

Mountain Flying

by K. Truemper

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Each time I plan a flight to the Rocky Mountains and beyond, I think “Now, what are the important things to consider when flying into mountainous areas?” and then, “Wouldn’t it be nice if I had a summary of those things for review!” So, here is an attempt at such a summary. It is based on many sources: flight instructors, fellow pilots, various publications such as *Sport Aviation* and *AOPA Pilot*, and, last but not least, Nature, which has had an impressive way of teaching me lessons.

The discussion below introduces some formulas that I have found useful. If you hate mathematics and formulas, just ignore that stuff. For me, doing these computations while flying is a way to stay alert and to have something to talk about with my copilot.

1. Takeoff

1.1 Density Altitude

We must know the density altitude to estimate the minimum runway length required for takeoff. An approximate formula for density altitude is

$$D = A + (T/20) + (A/4) - 3$$

where

D = density altitude in 1,000 ft

A = altitude in 1,000 ft MSL

T = temperature in deg F

For example, if A = 6 (= 6,000 ft) and T = 80 (= 80 deg F), then $D = 6 + (80/20) + (6/4) - 3 = 8.5$ (= 8,500 ft).

A more precise formula would use the pressure altitude P instead of A. To compute P, we subtract from A 1,000 ft for each inch of pressure setting above 29.92, and add to A 1,000 ft for each inch below 29.92. This correction is rarely needed, though, since the pressure setting typically lies in the interval 29.6-30.2 in., and P and A differ then by less than 300 ft.

A deceptively low density altitude occurs sometimes in the summer before sunrise. Due to radiation cooling of a clear night, the surface air is cool, but from 500 ft AGL on up the air is still hot. This phenomenon is typical for the southern Rockies, but may occur as far north as Montana. I have seen 60 deg F at the surface and 95 deg F at 500 ft AGL. In such a case, the high density altitude from 500 ft AGL on up significantly reduces the climb performance of the airplane right after takeoff.

1.2 Leaning of Mixture

If the plane has a carburetor without automatic altitude compensation, leaning of the mixture for maximum engine output is essential when the density altitude exceeds 5,000 ft. Just before takeoff, we go to full power while holding the plane with the brakes, adjust the mixture until maximum rpm is obtained, then release the brakes and begin the takeoff run. Below 5,000 ft density altitude, leaning is not needed, and is even dangerous, since the engine may overheat during the climb out. As an aside, leaning should be done en route below 5,000 ft density altitude whenever the power setting is 75% or less, and should always be used above 5,000 ft density altitude regardless of power setting. The leaning is done so that the engine is smooth and gives maximum rpm for the given throttle position, and so that any additional leaning would disturb that performance.

1.3 Sudden Weather Changes in the Morning

A sunrise with a clear sky and with unrestricted visibility usually promises perfect VFR conditions for the morning flight. Usually—but not always. Indeed, rapid fog development and cloud formation shortly after sunrise may within 30 minutes turn that scenario into IFR IMC. The spread between the air temperature and the dew point plus the surface winds are the best predictors for this potentially dangerous development. Any spread less than 5 deg F at sunrise combined with surface winds below 5 kts is cause for concern. When the spread is 1 or 2 deg F, then the problem is almost certain to occur. On the other hand, when the spread between the air temperature and the dew point is more than 3 deg F and surface winds exceed 5 kts, fog should not be a problem. However, in that scenario clouds may still form rapidly unless the spread exceeds 5 deg F.

The solution to the problem is simple. We do not take off at sunrise when a potentially troublesome situation is at hand, and instead monitor how things develop. If clouds and fog do not set in for an hour while the air temperature rises and the spread increases, the weather apparently is stable, and a takeoff is justified. On the other hand, if low areas develop fog or if mountain ridges begin to spawn cloud cover, we stay on the ground until stable VFR conditions return.

