Mountain flying

How do I fly safely in mountainous regions?

1. Introduction

Mountain flying offers some of the most awe-inspiring vistas and challenging piloting experiences in aviation. The rugged beauty of the Swiss Alps, Jura or similar mountainous regions around the world demands respect, preparation, and skill. Pilots must contend with unique hazards such as erratic weather, constrained navigation, and the effects of altitude on aircraft performance.

This month's bulletin provides an in-depth exploration of mountain flying, covering essential topics like weather phenomena, navigation, aircraft performance, and specific techniques for takeoff and landing in challenging conditions. Alongside these, you'll find practical tips, rules of thumb, and proven techniques to enhance safety and proficiency in this demanding environment.

> **Recommended reading:** Eye-opening report of the Swiss Transportation Investigation Safety Board on the crash of a Piper 28A in the Simplon Pass on 25 August 2019 [https://www.sust.admin.ch/inhalte/AV-berichte/G-BVDH_SB_e.pdf]

2. Aircraft performance

A crucial consideration in high-altitude operations is density altitude, which is pressure altitude corrected for nonstandard temperature. High temperatures and elevations increase density altitude, degrading aircraft performance. The physics behind this is simple: lift is directly proportional to air density, which depends on the number of air molecules in a given volume. Denser air, with more molecules packed into the same space, increases the interaction between the wing's surface and the air, generating greater lift. Similarly, for propeller-driven aircraft, denser air allows the propellers to produce more thrust by displacing a larger mass of air with each rotation. Most engines of G/A aircraft will lose power with increasing altitude.

For instance, Addis Ababa, Ethiopia (code HAAB, elevation 7,600 feet) poses a greater challenge than Sion (code LSGS, elevation 1,500 feet), as the hotter air at Addis Ababa further thins the already low air density. This is why high-altitude airfields often have longer runways (e.g. 3800m in HAAB). Cooler air in LSGS, by contrast, contains more molecules per unit volume, improving lift and engine performance relative to HAAB.

How different engine types are affected

The performance impact varies depending on the type of engine powering the aircraft.

Each aircraft and engine configuration brings forth its own advantages and risks when it comes to high-altitude performance. It is of utmost importance that you study documentation and are well familiar with the capabilities of your aircraft before flying. The PTD is only able to provide you with a general guide.

Let's break down how piston, turboprop, and jet engines behave in high-altitude conditions:

Piston Engines

Piston engines, particularly non-turbocharged ones, rely directly on atmospheric pressure to function. This means that as the altitude increases and air pressure drops, the density of air drawn into the engine decreases, leading to a reduction in power output. At higher altitudes, this power loss is significant, and climb rates are reduced. Non-turbocharged piston engines are particularly affected by this because they don't have the ability to compensate for the decreased air pressure.

Turbocharging – If the piston engine is turbocharged and you have the ability to do so, leverage the system to maintain power output. Be mindful of engine limitations and stay within the recommended operational ceiling for turbocharged engines.

Lean the mixture when able – As you climb higher, adjusting the fuel-air mixture is essential. This helps optimize engine performance by reducing excess fuel, which compensates for the thinner air.

Consider climb limitations – Expect reduced climb rates, especially in non-turbocharged engines. At high altitudes, consider performing a short-field takeoff even when the runway seems long enough, as the reduced engine power will affect your ability to accelerate and climb effectively in thin air. It is recommended to use the remaining runway length to fly over with a very gentle climb to accelerate sufficiently such that afterwards, climb performance is optimized due to greater lift. Beware of tall obstacles past the runway end.

Turboprop Engines

Turboprop engines are generally more suited to high-altitude operations than piston engines. While turboprops still experience a loss of power with altitude, they have a compressor, helping maintain a more consistent power output by compressing the thinner air at higher altitudes.

Takeoff technique – Like with piston engines, practice short-field takeoffs, but expect a slightly better climb performance due to the power-boosting effect of turbocharging.

