15 Emergency Procedures

Q: “What should I do if the door comes open in flight?”

A: “Fly the airplane”.

15.1 Engine Out Procedures

This section discusses what you should do if your engine quits while you are airborne.[1] This mainly applies to single-engine airplanes; additional procedures for multi-engine airplanes are covered in chapter 17.

15.1.1 Emergency Checklist

It is important to have an emergency checklist You should commit it to memory, and review it right before each flight. Do not wait until you are confronted with a “deafening silence” to figure out what is on the emergency checklist, and why.

If your aircraft manuals do not provide a suitable emergency checklist, you might consider adopting something along the following lines:

Aviate, Navigate, Investigate
Communicate, Secure.

In more detail, the emergency checklist is:

- **Aviate** --- best-glide K_{IAS} and trim; configure.
- **Navigate** --- pick a field; turn toward it.
- **Investigate** --- carb. heat, boost, tanks, primer, mags, mixture
- **Communicate** --- 7700 + 121.5 or current.
- **Secure** --- gear up for short, soft or water;
  throttle, mixture, mags, master, tanks --- off;
  belts --- snug.

This list has been designed to make it easy to memorize. You should make every effort to commit it to memory, so that if somebody wakes you up in the middle of the night and asks you “what is the emergency checklist” you should be able to shout, instantly, “***Aviate, Navigate, Investigate, Communicate, Secure!***”

The first item, **Aviate**, is clearly the first priority. No matter what happens next, you want to be in control of the aircraft when it happens. There are lots of scenarios where an engine failure results in a critically low airspeed (especially if somebody is dumb enough to try to maintain the pre-failure pitch attitude, or (worse) the pre-failure altitude while deciding whether or not there has been a failure). If the airspeed is low you *must* re-establish the proper glide speed[2] immediately, even if it means cashing in some precious altitude.

The opposite extreme is possible, too; namely it is quite possible that at the time the emergency begins, the aircraft is going much faster than the best-glide speed. This is not so immediately dangerous, but the longer you take the establish the proper glide speed the more energy will be thrown away in the form of unnecessary parasite drag. In this case, gently zoom upward, converting airspeed to altitude. Retrim.

In addition to trimming for the correct airspeed, you should configure everything else appropriately, as discussed in section 15.1.2.

The second item, **Navigate**, is clearly next in importance. In section 15.1.4 there is a discussion of clever techniques for judging which fields are within gliding range --- but you should not pick a field at the limits of this range if there is anything suitable that is close. In particular, start by looking down at a 45 degree angle, or even straight down. If it is right below you, it is probably within gliding range!

The next item is **Investigate**. Sometimes when the engine quits, you know immediately what the problem is. Ninety percent of the time, the problem is fuel-related, so you should reflexively switch tanks and turn on the boost pump as appropriate. Then turn on the carburetor heat, because it is only effective while the engine is still warm. Then go left-to-right across the panel, checking everything in turn. Make sure the primer is in and locked. See if the engine runs better on the left magneto, right magneto, or both. See if it is happier with a leaner or richer mixture. In most cases the propeller will keep turning, just due to the action of the relative wind, even in the total absence of engine power -- but if it stops, use the starter to get it going again. Give everything a once-over before spending too much time on one particular item, unless you are pretty sure you know what the problem is. And above all, don't forget to fly the airplane.

The next item is **Communicate**. If you are already in contact with a controller, it is almost certainly a good idea to stay on that frequency. If, on the other hand, you have any doubt about what frequency to use, go immediately to the international distress frequency, 121.5 MHz. That's what it's there for.

Similarly, if you have been assigned your own transponder code, don't bother to change it unless ATC asks you to. On the other hand if you are presently on the all-purpose code 1200, do not hesitate to switch to the emergency code, 7700. That rings alarm bells (literally) at ATC and highlights you on the controller's radar screen.

Some people argue you should Communicate even before you Investigate. Certainly if you are in instrument meteorological conditions you should tell the ATC of your predicament even before you Navigate, (1) so they can vector you to a landing field and (2) so they can clear out the airspace below you.

The fifth item on the list is **Secure**. It is amazing how easy it is to forget this item. Wouldn't you hate to make a beautiful power-off approach to an ideal field --- and then forget to extend the landing gear?

At 100 feet AGL, make sure you pull the throttle and mixture to idle cut-off. The main reason is that you don't want the engine to roar back to life just after touchdown. This could easily happen if (for example) there had been a fuel shortage, and the flare freed up some fuel from a corner of the tank. The reason for doing it at 100 feet AGL is to give the engine a chance to cool down, reducing the risk of a post-crash fire. Closing the fuel-tank shutoff valve helps reduce the risk of fire --- but in most planes it is *not* a sufficiently quick way of stopping the engine so be sure to pull the throttle and mixture also.

Shutting off the engine will be difficult; it will require overcoming a huge psychological barrier. After all, you've spent the last several minutes trying to restart the engine, and now you are supposed to shut it off. Make sure you have made this decision in advance: promise you will shut the engine off at

100 AGL.

Switching off the master also reduces (somewhat) the risk of fire, but in an aircraft with electric flaps and/or landing gear, you might want to save the master switch for last.

- Aviate.
- Navigate.
- Investigate.
- Communicate.
- Secure.

15.1.2 Configuring for Glide

In the “clean” configuration, the airplane will be able to glide much farther, perhaps twice as far as in the “dirty” configuration. If you start out at low altitude, twice nothing is nothing, so it may not be worth messing with the configuration; just configure for landing and be done with it.

On the other hand, if you start out at a reasonable altitude and are trying to glide a long ways, then you want flaps retracted, landing gear retracted, and propeller in the coarse pitch (low RPM) position.

Some other books say that once the flaps are down, you should leave them down; they point out that at a low airspeed (below the bottom of the green arc) retracting the flaps will cause an immediate stall.

I look at it somewhat differently. This situation actually arose on my private pilot checkride. I was at 1000 AGL, with two notches of flaps extended, on downwind just ready to turn base. Then Tower asked me to extend my downwind. By the time I was able to turn final, I was nearly two miles from the airport. At this point the examiner caused a simulated engine failure.

I went through the following thought process:

- It’s a long way to the airport. If I don’t do everything right, we won’t make it.
- It is important to glide at the right airspeed. I know what the best glide speed is in the clean configuration, but I have no idea what the best glide speed is in the current configuration.
- I’ll bet there is no such thing as best glide in this configuration. I’ve got to get the flaps up.
- I’m really slow, near the bottom of the green arc. If I just retract the flaps, I might stall.
- The airplane stalls at a definite angle of attack. No airplane ever stalled at zero angle of attack. It’s mathematically impossible.
- I’ve got full control over angle of attack. Watch this!

At that point I shoved forward on the yoke. Zero angle of attack. Zero *G*. The examiner started gently floating out of his seat. I retracted the flaps all at once. I continued the zero-*G* pushover until we approached the canonical best-glide airspeed. Then I raised the nose, trimmed for best glide, and quickly ran the rest of the emergency checklist. I even rolled in some left rudder trim.

The glide took us to a place in the weeds about 100 yards short of the runway. I flew right down into ground effect and then flared. While skimming in ground effect I extended the flaps. When we reached the runway the stall warning was already on. I plopped onto the runway. We were stopped before reaching the big painted number.

The point of this story is this: If you need to glide a long ways, retract the flaps. Just do it in such a way that you don't stall.[3]

You can, of course, glide with flaps and/or gear extended if you want to make a steep approach to a nearby field.

Also, when you are through gliding (i.e. when you are ready to flare), make sure the flaps are extended, so you can touch down at the lowest possible speed.

For landing on water, in most airplanes you want the gear up. For landing on most other surfaces, you want the gear down. Don't wait until the last moment to put them down; with the engine off it might take longer than usual to get them down. Make sure you know how to use the manual gear extension system on your airplane.

15.1.3 Return to Airport?

We now focus on the special case of engine failure shortly after departure, since that is a relatively common and very critical case. Many people are tempted to turn back to the airport, but this is not usually the right answer.

The right answer depends on many factors, including:

- the wind
- the length of the runway
- the capabilities of the airplane
- whether or not partial power is still available
- the capabilities of the pilot

Every situation is different, so the following analysis can't possibly fit them all exactly. On the other hand, it is worth your while to plan in advance. Know what your options are. For each phase of flight, make sure you have a backup plan ("Plan B") appropriate to the situation. Be ready to carry out Plan B at a moment's notice.

Here is a piece of simple but important advice: if you can land straight ahead, do so. As an extreme example, consider this: a small plane departing from runway 31L at JFK (length: 14,600 feet) could climb to 500 feet, lose the engine, and still land straight ahead on the same runway with plenty of room left over.

Here's another piece of simple advice: don't turn back unless you are sure you can make it --- and there are lots of situations where you *can't* make it.

For example, consider a fully loaded Cessna 152. It has a power-off glide ratio of ten to one. Unfortunately, in no-wind conditions the climb gradient is *less* than ten to one. Therefore, even if the airplane could turn on a dime, at every point on the return trip the airplane would be below where it had been on the outbound trip. Then when you take into consideration the altitude lost while getting the airplane turned around, it is easy to see why the airplane cannot possibly return to the point where it left the ground.

Under such conditions, the farther you have flown on the departure leg, the more options you have for an off-airport landing, and the more impossible the turnback becomes.

An important factor to take into account is that a simple 180 degree turn does not suffice to return you to the departure runway. The airplane will travel an appreciable distance *sideways* during the turn. You won't need to do a full-blown procedure turn, but you will need to do some additional maneuvering that makes an already-bad situation worse.

Given a sufficiently long runway, the airplane may be able to return to a point on the runway closer to the departure end --- which is just fine. Again, imagine departing runway 31L at JFK, and climbing straight ahead. Suppose the engine quits at a point 1/2 mile beyond the departure end of the runway. At that point you should have more than a thousand feet of altitude. You should be able to reverse course and make a downwind landing near the beginning of runway 13R[4] even though you could not glide back to the point where you lifted off.

A modest headwind on departure will help keep the airplane near the airport during the outbound leg, and will help hurry it back to the airport during the return trip. This sounds wonderful, because it increases the possibility that you can glide back to the runway. The trouble is that (whether or not you make it back to the airport) you are faced with a downwind landing. Even a modest amount of tailwind (say 15 knots) can have a tremendous effect. Suppose your airplane is capable of touching down at 55 knots. If you land into the wind, you have a groundspeed of 40 knots, but if you land downwind you have a groundspeed of 70 knots. Runway usage depends on the *square* of the groundspeed, so the downwind landing will use *three times* as much runway: $(70/40)^2 = 3.06$. Also, in a collision, the amount of damage and injury is typically proportional to the square of the groundspeed --- so if you turn downwind and *don't* manage to land on the runway you are in very big trouble indeed.

Here's another option for you to consider: suppose that your airport has a second runway running crosswise to the active runway. If your engine fails somewhere over the cross runway, you might be able to turn 90 degrees and land on it.

Even in less ideal cases, it is quite likely that a crosswind landing on a different runway (or even a taxiway) is easier and safer than a downwind landing on the departure runway.

If you are really concerned about engine failure during the departure climb, and the airport is the only safe landing zone for miles around, you should begin a gentle turn almost immediately after liftoff. Then if the engine quits, you're closer to the airport and you've got a more convenient heading. I don't recommend this in general, because engine failure is not the only consideration. For starters, we need to worry about causing a mid-air collision in the pattern. A turning departure climb toward the traffic-pattern side of the runway would cause you to enter the downwind leg from below at just about the point where inbound traffic is entering from the 45 degree leg.

In many cases, engine trouble results in partial rather than total power loss. You have to decide whether continued operation of the damaged engine is safe, but if so, it gives you some more options. Even if the aircraft is not capable of climbing on the remaining power, the rate of descent may be dramatically reduced. Think of the aircraft as a noisy glider with a good glide ratio. It may be capable of "gliding" to places that a totally unpowered aircraft could not.

I reiterate: don't try to turn back to the airport unless you are sure you can make it, and in most typical cases you can't. You should find a nice road or field and put it down under control. It helps a lot if you have practiced forced landings, so you know the power-off performance of your airplane and how to land from non-ideal approaches.

Another very serious consideration is this: reversing course smoothly wastes valuable time and energy, whereas reversing course quickly requires radical maneuvering. Nobody wants to recommend that pilots perform radical maneuvering at low airspeeds close to the ground in an unplanned situation. It might help you return to the runway, but there is a much greater chance that it will provoke a stall/spin accident. An off-airport landing is not usually fatal, whereas a stall/spin accident usually is.

Another reason for not attempting to turn back is that most people are so surprised by an engine failure that it takes them a few seconds to regain their wits. During this interval, precious time, energy, and distance have been wasted, so even though it might originally have been possible to turn back, it no longer is.

Indeed, (unless you are very well trained) your first reaction will be completely wrong --- not just late, but dead wrong. When the engine quits, the airplane's nose will tend to drop. The flight path has changed from, say, a 10-to-1 climb to a 10-to-1 descent, so to maintain constant angle of attack the nose *must* drop a huge amount --- 12 degrees. You may think "Gee, I don't want the nose to drop" and may be tempted to pull back on the yoke. This is a sure way to kill yourself. Please, do not think of the yoke as the up/down control. When the engine quits, the airplane is going to descend. The only question is whether you will spin in, or glide to a controlled touchdown. Remember, you can survive an off-airport landing if you touch down under control.

The obvious reason why you want to maintain control is that the rate of descent you get in a normal glide is much less than what you get if you stall and let it "drop in" --- not to mention what you get in a spin.

A less obvious but still very important consideration is this: If the airplane is not under proper control, it is likely that one wingtip will hit before anything else. This will cause the aircraft to cartwheel, causing tremendously more damage and injuries than if you had landed under control and just skidded to a stop.

It is important to have a plan. At the airport(s) you use regularly, scout out the territory near the departure paths, and formulate a plan for where you will land if the engine quits. (Further discussion of the power-off glide appears in the next section.)

In any case, you need a plan for what to do with the controls. Your first priority is to maintain a proper angle of attack. Do not attempt to hold the nose up; let the nose go down (or push briefly to help it go down). Fine tune the pitch attitude and trim to maintain the best-glide airspeed.

Land into the wind if possible.

15.1.4 Power-Off Glide Perception and Planning

In a forced-landing situation, your glide path will be rather steep. The lift-to-drag ratio of typical Skyhawk or Cherokee (in best-glide configuration) is about 10-to-1, which corresponds to an angle of six degrees. This is perhaps twice as steep as a typical power-on approach. It is even somewhat steeper than the typical "power off" approach, since that normally really means "engine idle" and an engine at idle produces noticeably more power (and less drag) than an engine that is really off.

We can use the rule of thumb: a thumb at arm's length subtends four degrees.[5] In figure 15.1, you can tell by the smoke drifting up from the shack that the wind is negligible, so you should be just barely able to glide to any point that is a *thumb and a half* below the horizon.

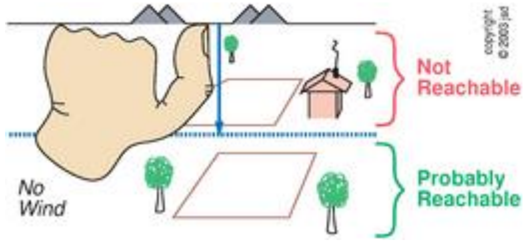

Figure 15.1: What Landing Sites Are Reachable?

