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Mountain Flying

From the basics to sharpening your skills.

eBook

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About the Author

Colin Aro is a FAASTeam member with the Reno FSDO (Flight Standards District Office), the local branch of the FAA and has lived in Reno, Nevada for nearly 20 years. He is a commercial pilot and flight instructor rated for single engine airplanes, multi engine airplanes, and gliders. He holds a Ph.D. in Engineering - Applied Science from the University of California, having studied atmospheric chemistry and dynamics. Colin’s favorite safety subject is mountain flying - an important topic according to the industry’s accident statistics. Colin’s past soaring experience in the Sierra Nevada and other mountain ranges, combined with his academic research background offer a slightly different and entertaining viewpoint on this important topic.

Colin enjoys volunteering with the Commemorative Air Force and flying antique aircraft. He currently serves as the operations officer for the High Sierra Squadron of the CAF in Reno, overseeing the operations of the squadron’s N3N-3 and L-19 aircraft. He also flies with the Northern California Beech Boys formation demonstration team.

High Country Basics

Done safely, flying a light aircraft through the mountains can be the adventure of a lifetime. The mountains of the North American west, where I fly most often, offer some of the most spectacular scenery available to a private pilot.

As beautiful as those majestic rocks can be, they can also be lethal. According to the Joseph T. Nall Report, mountain airports have an accident rate nearly three times that of flatland airports. The performance-robbing effects of high density altitude combined with the robust vertical convection so common in the mountains can be very dangerous when the terrain is in such threatening proximity.

I'll share my insights on mountain flying. Let's start with some general rules for safe flying in the high country.

Take your time and stay near landable terrain

Population centers are relatively sparse, so alternate airports are fewer and farther between. It is best to plan your route as a series of "doglegs" through the mountainous areas. In the GPS era, it is tempting to fly direct. Doing so, however, may take you over the highest, most inhospitable terrain. Not only is this practice much less safe in the event of a mechanical failure and subsequent forced landing, but the time and fuel savings earned by flying the shorter, direct routes may be squandered in the effort to climb above terrain in the thin mountain air. This is especially true if the winds are strong. The best practice is generally to plan routes that keep you near population centers and lower-lying areas. Remember, a 40-mile diversion in a typical light GA aircraft only takes approximately 20 minutes. The safest choice is to spend a little more time enjoying the scenery and stay over landable terrain.

Always have plenty of fuel in reserve

It is also advisable to be conservative with your fuel allowances. With fewer alternatives to complete the flight if the winds aloft change significantly, the only safe choice is to plan fewer miles with each leg and keep plenty of fuel in reserve.

File a flight plan and report position

Finally, file a flight plan and make regular position reports. It is surprising how many pilots are reluctant to take advantage of this free, easy-to-use insurance. I have a colleague who crashed on a snowy slope while talking to ATC. It took emergency personnel over 8 hours to reach him. If that's the best-case scenario, then you definitely don't want to face the worst.

Sparky's rules

Flight planning issues aside, the novice mountain pilot may find the simple proximity of terrain to be alarming: looking out the window at big rocks on either side of the aircraft while cruising at 9,000 feet or more can be disconcerting if you aren't used to it. The late Sparky Imeson has a couple of useful rules (Sparky's Rules) in his Mountain Flying Bible and Flight Operations Handbook for operating in close proximity to high terrain. He defines the "point of no return" as that point where the pilot could retard the throttle to idle and still have sufficient altitude for a turnaround. If the pilot continues climbing into terrain past this point, an engine failure could have serious consequences. Having defined the point of no return, Imeson's two rules are:

1. Always be in a position to turn toward lowering terrain
   (i.e. beware narrow canyons and ridge crossings)
2. Never fly past the point of no return

Adhering to these simple rules should keep the novice out of trouble in high terrain. Bear in mind that the typical light GA aircraft has an approximate 9-to-1 glide ratio, which produces a descent angle of only 6 degrees or so. If you lose the engine, a turn toward lowering terrain could buy you a lot of time, assuming the terrain falls away at a 6-degree slope or more.