Jet Engines

Jet engines are far less affected by altitude in terms of power loss. This is because jet engines use powerful compressors to compress air before it enters the combustion chamber, so they are not as reliant on ambient air pressure. As altitude increases, the engine continues to perform effectively, albeit with a slight reduction in efficiency at extreme altitudes. However, high-altitude performance is less of a concern for commercial jets, as they are typically designed for cruising at altitudes between 30,000 and 40,000 feet, where air is thin, but the engines are optimized for that range.

3. Weather hazards

Weather is often the most significant challenge in mountain flying, with rapid and unpredictable changes caused by the interaction of terrain and atmospheric conditions.

Mountain waves and downdrafts

When strong winds blow perpendicular to a mountain range, they generate mountain waves. These waves can lead to severe turbulence, downdrafts, and even altitudes where airspeed feels erratic due to rotor effects.

Cause: Air forced upward on the windward side descends violently on the leeward side.

Hazardous areas: The strongest downdrafts occur just leeward of ridges, where they can exceed the climb capability of most small aircraft.

Depending on meteorological conditions, a variety of dangerous phenomena occur as illustrated on the right. As it is often difficult to predict which of these (a, b, c, d) to expect, one must always exercise full caution.

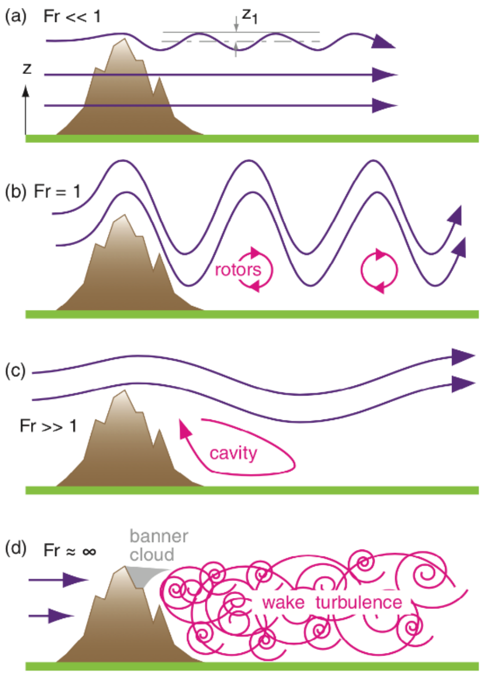

Figure: mountain wave formation
(Source: University of British Columbia)

<u>How to deal with mountain waves:</u>

- If it is necessary to fly over peak tops, maintain at bare minimum 1000ft AGL.
- Cross ridges at a 45-degree angle to allow for a safer retreat in case of an unexpected situation.
- If caught in a downdraft, increase airspeed slightly and avoid steep climbs; instead, aim to exit the downdraft laterally.

Turbulence and Wind Shear

Mountain terrain disrupts airflow, creating unpredictable turbulence, especially in narrow valleys. Wind shear, caused by abrupt changes in wind speed or direction, is particularly dangerous during takeoff, climb, and landing.

<u>Mitigation strategies:</u>

- Fly at or below manoeuvring speed (Va) of your aircraft in turbulent conditions to minimize stress on the airframe.
- A rule of thumb for most light single-engine aircraft in mountainous areas: Avoid flying where winds exceed 20 knots, especially perpendicular to ridges.
- Once you have crossed a ridge, turn directly away from it at a 90-degree angle to get away from the most likely area of turbulence quickly.

Icing Conditions and Pitot heat

Cold, moist conditions in mountainous areas often lead to in-flight icing, which can severely reduce lift and control. Ice accumulation on critical surfaces like wings and control surfaces disrupts airflow, reducing lift, increasing drag, and making the aircraft harder to control. Another critical concern is ice formation in the pitot tube, a vital component of the aircraft's instrumentation.