In the presence of wind, the circle of possible landing sites will be shifted downwind from the circle described in the previous paragraph. Suppose you are gliding at 60 knots (airspeed) into a 30-knot headwind. Your groundspeed has been cut in half, so your glide will be twice as steep as in the no-wind case. Your destination must now be at least three thumbs below the horizon.

It is well worth knowing how far you can glide. Suppose you are roughly one mile up, so that you can glide ten miles. There is more area in the ring between seven and ten miles away than there is in the entire disk between zero and seven. (On the other hand, if you see a nearby field, go for it. Don't glide a long way just because you can.)

Now let's assume you have picked a field and are gliding toward it. Now your ability to perceive angles really pays off. Whereas in a normal approach you use engine power to maintain a pre-determined glide angle and destination, in a maximum-distance glide the glide angle is fixed and you want to perceive what the destination is.

Here is the key idea: there will be *some* landmark that remains *some* fixed angle below the horizon, and that is the point toward which you are gliding. Pick a point. If its angle down from the horizon is decreasing, you will land short of that point. If its angle is increasing, you will overfly that point --- unless you do something.

There are two critical reasons why you always need to explicitly identify the point to which you are gliding. For one, you need this information for angle of attack control. Remember, the angle of attack is the angle between the wing and the direction of flight. If you can't perceive the direction of flight you won't be able to perceive the angle of attack (see chapter 2). Secondly, you need to know whether your present glidepath will cause you to land long or land short; the earlier you can perceive this the sooner you can make any necessary correction.

A small correction early is better than a big correction late.

You should not pick a field that is right at the limit of the airplane's gliding ability, because you'll wind up short if anything goes wrong. Pick a field that is substantially closer than the limit, since you can always lose altitude by circling, adjusting the length of the base leg, extending flaps, slipping, et cetera.

Strategic turns are appropriate early in the game; flaps and slips are more appropriate on short final.

S-turns on final are almost never the best way to eat up unwanted altitude. Small-angle turns have almost no effect, and large turns take too long to perform, and take your chosen field out of sight temporarily. Furthermore, after two turns (one to the left and one to the right) you will be back on your original heading, but offset laterally; you need to make two more turns to get back on course. If you have time and altitude to do all that, there are better things to be doing.

If you are on long final and can (using flaps and/or slips) keep the field a constant angle below the horizon, you are all set. Glide straight on in.

If you are on long final with excess energy, or if you are approaching the field from a substantial angle relative to the intended direction of landing, do not aim directly for the field. Aim for the so-called *base key point* (figure 15.2), i.e. the point where the base leg begins.

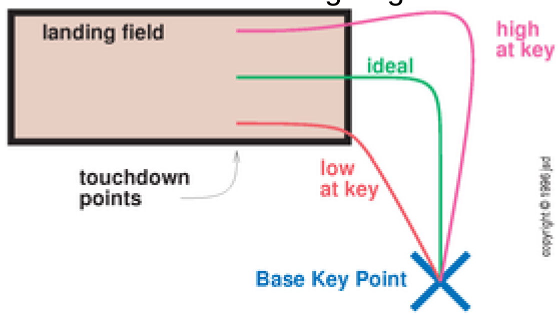

Figure 15.2: Forced Landing from Base Key Point

From the base key point, you have a lot of options. If you arrive with the ideal amount of energy, you can fly a nice base leg and then turn final. If you arrive with slightly more or less energy than that, you can angle the base leg away from or toward the field. Fly along the base leg until the desired destination is the appropriate angle below the horizon, then turn final.[6]

Another point that is made in the figure is that you can use the *width* of the landing field to your advantage. You may be unaccustomed to this, since at an airport the tradition is to land always as close as possible to the runway centerline.

Also, do not plan your final approach to take you to the threshold of your chosen field. No matter how long or short the field, aim for a point one third of the way along the field. Remember there are lots of things that could steal energy from your glide, and you *really* don't want to land short.

> It is better to hit the trees at the far end at 20 knots than to hit the trees at the near end at 60 knots.

The energy, the expected damage, and the expected injuries all depend on the *square* of the airspeed, so the 20-knot collision involves *nine* times less energy than the 60-knot collision.
The main reason why you might wind up landing short (despite a well-planned glide) is the infamous decreasing headwind on final, as mentioned in section 12.12. If you are gliding at 70 knots, and you lose just ten knots due to a windshear, you will have to descend 60 feet to regain your proper airspeed.[7] That 60 vertical feet (at a ten-to-one glide ratio) corresponds to 600 feet of horizontal travel. If you are unprepared for it, finding yourself 10 knots slow, 60 feet low, and/or 600 feet short during a forced landing is no fun.

15.2 Preventing Emergencies

15.2.1 Safety Margins

As discussed in section 21.3, you need to have *margins* of safety and *layers* of protection. You don't want to be in a situation where any one failure causes harm. As discussed in section 21.8, you always want to have not just plan A, but also plan B, plan C, plan D, et cetera.

15.2.2 Fuel Management

Far and away the most common reason for losing engine power is *fuel mismanagement*. This includes running out of fuel as well as contamination of the fuel. The good news is that such problems are relatively easy to prevent.

It pays to be careful. I am pretty methodical about checking the fuel sumps. I used to check for little droplets of water at the bottom of the sampler. Once, after completing the check, I was about to dump out the sampler and begin the flight, but I decided to take a closer look. Then I noticed tiny drops floating at the *top* of the sampler. It turns out the entire tube was full of water, with just a tiny bit of fuel mixed in. I went back to the plane and got another tube of water, and another, and another. It turns out that the fuel vendor had just switched to a new pump/tank system, and had sold me more than a quart of water (at AVGAS prices!) along with the fuel.

So, here are some suggestions:

- Check the fuel sumps if the aircraft has been sitting overnight or longer. Humid air in the tanks can condense at night. The problem is worse if the tanks are less than 100% full, because that leaves more room for air. Because of the daily temperature changes, new air gets into the tank each day. The condensed water, hiding underneath the fuel, does not re-evaporate --- it just accumulates day after day.
- Check the sumps if the aircraft has been refueled since the last flight.
- If you do detect water after refueling, notify the fuel vendor immediately, so that one of your less-meticulous fellow pilots doesn't get harmed. Then, wait a few minutes and check your tanks again. A fair amount of water can be suspended in the fuel in the form of tiny droplets that take a while to settle out.
- Check the fuel sumps if the airplane has been sitting in the rain even for a short time. The filler caps have been known to let water leak in.
- Check the color of the fuel. Different octane grades are color-coded differently. The color is rather pale, so it may help to look lengthwise down a long column of fuel.
- Check the odor of the fuel. If it smells like jet fuel, watch out. There have been many cases where an airplane that runs on AVGAS has been mis-fueled with Jet-A. The engine may run on the mixture for a while, but it will be rapidly destroyed because of detonation in the cylinders.
- If you suspect here is a mixture of Jet-A along with AVGAS in your tank, here's how you can check: Put a drop or two of the suspect fuel on a piece of paper. For comparison, put a similar amount of known pure AVGAS on the paper nearby. The AVGAS should evaporate rather quickly. The Jet-A, if any, will remain behind, leaving a translucent spot on the paper.
- There are several ways to detect a sample that is 100% water. For one, the water will not have the right color, since the fuel color-code dyes are insoluble in water. Secondly, water has a noticeably different density and viscosity --- it just doesn't "slosh" the same way. It also doesn't evaporate at the same rate. Last but not least, you can *add* a drop of water to your fuel sampler and make sure it goes to the bottom.
- Before each flight, peer into the tank to make absolutely sure the fuel *quantity* is OK. Cross-check what you see against the gauges. One fellow I know bought gas and got ready to take off, but noticed that the tanks were nearly empty. The service crew had refueled the wrong plane. Another fellow filled the tanks on Sunday and went to fly again on Friday. The tanks were nearly empty because of a leak.
- Don't switch tanks just before takeoff. On typical airplanes the engine can run for *two or three minutes* just using the fuel stored in the carburetor and engine sumps. That's just long enough to get you into big trouble if you use tank "A" for taxi and runup, and then switch to tank "B" for takeoff. What if tank "B" is contaminated? What if it is empty? What if there is a blockage in the lines? What if you accidentally select "Off" instead of "B" during the switch? Et cetera, et

cetera.... If there is a problem with tank “B”, you’d like to find out about it before starting your takeoff roll. If you absolutely must switch to tank “B” for takeoff, do a duplicate runup on that tank, and wait long enough to consume the fuel in the lines and sumps and prove that you are actually getting fuel from tank “B”.

- By the same token, it isn’t smart to switch to a new tank on final approach. Plan ahead; do your tank-switching at an altitude and at a location where if something bad happens you’ll have a chance to do something about it.

15.3 Dealing with Emergencies

As suggested in the epigraph to this chapter, the first step in dealing with any in-flight emergency is to *fly the airplane*.

This sounds simple and obvious, but there have been far too many cases where the aircraft stalled or flew into the terrain because the pilots were too busy fussing with something that should have been only a minor distraction.

For instance, what should you do if the door comes open during takeoff? Answer: fly the airplane. No general aviation airplane I know of will crash because the door is ajar. The door will be held open about an inch or so. There will be enough suction to make it rather hard to close that last inch. There will be a bit of noise and a bit of a draft, but perhaps less than you might imagine. You might not even notice at first. In any case, the safest thing to do is to ignore all the details and return for landing. When you are safely stopped you can fiddle with the door as much as you like.

As another example, suppose you are just about to turn onto final approach when you notice that only two of the three landing gear are indicating “down and locked”. What should you do? Go around! Do not try to debug the landing gear on final. For that matter, do not try to debug *anything* in the traffic pattern --- it is too close to the ground and (usually) too congested. Get out of there. If there is a control tower, don’t forget to tell ATC what’s happening: “Tower, Five Seven Tango has some uncertainty with the landing gear.[8] We’d like to leave the pattern while we investigate”. Then climb to a reasonable altitude, away from the airport, and take your time fixing the problem.

1
: Engine trouble (or other trouble) during the takeoff roll is discussed in section 13.7, especially section 13.7.4. Being lost, which might or might not be an emergency, is discussed in section 14.7.

2
: As part of the preflight briefing, remind yourself of the best-glide airspeed for the airplane you are flying. It varies a lot from plane to plane. Look at the airspeed indicator and think about how this speed will look, geometrically. (Don’t just remember the numerical value, because in an actual emergency you will probably be so excited that you lose your ability to remember numbers. Your ability to remember geometrical relationships will be less impaired.)

3
: In retrospect, I wish I hadn’t pushed quite so hard. A half-*G* pushover would have been more than sufficient, and would have kept the examiner from floating out of his seat. But basically I had the right idea.

4
: i.e. the reciprocal direction on the same piece of pavement.

5
: See section 12.3 for more discussion of how to measure angles.

6

Note this method gives you control of your destination using at most two large-angle turns, whereas S-turns on final would require using four.

7

Remember the law of the roller-coaster: 9 feet per knot, per hundred knots.

8

On a training flight, you might want to let Tower know it is only a *simulated* problem, so they don't get unduly worried. When in doubt, ask the instructor, but usually you know it's a simulation because of the satanic grin on the instructor's face.

16 Flight Maneuvers

A small correction early is better than a large correction late.
--- Aviation proverb

16.1 Fundamentals

During flight, you have quite a number of tasks and responsibilities:

- You are either speeding up, slowing down, or maintaining constant speed.
- You are either climbing, descending, or maintaining constant altitude.
- You are either turning left, turning right, or maintaining constant direction of motion.
- You are either slipping left, slipping right, or maintaining coordinated flight.
- You have control over the flaps, landing gear, various engine controls, et cetera.
- You must keep track of where you are, so you don't miss your destination, run into obstructions, or whatever.
- You need to keep track of weather conditions.
- You must keep watch at all times[1] to make sure you see and avoid other aircraft.
- Et cetera.

The first three items on this list are what I call the "fundamentals" of maneuvering.[2] Simple maneuvers (including plain old straight and level flight) and even some quite complex maneuvers can be broken down into combinations of these three fundamental tasks. Of course, while you are maneuvering you still remain responsible for all the other items on the list.

Some of the maneuvers in this chapter are important parts of everyday flying. For instance, final approach requires lining up on a "front window" ground reference. Flying the downwind leg of the airport traffic pattern requires paralleling a "side window" ground reference. Oftentimes you or your passengers want to get a good view of some landmark, which requires turning around a point. If there is some wind (as there almost always is) you will need to correct for it.

The other maneuvers in this chapter, even though they are not directly practical, serve important pedagogical purposes. Chandelles and lazy eights are good illustrations of several of the points made in this book, including (a) the importance of angle of attack, (b) the relationship between angle of attack and pitch attitude, and (c) the behavior of the plane when its airspeed doesn't equal its trim speed. Some of these maneuvers may seem daunting at first, because they require doing several things at once. Fortunately, though, the ingredients are not particularly hard and can be learned separately.

16.2 Seeing and Avoiding Other Traffic

Mid-air collisions are overwhelmingly most likely to occur at low altitudes, in the vicinity of an airport, in good VFR weather.

Alas there is no easy way to scan for traffic. There are right ways and wrong ways, but even if you do it right it isn't easy.

Airliners all have electronic traffic-detection / collision-avoidance systems. Probably the day will come when even the simplest light aircraft will have them too. In the meantime, your eyes are your primary defense. You must use them wisely.

The objective is to spot conflicting traffic while it is still a good ways away, while you still have time to take evasive action. But when traffic is far away it is hard to see. Trying to spot a typical single-engine airplane two nautical miles away, end-on, is like trying to spot a peppercorn or BB on a shag rug about 55 feet away. (That's a 6mm diameter, 17 meters away.) If a moderately-fast light aircraft is overtaking a slow one, a two-mile separation could be less than 90 seconds of flight time. If two moderately-fast aircraft are approaching head-on, a two-mile separation is less than 30 seconds of flight time.

In the central part of your visual field, there is tremendously high acuity. Unfortunately, the acuity falls off steeply as you move away from the center. Just 10 degrees off-center, the acuity is tenfold less than it is in the center, and it keeps getting rapidly worse after that.

Your periperhal vision can see extremely dim objects, quite a bit dimmer than can be seen with your central vision, but this is nearly useless for the task at hand. At night, other aircraft have lights. Spotting traffic is actually easier during the night than during the day.

Also note that your peripherhal vision excels at detecting motion. But that, too, is nearly useless for the task at hand. Traffic that is steadily moving across your field of view is not a threat. You need to be concerned about something that just sits there and gets bigger. (At night the it sits there and gets brighter.) In addition, you need to be concerned if nearby traffic is maneuvering.

Peripheral vision is good for noticing strobe lights, so it's not completely useless.

All this leaves us with a dilemma:

- You can't scan for traffic using the high-resolution part of the visual field; it just isn't big enough. It would take so long to scan a small part of the sky that you would be at the mercy of threats coming from other parts of the sky.
- Conversely, you can't scan for traffic using your whole visual field; the peripheral acuity isn't good enough to be useful.

