

The answer lies in something called *Baro-VNAV* or *barometric vertical navigation* capability. To fly the glideslope of a LNAV/VNAV approach without a WAAS-capable GPS receiver, you'd need an airplane with Baro-VNAV capability. This is a navigational system with a computer that provides vertical guidance between two waypoints (or a descending angle from a single waypoint) based on barometric altitude, as measured by a special barometric altimeter in your airplane in much the same way an altitude encoder measures pressure. If this is the first time you've heard of this, then there's a good chance that your airplane probably doesn't have Baro-VNAV capability.

Limits of Hand-Held GPS



Many hand-held GPS units have an inherent system limitation, as our reporter discovered. *Flying VFR, I was using a hand-held GPS for navigational reference. While en route, position and status seemed fine. According to the GPS position, a "big airport" was getting closer and closer, but still out of the overlying Class C airspace. From a visual standpoint, the position was definitely in Class C airspace. When I landed at ABC, the GPS indicated the location was XYZ [about 40 nm west]. I turned the unit off, then back on, and the position now indicated ABC.*

I called the manufacturer, which had received numerous calls about erroneous positions. A new satellite had been put in orbit; there were now a total of 26 satellites. My unit only showed 25. The manufacturer suggested leaving the GPS on for 45 minutes to acquire the information from the new satellite. I did so, and my unit now shows 26 satellites. The GPS positions seem correct.

Conclusion: use hand-held GPS as a reference only.

According to the reporter's conversation with the manufacturer, hand-held GPS units currently in use do not have the RAIM—Receiver Autonomous Integrity Monitoring—that is built into installed, IFR-certified units. The RAIM monitors the actual navaid signal to assure that there is adequate signal strength for navigation in the selected mode. If the signal is not sufficient, an error message will occur. This is analogous to the 'OFF' flag showing on the VOR receiver when the aircraft is out of range for adequate signal acquisition. Since the reporter's GPS unit did not have RAIM capability, there was no way to know that the unit was providing erroneous information.

Because of the inherent limitations of hand-held units, pilots should carry and use the appropriate charts as cross-reference material, rather than relying solely on GPS.

you could use the glideslope for descent to the MDA. For instance, suppose you were flying the RNAV (GPS) Rwy 30 approach to Jacqueline Cochran Regional airport (TRM) as shown in Figure 19. If the WAAS HPL and VPL limits are met and a glideslope is generated, the approach annunciator window will indicate LNAV+V as shown in Figure 20, position A (no LPV minimums are available on this approach). You simply follow the glideslope down to the lowest MDA allowed, which is 260 feet at TRM (Figure 19, position B). Following the glideslope allows you to cross FORKI, the stepdown fix (Figure 19, position C), at the appropriate altitude and make an uninterrupted descent to the LNAV MDA of 260 feet. If the requirements for landing aren't met, you stop your descent at 260 feet (i.e., level off or begin a climb) and fly to the missed approach point. If you do meet these requirements, you could remain on the advisory glideslope and ride it all the way to touchdown (and I hope you do because it's obstacle free, meaning it's good for your health and it contains no fat). Remember, RNAV (GPS) generated glideslopes take you to a runway intersection point approximately 1,000 feet past the threshold. Nevertheless, even though a glideslope exists, you must keep in mind that this is still a non-precision approach. The glideslope is for advisory purposes only. You don't have to follow it to and beyond the MDA, but there's really no good reason not to if you have the required visibility for the approach.

Take note that the glideslope angle is 3.04 degrees and has a threshold crossing height of 45 feet (Figure 19, position D). If, when reaching the MDA, you have