Rule #1

Always be in a position to turn toward lowering terrain

Rule #2

Never fly past the point of no return

Density Altitude and its Effect on Performance

Mountain airports are at relatively high elevations, where the air is thin—i.e., where its density is low. During the warmer months, the temperatures can be much higher than standard, and if there's any humidity present, we have the classic "high, hot, and humid" combination that results in very low air density. Low air density (mass per unit volume) means high density altitude. As pilots, it is not very intuitive to speak of the air's density being "x kilograms per cubic meter" or "y slugs per cubic inch," so we index the air's density into a standard atmosphere. This way, when we say that the density altitude is 3,000 feet, we're simply saying that the air's mass per unit volume is the same as it would be at 3,000 feet in a standard atmosphere.

Again, aircraft performance (the lift produced by the airfoil) is directly related to the air's density (mass per unit volume). Density altitude gives us an intuitive way to describe this important metric and to normalize aircraft performance figures. Apart from the wing itself, there are three additional components that suffer under the effect of high density altitude operations: the engine, the propeller, and the pilot.

The lift that an airfoil produces is directly proportional to the air's density—its mass per unit volume. If you cut the air's density in half, you cut the lift produced in half. Similarly, the lift produced by an airfoil is proportional to the square of the airspeed [(1)]. In this case, all things being equal, doubling the airspeed causes the airfoil to produce four times as much lift. Equating the two under the assumption of constant lift can be useful: if the air's density is cut in half, the square of the airspeed must be doubled in order for the lift produced by an airfoil to remain constant. Airspeed must be increased by approximately 41% in order for its square to be doubled, so in essence, cutting the air's density in half requires 41% more airspeed in order for an airfoil to generate the same amount of lift.

As noted above, the wing's performance degrades (less lift is produced) as the density decreases. At 18,000 feet, for example, where the air's density is half what it is at sea level, a wing needs to be flying 41% faster to generate the same amount of lift as at sea level. So, in order to takeoff from a hypothetical airport at an elevation of 18,000 feet, an aircraft would need to attain a true airspeed 41% higher than it would at sea level in order to generate sufficient lift for flight. Performing the same analysis with a density altitude of 10,000 feet shows that TAS (true airspeed) must increase by about 15%—not insignificant. Fortunately, indicated airspeed is unchanged, but the sight picture out the windscreen will be quite different.

Lighten your load—but not when it comes to fuel

Assuming that the engine is normally aspirated, we can expect to lose about 3% of its available power per 1,000 vertical feet. Pilots with manifold pressure gauges see this directly. This means that at 10,000 feet, that 180 horsepower engine is only making somewhere in the neighborhood of 125 horsepower. What's more, the propeller, being an airfoil just like the wing, creates less thrust just as the wing produces less lift. Aircraft equipped with cruise props will generally suffer more in this regard. All of this means that high-density altitude gives us a severely weakened engine, with a propeller that converts less of that engine's horsepower to thrust while it's attempting to drag the wing to a higher airspeed. There are suddenly lots of factors working against the pilot. The only viable way to deal with this is to lighten the load—although it's generally not a good idea to skimp on fuel. Quite a few four-seat aircraft turn into two-seat aircraft to lessen the weight.

Remember, getting airborne is only the beginning: carefully consider your aircraft's climb gradient and pay attention to the actual temperatures in the immediate vicinity of ridges. Radiation heating from the terrain could result in air temperatures well above standard, so density altitudes in excess of 12,000 feet are possible in the immediate vicinity of terrain. The bottom line is that your aircraft's performance could be shockingly poor.

