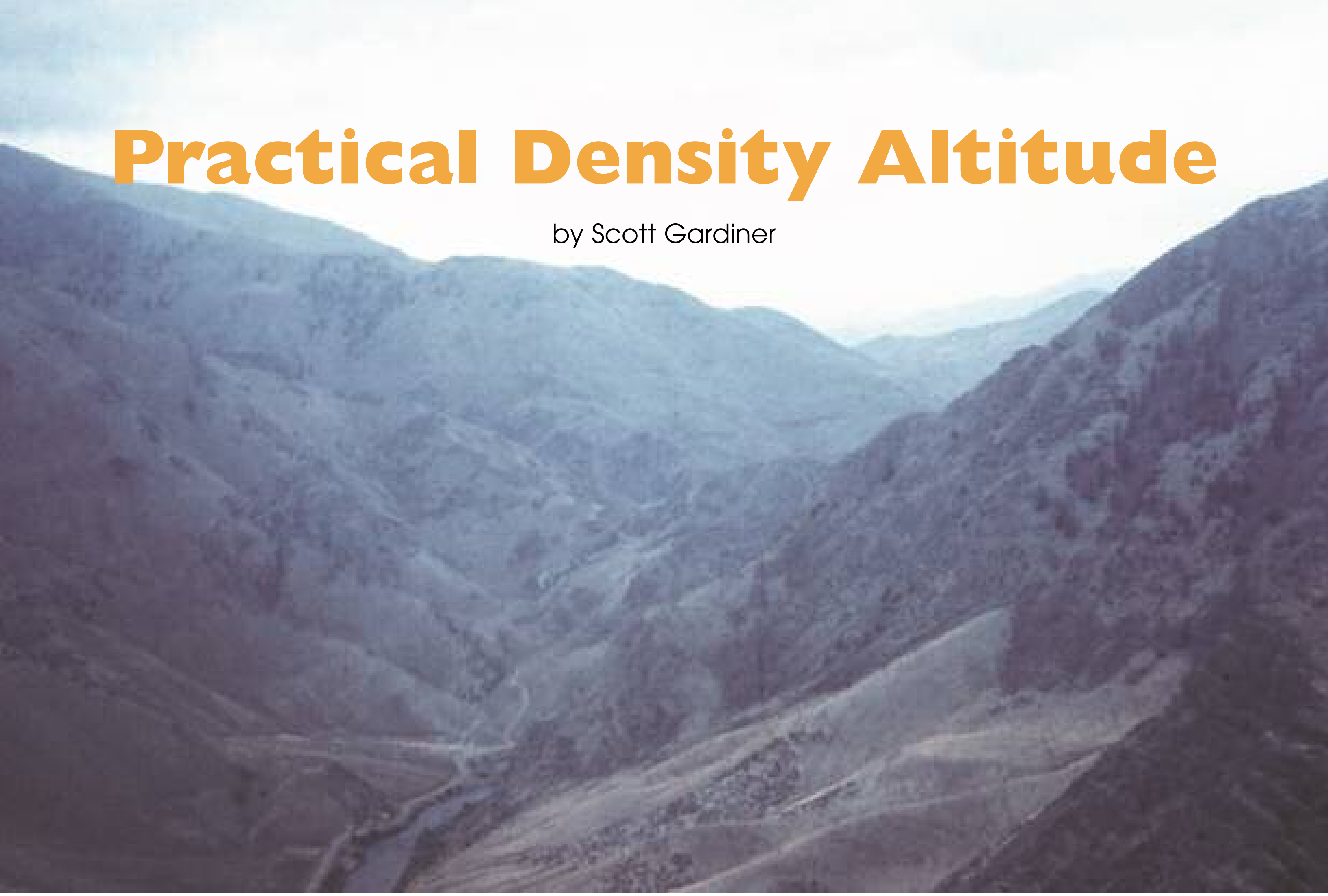


# Practical Density Altitude

by Scott Gardiner

*Editor's Note: The following article is based upon a collection of density altitude articles published in the FAA's Seattle Flight Standards District Office's Aviation Safety Program's safety newsletter. Whenever we publish an aircraft operational-type article like this one, we want to emphasis that the purpose of the article is to stimulate pilots and instructors thoughts on the subject topic. We want to remind all pilots that their respective aircraft's operating manual or handbook is the source of information for the operation of that aircraft. When operating at or near the operational limits of an aircraft, pilots need to remember that the aircraft's published performance information was determined through the use of company test pilots using "average" pilot skills flying new aircraft. Your flight skills and your older aircraft's performance may not match the performance information published in your handbook. You may want to be more conservative in calculating any critical performance data when operating into or out of airports or landing areas with limited or no margin of error..*

A few years ago, I had the pleasure of sitting in on a seminar on density altitude taught by National Transportation Safety Board (NTSB) Accident Investigator Kurt Anderson. It was the most insightful and, most inspirational seminar I have attended in 20 years. Mr. Anderson has interviewed many pilots who have survived airplane accidents, and he has gained incredible insight about what they were thinking just before they crashed.