The Advisory Vertical Glideslope: LNAV+V

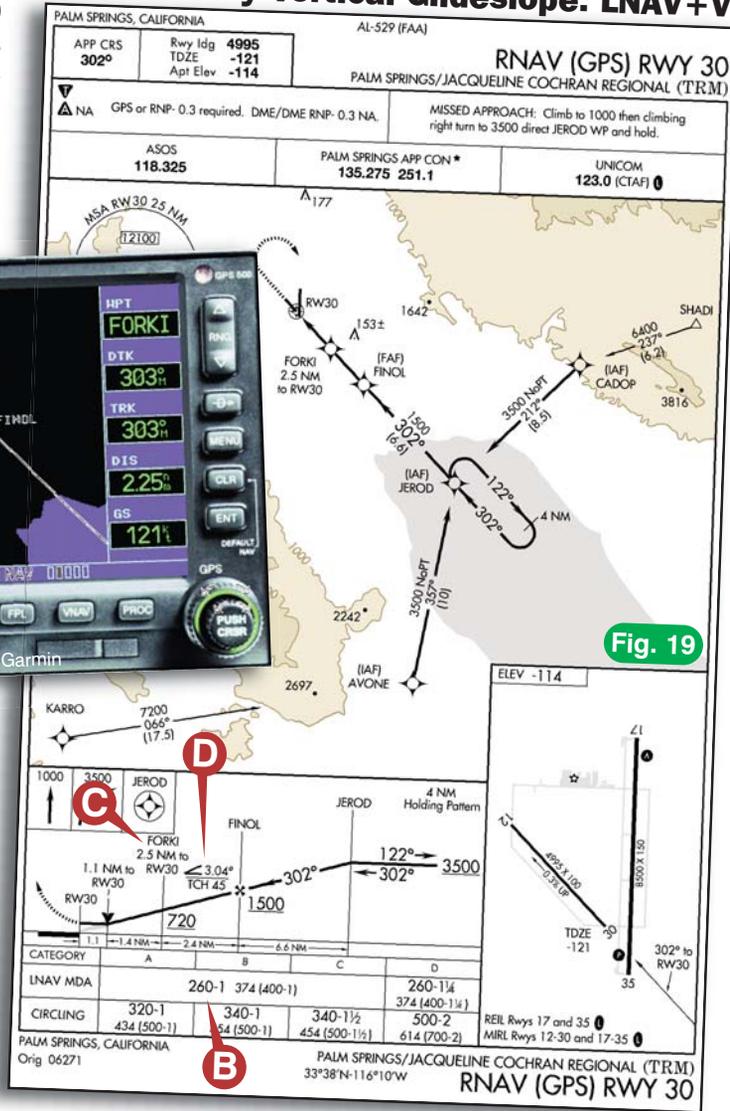


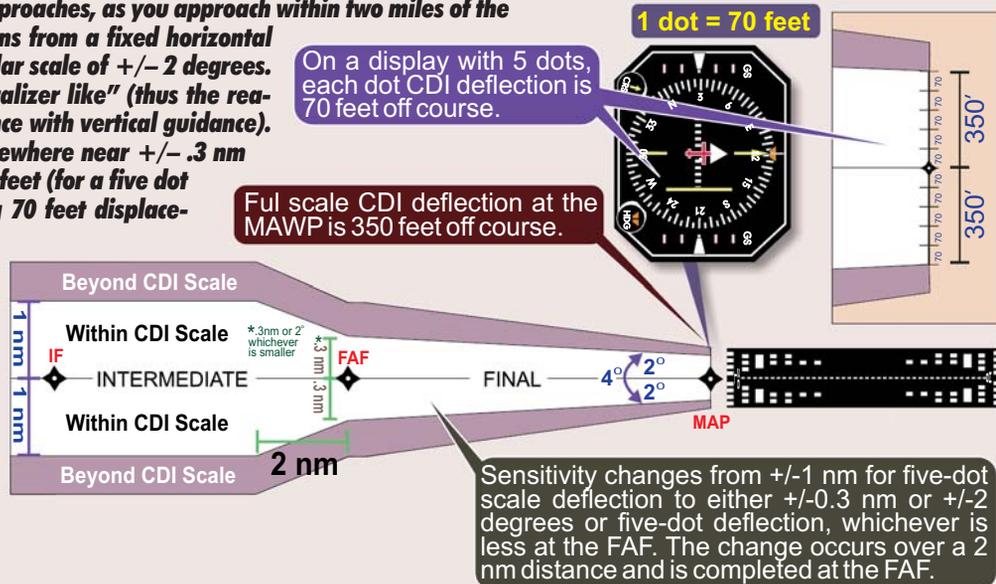
Fig. 20

Fig. 19

The approach to TRM has LNAV minimums but also provides an advisory vertical glideslope during descent to the MDA.