2. En Route Flying

2.1 Ceiling of Plane

The legal limit for flight without oxygen or pressurization is 12,500 ft MSL. That limit may be exceeded up to 14,000 ft MSL for up to 30 min. Naively, we may therefore conclude that a plane with a published ceiling of 14,000 ft can take advantage of these limits. But this is not so. First, a plane's ceiling is the density altitude where the climb rate at full power begins to fall below 100 ft/min. This is a very low climb rate. A better figure for the ceiling is the published ceiling minus 1,000 ft. So, a ceiling of 14,000 ft has become 13,000 ft. Suppose we fly eastbound, where we must elect odd-thousand-plus-500 ft as MSL altitude. Say we choose 11,500 ft MSL. If the temperature at that altitude is 50 deg F, a typical value for the Rockies in the summer, then the density altitude is $D = 11.5 + (50/20) + (11.5/4) - 3 = 13.9$ (= 13,900 ft), which is above the 13,000 ft the plane can reasonably reach. Hence, we are forced to the next lower altitude, 9,500 ft MSL, which is

too low for many regions of the Rockies. This example shows that a plane with published 14,000 ft ceiling is unsuitable for flight in the Rockies in the summer. On the other hand, a bit of calculations shows that a plane with a published 17,000 ft ceiling manages to reach altitudes up to 13,500 ft MSL in the Rockies in the summer, within reasonable time, unless temperatures are unusually high.

A normally aspirated piston engine loses power by about 3.5% for every 1,000 ft of density altitude. The formula below expresses this relationship.

$$PD = [1 - 0.035D]P$$

where

D = density altitude in 1,000 ft

PD = maximum power output in hp at density altitude D

P = maximum power output in hp at sea level

For example, if D = 12 (= 12,000 ft) and P = 100 (= 100 hp), then PD = [1 - (0.035)(12)]100 = 58 (= 58 hp).

If the propeller is not in-flight adjustable, the maximum engine output at altitude may no longer be sufficient to maintain cruise rpm. When that happens, the output is reduced below PD of the formula. To compute engine output for the reduced rpm, we apply the above formula for PD using as P the maximum output of the engine for the reduced rpm at sea level. For example, Rotax publishes 76 hp for the 912UL engine as maximum continuous output at 5,400 rpm, and 64 hp as maximum output at 4,400 rpm. Suppose at 14,500 ft density altitude the maximum rpm with full throttle is held to 4,400 rpm due to the propeller pitch. Using P = 64 and D = 14.5, the output for that density altitude and rpm is PD = [1 - (0.035)(14.5)]64 = 31.5 hp. On the other hand, if the propeller is repitched so that the engine can turn 5,400 rpm at the same density altitude, then P = 76 and PD = [1 - (0.035)(14.5)]76 = 37.4 hp, an increase of 19%. That increase could be realized if the propeller was in-flight adjustable. Hence, such a propeller can be advantageous even if the engine is normally aspirated.

2.2 Turbulence

An important predictor of severe turbulence is the wind aloft just above the mountains. When that wind exceeds 25 kts, flying can be extremely dangerous since turbulence may invert the plane. If such winds are approximately (= plus or minus 30 deg) perpendicular to mountain ridges, then they produce mountain wave conditions and turbulence up to 100 miles downwind from the mountains. Hence, if winds above 25 kts are forecast, we should not fly near mountains, and if we are downwind from mountains, we should not approach them.

Another predictor of turbulence is the temperature lapse rate, measured in deg F/1,000 ft of altitude change. A lapse rate below 4 deg F/1,000 ft signals stable air. When the lapse rate rises beyond 4 deg F/1,000 ft, turbulence can be expected. The severity depends on how far the lapse rate is above 4 deg F/1,000 ft. For example, a rate of 6 deg F/1,000 ft

is associated with strong turbulence. We can anticipate potentially troublesome situations by computing the lapse rate as we climb. The formula for the lapse rate is

$$L = [TG - TA]/[A - G]$$

where

L = lapse rate in deg F/1,000 ft

A = altitude in 1,000 ft MSL

G = ground elevation in 1,000 ft MSL

TA = temperature at altitude A in deg F

TG = temperature at ground elevation in deg F

For example, if A = 9.5 (= 9,500 ft), G = 4.5 (= 4,500 ft), TA = 70 (= 70 deg F), and TG = 100 (= 100 deg F), then $L = [100 - 70]/[9.5 - 4.5] = 6$, and severe turbulence is present.

The turbulence induced by the lapse rate stops at the base of clouds. Hence, if cumulus clouds are sufficiently low and widely spaced to permit safe VFR above the clouds, we can elect that option for a much smoother flight. We must exercise caution, though. Cumulus clouds in mountainous areas may within minutes grow to a solid cover, so when flying above such clouds we should continuously monitor the situation and be prepared for a rapid descent below clouds that are closing up.