During his NTSB career, Kurt has investigated more than 400 airplane accidents. His area of responsibility is the five northwest states. He is the owner of a light, single-engine airplane. He is also a Certificated Flight Instructor. Mr. Anderson has identified nine deadly sins, which he said are commonly involved in density-altitude accidents. Nine things pilots either learned and then forgot or didn't learn at all or learned wrong that contributed to the accidents.

## DEADLY SIN NUMBER ONE

When climbing out from an airport at which density altitude is a concern, do not climb at the same indicated airspeed you would use at a sea level airport! Assume you are flying a non-turbocharged, piston-driven airplane. At sea level, the indicated best rate of climb speed is a higher number than the indicated best angle of climb speed. As density altitude increases, the indicated best rate of climb speed decreases, and the indicated best angle of climb speed increases. The amount of change between sea level and a density altitude of 8,000 feet is typically five to eight knots of decrease in indicated best rate of climb speed, and four to seven knots of increase in indicated best angle of climb speed. At some point best-indicated rate of climb speed and best-indicated angle



of climb speed merge and become the same number. When this happens the airplane has reached its absolute ceiling.

The misconception that is leading many pilots to disaster is attempting to climb out of airports where density altitude is a concern at the same indicated airspeed they use to climb out of sea-level airports. If you are flying a non-turbocharged, piston-driven airplane, don't do it!!! You lose performance either way. Assume you are trying to climb over an obstruction at the departure end of the runway from an airport with an 8,000-foot density altitude. Your indicated best angle of climb speed is likely to be four to seven knots faster than the indicated best angle of climb speed at sea level (check your pilot operating handbook). If you mistakenly attempt to climb at your sea level indicated best angle of climb speed, you are probably four to seven knots too slow. You have taken an airplane whose climb performance may be poor at best and made it downright lousy! There is a really good chance the airplane will not climb at all and will simply mush into the obstacle.

Next, assume you are departing from an airport with an 8,000-foot density altitude in the same non-turbocharged, piston-driven airplane. The challenge this time is to climb over the ridge that is four miles away. Your indicated best rate of climb speed is probably five to eight knots lower than your indicated best rate of climb speed at sea level (check your pilot operating handbook). If you mistakenly attempt to climb at your sea level indicated best rate of climb speed, you are probably five to eight knots too fast. Some pilots even add a few knots, "just to be on the safe side." You have taken an airplane whose climb performance may be poor at best and made it downright lousy! There is a really good chance the airplane will get itself out of ground effect and then refuse to climb at that indicated airspeed and simply mush into the ridge. This is a big factor in density altitude accidents. The speculation is that since it is proper to use the same indicated airspeed, while approaching to land, regardless of the density altitude, quite a number of pilots have come to the mistaken conclusion that the same is true during takeoff. NOT SO!!!

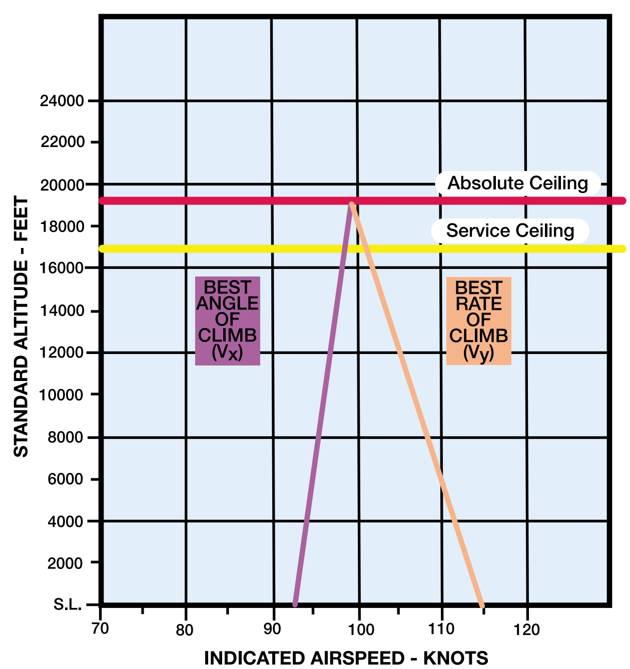



**Figure 1**

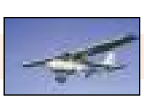
Airplanes with turbocharged, piston-driven engines must also use indicated best rate of climb speeds which are lower than sea level indicated best rate of climb speeds, but only above altitudes where the turbocharger begins to lose efficiency.