Therefore a compromise is recommended: Divide the sky into chunks about ten degrees across, so that no point is more than five degrees from the center. Check each chunk separately. This gives you a marginally-manageable number of chunks, and marginally-decent acuity within each chunk.

Scan along the horizon. Traffic at your altitude will appear at the level of the horizon. Traffic that is climbing or descending toward your altitude will be within a few degrees of the horizon. Similarly, if *you* are climbing or descending, you need to be particularly concerned about traffic slightly above or below the horizon, respectively.

The FAA recommends that you dwell on each chunk for at least one second. (That is, you should not try to scan by sweeping your eyes smoothly along the horizon.) At that rate, it will take you at least 18 seconds to scan a 180-degree stretch of horizon. That's a long time.

Beware: traffic that is below the horizon can be exceedingly hard to see. Also, the end-on view is a lot smaller than the side view. Once I spent about 10 minutes following another airplane, two miles in trail. We were both descending toward the same airport. I knew exactly where the other aircraft was. It showed up on our fish-finder, and I was talking to the pilot on the radio. I looked and I looked, but I didn't see anything until the other airplane flared for landing.

Beware: something like 80% of all mid-air collisions involve one airplane overtaking another one traveling in the same direction. (You might have guessed that head-on collisions would be more prevalent, but just the opposite is true. Evidently we are getting a big payoff from the rule that keeps opposite-direction traffic at different cruising altitudes, and the rule that keeps everybody going the same direction in the traffic pattern.)

It is also worth knowing that your eyes won't focus properly if they don't have anything in particular to look at. This is called *empty-field myopia*. This can become relevant if you are flying between layers, or below a featureless ceiling above featureless terrain or water. Haze of course makes it worse. When you switch from looking inside the cockpit to looking outside, you should take a moment to focus on something far away -- a wingip, perhaps -- before you begin scanning a featureless sky.

Some other bits of advice:

- When approaching an airport with a left-hand traffic pattern, do not fly anything resembling a right-hand traffic pattern. The FARs forbid this, for a good reason. Consider what happens if one aircraft is turning from left base to final at the same place where another aircraft is turning from right base to final. They will meet belly-to-belly. They won't be able to see each other during the turn.

- Similarly, never overfly the field at pattern altitude to join the downwind leg from the inside of the pattern. This is not forbidden by the FARs, but it is a really, really bad idea, for the same reason as before: You don't want to meet belly-to-belly with another aircraft that is coming in on the "45" and joining the pattern from the outside. If you are approaching the field from the non-pattern side, you can enter on crosswind. Another option is to overfly the field at some random height above pattern altitude, descend somewhere far outside the pattern, and then come back in on the "45".

- Never descend onto the traffic pattern from above. Never climb into the traffic pattern from below. Airplanes ought not to play piggy-back. Having a low-wing aircraft above a high-wing aircraft is particularly bad, but it is not the only bad scenario. Pilots can't see straight down, commonly can't see straight up, and aren't accustomed to looking straight up anyway.

- If you are performing a slip to lose altitude on final approach, slip by pushing right rudder if you are seated in the left seat. This gives you better forward visibility.

- Use the radio to announce your position in the pattern at frequent intervals. Do this even if you think nobody else is around.

- When reporting your position, avoid referring to landmarks such as "Kelly's Barn" that aren't necessarily meaningful to other pilots. Instead, report "three miles west, entering on the 45 for runway 31".

- Similarly, avoid using IFR terminology on the airport traffic-advisory frequency, since not all pilots are instrument rated. For example, if DOPEY is the final approach fix for runway 6, do not report “DOPEY inbound”, but rather “five mile final for runway 6”.

- Use strobe lights. Use them always. They are bright enough to be visible even in daylight. If you can afford an airplane, you can afford to put strobes on it. Similarly, it is a good practice to turn on the landing light whenever you are below 5000 feet AGL and within 10 miles of an airport, even during the day, but the landing light is no substitute for strobes.

- Keep your transponder turned on, including Mode C, at all times during flight, even when it’s not officially required. It won’t help you see other traffic, but it will allow them see you on their collision-avoidance instruments.

- Be particularly careful around VOR stations. All the IFR-wannabes in the world are trying to overly that VOR at *exactly* a round-number altitude, with the CDI *exactly* centered, with their heads down-and-locked, looking at the gauges, not looking for traffic, even though it’s good VFR weather. You should miss the VOR by a mile if you can. If you need to look at a chart to figure out your outbound heading, do it *before* approaching the station. If you want to practice holding, hold at an intersection, not a VOR. Make sure you can keep the needles centered *and* scan for traffic at the same time.

- Avoid round-number altitudes if you’re below 3000 AGL.

- Eat enough carrots. Don’t smoke.

- Keep the aircraft windshield clean. A bug-corpse nearby looks like traffic far away.

- Move your head as needed to peer around window frames and other obstructions.

- Use your hand (or perhaps a window frame) to block the direct rays of the sun while you scan the block of sky nearest the sun.

- Don’t fly a course directly into the morning or evening sun. Instead, pick a course that is at least 10 degrees to one side, even if you have to do some zig-zagging. This will add at most 1.5% to the distance, which is a small price to pay for reducing the chance of clobbering somebody directly up-sun of you. It will also reduce your chance of being clobbered from behind.

- Remember: the bogey you see isn’t the one that’s gonna sneak up on you. Keep looking to see if there are others.

- Get radar advisories at every reasonable opportunity. But remember this service is only advisory, and does not relieve you of your see-and-avoid responsibility.

- You need to keep scanning. Keep scanning until your aircraft is parked. Don’t allow any lapses in your scan.

The aforementioned scanning techiques are important, but they are worthless if you don’t put them into practice. The biggest threat comes from people who know all the techniques, and perform a fine scan on those rare occasions when they remember to scan at all.

If your last scan was a long time ago, it doesn’t matter whether that scan was super-excellent or merely passable. What matters is how long it has been since your last good scan. (This is the minimax principle, as discussed in section 21.11.) Make sure you always have a good scan, without lapses.

16.3 Speeding Up and Slowing Down

This is a very important maneuver which has not always been sufficiently stressed during pilot training. The idea is to change speed while maintaining constant altitude, constant heading, et cetera.

Here’s a good exercise: Start from level cruising flight. Slow down to V_Y, while maintaining constant altitude. When you reach the new speed, set the engine controls and trim so that the plane will maintain the new speed. After you have flown in this configuration long enough to convince yourself that everything is stable, slow down to a speed well below V_Y (but with a reasonable margin above the stall). Again, stabilize the plane at the new speed, still maintaining constant altitude. Then increase speed back to V_Y and stabilize. Then increase speed to cruise and stabilize. Iterate this a few times until you are sure you’ve got the hang of it.

You will have an easier time understanding how to use the throttle (especially at speeds below V_Y) if you keep in mind the concepts of *kinetic energy* and *power curve*. These are discussed at length in section 7.2.

You will also want to keep in mind the relationship between trim and airspeed, as discussed in section 2.6.

An interesting variation of this maneuver is to practice speeding up and slowing down with the flaps extended. (Make sure you observe the speed limit for flaps-extended operations, which is typically quite a bit lower than for flaps-retracted operations.) This is interesting because on some planes, adding power with flaps extended causes a huge nose-up trim change; you will need to roll in some nose-down trim to compensate.

16.4 Phugoids

In flight it is fairly common for the airplane to find itself at an airspeed rather different from its trim speed. This situation will result in a *phugoid oscillation*, as discussed in section 6.1.12. It is definitely worth seeing this behavior for yourself.

Start with an airspeed, say, halfway between V_Y and cruise. Pull back on the yoke until the airplane slows down about ten knots, and then let go. As discussed in section 6.1.12, the airplane tries “too hard” to return to its original airspeed, altitude, and attitude; it will overshoot and oscillate for several cycles.

From time to time during this maneuver, look at the airspeed indicator and altimeter. This will provide a good illustration of the law of the roller coaster (9 feet per knots, per hundred knots). See section 1.2.1. This maneuver is also a good illustration of the principle of angle of attack stability, as discussed in chapter 6.

Practice “catching” the phugoid at various points in the cycle. That is, by pushing or pulling on the yoke, maintain constant altitude until the airspeed returns to normal. It is particularly interesting to catch it right when the airspeed equals the trim speed. By returning it to normal attitude at that moment, you can instantly end the oscillations.

If you use the wrong procedure (pushing on the yoke when the altitude is highest and pulling on the yoke when the altitude is lowest) you will just make the situation worse. This an example of a *pilot-induced oscillation* (PIO). It is more common than you might think, and can cause serious trouble if it happens near the ground, as discussed in connection with evil zooms in section 12.11.8 and section 16.20.6.

16.5 Turns

Flying around in an established turn is relatively simple. For perfect coordination, you ought to deflect the rudder toward the inside of the turn (to compensate for the long-tail slip effect, as discussed in section 8.9). Then you need to deflect the ailerons toward the outside of the turn (to compensate for the overbanking tendency, section 9.4). This is remarkably unlike a car, in which you must keep the wheel deflected to the inside, and you can judge the tightness of the turn by the deflection of the wheel. In the airplane, don't look at the yoke. Judge the tightness of the turn by looking at the bank angle. Then do whatever you need to do with the yoke to maintain the chosen bank angle.

If you are turning to intercept a landmark, you need to think a little about how steep a turn to make and when/where to start the turn. It so happens that for any particular bank attitude, the turning radius depends on the *square* of your speed. A turn that consumes a tenth of a mile at 60 knots will consume nearly a mile at 180 knots.

speed	rate	radius	bank	load
(knots)	(°/sec)	(nm)	(degrees)	factor
60	10.5	0.09	30	1.15
75	8.4	0.14	30	1.15
90	7.0	0.20	30	1.15
105	6.0	0.28	30	1.15
120	5.3	0.36	30	1.15
135	4.7	0.46	30	1.15
150	4.2	0.57	30	1.15
165	3.8	0.69	30	1.15
180	3.5	0.82	30	1.15

Table 16.1: Constant-Bank Turn

A *standard rate turn* is defined to be three degrees per second. This is what ATC expects when you're on an instrument clearance. It is also called a two-minute turn, because at that rate it takes two minutes to make a complete 360° turn. You can see from the following table that the bank angle required grows in proportion to the airspeed. Because of the changing bank, the radius of turn grows in proportion to the airspeed (not the square thereof).

You should figure out the bank angle that corresponds to a standard-rate turn for the airspeed(s) you normally use.

speed	rate	radius	bank	load
(knots)	(°/sec)	(nm)	(degrees)	factor
60	3	0.32	9.4	1.01
75	3	0.40	11.6	1.02

90	3	0.48	13.9	1.03
105	3	0.56	16.1	1.04
120	3	0.64	18.2	1.05
135	3	0.72	20.3	1.07
150	3	0.80	22.4	1.08
165	3	0.88	24.4	1.10
180	3	0.95	26.3	1.12

Table 16.2: Standard-Rate Turn

16.6 Coordination Exercises

Here is a good maneuver for learning about your plane's roll-wise inertia and adverse yaw, called "coordinated wing rocking". The procedure is: roll rather rapidly into a 45 degree bank to the left. Pause for a moment, then roll to wings level. Pause again, then roll 45 degrees to the right. Pause again, roll wings level, and repeat.

Refer to chapter 11 for a discussion of various techniques for perceiving whether or not your maneuvers are accurately coordinated.

The rolls should be done sufficiently rapidly that significant aileron deflection is required. Do the maneuver at cruise airspeed, and then do it at approach speed and even slower speeds, so you can see how the amount of rudder required increases as the speed decreases. Do the maneuver while looking out the side (wings should go up and down like a flyswatter, with no slicing) and while looking out the front (rate of turn proportional to amount of bank, no backtracking on roll-in, no overshoot on roll-out). Pay attention to the seat of your pants.

You should do the maneuver two ways: once with large aileron deflection applied gradually, and once with large aileron deflection applied suddenly. The difference between the two demonstrates adverse yaw.

16.7 Constant-Heading Slips

Unlike the previous exercise (which involved *coordinated* wing rocking) this one involves intentionally uncoordinated wing rocking. Put the airplane in a slight bank (15 degrees or so), then apply top rudder to keep it from turning. Hold it there for a few seconds, then roll back to wings level, hold it there, then roll to the other side, etc., maintaining constant heading throughout. This is grossly uncoordinated, but it is amusing and educational because it lets you learn the feel of the controls and the response of the airplane.

When you first put the airplane into a bank, it has a sideways force but no sideways motion, so there is no weathervaning tendency and no need to apply top rudder. It takes a couple of seconds for the airplane to build up sideways velocity, during which time you feed in progressively more top rudder.

The same logic applies in reverse when you roll out: keep the rudder deflected during the roll-out, to maintain heading; then, as the sideways velocity goes away, gradually relax the rudder pressure. For a discussion of the physics of the situation, see the end of section 16.9.

This exercise is good practice for crosswind landings, in a funny sort of way. If you make a crosswind landing using perfect technique under ideal conditions, it seems easy, because it involves simply a transition from crabbing flight to slipping flight without any change in direction of motion. But now consider the case where due to a sudden gust (or a lapse in technique) you are slightly off-center above the runway and/or drifting sideways. That's a lot harder, because you have to maneuver the plane sideways to get things back where they belong. You need to know how the airplane will respond to the controls, and constant-heading slips are the easiest way to learn how it responds.

Slipping along a road (section 16.9) is another relevant exercise.

Constant-heading slips are essentially the same as the top three "points" of an an aerobatic 8-point roll. These are sometimes improperly called Dutch rolls, but they are not the same as the natural aerodynamic Dutch roll oscillations discussed in section 10.6.1. Both involve slipping to one side and then the other, like a Dutch kid on skates, making a series of slips (left, right, left, right) without much change in "direction", depending on what you mean by "direction". But note the differences:

- Natural aerodynamic Dutch roll oscillations change the heading, with more-or-less unchanging direction of motion.
- Constant-heading slips change the direction of motion, with unchanging heading.

Another amusing and educational exercise is called "drawing with the nose". It goes like this: keeping the wings level at all times, yaw the nose to the left with the rudder. Then raise the nose with the flippers. Then yaw the nose to the right with the rudder. Then lower the nose with the flippers, and repeat. Imagine you are drawing a rectangle on the sky in front of you, using the axis of the airplane as your pencil.

Because of the slip-roll coupling described in section 9.2, while pressing right rudder you will need to apply left aileron to keep the wings level. The purpose of this exercise is to illustrate yaw-wise inertia, yaw-wise stability, and yaw-wise damping. Among other things, you will notice that if you make a sudden change in rudder deflection, the nose will overshoot before settling on it steady-stage heading. (Once again, the combination of controls used here is very different from proper turning procedure.)

16.8 Crabbing Along a Road

One of the most basic maneuvers involves choosing a ground reference such as a long, straight road and flying along it. The point of the maneuver is to practice perceiving and correcting for crosswinds, so choose a road that has a significant crosswind component.