3% Power Loss

per 1,000 vertical feet

Do the math for your aircraft

Let's look at the Piper Arrow PA-28RT-201 as an example [2]. Assuming a pressure altitude of 5,000 feet and an air temperature of 30 degrees C, with the aircraft at full gross weight and no wind present, the book tells us that 1,800 feet is needed for the takeoff roll and 2,350 feet in total is required to clear a 50-foot obstacle. Once airborne, we can expect a rate of climb of 375 feet per minute at 7,500 feet (assuming 22 degrees C) and 325 feet per minute at 9,500 feet (assuming 18 degrees C). These climb numbers are half of what they are at sea level. Bear in mind that the handbook is quoting performance numbers for a new aircraft flown by a test pilot—your performance may vary, so it is wise to be conservative. The bottom line is that it may take 20 minutes or more to climb sufficiently to permit terrain crossing.

The Arrow is no hot rod, but it's also not the weakest ship out there. These numbers show us what we have to work with in terms of typical light aircraft performance.

½ Climb Rate

of what is at sea level:

- 375ft per minute at 7500ft
- 325ft per minute at 9500ft

Footnotes:

1. Mountain Flying Bible and Flight Operations Handbook, Sparky Imeson, Aurora Publications, Jackson, WY, 2001

2. Piper PA-28RT-201 Pilot Operating Handbook

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Negotiating the Clouds

Weather, Gliders, and Clouds

When thinking about density altitude and performance vs. mountain weather, the issue is really "What do we have to work with?" vs. "What are we up against?" Being glider-rated, it seems obvious to use soaring techniques to gain advantage in the mountains. In my neighborhood, the eastern Sierra Nevada Mountains, glider pilots are able to keep their craft aloft for hours and cover hundreds of miles on a good day. In similar geographic locales, "power" pilots should be able to use the same techniques to be not only safer, but more efficient mountain pilots.

The Up- and Downsides to Thermal Lift

Mountain weather by itself is worthy of an extended discussion—this part of the series will primarily consider weather phenomena relating to vertical convection. In most areas, including the flatlands, vertical convection is most commonly the result of differential heating of the earth's surface. This differential heating can create rising columns of air sometimes topped by afternoon cumulus clouds. Glider pilots use these "thermals" to stay aloft and perform cross countries during the warmer months. In Photo A, the glider is being maneuvered in a tight turn in order to circle (and loiter) within a rising column of air. Doing so allows the glider to gain altitude: note that the glider's rate of climb (center instrument) is nearly 1,000 feet per minute at 12,500 MSL.

As the photo demonstrates, mountain thermals can be quite robust. They can also be predictable: for example, the eastern-facing slopes are the first to receive sunshine in the morning, commonly long before the valley floor. It stands to reason, then, that the eastern-facing slopes are good places to look for thermal activity, at least early in the day. In Photo B, taken late in the morning, a line of budding cumulus clouds marks the beginnings of thermal activity along the eastern-facing ridgeline at Lake Tahoe.

Lines, or "streets," of thermals are quite common. In Photo C, the glider is wings-level beneath a "street" of cumulus clouds in the Smith Valley, east of Minden, NV (KMEV). The glider is climbing through 13,000 feet at a rate of climb near 800 feet per minute (instrument upper right). Your Piper Arrow, in still air, climbs at less than 300 feet per minute at this altitude. Wouldn't it be great to add 800 feet per minute to your climb rate?

Given the performance capabilities of the typical light GA aircraft in the mountain environment, getting a 500-1,000 foot per minute boost would make a big difference in the aircraft's total time-to-climb. More importantly, where there is lifting air, there is also sinking air, so beware: a 500-1,000 foot per minute downdraft is far more than your Piper Arrow can compete with. We'll revisit this scenario when we discuss speed-to-fly.

The bottom line with thermals is that they're parcels of rising air—turbulent rising air. So even though thermals can boost performance, passengers may find them uncomfortable because of the resulting turbulence. Best practice in avoiding the worst convection and turbulence is to fly early, give your passengers a smooth ride, and wait out the worst of the afternoon's turbulence.. Many areas have a "Soaring Forecast" that contains useful information on atmospheric stability, moisture content, and thunderstorm potential—along with useful info like "trigger temperature" and trigger time. At trigger time, thermal strength of 260 feet per minute can be expected to rise to 4,000 feet AGL. In other words, trigger time is the point in the day when the strength of updrafts and downdrafts will begin to rival your light aircraft's performance—useful information indeed.