Most all of the density altitude accidents within the five northwest states involve situations requiring climbs at best rate of climb speed. Seldom do they involve climbs at best angle of climb speed. But either way, using sea level indicated climb speeds in high-density altitude situations has the ability to transform poor climb performance into zero or even negative climb performance.

When this article was originally published in *AeroSafe*, the Aviation Safety Program's newsletter in FAA's Northwest Mountain Region, one of our readers sent a letter detailing his encounter with density altitude.

*Several years ago, I was returning to Seattle from Winnemucca, Nevada, in my Cessna 152. I was given a clearance to takeoff on Runway 20. The elevation of the airfield is 4,303 feet and the temperature was about 80 degrees F. There is a 7,449-foot peak straight out from the runway about six or seven miles away. Since I would be turning to the northwest after takeoff, this didn't seem to be a factor. At full gross weight, I lifted off as usual and planned to continue on runway heading until I could gain enough altitude and airspeed to make my turn. When I got out of ground effect, however, I did not climb very much at all! I was scooting out over the sagebrush, barely climbing, and heading for the obstacle that now seemed to be a lot closer than I had originally thought. I checked the mixture control and confirmed that it was adjusted properly. I couldn't afford to lose any lift by banking. For a sickening moment it looked like I was doomed to either fly into the hill or land on the open grazing land covered with sagebrush and whatever rocks or other impediments were hidden from view. The latter was the preferred choice, but I was still flying.*

*As gently as I could, I raised the nose to see if I could get any climb out of it. There was no buffet. I raised the nose some more. At this point I wasn't looking at airspeed; I was flying by feel. Slowly I began to gain altitude. It seemed terribly slow, but after a while I felt it was safe to attempt a shallow banked turn to the right. It worked! I had about 5,000 hours total time and had flown many different types of aircraft—military and civilian. I was now a private pilot, but I had been trained in the Army Air Force during WWII and had been a professional pilot for*




*Remember to always check your pilot's operating handbook before a flight to avoid nasty surprises after takeoff.*

*many years after that War. My first 60 hours of flying were completed without an airspeed indicator as a matter of standard practice. But this experience taking off from Winnemucca was not like any I ever had before—or since. After that flight, I checked my flight manual and the correct airspeed for the conditions was 63 KIAS, not the 70 that I was using!!!*

A resulting letter questioned the reader's attempt to climb at best rate of climb speed. Shouldn't he have been using best angle of climb speed? The misconception is a common one. In fact, it is one of the Deadly Sins that we were going to cover later, but we might as well cover it now.

You should not climb at best angle, unless it is absolutely necessary to do so. And the only time it is absolutely necessary to do so is when climbing toward an obstacle with no maneuvering room whatsoever. If there is enough room for an S-turn, or a 180 or 360-degree turn, or any other combination of turns, we're going to be climbing at best rate. When you have maneuvering room, you have the luxury of using best rate of climb; you're not stuck with best angle.

Instructors tell students to use best angle of climb speed to clear obstacles. This is generally good advice. Best angle gives you the most altitude for the distance traveled. But a lot of students come to the conclusion that best angle should be used for all situations requiring obstacle clearance. Not so. There are some serious drawbacks to using best angle. For instance, a full-power climb at best angle requires that the nose of the airplane be up so high that you can't see where you're going, making "See and Avoid" virtually impossible. Also, at such an attitude, there is little margin for error between best angle and stall! If you get that nose just a little too high, it is only seconds to disaster! You are doing all of this while still close to the ground and with an obstacle ahead. Additionally, engine cooling is reduced during climbs at best angle. Finally, if the engine even coughs with the nose that high, you're in a world of hurt.

We recommend that you not climb at best angle in situations where best rate will do. If there is room to climb straight ahead at best rate and clear the obstacle, use best rate. If there is room to maneuver while climbing at best rate and clear the obstacle, maneuver and climb at best rate. You will only see us climbing at best angle when it is absolutely necessary to do so, and then, only if we are proficient and absolutely certain we know the attitude that will produce best angle of climb speed for the given density altitude. So, in answering the letter, we thought the pilot of the C-152 was correct in selecting best rate, he simply did not know what the best rate of climb speed was under the prevailing density altitude conditions.