Actually, correcting for the crosswind is the easy part. If the plane starts getting blown off to the left of the road, you will instinctively turn the plane a little to the right to compensate. The tricky part is to *notice* that you have done so. The situation shown on the left side of figure 16.1 (crosswind from the left) seems quite normal. Similarly, the situation shown on the other side (crosswind from the right) also seems quite normal. It is important to be able to perceive the difference. The outside world looks the same in both cases; the difference is that the alignment of the airplane has changed relative to the outside world.

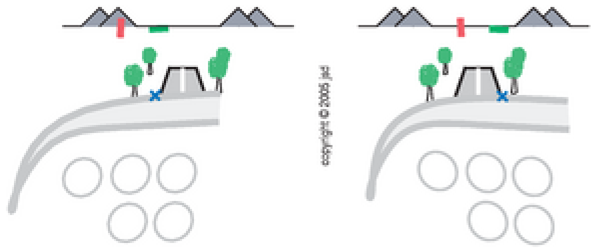

Figure 16.1: Crosswind from the Left or Right

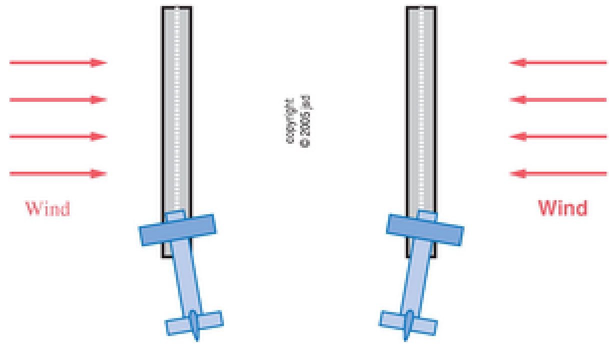

Figure 16.2: Crosswind from the Left or Right --- Bird's Eye View

You should always make a point of noting your direction of flight (which is aligned with the road in this case) relative to bolts on the cowling, marks on the windshield,[3] and other parts of the airplane. In particular, in figure 16.1, there are short red and green lines on the windshield, and blue X on the cowling. Pay attention to how these line up relative to the course line your are following.

Figure 16.2 show bird's eye views of the same two situations, to help you understand what's going on ... but remember, when you are piloting the plane, such views are not available to you.

You should be especially alert to these perceptions during final approach, since you need information about the wind in order to prepare for a proper crosswind landing.

It also pays to notice the crosswind during the base leg. If the crosswind is trying to blow you toward the airport then you will have a tailwind on final and (most likely) a tailwind during landing. You might want to break off the approach and take a good look at the windsock before trying again. See section 12.7.4.

A less-common possibility is that you have a tailwind on final that shears to a headwind at runway level. This is the *opposite* of the decreasing headwind that you normally encounter on approach. For details on this, see section 16.17.3.

These perceptions can give you precise information about the amount of crosswind. It is proportional to the wind-correction angle and airspeed:

- At 60 knots one degree corresponds to 1 knots of crosswind.
- At 90 knots one degree corresponds to 1.5 knots of crosswind.
- At 120 knots one degree corresponds to 2 knots of crosswind.

16.9 Slipping Along a Road

The goal of this maneuver to fly with the airplane's axis *and* its direction of motion both aligned with a road. In the presence of a crosswind, this is nontrivial. This is excellent preparation for crosswind landings (section 12.9).

The crosswind component will be hitting the side of the airplane. That means you are in a slip. To maintain the desired slip angle, i.e. to keep the axis aligned with the road, you must maintain pressure on the rudder pedal on the downwind side.

Meanwhile, the force of the crosswind will tend to blow the airplane downwind. To counter this force, you must bank the airplane. Lower the upwind wing. Note that this is a proper slip, not a skid: you are banked toward the upwind side, and applying downwind rudder (i.e. top rudder).

Here's the procedure: In preparation for the maneuver, choose a long straight road with a crosswind. Ten or fifteen knots of crosswind component will serve the purpose nicely. During the maneuver, the first ingredient is to perceive the heading (i.e. yaw angle), and to align it with the road using the rudder. That's the easy part. The second ingredient is to perceive the rate of left/right motion, and to bring it to the desired value -- usually zero or nearly zero -- by adjusting the bank angle. The third ingredient is to perceive the left/right position. If you are not centered over the road, set up a slight drift to bring you back to the center.

Here's an interesting variation: Drift over to the upwind side of the road. Stay there a moment, flying parallel to the road, offset 10 or 20 yards to the side. Then drift over to the downwind side of the road. Stay there for a moment, then repeat. Maintain heading parallel to the road at all times, even while drifting sideways. This will teach you some interesting things about sideways inertia.

Here's the procedure: Start from steady flight, slipping along the road as previously discussed. Then smoothly but quickly increase the bank angle. At first not much happens, and you can maintain heading without much additional rudder deflection. A sideways acceleration has begun, but there is not yet much sideways velocity relative to the ground. That's because there's a lot of sideways inertia. Gradually, over a period of a couple of seconds, the airplane starts going sideways faster and faster. You need to feed in more and more rudder deflection to maintain heading.

After this motion has carried you a ways to the side of the road, level the wings. For a while, the airplane keeps drifting sideways, due to its sideways inertia, and you need to maintain the rudder deflection to maintain heading. Then, over a period of a couple of seconds, the sideways velocity gets smaller and smaller and you need gradually less rudder deflection. When the sideways velocity reaches zero relative to the ground, re-establish the bank angle necessary for steady slipping flight. The rudder deflection will be nonzero at this point, because you are still fighting the crosswind component.

If you are surprised by the long timescale of the sideways velocity buildup and decay, remind yourself that airplanes have lots of inertia and not much drag. If there were no sideways drag, any force would cause the sideways speed to grow and grow forever, in accordance with Newton's second law (section 19.1).

In all cases, keep in mind that the slip will cause added rearward drag. You will need to add power to maintain altitude. For goodness sake don't pull back on the yoke; you will be at a fairly low altitude (since this is a ground-reference maneuver) and you really don't want to stall in such a situation. Maintain a constant angle of attack by watching the angles as described in chapter 2. The angles are more reliable than the airspeed indicator, because the slip perturbs the pressure at the static port. I've seen situations where the indicated airspeed differed from the calibrated airspeed by 40 knots (due to a pedal-to-the-floor slip).

Make a note of how much bank angle and how much rudder pressure are needed for a given amount of crosswind. This varies considerably from one type of airplane to another. This knowledge comes in handy during crosswind landings; you don't want to wait until you are in the midst of a landing to figure it out.

16.10 Familiarization Exercises; Configuration Changes

Imagine you are not completely familiar with the aircraft you are flying. You are have just flown an instrument approach, and have broken out of the clouds about 150 feet above the runway. You are flying at 100 knots. Within the next 15 seconds or so, you need to slow down to 71 knots in preparation for landing. To deal with this situation, you take the following actions:

1. Pull the throttle to idle
2. Extend the flaps the rest of the way
3. Deploy the speed brakes[4]

Now imagine that those actions do not cause the airplane to slow down! You discover that on this airplane, each of those actions causes a nose-down trim change. The airplane pitches over and dives toward the ground at high speed. This is not good.

Therefore, in this airplane, a much better procedure would be to take the following actions:

1. Pull the throttle to idle and apply some nose-up trim to compensate.
2. Extend the flaps the rest of the way and apply some more nose-up trim to compensate.
3. Deploy the speed brakes and apply even more nose-up trim to compensate.
4. As you slow down, apply yet more nose-up trim.

For any given airplane, you need to know how much trim it takes to compensate for each configuration change. This information is typically not provided by the Pilot's Operating Handbook. You need to obtain it empirically. Go to the practice area and do some experiments at a safe altitude.

First, just fly around for a while at normal cruise airspeed. This lets you see what the cruise angle of attack looks like; this information comes in handy on final approach, as discussed in section 12.11.3.

You should also take this opportunity to learn how the airplane responds. Practice the basic maneuvers as described in previous sections of this chapter. Speed changes are worth practicing; some airplanes are much harder to slow down than others. Coordinated turns are worth practicing; different airplanes require different patterns of rudder usage. Nonturning slips are important for landings; you need to know how much yaw and how much drag is produced by a given amount of rudder pressure. Phugoids are definitely worth investigating; different airplanes respond differently.

Next, investigate the effect of the trim wheel. The wheel has bumps on it, which we can use as our unit of measurement. Move the wheel one bump, and see what effect that has on the airspeed. If you have electric trim, figure out how fast it moves (how many bumps per second).

Next, slow down to the airspeed you normally use in the traffic pattern. Again, get the airplane nicely trimmed and just fly around a while. Make a note of the angle of attack.

After the airplane is once again flying along, nicely trimmed at pattern speed, extend one notch of flaps. Maintain the same speed. Make careful note of how many bumps of trim it takes to maintain constant speed, compensating for the flap extension. Do not bother to maintain level flight. Leave the power setting alone, and make a note of how much rate of descent is caused by the drag of the flaps. Also note how the pitch attitude changes; remember that extending the flaps changes the angle of incidence, as discussed in section 2.4.

Do the same for each successive notch of flaps. In each case, make careful note of how much you have to move the trim wheel to maintain constant speed. Also observe the resulting rate of descent, and observe the change in incidence.

Do the same for other possible configuration changes (landing gear, speed brakes, et cetera).

After you have done that, investigate the effect of power changes. Determine how many RPM (or how many inches of manifold pressure) you need to remove in order to change from level flight to a 500 fpm descent. Also observe the effect that such a power change has on the trim speed.

Now, during the descent, check the effects of configuration changes again. You need two sets of observations: one using a power setting appropriate for level flight in the traffic pattern, and one using a power setting appropriate for final descent. In an ideal airplane, configuration changes would not affect the trim, but in a real airplane they do, by an amount that depends on the power setting.

At this point, you should be able to construct a crib card along the following lines:

- 300 RPM power reduction (clean), compensate with _____ bumps
- 300 RPM (approach configuration), compensate with _____ bumps
- first notch of flaps (level flight), compensate with _____ bumps
- first notch of flaps (descent power), compensate with _____ bumps
- second notch (descent power), compensate with _____ bumps
- third notch (descent power), compensate with _____ bumps
- extend gear, compensate with _____ bumps
- extend speed brakes, compensate with _____ bumps

Each of the blanks gets filled in with some positive number (for nose-up trim application) or negative number (for nose-down trim application). The exact values aren’t important; the idea is to have enough information to prevent nasty surprises like the situation described at the beginning of this section.

Finally, fly around for a while slightly above minimum controllable airspeed, with flaps extended. See section 16.19 for more discussion of slow flight procedures. Practice rocking the wings. Make sure you can bank the plane left or right, with reflexively correct use of ailerons and rudder.

Additional familiarization exercises are discussed in connection with landings in section 12.11.4.

Familiarizing yourself with a new type of airplane can take a goodly amount of time, especially if you have modest total pilot experience. On the other hand, if you are just re-familiarizing yourself with the plane after a period of inactivity, you can run through the maneuvers fairly quickly.

16.11 Transitioning to Fast and Complex Aircraft

Pilots who have been properly trained in a slow, light, simple aircraft should be able to transition to a fast, heavy, complex single, or a light twin, or even a three-engine jet -- with only a few surprises. I've seen it done. In contrast, though, far too many pilots have picked up a load of bad habits and dirty tricks that only work in one type of aircraft, so for them transitioning to other types will be traumatic.

Here are some of the things to watch out for.

- A higher-performance airplane will typically operate over a wider range of speeds. For example: in a Cessna 172, you might climb at 78 knots and cruise at 105 knots, whereas in a Mooney you might climb at 90 knots and cruise at 170 knots. This has multiple consequences.
    - One consequence has to do with angle of attack, which is inversely dependent on the ratio of speeds, or rather the square of that ratio. (Recall equation 2.1 and figure 2.15.) For the C-172, the result is $1.3^2 = 1.7$, while for the Mooney the result is $1.9^2 = 3.6$. That means that the fancy airplane will cruise with noticeably less angle of attack --- about half as much. This puts a premium on your ability to perceive angle of attack, using methods discussed in chapter 2. Tiny changes in angle of attack have a big effect at high airspeed.

    - Another consequence has to do with trimming. Think about the speed difference in terms of energy: nine feet per knots per hundred knots (section 1.2.1). For the C-172, the speed range represents 240 energy units (feet). For the Mooney, the speed range represents 920 energy units -- nearly four times as much. Under ordinarly conditions, the fancier plane spends *more* time speeding up, even though it has greater acceleration. It's ironic but true.

- If you don't trim the airplane properly, the result will be a phugoid oscillation (in the short term and perhaps longer). In a high performance airplane, it is likely that the phugoid will last for more cycles, and each cycle will be bigger. Poor pilot technique will make things even worse. See section 6.1.12 for the proper technique. Also remember to lead with the yoke, hold the correct angle of attack, and then trim off the pressure; don't lead with the trim.

- Remember that airspeed goes with trim, and trim goes with airspeed (or, more precisely, angle of attack). You can't trim by reference to pitch attitude alone, partly because you usually can't perceive pitch precisely enough, and partly because pitch isn't synonymous with angle of attack anyway, as emphasized in section 16.14 and elsewhere. Therefore keep the airspeed indicator in your scan. It's your best means of perceiving the difference between a phugoid and an updraft ... which you need to perceive, since the correct reaction is different in the two cases.

- A high-performance plane will have a higher rate of climb, so you will reach your intended altitude sooner. Anticipate this, so you don't wind up too high. Also: The pitch attitude during climb will be higher. This may "look funny" and it may require you to work harder to see and avoid other traffic. For a steep climb at low speeds, partially extending the flaps may help you see out. Another option is to climb at a higher airspeed: a "cruise climb".
- A typical twin has a noticeably higher stalling speed than a typical single.[5] Other critical speeds are increased in proportion. One notable consequence is that normal turns in the traffic pattern require considerably more room.

- To the extent that the fancy plane operates at a higher altitude and a higher speed, you will need to start your descent somewhat earlier (in terms of time) and dramatically farther out (in terms of distance).

- You ought to learn the main points about how the airplane's systems work: the propeller pitch control, the landing gear retraction, the electrical system, et cetera. The details are beyond the scope of this book, but they are important. More than once I've been in a situation where the indicator that says "gear down and locked" failed to come on, but I was able to convince myself by other means, based on an understanding of how the system worked, that the gear were in fact safely down and locked. This was very comforting. On the other hand, if you are primarily doing recreational flying in rented aircraft, you shouldn't drive yourself crazy learning every detail of every widget. In a typical GPS instrument, 90% of the value comes from 10% of the features. A good instructor should be able to tell you which features can be left unlearned for a while.

Let's talk more about trimming. Suppose you are leveling off after a climb, in a high-performance airplane. You let it speed up for a few seconds, and then trim it --- but then it will speed up some more and you will need to trim it some more. You should plan on prolonged acceleration and repeated trimming.

If you take any non-turbocharged airplane up to a typical cruising altitude, the throttle will be wide open at cruise. This means that when you level off after a climb, the airspeed will converge only asymptotically to the final value. This is the mirror-image of the problem shown in figure 7.1. It could easily require several minutes for the airspeed to get "close enough" and you will have to re-trim repeatedly during the process.