Certain cloud formations are telltale signs of strong turbulence. A rotor cloud, which is a small, round cloud downwind of and slightly higher than a mountain ridge or peak, indicates severe turbulence and must be avoided at all times. Lenticular clouds, which have the shape of a lens, by themselves indicate smooth airflow at the altitude of the clouds, but signal strong turbulence below them. Fuzzy, streaky, torn clouds above a ridge are a third indicator of severe turbulence. Cumulus clouds with veils below that do not extend to the ground send yet another message of strong turbulence. The veil is called virga and is rain that evaporates before reaching the ground. Virga clouds can turn into thunderstorms within minutes, so we should monitor them continuously.

Thunderstorms in mountainous terrain can be very violent. They typically produce extensive lightning, strong downpours, severe turbulence, and often hail. A respectful distance of at least 20, and preferably 30, miles should be kept.

A flight started early in the morning usually begins with a smooth ride. As the air warms and winds increase, turbulence sets in. Around noon, the turbulence typically has become so strong that the flight should be terminated. For the latest, we should stop at 1 pm. There are exceptions where the air is still smooth after 1 pm and where flying is still safe. But we should carefully consider winds, terrain, and weather before claiming that this unusual case is hand. If we miscalculate, then in the best of cases we have an uncomfortable flight. In the worst of cases, passengers toss their cookies, the flight becomes almost uncontrollable, and possibly metal is bent in an unintended termination.

2.3 Winds

When air moves up due to sloping terrain, say toward a mountain ridge, the air remains mostly smooth and provides an updraft. However, on the lee side of the ridge, the air becomes a turbulent downdraft with a rate of descent that may exceed the maximum climb rate of the plane. When planning the route, we should therefore take both the direction of the winds aloft and the terrain into account. If the route can be planned along the upwind side of a ridge, then the flight is smooth, and the updraft provides extra energy that can be converted into added speed. On the other hand, if the route by necessity is on the lee side of a mountain or ridge, we must fly at least 2,000 ft above the highest point of the terrain to avoid strong down drafts and turbulence.

We should never approach a mountain ridge at a right angle. If turbulence is encountered and we must turn back, then in the first part of the turn we get even closer to the ridge and thus into more severe turbulence, and possibly begin unplanned inverted flight. This dangerous scenario can be avoided by approaching the ridge at a shallow angle not exceeding 45 deg. If turbulence is encountered, we can turn away from the ridge without first getting closer.

We should avoid flight in valleys since by definition this moves us well below the surrounding mountain ridges. But sometimes that is not an option. For example, we may have to enter a valley to approach an airport. In that case, we should always stay near the mountain ridge that forces the wind up, and should avoid the center of the valley as well as the ridge with the downdraft. It is clear why we should avoid the ridge with the downdraft, but why should we shun the center of the valley as well? If we fly there, we do not have a good look at the valley below for emergency landing sites, and we may have difficulty turning if unexpected turbulence forces us to do so.

2.4 Restricted Areas and Military Operations Areas (MOAs)

Restricted areas are off-limit for general aviation, and we must stay clear of them at all times. In recent years, restricted areas have moved or changed shape, and a GPS radio with last year's or older database does not reliably indicate the current restricted areas. Hence, unless the database contains the most recent information, we can only use the sectional to identify and avoid restricted areas. A recent development are small, round restricted areas of 5-10 miles diameter. They contain tethered balloons. Entering such an area is likely to terminate the flight by collision with the balloon cable.

MOAs legally pose no restriction for general aviation. But when an MOA is "hot," that is, in use, we assume a great risk when entering it. The sectionals have rather imprecise information about MOAs, since they typically specify sunrise to sunset for certain days of the week as possible times of use. During those specified times the MOA may or may not be hot. We just cannot tell which is the case from the sectional. But we can get precise information from the nearest FSS.

Recently, sectionals have begun to provide contact frequencies for some MOAs that result in something akin to flight into C space. We declare the intentions, are assigned a transponder code, and follow the instructions of the military controller. We should make sure to request permission for any deviation from the assigned altitude or course. Just

telling the controller the entire planned route through the MOA at the first contact is not good enough. Another recent development are grey-shaded Special Military Activity areas. For transit, we must establish contact on the frequency listed on the sectional unless we desire to be mistaken for a drug runner.