May the force—of mechanical lift—be with you

Unlike the flatlands, the mountains have mechanical deflection as another major source of vertical convection: imagine water flowing over rocks in a stream. When the winds aloft pick up, the mountain ridges deflect them, giving rise to convection and turbulence. If the atmosphere is unstable, the result could be orographic thunderstorms. Stable atmospheres give rise to other types of convection. Make note that one knot is approximately 6,000 feet per 60 minutes, or 100 feet per minute. Therefore if we were able to deflect even a light 5-knot breeze straight up, it would be a 500-foot per minute updraft. For this reason, it's good advice to take the winds aloft over the ridgelines seriously. More realistically, if we deflect a horizontal wind up (or down) at a 45 degree angle, its vertical component will be approximately 70% of the total velocity. For example, a 10-knot breeze over the ridgeline turns into a 700 foot per minute downdraft in the immediate vicinity of the ridge if it's deflected down at a 45 degree angle. The aircraft's crab angle in the vicinity of the ridge will provide a clue as to what the winds are up to: expect lifting air on the windward side of the ridge and sinking air on the leeward side.

The bottom line with thermals is that they're parcels of rising air—**Turbulent Rising Air**


A


B


C

Surfing the Mountain Wave

When conditions are right, a standing wave will form downwind from the ridgeline. Mountain wave can be thought of as ridge lift's "muscular cousin." The "right conditions" begin with at least a 15-knot wind nearly perpendicular to the ridge. The direction of the winds aloft should be nearly constant with altitude—atypical due to the Coriolis Effect. The wind velocity should increase with altitude—a speed gradient. Finally, the atmosphere should contain a stable layer of air sandwiched between two "less stable" layers. This is analogous to a stiff spring sandwiched between two "less stiff" springs: if you whack the three-spring system and set it in motion, eventually it settles into a steady state in which the stiff spring barely flexes at all while bouncing back and forth between the looser springs.

Beware of Cloud "Baguettes"

The crest of the mountain wave is often marked with altocumulus standing lenticular clouds, provided there's sufficient moisture. These clouds don't necessarily mark conditions of greatest lift, just areas of sufficient moisture. At the lower levels, moisture may condense on its ascent, blanketing the ridgeline with a cap cloud. After cresting the ridge, the air descends (of course) and commonly dries out, resulting in what's called a foehn gap. Further downwind is the rotor zone: rotor clouds mark turbulent eddies being shed by the ridgeline. These clouds often parallel the ridgeline like a giant loaf of French bread and may indicate severe turbulence. This pair of photos shows a classic wave system, with the winds aloft blowing from left to right.

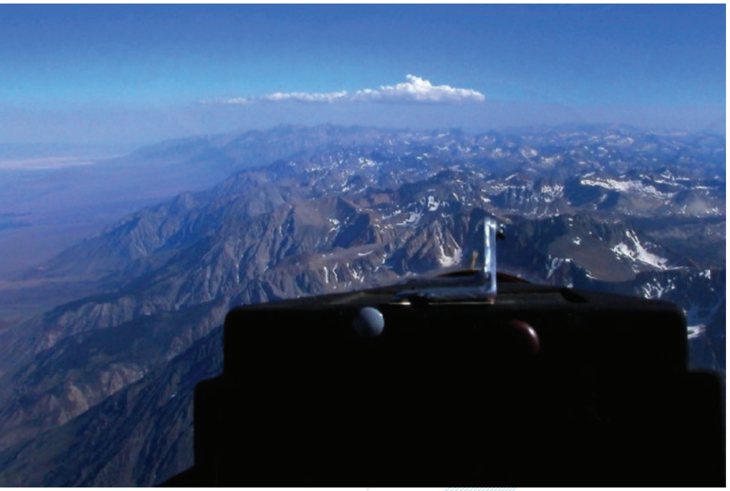
Mountain waves contain tremendous amounts of energy and often extend well into the flight levels. The upper levels are very smooth, but the lower levels (near ridge level) often contain dangerous turbulence. Best practice is for the light-aircraft pilot to steer clear of a mountain wave, unless armed with a lot of experience and instruction. In Photo D, a glider is climbing through 21,000 feet MSL on an altitude flight in a mountain wave—the rate of climb (upper right) is approximately 800 feet per minute. The lesson here is, the vertical convection in mountain waves is not to be trifled with.