It would be a mistake to think you can just trim the aircraft and then move on to other tasks. Rather, you must carry out other tasks *while* the airplane gradually speeds up, *while* you continually adjust pitch and trim. Turbulence and/or passengers shifting their weight around make trimming a never-ending task. Ideally, trimming is like breathing: it's important, you do it all the time, and it doesn't distract you from other tasks. See chapter 2 for a discussion of the basic ideas of angle of attack. See section 7.2 for the particular case of speed-changing maneuvers. See section 16.10 for other trim-related issues.

16.12 Turns around a Point

Turns are more challenging if you are trying to turn around a specific ground reference, maintaining a constant distance from it. If there is any significant wind (which there almost always is), this requires constantly changing bank angles.

The best way to analyze this situation is to begin by considering what happen if you do *not* make any correction for the wind. Figure 16.3 shows three complete turns made using a constant bank angle.

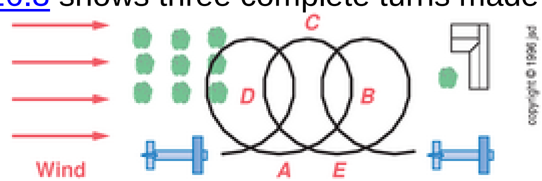

Figure 16.3: Turns Not Quite Around a Point

In the absence of wind, you would have performed three perfect circles around the southeasternmost tree in the orchard. However, since there is some wind, we can use the principle of relativity. Relative to the air, you have still made three perfect circles. However, the air itself has moved during the maneuver, carrying the whole pattern downwind. Therefore relative to the ground, we see the cycloid pattern shown in the figure.

To transform this pattern into one that is circular relative to the ground, you need a steeper bank at the points where you are headed downwind (e.g. point *A* and neighboring points), and a shallower bank at the points where you are headed upwind (e.g. point *C* and neighboring points). As you can see from table 16.3, the effect can be fairly large.

speed (knots)	rate (°/sec)	radius (nm)	bank (degrees)	load factor
60	2.9	0.33	9	1.0
75	3.6	0.33	14	1.0
90	4.3	0.33	19	1.1
105	5.0	0.33	26	1.1
120	5.7	0.33	32	1.2
135	6.4	0.33	39	1.3
150	7.2	0.33	45	1.4
165	7.9	0.33	50	1.6
180	8.6	0.33	55	1.7

Table 16.3: Constant-Radius Turn

If you fly the maneuver at 90 K_{IAS}, your groundspeed will vary from 105 (downwind) to 75 (upwind). That's a ratio of 1.4 to 1. Let's assume you remain 1/3rd of a mile from the landmark, since that is the distance to which the table applies. The speed in the left-hand column of the table should be taken as a *ground* speed, since we want the radius to remain constant as seen from the *ground*. The table tells us the required bank angle will vary from 26 degrees at point *A* to 14 degrees at point *C*.

At points *B* and *D* in the figure, the bank angle will be the same as in the no-wind case --- but you will need apply wind corrections to your heading, as discussed in section 16.8.

16.13 Eights Around Pylons

Eights around pylons are performed by flying turns around a point clockwise around one pylon, and counterclockwise around another pylon, as shown in figure 16.4.

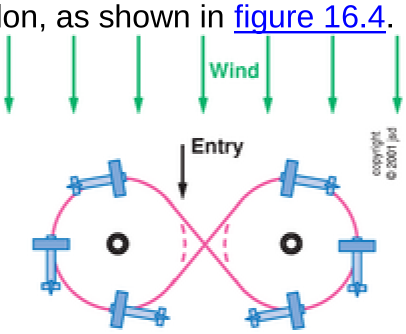

Figure 16.4: Eights Around Pylons

If you can do turns around a point, you can learn eights around pylons very quickly. The techniques for wind correction etc. are just the same.

The only new element in this maneuver is choosing the right place to roll out of the turn and begin the straightaway section, so that the two circles will be the same size. It may help to visualize the desired figure-eight shaped ground track on the ground, and then just follow that track.

It is best to enter on a downwind heading, so that the first turn will be the steepest.

Note: This maneuver is not to be confused with eights *on* pylons (which are discussed in section 16.16.2).

16.14 Chandelles

A *chandelle* is a stylized climbing turn. The key elements are:

- There is a total heading change of 180 degrees.
- During the first 90 degrees, there is a constant bank and smoothly increasing pitch attitude.
- During the second 90 degrees, there is a constant pitch attitude and smoothly decreasing bank.
- Climb power is used.
- At the 180 degree point, the wings are level and the airspeed is just above the stall.

You must choose what entry speed to use. Here are some considerations to guide your choice:

1. If your airplane's manufacturer has specified a maximum entry speed, abide by that restriction.
2. You are allowed to choose an airspeed higher than V_A if you want, since the maneuver doesn't place much stress on the wings.
3. Previous versions of the FAA Commercial Pilot Practical Test Standard demanded entering at exactly V_A, but now you get to choose.
4. For most airplanes, cruise speed is fast enough, and has the advantage of being conveniently attainable. Typically, this works just fine.
5. In contrast, if your airplane is horribly underpowered, you might want to dive a little bit before starting the maneuver, so you can enter at a higher-than-cruise airspeed.
6. At high airspeed, you might need less than full throttle, to avoid overspeeding the engine. (You should re-open the throttle during the maneuver, after the airspeed has decayed.)
7. A higher entry speed makes the maneuver last longer. This may make it easier, other things being equal.
8. A higher entry speed produces more gain in altitude during the maneuver. Some people think this makes the maneuver more impressive, but this should not be overemphasized. A chandelle is in sometimes characterized as a "maximum performance" turn, but that is misleading. The maneuver should be judged primarily on precision and smoothness, not on the amount of altitude gain, so don't feel obliged to use the highest imaginable entry speed. (If people wanted maximum altitude gain, they would use a rather different sequence of bank and pitch attitudes.)
9. Once you choose a suitable entry speed, stick with it, so that the maneuver is the same each time.

The maneuver emphasizes headings and attitudes. You should use ground references to judge the correct headings, but you shouldn't bother to remain over a particular point or to correct headings for wind drift.

You have some discretion when selecting the initial bank angle. Usually 30 degrees works fine. If the bank is too shallow, during the second half of the maneuver you will find that the airplane has slowed to its final speed before the turn is completed; ideally the final speed and the final heading should be reached simultaneously. Happily, since the airspeed is changing only rather slowly at the end, this is relatively easy to arrange.

The end of the maneuver depends on airplane performance:

- If your airplane has more than enough power to sustain level flight at stalling angle of attack, you are in luck. At the end of the maneuver you should speed up at constant altitude, by gradually lowering the nose.
- If your airplane cannot sustain level flight at stalling angle of attack, you should arrange the timing so that at the end of the maneuver you are momentarily in level flight, at the top of the climb. Then you should lower the nose and dive gently to obtain an airspeed that will permit speeding up in level flight. Then continue speeding up in level flight. You will need more skill and judgment than you would in a more powerful plane.

If you want to learn to do chandelles, it may help to divide the maneuver into separate “climb” and the “turn” components. It is sometimes useful to analyze and practice these components separately.

The second half of the climb contains an interesting lesson. The pitch attitude and power setting are constant, but the result is very far from being constant performance. The angle of attack is increasing, the airspeed is decreasing, and the rate of climb is decreasing.

This second part of the maneuver begins with the airplane climbing rapidly. The climb angle is, intentionally, unsustainable. The airplane will nevertheless climb in the short run. For a while, it can climb by cashing in airspeed, according to the law of the roller coaster.

As the airspeed decreases, the airplane must fly at an ever-higher angle of attack in order to support its weight. Since the pitch attitude is being held constant, this means that the direction of flight must be bending over. This is illustrated in figure 2.11 in section 2.10.

This should drive home the lesson that pitch attitude is not the same as angle of attack, and that angle of attack (not pitch attitude) is what directly determines performance.

You should not attempt to micro-manage the altitude during a chandelle. You should maintain the chosen pitch attitude and let the airplane’s intrinsic vertical damping (and energy budget) take care of the vertical motion.

The choice of pitch attitude with which you begin the second half of the chandelle is obviously critical, since you will be stuck with it for the rest of the maneuver. If it is too nose-high, the airplane will slow down too quickly and you will run out of airspeed before the turning part of the maneuver is completed. Conversely, if the pitch attitude is too low, you will have airspeed left over at the end of the turn. The right answer depends on the performance of the airplane (and on the timing of the turning part of the chandelle). The answer can be determined by trial and error. About 15 degrees is a good initial guess for typical training airplanes.

Now let’s examine the turning component of the chandelle. Again, the second half is the interesting part. It will take a certain amount of time, and during this time you must roll the wings level, using a uniform roll rate. If you roll too slowly, the airplane will turn through 90 degrees before the rollout is completed. Conversely, if you roll too quickly you will run out of bank before the 90 degree turn is completed. At each instant, you should estimate the amount of turn remaining and the amount of bank remaining, and fudge the roll-rate accordingly. As always, a small correction early is better than a large correction late. It is useful to practice this a couple of times in level flight, before combining it with the climbing component.

When performing the complete maneuver (climbing and turning together) there is one more wrinkle: Remember that rate of turn depends not only on bank angle but also (inversely) on airspeed. Since the airspeed is decreasing during the maneuver, you must take this into account when planning the roll rate for the complete maneuver.

Also, as the airspeed decreases you will need progressively more right rudder to compensate for the helical propwash, and progressively more right aileron to compensate for the rotational drag on the propeller blades. Furthermore, remember that adverse yaw and the effects of yaw-wise inertia become more pronounced at low airspeeds (as always). Maintain proper coordination (zero slip) at all times.

16.15 Lazy Eights

The *lazy eight* derives its name from the motion of the airplane's axis during the maneuver. In particular, imagine that the airplane is at a very high altitude, so we don't need to worry about the ground getting in the way. Further imagine that the airplane is centered in a cylinder of paper, 10 miles in diameter and 5 miles high. Also imagine that the airplane carries a very long pencil sticking out the front, aligned with airplane's axis. During the course of a lazy eight, the pencil will draw a giant figure eight, sideways, on the paper. The very long pencil provides lots of leverage, so that the drawing depends on attitude, not altitude.

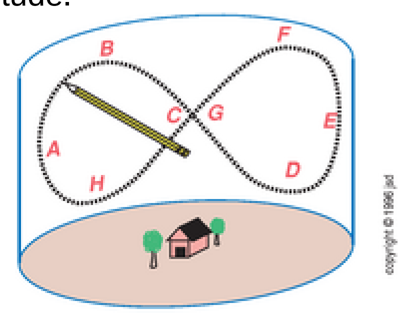

Figure 16.5: Lazy Eight

Figure 16.5 shows some of the details. Start at point *A*, in level flight. Pull the nose up. Gradually start banking to the right. At point *B*, stop pulling the nose up; let it start going down. Keep the bank; keep turning to the right. At point *C*, the pencil slices through the horizon. The body of the pencil is horizontal, while its tip is moving down and to the right. Start rolling out the bank. Point *D* is the lowest pitch attitude. The bank is about half gone; keep rolling it out. At point *E* the pitch attitude and the bank attitude should be level. Pull the pencil straight up through the horizon. Start rolling to the left. At point *F*, start letting the pitch attitude back down again. At point *G*, the pencil-point slices through the horizon again, this time moving down and to the left. Start rolling out the bank. Point *H* is the lowest point in the leftward stroke. By the time you return to point *A*, the pitch and bank attitudes should be level again. Pull the pencil straight up through the horizon again, and repeat the maneuver.

For the next level of refinement, arrange the timing and the bank angles so that point *B* is 45 degrees of heading away from point *A*; point *C* is at 90 degrees, point *D* is at 135 degrees, and point *E* is at 180 degrees.

For the next level of refinement, arrange the push/pull forces so that points *B* and *F* are about 20 degrees above the horizon, and points *H* and *D* are about 20 degrees below the horizon.

Note that up to this point we have not mentioned anything about altitude or airspeed. This is primarily an *attitude* maneuver, and you should learn it in terms of attitudes.

When learning the maneuver, it helps to separate the “up/down” part from the “left/right” part. The left/right part of the maneuver is quite simple. You just very gradually roll into a turn to the right, then very gradually roll out. You continue the roll so it becomes a turn to the left, and then gradually roll out.

The up/down part of the maneuver is almost as simple. You just pull the nose above the horizon for a while, then lower it to the horizon; let it go below the horizon, then pull it back to the horizon and repeat.

One tricky part about combining the left/right part with the up/down part: the vertical motion goes through *two* cycles (ascending, descending, ascending, descending) while the horizontal motion is going through only one (rightward, leftward).

To get a deeper understanding of the maneuver, we must think a little about the altitudes and airspeeds.

During the whole quadrant from *A* to *C*, the nose is above the horizon. The airplane is climbing and slowing down. Therefore *C* is the point with the highest altitude and the lowest airspeed. Point *C* has a high altitude even though we (correctly) drew it in the figure on the same line as point *A*. That is because the maneuver is defined in terms of attitude, not altitude, and we imagine that the paper on which the lazy eight is drawn is so far away that the pencil has lots of leverage --- the angle matters a lot, and the altitude matters hardly at all.

To you, the low airspeed at *C* is more immediately noticeable than anything else. The airplane is below its trim speed, so the nose wants to drop all by itself. At this point you will not need to push on the yoke; you just need to reduce the back pressure to let the nose go down at the desired rate.

During the whole quadrant from *C* to *E*, the nose is below the horizon. The airplane is descending and speeding up. Therefore point *E* has a much lower altitude than point *C*, and indeed should be level with point *A*.

The second ascending/descending cycle (from *E* back to *A*) should be pretty similar to the first.

The commercial-pilot Practical Test Standard requires that you return to your initial altitude and airspeed every time you pass point *A* and point *E*. You might hope that this would happen automatically if you leave the throttle setting alone, relying on the law of the roller coaster. But that hope is in vain, for the following reason: Normally you start the maneuver at a speed well above V_Y, with a power setting appropriate for level flight at this speed. Now suppose you fly a nice smooth symmetric maneuver that returns to the original airspeed. The maneuver starts with a pull, and at all times you will have an airspeed at or below the initial airspeed. You will be flying the maneuver at more-efficient airspeeds, closer to V_Y.[6] You will gain energy. You will gain altitude. If you try to fix the altitude by diving, you will end up with excess airspeed. The only way to make things come out even is to fudge the power setting; usually you need slightly less power than for level flight. This is most noticeable in airplanes with big engines and long wings, where the normal operating speeds are large compared to V_Y.

This maneuver contains a very nice lesson about the principles of flight. Much of the vertical part of the maneuver can be considered a “controlled phugoid”. In particular, during the phase from *B* to *D* the nose is dropping but you are not pushing it down --- indeed you are maintaining back pressure as you gently lower the nose. The feeling is sort of like the feeling you get when lowering a heavy object on a rope, and is quite striking.

This should drive home the message that the airplane is definitely not trimmed for a definite pitch attitude --- it is trimmed for a definite angle of attack (or, approximately, a definite airspeed). At point *C*, among others, the airplane is well below its trim speed, so it wants to dive and rebuild its airspeed.