2.5 Endurance

The legally required minimum endurance for day VFR, which is 30 min beyond the destination airport, is not even close to sufficient, due to the vagaries of mountain weather and winds. A good rule is 1 hr of fuel beyond the planned flight time, and 1 1/2 hrs if the route has few nearby alternate landing sites or if the weather is potentially unstable.

3. Landing

3.1 Turbulence

It is rare that the approach to landing does not encounter some turbulence. To minimize the effect, we should plan a comparatively steep descent to the destination airport. Such an approach also provides a good overview over the terrain near the airport.

3.2. Traffic Pattern

At uncontrolled airports in mountainous terrain, we should not expect pilots to adhere to the published traffic pattern. Instead, we should count on any pattern, on any entry, and even on use of runways in both directions. The key to a safe approach and landing is monitoring of the traffic frequency, repeated broadcast of our position, and watching, watching, watching for traffic. Even on the ground, we should announce all steps such as clearing the runway or taxiing across another runway, due to the topsy-turvy way runways are sometimes used.

3.3 Landing Speed

When the density altitude of the airport is high, the groundspeed during landing is well above the indicated airspeed. When in that situation a gust factor is added to the indicated airspeed due to shifting winds, the groundspeed at the moment of touchdown becomes even higher. Thus, slowing the plane down after touchdown may require an extended rollout. For example, suppose the density altitude of the airport is 9,500 ft. If the landing speed is 50 kts plus a 5 kts gust factor, then, according to the formula for TAS given in the next section, the indicated airspeed IAS of 55 kts represents a true speed $TAS = [1 + ((1.5)(9.5)/100)]55 = 63 (= 63 \text{ kts})$. Suppose we have a 10 kts headwind as we land. Then we touch down with a groundspeed of $63 - 10 = 53 \text{ kts}$. In contrast, a normal landing speed of 50 kts in smooth air, at sea level, and with a 10 kts headwind produces a groundspeed of $50 - 10 = 40 \text{ kts}$. Effectively, the normal landing groundspeed of 40 kts in smooth air at sea level has become 53 kts. Since the kinetic energy of the plane increases with the square of the groundspeed, the energy that must be dissipated during the rollout by the drag of the airplane and by the brakes, is increased by 76%. Thus, the rollout is much longer than usual.

4. Two More Formulas

Here are two additional simple formulas. They give reasonable estimates for the true airspeed and the course correction for crosswind. En route, we can compare the true airspeed with the groundspeed displayed by the GPS radio to get an idea how far forecast winds aloft differ from actual winds. The course correction formula comes in handy during flight planning.

4.1 True Airspeed

Up to 15,000 ft density altitude, true airspeed is larger than indicated airspeed by approximately 1.5% for each 1,000 ft of density altitude. The formula below expresses this relationship.

$$\text{TAS} = [1 + (1.5D/100)]\text{IAS}$$

where

TAS = true airspeed in kts

IAS = indicated airspeed in kts

D = density altitude in 1,000 ft

For example, if IAS = 95 (= 95 kts) and D = 10 (= 10,000 ft), then TAS = $[1 + ((1.5)(10)/100)]95 = 109$ (= 109 kts).

4.2 Crosswind Correction

The magnetic heading is the magnetic course plus or minus the course correction for crosswind. That correction, in deg, can be estimated as follows.

$$\text{CC} = \text{CW}/\text{K}$$

where

CW = crosswind in kts

K = factor depending on plane speed

(K = 2 for 100 kts; K = 3 for 150 kts, K = 4 for 200 kts)

For example, if the crosswind is CW = 10 (=10 kts) and the plane does 100 kts, then K = 2, and CC = $10/2 = 5$ (= 5 deg) is the correction for the crosswind.

This is the end of the summary. I have tried to cover the most important aspects of safe summer flying in mountainous terrain. But the summary is not complete: It does not tell about the excitement of an early morning takeoff from a mesa into a clear sky, with mountain tops tinged red by the first rays of the sun and with dark valleys below; does not speak of the peace and serenity of a midmorning flight across a majestic mountain range topped with snow. And does not even mention the great feeling of a slow descent into an airport nestled on a picturesque mountain side, with friendly FBO folks and fellow pilots just waiting for us to land and visit and talk. Talk about what? About flying, of course!