Mastering the Art of Soaring

I've learned that most power pilots are uninformed about the glider world. I've run across so many who think that flying a glider consists of launching behind a tow plane, climbing to altitude, releasing, and gliding back to the airport. That's a dangerous oversimplification. "Soaring" is a sport that hones a pilot's ability to read and use the weather effectively. The object of the sport is to keep the glider aloft using vertical convection to the pilot's advantage—and mastering that takes a lot of skill. Power pilots can and should use knowledge and techniques to take advantage of the weather, same as glider pilots do.

FOEHN GAP

D



Speed to Fly

We've examined aircraft performance and mountain weather: what we have to work with vs. what we are up against. Speed to fly starts by developing some simple rules to operate by and then digresses into an important glider concept.

When approaching and crossing ridges, first notice the aircraft's crab angle. This will tell you whether you are on the windward or leeward side of the ridge line. This, in turn, will tell you whether lifting or sinking air is more likely. Regardless, approach the ridge at a 45 degree angle (Sparky's 1st rule – be in a position to turn toward lower terrain). You can commit to crossing the ridge if the aircraft's throttle could be retarded to idle while still being able to glide to the ridge top (Sparky's 2nd rule – never fly past the point of no return). A good rule of thumb is to plan to cross ridge lines with 2,000 feet of clearance for safety.

With regard to canyon flying, the biggest mistake a pilot can make is to fly straight down the center of the canyon. Flying the center may limit the aircraft's turning radius in both directions so as to make a turnaround impossible without some extra maneuvering, assuming there is space to do so. If there is wind, it is probably best to choose the downwind side of the canyon. There are several reasons for this. Should a turnaround be necessary, the pilot has the whole canyon AND the turnaround is into the wind, shortening the aircraft's turning radius. Furthermore, due to the aircraft's crab angle, the turnaround is actually slightly (or significantly, depending on the wind strength) less than a full 180 degrees of heading change.

Sticking to these simple principles should keep the inexperienced mountain pilot out of trouble, but what if the worst happens? What actions do we take if we do manage to blunder into a 1,000 foot per minute downdraft? For this discussion, we will digress into a concept from the glider world called "speed-to-fly."

Approach and cross ridgelines at
a 45 Degree Angle

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What is “speed-to-fly”?

In his seminal work The Joy of Soaring, glider Carl Conway defines speed-to-fly as “the indicated airspeed that produces the flattest glide in any situation of convection.” For pilots, strong updrafts and downdrafts are realities of flying. But what’s the best course of action should you blunder into a strong downdraft? The natural temptation is to attempt to maintain altitude, but glider pilots, like Conway, are taught to react differently.