You have considerable discretion as to the steepness of the banks. Increasing it just speeds up the whole maneuver. A typical choice is to have 30 degrees of bank at points *C* and *G* (the points of maximum bank). A lesser bank is also fine, but then you will want to choose a lesser nose-high attitude at points *B* and *F*. This is because you will be spending more time ascending, and you don’t want to run out of airspeed. Make sure the airspeed at points *C* and *G* is 5 or 10 percent above the stall.

As with the chandelle, you will have to work a bit to maintain proper coordination. There is nothing surprising --- just a wide range of roll rates and a wide range of airspeeds.

16.16 Eights and Turns on Pylons

The “eights on pylons” maneuver is required on the commercial and flight instructor practical tests. Being able to do this maneuver well, especially if there is a wind, definitely demonstrates that you can control the airplane around all axes at once. This maneuver is not to be confused with eights “around” pylons (which are discussed in section 16.13). The ambiguous term “pylon eights” should be avoided.

16.16.1 Turns on a Pylon

Before we cover the “eights on pylons” maneuver (section 16.16.2, we need to discuss a little theory. We begin by considering turns on a (single) pylon.

The idea is simple: Imagine a pointer that pokes through the plane from wingtip to wingtip; you want this pointer to remain pointed directly at the base of the pylon. This is quite a restriction; it means that at each point in the maneuver your bank and heading are completely determined by your altitude and position relative to the pylon. The only thing that makes the maneuver possible at all is that you are free to adjust your altitude.

* No-Wind Case

In the absence of wind, the maneuver will work at a particular altitude --- the so-called pivotal altitude --- and not otherwise. Interestingly, the pivotal altitude does not depend on what you choose as your distance from the pylon. As shown in figure 16.6, if you start close to the pylon, you will have a large bank angle and therefore a lot of *G*s. But since you are close to the pylon, the circle will be small, and you will need a lot of *G*s in order to change the airplane’s velocity (from northbound to southbound and back) in the small time available. In contrast, if you start out far from the pylon, the bank will be shallow, and you will pull a smaller number of *G*s for a longer time.

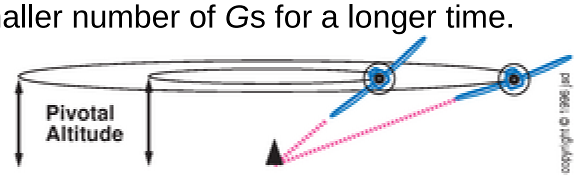

Figure 16.6: Turns on a Pylon --- Pivotal Altitude

The pivotal altitude is proportional to the square of the airspeed: 0.0885 feet per knot squared, or 885 feet per (hundred knots) squared.

If you happen to be above the pivotal altitude, the airplane will be banked too steeply and will turn too quickly. Your sight-line past your wingtip, which is supposed to be pointed at the pylon, will be swept backward and will appear to fall behind the pylon. Or to say it the other way, the pylon will appear to be moving ahead of where you want it to be. The solution is to descend. At the lower altitude your bank will be less, and the problem will correct itself. Any airspeed you gain during the descent can only help you by further reducing the rate of turn.

Conversely, if you are too low, the bank will be too shallow and the pylon will appear to fall behind where you want it to be.

The rule is simple: go down to speed up and “catch” the pylon; go up to slow down and “wait for” the pylon.

You may be tempted to use the rudder to swing one wingtip a little bit forward or backward, but this defeats the purpose of the maneuver and is *not* the correct procedure.

* Windy Case

In the presence of wind, the pattern is no longer a perfect circle. In fact, the ground track is an ellipse with the pylon at one focus. You are nearest the pylon when the airplane is headed directly downwind. This gives max bank when flying downwind, which makes a certain amount of sense --- you want to bank more steeply when the groundspeed is highest. This is shown in figure 16.7.

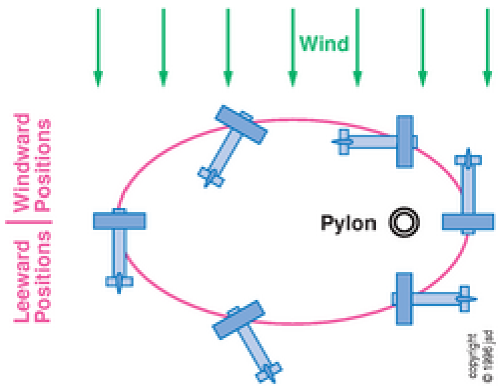

Figure 16.7: Turn On Pylon --- Headings

The wind also prevents you from flying the pattern at constant altitude (for reasons that will be discussed below). The altitude is highest when the airplane is headed directly downwind. This is shown in figure 16.8. Once again, this contributes to creating max bank when flying downwind, which makes sense.

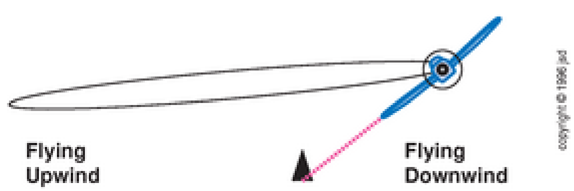

Figure 16.8: Turn On Pylon --- Altitudes

There are two strategies, depending on how much the plane speeds up when it descends.

a)

If you fly the pattern at high speed (i.e., well above V_Y), then tiny changes in airspeed will give you plenty of up-and-down action. I call this the constant-airspeed case.

b)

If you fly the pattern at a speed near V_Y, then changing the airspeed has only a small effect on the long-term power required --- all you are doing is making a one-time exchange of potential energy for kinetic energy according to the law of the roller-coaster. I call this the constant energy case.

The typical case will lie somewhere in between; fortunately the answers in the two cases are not very different.

a)

In the constant-airspeed case, the ground track is a mathematically perfect ellipse. The altitude turns out to be inversely proportional to your distance from the pylon, which can be a surprisingly large excursion even in moderate winds.

b)

In the constant-energy case, the ground track deviates only imperceptibly from an ellipse (the distance deviation is less than 1%, even when the wind is 30% of your airspeed). The altitude variation (as a percentage) is about one-third as large as the variation in distance from the pylon.

When going upwind, you need to have a much gentler rate of turn. There are three factors at work:

1. you are farther away, so the bank angle is less (by geometry);
2. you are lower, so the bank angle is less (also by geometry); and
3. in the constant-energy case, you are going faster (making more forward progress per unit turn).

The first two factors are diagrammed in figure 16.9. In the constant-airspeed case factor 1 does half the job and factor 2 does the other half. In the constant-energy case they all three divide the job, roughly in the ratio 50% : 20% : 30%.

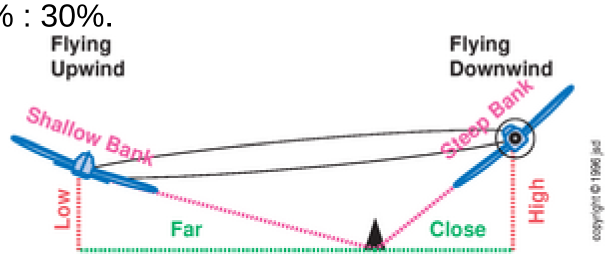

Figure 16.9: Turn On Pylon --- Bank Geometry

By geometry, the angle of bank is inversely proportional to the distance r from the pylon. It is also proportional to height. In the constant-airspeed case, the height is itself inversely proportional to r. Combining these, you get that the airplane is “attracted” toward the pylon with an acceleration that goes like $1/r^2$. (Remember that the horizontal accleration is one G times the tangent of the bank angle, which is simply proportional to the bank angle when the angle is not too large.)

You may recognize this situation as analogous to astronomy: Whenever you have an inverse-square central force, you get an elliptical orbit. What’s more, the analogy says you can apply Kepler’s law of equal areas in equal time, which is equivalent to saying the airplane’s angular momentum about the pylon will be constant. This allows you to figure out how much the ellipse differs from a circle: Suppose the wind is 10% of your groundspeed. Then when you are going directly downwind, you will have to be 10% closer to the pylon. Similarly when you are going directly upwind, you will have to be

10% farther from the pylon.

In the zero-wind case, the pivotal altitude is simply proportional to groundspeed squared. Several well-known books try to argue that on the upwind leg of the turn on pylon, the groundspeed is lower, so the altitude should be lower. That is a false explanation (even though the altitude is indeed lower there). The actual altitude change is much less than you would predict by the groundspeed argument (by a factor of 2 in the constant-airspeed case and by a factor of 4 or so in the constant-energy case).

You may wonder how this can be --- how can the airplane keep the wing on the pylon if it is not at the pivotal altitude?

The answer is simple: we are not trying to fly a circular pattern. Recall that if you are *above* the pivotal altitude, the airplane will spiral toward the pylon. This is exactly what is happening in half of the elliptical pattern --- the airplane is above the pivotal altitude and flying gradually closer to the pylon.

Why is the center of the pattern shifted crosswind rather than downwind of the pylon? For sake of discussion, let's divide the pattern in half along the long axis (which includes the pylon). If the airplane is positioned to windward of this line, it is subject to a crosswind from outside the pattern, which tends to drift the plane sideways closer to the pylon, making the bank steeper. This effect occurs throughout the windward half, so the plane is *closest* and *steepest* when it crosses from the windward to the leeward half (at which point it is headed directly downwind).

For these turns *on* pylons (unlike turns *around* pylons), there is nothing you can do to prevent the plane from being blown sideways. Consider the point where the plane is directly upwind of the pylon. The heading is constrained to be directly across the wind. The pilot cannot crab into the wind. Therefore the plane will be blown toward the pylon.

By the same token, whenever the airplane is on the leeward side of dividing line, it is subject to a crosswind from inside the pattern, which tends to drift the plane sideways farther from the pylon and hence make the bank shallower. The effect is cumulative, so the plane is *farthest* and *shallowest* when it crosses from the leeward to windward half (at which point it is headed directly upwind).

Also, draw a line from the pylon to a generic point on the ellipse. The wings of the plane, at that point, will lie on that line; the heading of the plane will be perpendicular to that line. Except for the two special points at the ends of the ellipse, the heading will not be tangent to the ellipse; the angle between the heading and the tangent is precisely the crosswind correction angle. You will note that the plane is always crabbed into the wind. This can be seen in figure 16.7.

In flight, you can follow these simple rules:

1. If the pointer is above or below the base of the pylon, it's easy to fix; just change your bank angle.
2. If the pointer is behind the pylon, go down to increase speed and "catch" the pylon.
3. If the pointer is ahead of the pylon, go up to decrease speed and "wait for" the pylon.

In principle, these rules are all you need to know. However, the other information in this section makes your job 1000% easier. It allows you to anticipate the required altitude changes and the elliptical ground track. Anticipating the required actions is easier than waiting until there is an error and then making corrections.

16.16.2 Eights on Pylons

The eights-on-pylon maneuver consists of a turn on one pylon followed by an opposite-direction turn on another pylon, as shown in figure 16.10. The two-pylon maneuver adds the complexity of planning when to shift from one pylon to the other, but is actually *easier* to perform because you can use the straightaway between turns to recover from any small errors.

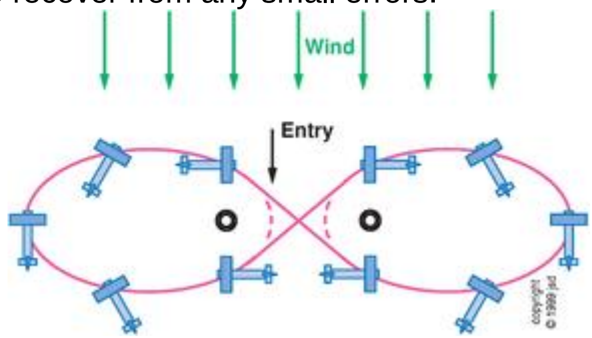

Figure 16.10: Eights On Pylons

You don’t want to pick pylons that are too close together. You do want pylons that are crosswind from each other, so that the pattern will be symmetric. As usual, it is best to enter on a downwind heading, as shown in the figure, so that your first turn will be your steepest turn. Maintain coordination; don’t fudge things with the rudder.

16.17 Changing Headwinds and Tailwinds

In some ways, an airplane performs differently when going downwind as opposed to upwind --- and in other ways it doesn’t. There are a lot of misconceptions about both halves of this statement.

16.17.1 Steady Wind

Let us first consider the situation where there is a steady wind; that is, a wind that does not vary with time or with altitude.

Maneuvers relative to a ground reference will be different when headed downwind as opposed to upwind.

For instance, the airplane will climb and descend at a steeper *angle* (in terms of altitude per unit distance over the ground) when headed upwind.

Similarly, a constant-radius turn relative to a ground reference will require a steeper bank on downwind and a shallower bank on upwind.

Maneuvers that do not involve a ground reference will be unaffected by the wind.

For instance, the airplane will climb and descend at a *rate* (in terms of altitude per unit time) that is independent of the wind.

Similarly, a constant-radius turn relative to a cloud will require the same angle of bank throughout the maneuver.

The point is that the airplane, the cloud, and the airmass are one big uniform moving system. By Galileo’s principle of relativity, the overall uniform motion doesn’t matter.

Note that *obstacle clearance* is an important ground-reference maneuver. Your rate of climb is unaffected by the wind, but your *angle* of climb is affected. You can climb at a steeper angle on an upwind heading.

Finally, consider ground observers' perceptions. There are some maneuvers, such as an aerobatic loop, that *should not* be corrected for the wind. Imagine you are using a smoke generator. You want the smoke to form a nice round loop. Like the cloud mentioned above, the smoke is comoving with the air, so the overall wind speed shouldn't matter. However, especially if the smoke generator is turned off, the maneuver will *appear* different to an observer on the ground. This appearance does not (and should not) matter to the pilot in the cockpit, but it does matter if you are on the ground piloting a radio-controlled model, or judging an aerobatic contest.

There are several good reasons for being *aware* of your groundspeed, including:

- You need it for navigation, as discussed in section 14.2.
- If you are flying cross-country and the groundspeed is lower than you planned for, recalculate your arrival time and re-appraise your fuel situation. All too many people run out of fuel because of unexpected headwinds.
- If you are about to land and the groundspeed seems abnormally high, you should consider the possibility that you have a tailwind. Go around, check the windsock, and try again. (See section 12.7.4 for more on this.)

On the other hand, during turns and other maneuvers, it would make absolutely no sense to try to maintain constant groundspeed.

We shall have more to say about the effects (or non-effects) of a steady wind in section 16.17.4, in connection with the infamous "downwind turn".

16.17.2 Albatross Effect: Winds that Vary with Altitude

In the real world, the wind almost always changes with altitude. In particular, it is very common to find that the wind at ground level is blowing in the same general direction as the wind at 3000 feet AGL, but at a much lower speed. This is because of friction between the air and the surface.

Most of this frictional windshear is concentrated at the lowest altitudes. At low altitudes, it is common to see a windshear of several knots per hundred feet, while at enroute altitudes (several thousand feet AGL) it is more typical to see a windshear of a few knots per *thousand* feet.

Wooded areas, tall buildings, and/or steep hills upwind of your position can create particularly sharp shear layers.

On top of this, frontal activity (especially warm fronts) can cause very large windshears that are more complicated and less predictable than the normal, every-day frictional wind shear. This can be very significant when you're on approach, as discussed in section 16.17.3.