## DEADLY SIN NUMBER TWO

When departing from airports in a general aviation airplane at less than maximum gross weight because of density altitude considerations, do not climb at your maximum gross weight, best rate of climb speed! It seems that a great number of pilots memorize only one best rate of climb speed—the one for maximum gross weight at sea level. In truth, best rate of climb speed (indicated) decreases as gross weight decreases. Depending upon which airplane you fly and how far below maximum gross weight you are operating, best rate of climb speed (indicated) can drop as much as 10 knots or more. (check your pilot's operating handbook.) Attempting to climb at your maximum gross weight best rate of climb speed in a lightly loaded airplane, can take climb performance, which may be poor at best, and make it downright lousy.

If you attempt to climb out of a high density altitude airport at a reduced gross weight while using your sea level, maximum gross weight best rate of climb speed (indicated), you combine Sin One with Sin Two. The result can easily be that you are attempting to climb at a speed that could be 15 knots too fast! Such a mistake can turn minimal climb performance into negative climb performance!! This deadly combination is precisely what is leading to our most common density altitude accidents!

## DEADLY SIN NUMBER THREE

A lack of understanding of the significance of true airspeed and its affect on turn diameter is Deadly Sin Number Three. The situation in Deadly Sin Number Three is the need for a course reversal to fly out of a tight, blind canyon situation. The pilot has waited far too long to initiate the turn and now needs to make a tight radius, 180-degree turn without losing any altitude. At sea level on a standard day, if we ignore calibrated and equivalent airspeeds, an indicated airspeed of 150 knots results in a true airspeed of about 150 knots. But at 8,000 feet MSL on a 95 degree Fahrenheit day, an indicated airspeed of 150 knots results in a true airspeed of 180 knots. Big deal, what is 30 knots?

If we use a bank angle of 45 degrees, the formula for radius of turn is velocity squared divided by 11.26. At a true airspeed of 150 knots, the math works out to 1,998 feet (we're going to call it 2,000 feet). At a true air speed of 180 knots, the math works out to 2,877 feet. All right, so that's an additional 877 feet. But that's an additional 877 feet of radius. To make the famous 180-degree turn out of a valley where you are unable to out climb the terrain, you need to know the turn diameter. At the same indicated (150 knots) the 8,000 foot MSL, 95 degree Fahrenheit day turn diameter requires 1,754 feet more than the sea level, standard day turn. That's an additional third of a mile because of the fact that the true airspeed is 30 knots higher than indicated! The 180-degree turn requires 4,000 feet at 150 knots. At 180 knots it requires 5,754 feet. That's an increase of 44 per cent!

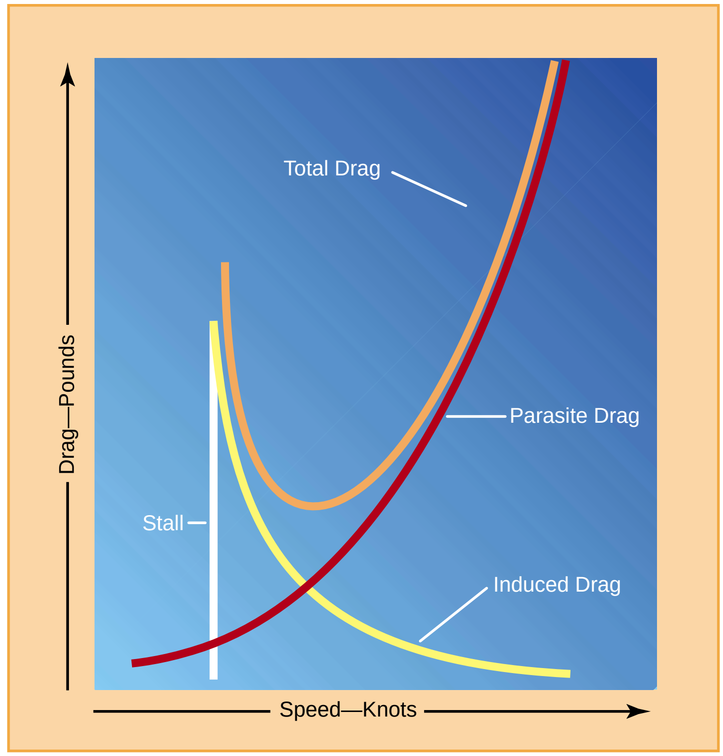
This is all complicated by the fact that we all have a pretty good mental picture of just how much room is required to make a 180-degree turn. After all, the turn from downwind to final is a 180-degree turn. And when we're on downwind we all know how far to space ourselves from the runway. But, if you fly up the high density altitude canyon and delay your escape turn until the cliff on the far side of the valley is about the same distance as the distance from sea level downwind to final (at 150 knots), there is a good chance you'll smash into the cliff about 44 percent of the way through the turn. As alarming as that sounds, it is happening far too often.