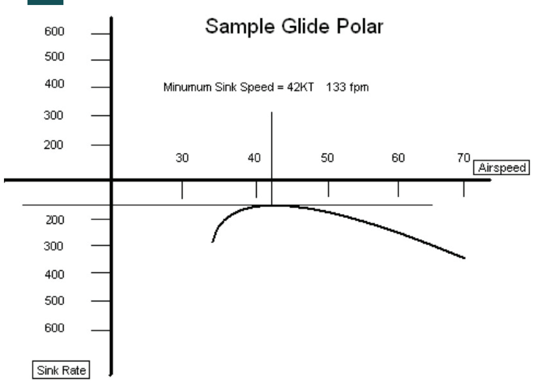
A glider POH contains something called a glide polar—see Figure A as an example. The polar is a simple plot of the glider’s sink rate vs. airspeed; it shows the glider’s L/D performance at various speeds. Immediately obvious is the glider’s “minimum sink” speed—the speed at which it loses minimal altitude per unit time. Minimum sink speed is the appropriate speed-to-fly in a parcel of lifting air—it will optimize the glider’s climb.

A line drawn from the origin represents a particular L/D, and the one tangent to the polar (see Figure B) represents the glider’s max L/D. The corresponding speed is the glider’s best glide speed absent any atmospheric convection.

Notice in the Figure C that there are two speeds which yield any L/D less than max L/D, one lower and one higher than best glide speed. The salient fact is that the slower speed differs from best glide speed by only 12%, while the faster speed differs from best glide by a whopping 43%. In other words, the penalty for flying too fast is not as severe as the penalty for flying too slow. This is typical of most glide polars.

Penalty for flying too fast not as severe as the penalty for flying too slow

A



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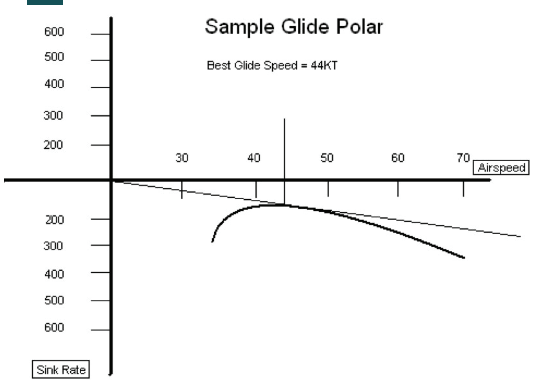

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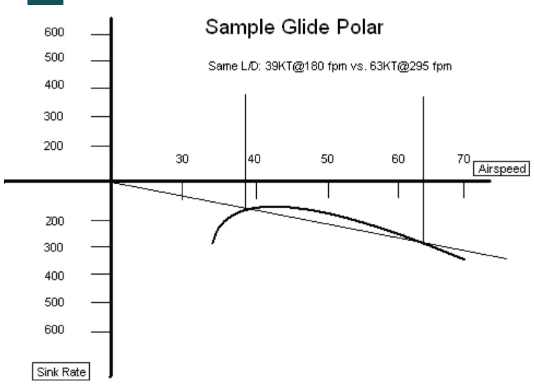

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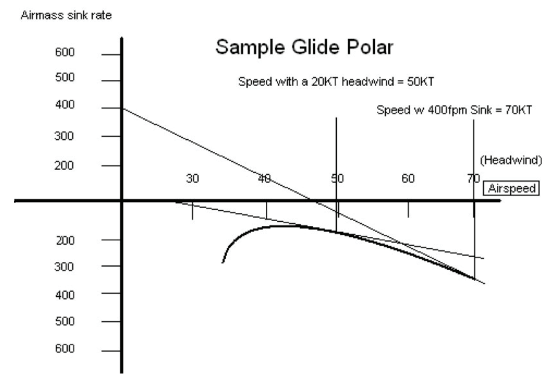
That sinking-air feeling

If the glider is flying in a parcel of sinking air, the tangent line's origin can be adjusted in order to find the correct speed-to-fly. If the parcel is sinking at 400 feet per minute, we would have to adjust the entire polar downward by 400 feet per minute. Instead of moving the whole polar, the tangent line's starting point can be adjusted, as in the Figure D; note that, in this case, the tangent line contacts the polar in a different spot, and therefore implies a different speed-to-fly. The adjustment is similar in the presence of a headwind. In both cases, the recommended speed-to-fly is higher than with no convection or wind.