Let's analyze how windshear affects the airplane. Suppose you start out at point *A*, and fly to point *B* where there is more headwind or less tailwind. If the windshear is sudden, you will notice a sudden increase in airspeed. The windshear has added something to your energy[7] budget. If the shear is more gradual, the airplane (because it is trimmed for a definite angle of attack) will probably convert the extra airspeed into extra altitude, but you will still wind up at point *B* with more energy than you would have without the windshear. It makes it look like your engine is putting out more power than it actually is. (Section 16.17.3 discusses how this affects approach and departure.)

We can apply the same line of reasoning to the opposite case: Suppose you start out at point *C* and fly to a point *D* where you have less headwind or more tailwind. This means you will arrive at point *D* with less energy than you would have without the windshear.

I define the term *albatross effect* to refer to the energy that comes from an increasing headwind or decreasing tailwind. An albatross is a huge bird that spends its life flying over the oceans of the world. It rarely needs to flap its wings, but it doesn't soar in updrafts the way hawks do. Instead, the albatross flies a figure-eight pattern in the shear zone near the surface, climbing into an increasing headwind on the upwind legs and descending into a decreasing tailwind on the downwind legs --- gaining energy both ways.

16.17.3 Windshear on Approach and Departure

Think for a moment how you would handle the following scenario:

You are trying to land at Smallville Municipal Airfield, which is rather short and obstructed. The windsock indicates that you have five or ten knots of headwind on the chosen runway. The airplane is acting "funny" on final. That is, even with zero engine power and full flaps you cannot get the airplane to descend steeply enough to stay on the glide slope. Three approaches in a row have ended in go-arounds (which allowed you to carefully check the windsock three times).

Obviously something nasty is happening --- something that's not easy to figure out, especially if you've never seen it before, so I might as well tell you:

- Most of the way down final you've got a 20-knot tailwind. This tends to make you drift above the intended glide path and land long, for a simple reason: it hurries you toward the runway, so unless you can arrange a huge rate of descent, you don't have enough time to descend.
- Then you encounter something worse, namely a windshear. The tailwind shears to a headwind. This tends to take you quite a bit more above the intended glide path, because of the albatross effect, as explained in section 16.17.2.
- Below the shear layer there is a headwind. This tends to shorten your landing distance, in the usual way -- but it is too little, too late. By the time you reach the altitudes where there is a headwind, you have already overshot your landing zone and are committed to going around.[8]

We are talking about a situation where a tailwind shears to a headwind on final. There is a decreasing tailwind followed by an increasing headwind. In terms of the albatross effect both contribute in the same way, i.e. both add energy to your energy budget.

This scenario is fairly uncommon yet still common enough to cause trouble. By that I mean that it is sufficiently uncommon that you probably won't encounter it during training, but eventually you will encounter it. So you'd better think about the situation, figure out how to recognize it, and plan what you're going to do about it. (You can contrast this scenario with the normal situation, as discussed at the end of this section.)

There are many cues that you should be using to make sure you land at the right spot with the right airspeed. See section 12.7.4 for details. The cues most directly helpful in the present scenario (windshear on final) are

- Observe the wind-drift during your base leg. If you're drifting toward the airport, you'll have a tailwind on final. That means you'll either land with a tailwind, or you'll have a windshear between now and the landing.
- Check the forecasts -- and know what to look for. If there is a warm front passing through the area, there is almost guaranteed to be some low-level wind shear somewhere. If you encounter a frontal boundary slicing across your final approach course, your best strategy might be to wait until it goes away. Also, the front can't be everywhere at once, so you may want to go land somewhere else -- perhaps a larger, less-obstructed airport -- and read a book for a while. You will know that the front has passed because there will be approximately a 180 degree shift in the surface winds. (Be sure you adjust your choice of runway accordingly!)
- Check both your descent rate and your descent angle. Your normal configuration and normal power settings should produce a normal descent rate. If a normal descent *rate* results in a shallower-than-normal descent *angle*, watch out!

By way of contrast, let's take another look at the normal approach situation. Ordinarily you expect to see a headwind on final, in particular a decreasing headwind. The surface wind has the same direction as the wind aloft, but its magnitude is reduced due to surface friction.

A decreasing headwind makes the angle of descent steeper in two ways:

1. the groundspeed is lower, due to the ordinary *average overall* headwind (as discussed in section 16.17.1), and
2. the rate of descent is faster, due to the *decreasing* headwind (the albatross effect, as discussed in section 16.17.2).

By the same logic, you ordinarily expect to see an increasing headwind on a straight-out departure, which helps you climb steeply.

16.17.4 Turning Downwind; Energy Budget

In section 16.17.2 and section 16.17.3 we discussed how you could gain or lose energy *due to a windshear*. In this section, we return to considering only a steady wind, and discuss what happens if you convert a headwind into a tailwind simply by turning the airplane.

Let's consider the scenario described in table 16.4.

true airspeed	100 knots
initial heading	north
final heading	south
time spent turning	1.2 min = .02 hour
mass of airplane	1 ton
wind speed	20 knots
wind direction	from the north

Table 16.4: Downwind Turn Scenario

Let's calculate the energy and momentum twice, as shown in table 16.5. In the "balloon" column everything is measured relative to an observer in a balloon (comoving with the air mass), and in the "ground" column everything is measured relative to an observer on the ground.

	balloon	ground
initial momentum	100	80
final momentum	-100	-120
change in momentum	-200	-200
average N-S force	10000	10000
initial energy	5000	3200
final energy	5000	7200
change in energy required	0	4000
N-S distance during turn	0	.4
energy provided by wind	0	4000

Table 16.5: Downwind Turn Analysis

Here's what the first four rows mean: The momentum is calculated using the usual formula: mass times velocity. (The units here are rather strange, tons time knots, but it's OK as long as consistent units are used throughout the calculation.) The North-South component of the average force is just the change in momentum divided by the time. We see that although the initial and final momenta appear different in the two columns, the change in momentum is the same. This upholds Galileo's principle of relativity: the force required to turn the airplane is independent of the frame of reference.

Here's what the last five rows mean: The energy is calculated using the usual formula: one half of the mass times velocity squared. According to the ground observer, the airplane needs to gain quite a lot of energy during the turn. You may be wondering where this energy comes from. Obviously it does not come from the airplane's engine. Actually it gains energy the same way a baseball gains energy when it is struck by a bat. You know that although a ball does not gain any energy when it bounces off a stationary wall, it does gain energy when it bounces off a fast-moving bat. The energy gain is force times distance (counting only distance in the same direction as the force). According to the observer in the balloon, the force of the turn is (at every instant) perpendicular to the direction of the force, so there is no energy gain. Meanwhile, according to the observer on the ground, the *wind* moves the airplane 0.4 miles in the North-South direction during the turn, and turning the airplane requires a huge force in this direction. This effect --- the airplane being batted by the wind --- supplies exactly the needed energy. Again, we see that the principle of relativity is upheld: the energy budget works out OK no matter what frame of reference is used.

Note that if you overlooked the bat effect you would fool yourself into thinking that turning downwind caused a huge energy deficit. It doesn't. Don't worry about it.

16.17.5 Section Summary: Headwinds and Tailwinds

- For ground-reference maneuvers, a steady wind has a direct effect.
- For other maneuvers, a steady wind has no effect on the airplane or on the pilot in the cockpit. However, the maneuvers will appear different to ground-based observers.
- In the presence of windshears, you can gain or lose energy due to the albatross effect. In real life, this means for instance that you will get slightly better performance climbing into the wind. This gives you a reason to turn downwind a little later than you otherwise would.
- For any maneuver that doesn't depend on a ground reference, a steady wind has no effect on the maneuver. For example, a standard-rate turn to upwind is just the same as a standard-rate

turn to downwind. You can’t even determine the magnitude or direction of the wind without using a ground reference.
- If you want to calculate the energy in the ground-based frame of reference, you must account for the airplane being batted by the wind.

16.18 Ground Reference Strategy

16.18.1 Accounting for the Wind

Throughout each flight --- and certainly before starting any ground reference maneuvers --- you should have in mind a good estimate of the speed and direction of the wind.

There are various ways you can figure this out:

- Remember the “winds aloft” forecast. Sometimes it’s even right.
- ATIS and AWOS broadcasts give the surface winds.
- The airport windsocks give information about surface winds.
- Ordinary flags provide similar information.
- The smoke or vapor from smokestacks is an excellent indicator of the winds near the ground and sometimes winds aloft.
- If you see ripples on a pond at one side and not the other, the wind is very likely blowing from the unrippled side toward the rippled side. Also, the texture of the ripples generally runs crosswise to the wind.
- Last but not least, you can note the amount of wind correction needed to perform ground-reference maneuvers.

It is a good idea to know the wind *before* starting a maneuver (rather than trying to figure it out “on the fly”). It really helps to be able to plan the maneuver and anticipate the necessary wind corrections.

16.18.2 Entry Strategy

It is a good idea to begin ground-reference maneuvers such (as turns around a point) a downwind heading, as shown in figure 16.3, so that your first bank will be your steepest bank. You don’t want to be a position where (late in the maneuver) you must choose between abandoning the effort or using an excessive bank angle.

16.18.3 Visual Reference

It really helps to have a precise visual reference for pitch and yaw, as discussed in section 11.5.2.

You can use your finger and/or a mark on the windshield, as illustrated in figure 11.3. If you can’t find a suitable mark on the windshield, you can make one.

The reference should be directly in front of your dominant eye. It is a common mistake to choose a mark on the cowling. Such a mark is below where it should be, and tempts you to use too much rudder when rolling into right turns, and too little rudder when rolling into left turns. It is another common mistake to choose a reference point that is on the centerline of the airplane. Assuming your eye is quite a bit to the left of the centerline, your sight line through this point is very far from being parallel to the axis of the airplane. This tempts you to make diving left turns and climbing right turns.

As you become more experienced, you won’t need to use your finger or an explicit mark on the windshield; you can just *imagine* where the reference point must be. Just make sure you use a point directly in front of your dominant eye.

16.18.4 Checklist

You want to take a systematic approach to all maneuvers. I learned the following “maneuver checklist” from John Beck:

- Pick a mark on the windshield; trace a line along the horizon.
- Check for traffic.
- Check your ground reference.
- Check your instruments.

Repeat this list to yourself over and over again as you do the maneuver. Chant it aloud if you wish. Doing each thing as you say it not only keeps you from overlooking something, but also gives a nice rhythm to the work.

16.19 Slow Flight

If you are not proficient in handling the plane at low speeds, you have no business trying to land the plane.

To begin a practice session, go up to a safe altitude and make sure there are no other aircraft nearby. Slow down to a speed, say, 15 knots above the stall speed. Once you are comfortable with this, reduce the speed another 5 knots. Again, once you are comfortable, reduce the speed another 5 knots.

During the maneuver, you should

- Maintain coordination --- keep the ball in the center.
- Maintain a definite altitude.
- Watch out for other traffic. Your pitch attitude will be so high that it will be difficult or impossible to see over the nose, so you should change heading every so often and look around.
- Between turns, maintain a definite heading --- don’t let the nose wander willy-nilly.
- Keep an eye on the engine gauges --- there are some aircraft that will overheat if you spend too much time in a low-airspeed, high-power configuration.

16.19.1 Airspeed and Altitude

As discussed in section 7.3 and elsewhere, it would be OK to use the yoke to control altitude *if* you were on the front side of the power curve *and* you were willing to accept an airspeed excursion. However, during this slow flight maneuver, you definitely are not on the front side of the power curve and you definitely cannot tolerate airspeed excursions. Therefore you will need to use the yoke (and trim) to control airspeed, and once you’ve got the desired airspeed, you will need to use the throttle to control altitude. (To adjust airspeed at constant altitude, you will need to use the throttle and yoke together, as discussed in section 16.3.)

16.19.2 Yaw and Roll

Remember that the airplane is optimized for cruise flight. During cruise, you can fly straight and level with little or no control force, and you can make gentle turns with little or no use of the rudders, using ailerons alone.

In contrast, during slow flight

- You will need steady rudder deflection to overcome the helical propwash effect.
- You will need steady aileron deflection to overcome the rotational drag of the propeller.
- You will need considerable rudder deflection whenever the ailerons are deflected, to deal with adverse yaw and roll-wise inertia.

Because (as discussed in section 5) there will be very little roll damping, you will need to apply lots of little aileron deflections to maintain wings-level flight, especially in the presence of turbulence.

16.19.3 Procedures and Perceptions

Make a note of the pitch attitude that corresponds to level flight at minimum controllable airspeed (with and without flaps). Note the pitch attitude of the nose against the forward horizon, and the wingtip against the lateral horizon. This information will come in very handy during landing, as discussed in section 12.11.3.

Practice rocking the wings. Make sure you can bank the plane left or right, with reflexively correct use of ailerons and rudder. Practice making turns to a precise heading.

Practice diving 50 feet. That is, push the nose down a few degrees (not so much that you experience negative *G* loads), dive for a few seconds, and then pull back and level out. Make a note of how much airspeed you gain by diving 50 feet. This information will come in handy during stall recoveries, as discussed in the next section.

16.20 Stall Practice

16.20.1 Preliminaries

- It should go without saying, but here goes: Make absolutely sure there are no other airplanes near you during stall practice. In particular, you will need to make frequent clearing turns to rule out the possibility that there are some folks behind and below you, who might be very surprised and annoyed if your drop down onto them.
- Make sure you practice stalls at an altitude that gives a generous margin of safety. An intentional stall can easily lead to an unintentional spin, and a spin recovery can eat up a lot of altitude.
- Finally, a word about the philosophy of stall recovery: Try to recover with minimum loss of altitude. Imagine that you were flying at 100 feet AGL and then did something stupid that led to a stall. The idea is to recover from the stall and climb back to a safe altitude, without ever losing more than 100 feet. Therefore the emphasis is on *recognition* and *recovery*: prompt recognition that the stall has occurred, and proper technique during the recovery.

There are many variations on the stall maneuver. You can stall the airplane with or without flaps extended, with or without power, during straight or turning flight, while pulling one or multiple *G*s, and during level, climbing, or descending flight.

To keep the discussion simple, let’s first go through one specific scenario, and discuss the possible variations later.

Scenario #1: Start out in level flight at a typical traffic-pattern speed, in the landing configuration (full flaps extended,[9] landing gear extended, carb heat on, et cetera). Then reduce the power to idle. As the airplane slows down, pull back on the yoke at a steady rate, cashing in airspeed to pay for drag, maintaining altitude. Maintain constant heading. Maintain coordination. When the airspeed gets low enough, you may observe a sudden, distinct stall. The nose will drop, even though you are pulling back on the yoke. Obviously it is time to begin your stall recovery, as discussed below.

16.20.2 Provoking a Distinct Stall

However, it is quite possible you will not always observe a sudden, distinct stall. In particular, if your airplane is loaded so that its center of mass is right at the forward edge of the weight and balance envelope, you may be unable to deflect the elevator enough to cause a stall using the procedure described above.[10] At this point you are at a very low airspeed, unable to stall the airplane, and unable maintain altitude by pulling back on the yoke. At this point you should declare an end to the attempted stall and begin your stall recovery procedure. The ability to recognize the low-speed limit of performance in this situation is valuable, and should be practiced, but you should practice full-blown stalls also.