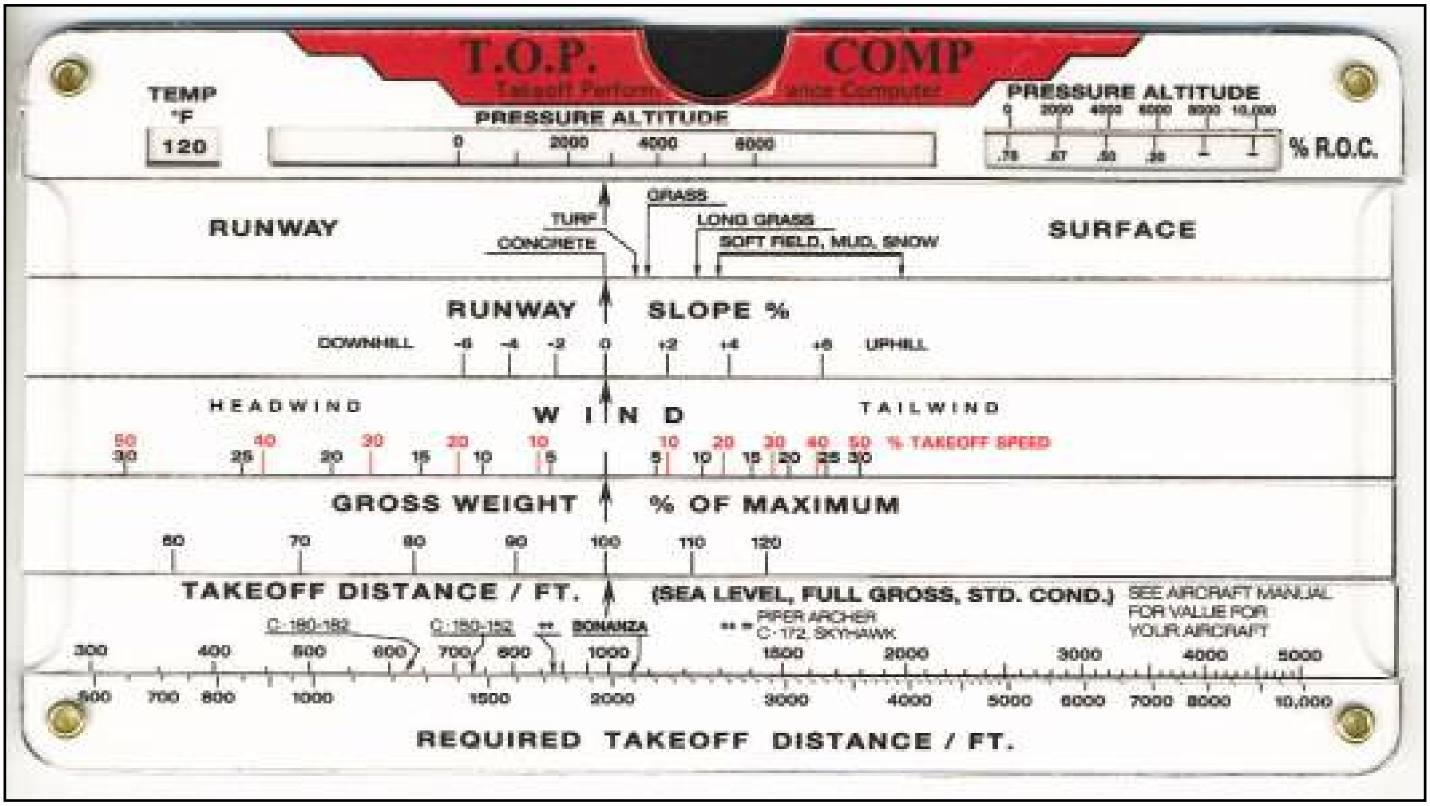
The fix? A lot of pilots think they can reduce the radius of that turn by slowing the airplane down. Slowing the airspeed does reduce the radius, but there is a trap if you slow it down too much. Keep in mind your density altitude induced power requirement for slow speed flight.

Let's discuss how induced drag increases as bank angle increases. In his lecture, Kurt Anderson pointed out that a 30 degree angle of bank will increase induced drag by 33 percent, a 45 degree angle of bank will increase induced drag by 100 percent, and that in a 60-degree bank induced drag will increase by 300 percent!