WAAS Protected Horizontal Limits

When using WAAS for LNAV and LPV approaches, as you approach within two miles of the FAF, your CDI scale gradually transitions from a fixed horizontal distance scale of +/- 1 nm to an angular scale of +/- 2 degrees. In other words, your CDI becomes "localizer like" (thus the reason LPV stands for localizer performance with vertical guidance). At the FAF, your CDI scaling starts somewhere near +/- .3 nm then reduces to a CDI scale of +/- 350 feet (for a five dot deflection, with each dot representing 70 feet displacement from the course centerline) at the missed approach point and remains at +/- 350 feet until a missed approach is initiated. Keep in mind that the CDI shown electronically at the bottom of the Garmin 500W box (Figure 16, position N) only shows two dots for a full scale deflection. This means that, on the WAAS' two-dot built-in CDI Scale, each dot deflection at the missed approach point equals 175 feet displacement from the course centerline.



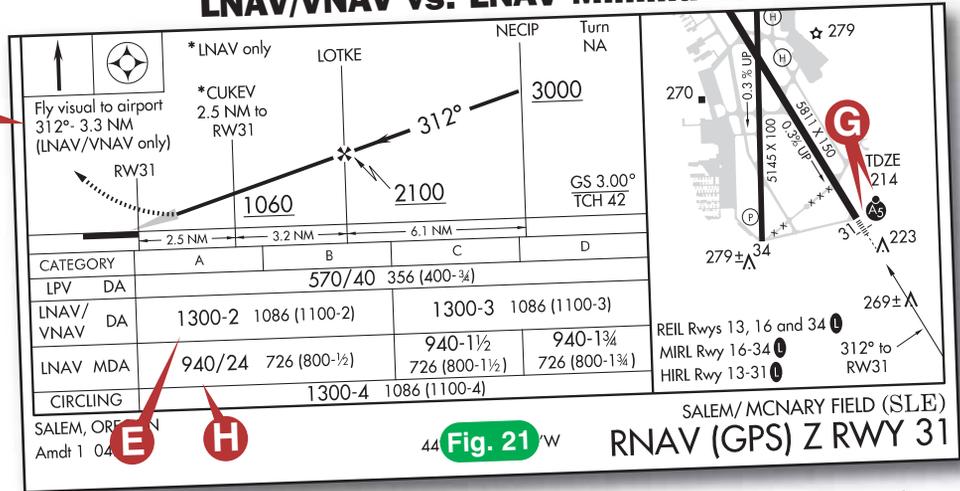
the requirements to descend below it (i.e., visibility and runway environment) you could remain on the glideslope and ride it all the way down to the touchdown zone if you desire.

At some locations, obstacle or terrain limitations won't allow the approval of RNAV (GPS) approaches ending in LPV or LNAV/VNAV minimums. These locations are similar to airports having terrain or obstructions that permit the establishment of a localizer but no glideslope. In other words, if a glideslope were created, it would be so steep that it would be impractical to fly (unless you were flying a manhole cover). Instead, in these locations, the FAA may establish an approach with "LP" or *localizer performance* minimums (Figure 21, position Z).

LP approaches are WAAS procedures without vertical guidance, and are flown the same way you'd fly the localizer portion of an ILS (without using the glideslope, that is). Since LP approaches offer localizer-type course sensitivity, the lateral protected area is much smaller than that found on LNAV courses. The result is that the FAA can often provide lower MDAs, which are typically about 300 feet above the runway.