D



Gliding through the math

Let's look at another abstract instructional light-airplane example: say a light aircraft with a best climb speed of 80 KIAS and a maneuvering speed of 120 KIAS is flying into a 20-knot headwind and encounters a 1,400 foot per minute downdraft. This situation smacks of a ridge or wave encounter, and 1,400 feet per minute is the vertical component of a 20-knot wind deflected downward at a 45-degree angle. Let's further assume that the aircraft is capable of climbing at 400 feet per minute (a high-density altitude), and that the downdraft is a half-mile wide. If the aircraft maintains best climb speed during the encounter, it experiences a 1,000-foot per minute sink rate for 30 seconds—a net loss of 500 feet. If it maintains maneuvering speed, it experiences a 1,400 foot per minute sink rate for only 18 seconds: a net loss of only 420 feet.

Yes, the examples I give are abstract, but they'll make pilots of light aircraft nod their heads in recognition. When it comes to speed-to-fly, perhaps the glider folks are onto something.

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Mountain Flying Summary

Mountain flying legend Sparky Imeson had some solid rules for operating around tough terrain. First and foremost, check the density altitude and know your aircraft's expected performance. In planning your flight, stay near low-lying areas and population centers. Plan to fly early in the day, preferably before sunrise, and stay on the ground if the winds are stronger than 15 to 20 knots. Carefully consider the aircraft's expected climb gradient and account for any time and fuel needed for circling. Carry plenty of reserve fuel (or stop often) and just expect to cover fewer miles in a day. Carry water and emergency supplies on board, file a flight plan, and make regular position reports.

When you're departing a mountain airport, the terrain may dictate that you fly a non-standard pattern–remember: always be in a position to turn toward lowering terrain. Furthermore, some mountain airports have one-way runways. Each situation is different and deserves careful consideration. Cross check airspeed on climb out: IAS should be the same as sea level, but the sight picture out the windshield will be different. Approach ridges at a 45-degree angle (Imeson's first rule) and plan to clear the ridge by at least 2,000 feet for safety. When flying in a canyon, the standard advice is to hug one side of the canyon to permit a turnaround. Either the sunny side or the windward side is likely to be the best choice—there may be lifting air, and it's better to turn into the wind should a turnaround be necessary. Pay attention to the clues seen in the clouds as to thermal activity or winds over the ridge tops. It's a cliché, but it's true: the clouds really are signposts in the sky.

Plan to clear ridges by at least
2,000 feet for safety

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Speed Up for Safety's Sake

Should you encounter sinking air, consider maintaining your airspeed. A study from 1993 recommends "speeding up" (but not above maneuvering speed) if the aircraft's sink rate exceeds its expected climb rate. Simple examination of glider polars shows us that we should speed up in sinking air (especially if there is a headwind) and if you fly the wrong airspeed, it's better to be too fast than too slow. When in doubt, maintain airspeed and attempt to fly out of the sinking air as expeditiously as possible. Intuitively, that is what speed-to-fly is all about–minimizing the time the aircraft spends being subjected to the sinking air mass. Don't forget to slow down in the lifting air!

When arriving at a mountain airport, remember to anticipate a potential go-around: be sure to lean for best power. As with mountain departures, terrain and/or conditions may dictate that the pilot make a circling descent and adjust his or her traffic pattern. As with departure and climb out, fly the same IAS on approach and landing that you would at sea level, but remember that the sight picture will be different. Thermal activity sucks in air from surrounding areas at the surface, often leading to brisk afternoon breezes that come and go. So sharpen your crosswind landing skills prior to your mountain trip because shifting, gusty crosswinds are quite common in the afternoons.

Perhaps the best idea would be to add a glider rating and take a look at what soaring has to offer. What better way to build skill at piloting an underpowered aircraft in the higher elevations than to spend the day aloft in one that has no power at all?

Carry plenty of reserve fuel
(or stop often)

Stay on the ground
if the winds are stronger than 15 to 20 knots

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