The most elegant way to improve your chances of observing a full-blown stall is to move the center of mass farther aft, using ballast. As described in section 6.1.9, 100 pounds of water stowed securely in the back of the airplane[11] should make it a whole lot easier to raise the nose.

Another trick that might increase your control authority is to use a little bit of engine power, a few hundred RPM above idle. On many airplanes this extra propwash flowing over the elevator increases the control authority just enough to permit a quite distinct stall. On other airplanes (including those with high T-tails) this trick doesn't work at all --- the propwash over the wings lowers the stalling speed more than the propwash over the tail improves the control authority.

A third way to provoke a distinct stall is to zoom a little bit. That is, you maintain constant altitude while you slow down *most* of the way. Keep track of how far back you have pulled back on the yoke. When you have used up most of the available backward motion, use the last inch or so to pull back faster than would be needed to maintain 100% level flight. The airplane will rotate to a more nose-high attitude, climb a few feet, then stall.

16.20.3 Stall Recovery

Stall recovery, especially for poorly-trained pilots, poses psychological problems. In particular, if you are laboring under the dangerous misconception that the yoke is the up/down control, your instincts will be all wrong: the nose is dropping and the airplane is losing altitude, so you will be tempted to pull back on the yoke. This makes a bad situation much worse.

The correct way to think about the stall is to realize that the shortage of airspeed is your biggest problem. You need to push on the yoke and dive to regain airspeed.

In addition to the airspeed problem, you also have an energy problem. Therefore, while you are pushing on the yoke with one hand, you should be pushing on the throttle with the other hand.

As a further step to improve the energy situation, remove unnecessary drag. On most airplanes with *N* notches of flaps, the first several notches are somewhat helpful, because they allow you to fly slowly without stalling. The *N*th notch, however, typically doesn't contribute much to lowering the stall speed, and just adds a lot of drag. This would be useful if you were trying to descend, but since we are trying to climb at the moment, you should retract the *N*th notch of flaps as early as possible during the stall recovery. If the maneuver began with less than full flaps extended, leave the flaps alone, dive to regain airspeed, and then gradually retract the flaps.

While all this is going on, you should use the rudder and ailerons to keep the wings level and maintain a more-or-less constant heading.

You don’t need to dive very far to regain a reasonable flying speed. According to the law of the roller coaster (as discussed in section 1.2.1), if you start out at 45 knots and dive 45 feet, you will wind up at 55 knots. If you start out at 50 knots and dive 80 feet, you will wind up at 65 knots.[12]

At the bottom of the dive, perform a nice gentle pull-out. If you pull too rapidly, you put a big *G* load on the wings, which will cause them to stall at a speed that would otherwise have been just fine.

After you have leveled out at the bottom of the dive, speed up in horizontal flight until you reach best-climb airspeed. Retract any remaining flaps as you speed up. Then climb at V_Y to a safe altitude.

To summarize: the key elements of stall recovery include

- Dive to regain airspeed.
- Apply power.
- Reduce drag.
- Maintain wings level.
- Climb back to a safe altitude.

16.20.4 Power-On Stalls

A non-pilot might have thought that it would be hard to stall an airplane with the engine at full power, but in fact it is quite possible, and the accident statistics show that it happens fairly frequently. Therefore let’s consider another scenario:

At a safe altitude in the practice area, set up for a power-off descent in the landing configuration. In particular, let this be a short-field approach, with the airplane trimmed to fly at the lowest practical airspeed. Then apply full power, as if for a go-around. In some airplanes (including the widely-used C-152, C-172, and C-182), and depending on where the center of mass is, this combination of trim, flaps, and power will cause the nose to pitch up quite dramatically. The airplane will climb very steeply and then stall. You don’t need to pull back at all. Indeed, you may want to push a little bit so that the stall won’t be too extreme.

In airplanes with better go-around characteristics (including a C-172 with the flaps retracted) you will need to work a little harder to perform a power-on stall. A possible --- but not very stylish --- way to perform this maneuver would be to start from cruising flight, add full power, and pull back until you get a stall. This is perhaps worth doing once, but it is not the recommended way of demonstrating a power-on stall, because results in climbing an unnecessarily long way. That is, it just isn’t logical to apply full power while you are trying to slow down. Therefore the conventional procedure is this: At a safe altitude, *reduce* power and slow down in level flight to a speed a few knots above the stall. Then add power. (Use partial power the first time, and then use progressively more power as you learn how the airplane behaves.) Then gradually pull back some more.

As the airspeed bleeds off, you will need to apply more and more right[13] rudder to maintain coordination (i.e. to compensate for the helical propwash). Coordination is very important, because even a slight slip angle will cause one wing to stall before the other. This could easily result in a spin, and even if you don't get a full-blown spin, the sudden change in bank angle is pretty unpleasant.

Also, in this high-power low-airspeed situation, you will need to apply steady right aileron (to compensate for the rotational drag of the propeller). Note that (as discussed in section 5.4.2) the roll damping goes to zero at about the same point where the stall occurs, so you will need to intervene rather actively to keep the wings level. The standard advice applies: make sure you use the ailerons and rudder together. Because the airspeed is low, you will need a whole lot of rudder deflection to coordinate with a small amount of aileron deflection, and indeed right near the stall you can quite nicely control the bank angle using the rudder alone. Imagine that the left wing is about to stall. By stepping on the right rudder pedal, you can swing the nose to the right, causing the left wing to speed up and become unstalled. During this maneuver, you might want to lower the nose a tiny bit, so the right wing, which is swinging backwards, doesn't stall.

If you manage to maintain perfect coordination and perfectly level wings right up to the point of the power-on stall, you can still expect that the airplane will want to yaw and roll to the left just after the stall. There are several factors at work:

1. As discussed above, you are holding steady right aileron. This increases the effective angle of attack of the left wing, so it will stall first. The airplane will roll to the left.
2. The helical propwash causes the airflow to hit the left wing root area at a higher angle, and the right wing root area at a lower angle. This also causes the left wing to stall first. The airplane will roll to the left.
3. There is gyroscopic precession. That is, when the lift of the wings is suddenly reduced (while the lift at the tail is unchanged), it produces a torque --- a nose-down pitching moment. In the absence of gyroscopic effects, this would cause the nose to pitch down. However, as discussed in section 19.9.2, if you have angular momentum in one plane and apply a torque in a perpendicular plane, the system will precess, according to the bivector addition rule shown in figure 19.15. To prevent this, you need to apply a little bit of right rudder while the nose is dropping. If you forget to apply the right rudder, precession will swing the left wing backwards, making it more stalled, so after the airplane yaws to the left it will roll to the left.

Of course, you can anticipate this, and apply additional right rudder as the nose drops. With a little experience, you can arrange that the wings remain level and the nose drops without yawing. If the left wing starts to drop, you can pick it up by using right aileron (coordinated with right rudder) and/or using uncoordinated right rudder to swing the left wing forward.

The recovery from a power-on stall is basically the same: dive to regain airspeed, add power (if you were not already at full power), maintain wings level, reduce drag, and climb back to a safe altitude.

The practical test standard calls for performing power-on stalls with the flaps in the takeoff configuration and gear down (the takeoff configuration) or gear retracted (departure configuration) which simulates a stall happening shortly after takeoff. It is well worth practicing other configurations, too --- particularly the approach configuration, which simulates what might happen if you mishandle a go-around.

16.20.5 Accelerated Stalls

The stall occurs at a definite angle of attack. This is not quite the same as a definite airspeed, for reasons discussed in section 2.12.5. At any speed below maneuvering speed, if you pull the yoke back far enough, you will stall.[14]

Suppose you are in a dive, and you want to pull up into a climb, as shown in figure 16.11. If you pull back back on the yoke to the point where you are developing 2 *G*s, the stalling speed will be 41% higher than it would be in unaccelerated flight. The rule is: stalling speed goes like the square root of the load factor.

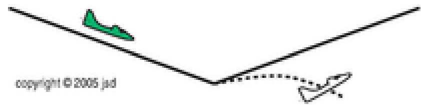

Figure 16.11: Nonturning Accelerated Stall

In an aerobatic loop, you are pulling about 4 *G*s at the bottom, so the stalling speed is about twice what it would be in ordinary unaccelerated flight. Also, since you might be rapidly approaching the ground at this point, you may be tempted to pull back extra-sharply ... but be careful, because this would be a really inopportune time to stall. Make sure you have plenty of altitude and plenty of airspeed before attempting any high-*G* maneuvers.

Any stall that happens during the recovery from a previous stall is called a *secondary stall*. It is not uncommon for secondary stalls to be accelerated stalls.

An even more-common type of accelerated stalls occurs during turns. If you are in a nice steady turn with 45 degrees of bank, the load factor is 1.4, so the stalling speed will be 20% higher than it would be in ordinary one-*G* flight. Therefore, if you are relying on the airspeed indicator to warn you of an impending stall, you will be fooled.

To a first approximation, the recovery procedure for an accelerated stall is the same as for any other stall: reduce the back pressure, dive far enough to obtain a reasonable airspeed, roll the wings level, add power, reduce drag, and climb back to a safe altitude. One helpful difference is that because you had extra airspeed at the time of the stall, you might not need to dive very far, if at all.

During a turn, if you stall inadvertently, it is common (but not guaranteed) for the outside wing to stall. That’s because if you were paying so little attention to the airspeed that you stalled, you probably weren’t paying attention to coordination, either. That means it was probably a slipping turn, due to the long-tail slip effect (section 8.9). A little slip goes a long way toward determining which will will stall first.

In contrast, if you stall during a *coordinated* turn, the inside wing ought to stall first, because it has less airspeed and higher angle of attack, as discussed in section 9.4. Additional complicating factors are discussed in section 16.20.4. See section 16.21 for how to recover from this.

Another thing that makes accelerated stalls a bit more challenging has to do with *perception* of the stall. Imagine an airplane where the stall doesn’t exhibit a sudden “break”. Then as you approach an ordinary, straight-ahead stall, you have a constant heading and everything looks fairly normal. Nothing is changing much, so any change stands out.

Now contrast that with a stall during a 60-degree bank. The pitch-wise direction of rotation is far from vertical, so any pitch change will move the nose mostly along the horizon, and might not stand out relative to the already-rapid turning motion.

During accelerated-stall practice, a student once complained “I can’t get this thing to stall”. I replied

“We’re going down more than 2000 feet per minute. This is stalled enough for me”. The point is, it is possible to be very deeply stalled and not realize it, if you don’t know what to watch for.

16.20.6 Evil Zooms

As discussed in section 12.11.8, it is fairly easy to get into a situation where you have a nose-high pitch attitude, very little airspeed, and very little altitude. In this situation, the usual stall-recognition and stall-recovery techniques will do you no good whatsoever. You need to recover *before* the airplane stalls, and you need to recover with zero loss of altitude.

Therefore it is a good idea to practice recovering from this situation. The procedure is:

1. Go up to a safe altitude.
2. Set up for a power-off glide in the landing configuration.
3. Gradually pull back on the yoke until you are a few knots above the stall speed.
4. Then pull back on the yoke quite a bit more. Observe that the airplane rotates to a very high nose-up attitude and begins to climb.
5. Before the airplane has climbed more than a few feet, and *before* it stalls, push the nose back down to the attitude that corresponds to level flight at a very low airspeed.
6. At the same time, apply full power.
7. Fly level until you regain airspeed, using the usual go-around procedures.

Practice this over and over, until you are confident that you can recover from a pitch excursion with zero loss of altitude.

16.21 Recovering from Inverted Attitude

If you start out steeply banked, and then for any reason the inside wing drops, you could wind up in a knife-edge attitude, or even inverted. This is probably not what you wanted.

You should take the opportunity right now to think about how to recover from such a situation. You want to dive to gain airspeed, but in an unfamiliar bank attitude, banked 90 degrees or more, it might not be 100% obvious how to accomplish this.

You should start by pushing on the yoke. Push to the position that corresponds to zero angle of attack, so there is no load on the wings. (As part of the check-out process, make a point of figuring out where that point is. On most non-aerobatic planes, it is pretty close to all the way foward.) Then just sit there for two or three seconds. The airplane will fly like a dart -- like any other object that flies at zero angle of attack. This works whether the airplane is upright, inverted, or anything in between. Gravity ensures the airplane will soon be desecending (in addition to whatever horizontal velocity remains). The rudder and horizontal tail guarantee that it fly nose-forward. After the airplane has dived a couple dozen feet, you will have enough airspeed that the ailerons are effective. At this point, use the ailerons to roll upright and level the wings. Then pull out of the dive and proceed with normal stall recovery.

If you ever find yourself upside-down, you might think you have the choice of performing a half-loop or a half-roll. In theory, either one will do, but in practice you should *roll*, because it is quicker and easier, and puts less stress on the airplane.

Roll upright.

1

... unless you are inside a cloud, in which case you hope everybody in that cloud is on an IFR clearance so that ATC can provide separation.

2

You may have seen some books that refer to the “four fundamentals”. Here’s how they get from three to four:

- They list straight-and-level as a separate item, whereas I consider it the natural consequence of zero change in altitude, zero change in airspeed, and zero turn.
- They treat climbs as different from descents.
- They treat left turns the same as right turns.
- They entirely disregard speeding up and slowing down, whereas I consider airspeed control to be quite fundamental.

3

If you can’t find a suitable scratch or bug corpse on the windshield, it may be instructive to make a mark, as discussed in section 11.5.2.

4

These are flat plates the pop up from the top of each wing. The air hits them broadside. They approximately double the airplane’s coefficient of parasite drag.

5

A single-engine aircraft is required (by FAR 23.49) to have a stalling speed of 61 knots or less, and in certain models it is quite a bit less. This is important for safety in case of a forced landing. In contrast, a twin with sufficiently good engine-out performance is exempt from this restriction. The theory is that a twin that can climb on one engine should never need to make an off-airport landing.

6

...unless you spend a lot of time on the back side of the power curve, which is usually not practical.

7

The physics works like this: Your kinetic energy relative to the new air is greater than your kinetic energy relative to the old air. Your airspeed relative to the ground has not changed, or may even have decreased slightly, but that is irrelevant. The airplane doesn’t care about the ground. The local air is the only thing that matters.

8

To rub salt in the wound, the factors that made you too high during the approach will tend to make you too low during the go-around.

9

It is a little hard to explain why, in everyday flying, you would be flying level with full flaps extended, but don’t worry about that. This maneuver (a) is a good training exercise, and (b) is an important part of the FAA practical test.

10

There is, after all, a physical limit to the amount of force any finite-sized elevator can produce, and this typically explains why the forward edge of the envelope is where it is.

11

This works fine in a four-seat aircraft with two people aboard, or a two-seater with one person aboard, but it may not be possible in a two-seater with two people aboard, because of limits on the total weight.

12

You can practice most elements of the stall-recovery maneuver without actually stalling the plane. hat is, starting from level flight a few knots above the stalling speed, push the nose over, dive 50 feet or so to gain airspeed, and then level off. Don’t forget to apply power, reduce drag, and maintain wings level. This sort of practice often helps students overcome their fear of stalls, by building up their confidence in their recovery procedures.

13

Assuming a standard American engine that rotates clockwise as seen from behind.

14

At higher speeds, you might break something before you stall, so be careful.