The pitot tube is a small, forward-facing device that measures the dynamic air pressure caused by the aircraft's movement through the air, determining airspeed. If the pitot tube becomes blocked by ice, the airspeed indicator may provide incorrect or erratic readings, leaving pilots unaware of their true speed —dangerous by possibly resulting in a pilot-induced stall, especially in mountainous terrain or during instrument conditions.

Pitot heat tips:

- Turn on pitot heat before entering visible moisture in temperatures below +5°C.
- Monitor electrical loads when using pitot heat, especially in smaller aircraft.
- If noticeable icing is encountered, descend to warmer air or divert to safer conditions immediately.

Rapid weather changes

Mountain weather can completely change in a matter of minutes due to the interaction between terrain and atmospheric conditions. As moist air is forced upward over mountains (orographic lifting), it cools and condenses, forming clouds and precipitation that can quickly develop into snow showers or thunderstorms. Uneven heating of slopes during the day creates localized temperature gradients, generating unpredictable winds and turbulence. Additionally, valleys can trap cold air, while ridges funnel stronger winds, intensifying conditions. These factors combine to produce sudden and dramatic shifts in weather, making vigilance essential for safe mountain flying.

Planning for rapid changes:

- Always carry enough fuel for an alternate airport with safer weather conditions. Keep in mind the importance of optimising aircraft performance and not overloading the fuel tanks to the point where the increased load means steep climb gradients are impossible to obtain. You can always plan for a fuel stop at an airport on the way!
- Monitor weather updates en-route. If visibility deteriorates, execute a 180-degree left-hand turn at a key point where it is feasible.
- Familiarize yourself with valley-specific weather patterns; for example, katabatic winds often occur in the early morning or late afternoon, creating sudden gusts. Consult weather and wind charts to better assess the direction and strength of the winds.

GAFOR

GAFOR (General Aviation Forecast) weather forecasts in Switzerland are along pre-defined routes (which can be found in Skyguide's [Swiss VFR Manual]), focusing on visibility and cloud ceilings along valleys and passes for safe navigation.

Each route is identified by a number and a reference height, representing the highest terrain or obstacle along the route in feet above mean sea level (AMSL).

GAFOR uses a four-letter code to indicate VFR conditions:
O (Open): No significant restrictions (visibility ≥ 8 km, ceiling ≥ 2,000 ft).
D (Difficult): Limited visibility (5–8 km) and/or ceiling (1,500–2,000 ft). Experienced pilots may proceed with caution.
M (Marginal): Poor conditions (2–5 km visibility and/or 1,000–1,500 ft ceiling). Only highly trained pilots familiar with the terrain should fly.
X (Closed): VFR is impossible (visibility < 2 km and/or ceiling < 1,000 ft).

Whilst GAFOR is paid and mainly used IRL, if you are subscribed to software such as *SkyBriefing* or *ForeFlight*, it is highly recommended that you consult the forecast there, even for flights in the simulator.

4. Navigation and flying techniques

Charts and weather analysis

Before flying, check charts and weather to confirm whether your destination airport has instrument procedures or requires a visual approach. Be aware that deteriorating weather could make landing impossible at visual-only airports.

Airspace classifications in mountain regions

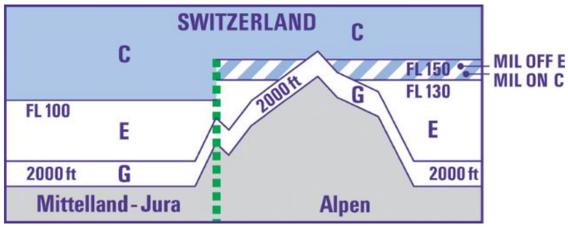

Figure: general vertical airspace structure
(Source: ICAO Chart Switzerland)

In Switzerland, mountainous areas often feature Class G or E airspace, which allows for flexible VFR operations but places responsibility for separation squarely on the pilot. Controlled airspace boundaries can vary with altitude in mountainous regions, with Switzerland's special case illustrated on the right. Always consult charts to avoid unintentional airspace infringements. Note that on VATSIM, we simulate a MIL OFF configuration. Restricted or danger areas may exist around ski resorts, wildlife zones, or due to special high-risk VIP events (e.g. World Economic Forum). Check NOTAMS and DABS prior to flight.