Now, please study Figure 2. Figure 2 shows a lift over drag (L/D) curve for a very typical light general aviation airplane. Notice that to the right of the L/D max point (where indicated drag and parasite drag intersect), induced drag is a relatively small part of the total drag. But to the left of the L/D max point, induced drag is a very large part of the total drag. Notice how the induced drag and total drag curves spiral upwards as you move left of the "Minimum Drag or (L/D) Max" point. As airspeed slows below the minimum drag point, drag increases rapidly. Now, take a really close look at the title of the vertical line that defines the left side of the graph. It is titled "Drag—Pounds." Once you slow below the "Minimum Drag or (L/D)" point, thrust required is increasing just as rapidly as is drag.

**Figure 2**






*This takeoff performance calculator is non-technical and requires no batteries. It works like an old-fashion slide rule.*

Near stall, induced drag makes up a huge percentage of the total drag. Assume you decide to slow to some speed close to stall because after all, the slower the speed the tighter the radius of the turn, right? And you need a tight radius turn to get out of this bloody canyon. Keep in mind that in a 45-degree bank, induced drag increases by 100 percent.  At a near stall situation, induced drag amounts to approximately 80 percent of the total drag. If we try to use a 45-degree bank in this situation we will double the induced drag, which increases the total amount of thrust required by 90 percent. This means we would need to increase total thrust by 90 percent to maintain level flight. In situations where you are flying near stall on an 80-degree day at 8,000 feet MSL, how many times do you have a spare 90 per cent unused thrust available?

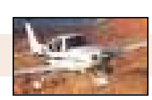
Remember the situation: you are attempting to do a 180-degree course reversal within the confines of a high-density altitude canyon. The slower you go, the more thrust required if you are going to maintain altitude during the turn. But just how much excess horsepower do you think you have in a high-density altitude situation? You can prove it to yourself. Fly your favorite airplane to 8,000 feet or more. Make sure you are NOT in a canyon. The hotter the day, the better the demonstration will be. Now, slow down. Slow way down. Slow to the point the stall warning horn is honking. Lower half flaps. Now roll into your 45-degree bank angle "escape turn" and try to maintain altitude. We'll bet if you're flying behind a non-turbocharged piston engine, you don't have enough excess horsepower to do it.

The bottom line is that when pilots delay their escape turn too long, then try to reverse course using a steep, constant altitude turn at very slow speeds, they are asking their airplanes to do something they simply cannot do!  All too often the airplanes don't make the turn, they stall and crash into the side of the canyon.

Our advice? Make the turn long before the canyon becomes confined. Make the turn early enough that a shallow bank is all that's necessary to complete the turn. Better yet, you should stay out of those canyons. The only time you should be maneuvering within the confines of a canyon is shortly before landing at an airport located within the canyon or shortly after taking off from an airport located within the canyon. Other than that, you should be flying over the canyon, not through it.

## DEADLY SIN NUMBER FOUR

Probably every pilot has seen Figure 3 at least once. However, misapplication of the information presented has been known to happen.  It comes with an official explanation that goes something like, "Flying in the vicinity of a ridge results in downdrafts for the pilot of Airplane 1.  Airplane 2 might escape the downdrafts, but a course reversal either to the right or to the left would leave little maneuvering room between the airplane and the ridge. Airplane 3 takes advantage of free lift from the up slope airflow and retains the advantage of an into-the-wind es-

cape route."

The official explanation is technically correct, but it does not go far enough. Since it is questionable whether or not Airplane 2 can complete a 180-degree turn, we can assume this valley is not very wide. Most pilots choose to fly up the correct side of the valley (Airplane 3 in this case), but push on too far before deciding to reverse direction. As long as things are going well for Airplane 3, the pilot continues bravely on course. It's only when things get tight that the pilot of Airplane 3 decides to make the 180. But turning around at this point results in a radius of turn that places the airplane somewhere between Airplanes 1 and 2. This is precisely the valley location described in the official explanation as an area of downdrafts! The trap has been sprung. Another aircraft smacks the terrain and generally with fatal results.

If you are going to fly through such a valley or canyon you must must decide to make the 180-degree turn while the valley is still wide enough to complete the turn using less than half of the valley! You've got to avoid the area of the valley left of Airplane 2. Too many pilots have not. Our search and rescue friends offer the following advice. If you absolutely, positively must fly in the valley, never fly up the valley. You should stay high and familiarize yourself with the terrain before you descend into the high end of the valley and fly down the valley.