There are a few additional aspects of the RNAV minimums section that you should pay attention to. Referring to McNary Field (Figure 22), notice that the LNAV/VNAV minimums list a DA of 1,300 feet and a required visibility

LNAV/VNAV vs. LNAV Minimums

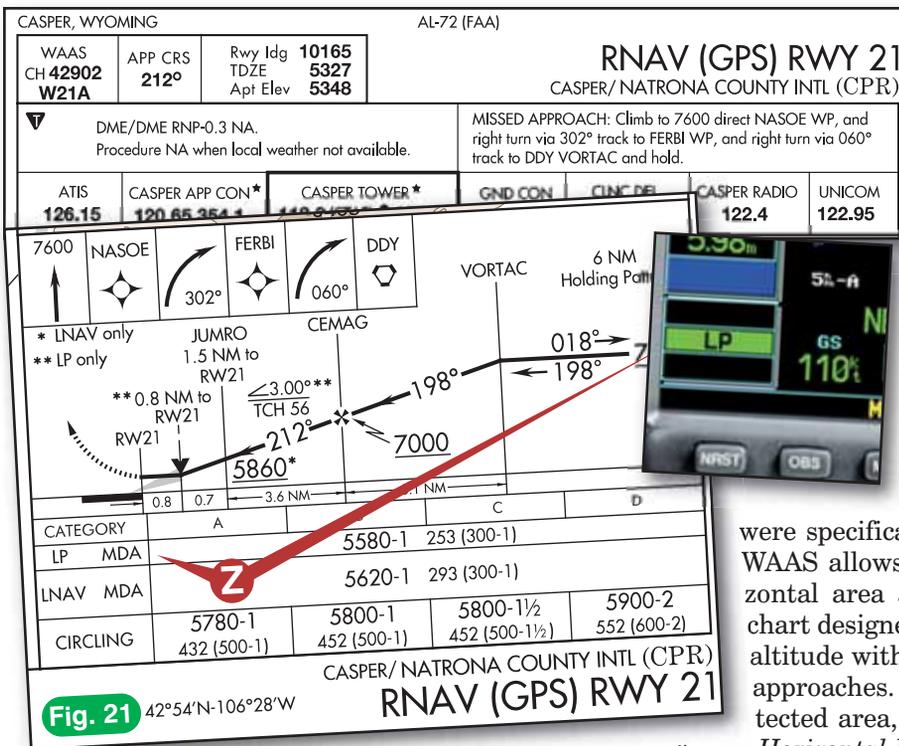


The LNAV/VNAV minimums can sometimes be much higher and require a greater flight visibility for landing than the LNAV minimums.

of 2 miles (Figure 22, position E). Looking at the chart note in the profile section (Figure 22, position F), once you're at the LNAV/VNAV DA and meet the visibility and runway requirements for landing, you fly 3.3 nautical miles "visually" to reach the runway. In this instance it would be wise to descend the 3.3 miles while remaining on the glideslope. Nevertheless, now you know why the LNAV/VNAV visibility minimum is 2 miles. At DA, if you had 2 miles visibility and you saw the approach lights (which can be 2,400 to 3,000 feet in length), you could legally continue your descent (I am not suggesting this is always wise to do).

In addition to the Baro-VNAV temperature errors we discussed earlier, there's another reason the LNAV/VNAV minimums (Figure 22, position E) are so much higher than the LPV minimums. As I've mentioned previously, the LNAV/VNAV minimums were designed with the GPS concept (TSO-C129a), not the WAAS concept (TSO-C146a) in mind. Since plain GPS doesn't offer the same precision and position error correction as WAAS, there is a wider horizontal area of obstacle protection along the final approach segment for approaches using LNAV or LNAV/VNAV minimums, with obstacles on the periphery of the approach course often causing an increase in the DA. This is one of the reasons the LNAV/VNAV DA minimums are so high at McNary. On the other hand, your WAAS unit offers a high degree of horizontal and vertical precision. Since LPV minimums were specifically designed for use with WAAS, and since WAAS allows you to remain confined to a smaller horizontal area along the final approach, this means that chart designers can allow you to descend to a much lower altitude with much less visibility required on many LPV approaches. To learn more about this horizontal protected area, look at the sidebar titled: *WAAS Protected Horizontal Limits* on page 13-20.

LP or Localizer Performance Minimums



Approaches with "LP" minimums are similar to localizer approaches in their precision and their lack of glideslope.

An important point to consider here is that until you've reached the intermediate fix on most RNAV