## DEADLY SIN NUMBER FIVE

Another mistake pilots make is not understanding the effects of density altitude on airplane landing performance. For example, suppose you find yourself in a situation where the field elevation is 8,000 feet MSL, and the temperature is 90 degrees Fahrenheit. The wind is blowing 10 knots and gusting to 18. The surrounding mountains are causing the wind to be quite variable and turbulence is abundant. Your aircraft flight manual recommends an approach speed of 70 to 75 miles per hour. What speed are you going to fly on final, and how will this landing compare to landings under similar conditions at sea level? Fly the same indicated airspeed that you would use at sea level, but remember that 75 mph indicated is 90 mph true in these conditions, so your ground speed is going to be 15 mph faster than at sea level.

Then you want to add one half of the gust factor. In this case add one half of the difference between 10 and 18, or four. The common mistake is to add one half of the 18, or nine. Don't add nine, just add four, but four indicated is five true. So now you're approaching at 95 true. With the same indicated approach speed your ground speed is 20 mph faster than it would be at sea level!

All things being equal, if you have precisely flown your approach at the correct indicated airspeed, your time in the flare will be the same at altitude as it is at sea level. But at altitude, your groundspeed is significantly higher than at sea level and your stopping distance is longer.

So the distance covered during the flare at altitude is considerably more than what you're use to at sea level. Combine this with the fact that most mountain airports are relatively short and often have cliffs, dense forests, or streams at the far end and the problem becomes clear.

## DEADLY SIN NUMBER SIX

When departing airports, be aware of your climb gradient. We are all familiar with aircraft rate of climb — it's figured in terms of feet per minute. Climb gradient is figured in terms of feet per mile.

Consider two airplanes, each climbing at 500 feet per minute. But one is climbing at 60 miles per hour, and the other is climbing at 90 miles per hour. Each will climb 500 feet in one minute. But the first will cover one mile during that minute, and the second will cover a mile and a half during the same minute. The first airplane is climbing 500 feet per mile, and the second is climbing only 375 feet per mile.

When trying to out climb rising terrain, you need to think in terms of feet per mile as well as feet per minute.

## DEADLY SIN NUMBER SEVEN

Not knowing the aircraft's takeoff and initial climb-out performance numbers is another cause of accidents. Manufac-

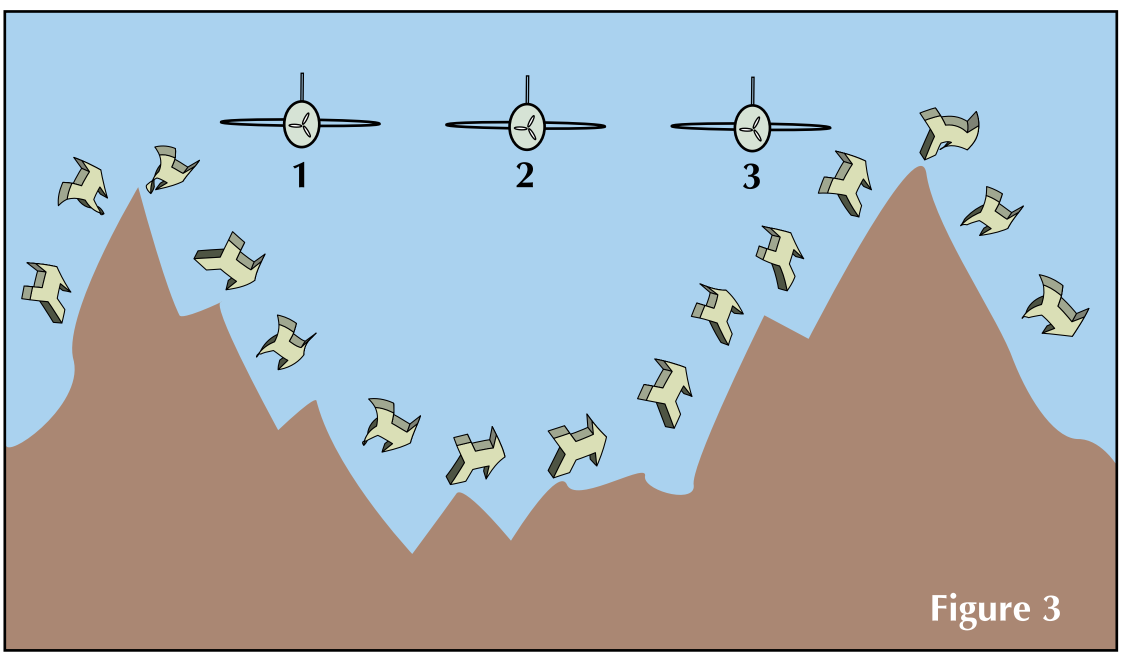


Figure 3

turers give us performance charts to figure required runway length to get off the ground and distance required to out climb obstacles. They take into consideration such things as airport elevation, temperature, headwind component, and type of runway surface.

Just imagine you wanted to depart a dirt strip with a two-degree upslope, a 100-foot tree at the far end, at a pressure altitude of 6,700 feet MSL, and a temperature of 85 degrees. The charts work great—if you have a master's degree in mathematics. The problem is that the mathematical formulas required to determine the performance values for a specific aircraft at a specific airport on a specific day are cumbersome to say the least.

So, far too often, pilots give up on the charts and take a guess at the answers to those questions (and we pilots are notoriously optimistic). The problem is that your life and the lives of any passengers you might have onboard depend upon accurate answers to those questions. Wouldn't it be great if there were a simple, easy-to-use device that would quickly help you ascertain the answers?

There is one. It is a takeoff-performance calculator that is non-technical and requires no batteries. It looks like an old-fashion slide rule. The "Takeoff Performance Computer" is available from Sporty's Pilot Shop. It is item 2091A on page 45 of the current Sporty's catalog.

Today, there are also electronic calculators and computer programs that can help you calculate your aircraft's performance data. The important thing is to know your aircraft's performance data, especially when you are planning for critical situations involving high-density altitude or short-field operations.

## DEADLY SIN NUMBER EIGHT

Using the wrong flap setting for takeoff was identified as another accident cause. Many light general aviation airplanes have a takeoff flap setting other than zero for operations on hard surfaced runways. When manufacturers recommend a takeoff flap setting other than zero (usually between 10 and 20 degrees) they do so to reduce the ground roll. Your use of the recommended flap setting works just fine when operating at near sea-level altitudes.

But keep in mind that for airplanes powered by piston-powered, non-turbocharged engines, there comes a density altitude above which the use of takeoff flaps actually increases ground roll. This is because the thrust available has deteriorated to the point where it is no longer capable of pulling the increased drag (as compared to flaps completely up) efficiently. This is exactly the situation you need to avoid when taking off from a high-density altitude airport.

## DEADLY SIN NUMBER NINE

You should know the proper techniques for making obstacle takeoffs and for making soft-field takeoffs in the airplane you are currently flying at the density altitude you are currently contemplating, and you should not combine the two unless your airplane is turbocharged or turbine-powered. There are numerous instructors out there who routinely combine obstacle takeoff techniques with soft-field takeoff techniques to save time during training. But in actual density altitude situations, a pilot should not combine the two in a normally aspirated, piston-engine airplane.

The problem our fellow pilots are (literally) running into is having to takeoff in high density altitude situations with the need to climb over some obstacle. The obstacle may be a 100-foot tree at the departure end of the runway or a 100-foot tree on top of a 100-foot hill located a quarter of a mile past the departure end of the runway or a 100-foot tree located on top of a 1,000-foot mountain four miles from the departure end of the runway. In any case, typically the problem is not that the length of the runway is short; the fatal problem is the need to out climb an obstacle. So, for the purposes of this article, we are talking about obstacle clearance takeoffs and not minimum ground-run takeoffs.

The problem is that most airplanes in actual soft field situations call for the use of some flaps. The use of flaps help get you off the ground quicker, but in high density altitude situations the drag from those flaps will seriously hinder your efforts to climb over the obstacle.

Also, it is important to be able to recognize a soft field when you see one. Simply being unpaved does not make it a soft field. Soft field means the tires are sinking into something like mud or plowed earth or snow. Most mountain strips are not actually soft. And, it is a mistake to use soft-field technique when obstacle clearance is a concern. If you are taking off from an airport with rocks, ruts, and serious bumps, you might want to reduce the load on the nose wheel a little, but any more than that is not necessary and will only serve to increase drag and runway used if you increase your angle of attack too much.

For obstacle clearance takeoffs, follow the advice of your airplane manufacturer, which for the vast majority of non-turbocharged airplanes means flaps up and climb at best angle of climb speed for the density altitude.

If you ever find yourself in an actual soft-field situation in which obstacle clearance is a concern and you don't have the performance to fly out of the site, you should seriously consider removing the wings and trucking the plane home.

This wraps up the nine deadly sins that Kurt Anderson's years of accident investigation experience shows have lead to density altitude accidents. Please remember them when you are flying so that you don't become a density-altitude statistic.

*Scott Gardiner is an FAA Aviation Safety Inspector and the FAA Safety Program Manager at the Seattle Flight Standards District Office. This article originally appeared in the FAA's Northwest Mountain Region's safety newsletter,* AeroSafe.