Mountain landing sites

In the Swiss Alps, there exist many 'mountain landing sites', defined as landing sites outside of aerodromes and without infrastructure that are located at more than 1,100 metres ASL. Visiting one of these can be a fun way to diversify your flying! Find a list and map of these here.

Recommended North-South Alpine crossing routes

As stipulated by Skyguide in the Swiss VFR Manual, crossing the Alps in a N-S direction and vice-versa is to be planned in such a way that the shortest route over inaccessible terrain is taken.

The following main routes are prescribed as 'recommended' if weather is good:
a) Zurich - Lake Lucerne - Reusstal - Andermatt - Gotthard Pass - Val Leventina - Locarno;
b) Bern - Spiez - Kandersteg - Gemmi Pass - Visp - Brig - Simplon Pass - Domodossola;
c) Altenrhein - Sargans - Chur - Lenzerheide - Julier Pass - Samedan.

Climbing with a changing horizon – a danger to situational awareness

The horizon is the line where the land or sea appears to meet the sky and is a key reference for aircraft control. In clear skies and over flat terrain or the sea, it is usually well-defined. However, in mountainous areas, the horizon may not be clear, requiring you to visualize its position and adjust the nose attitude accordingly. The lower you are relative to the terrain, the harder it is to establish the horizon, especially during climbs with limited forward visibility. As you approach higher terrain, the horizon may appear to rise in the windscreen, leading to subconscious back pressure, loss of airspeed, or even a stall if distracted. To reduce risk, climb as high as possible well before reaching the terrain and carefully manage your climb attitude.

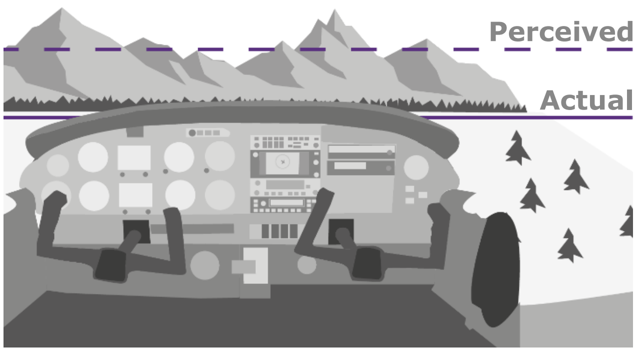

Figure: perceived vs actual horizon positions
(Source: UK CAA Mountain Flying Safety Handbook)

When commencing a climb, follow the process:

1. Power – select the correct power for climb;
2. Attitude – select the climb attitude, verify the correct airspeed;
3. Trim – trim the aircraft so that the attitude and speed remain stable.

As you climb, aircraft performance will gradually reduce, so the nose attitude will have to be periodically lowered and retrimmed to maintain a safe airspeed.

Low sun – a danger to situational awareness

Flying toward a low sun surrounded by high terrain can be hazardous, as it reduces depth perception and obscures potential dangers ahead. When planning your flight, check sunset times and account for the sun's position along your route. If low sun interferes with visibility, climb to a safer altitude to stay above obstacles in the area.

Alpine passes

In the Alps and other mountain ranges throughout the world, there exists a series of recommended predefined 'pass' routes to fly between many valleys. You will find these on the ICAO Chart Switzerland. You should reach the published altitude (e.g. 9200ft for the Gemmi Pass as seen on the right) to cross an alpine pass prior to flying into the valley leading to that pass (unless the valley is long and shallow, where this is not necessary). Monitor your heading once following the routing and cross-reference with charts, as it is easy to accidentally fly into the wrong valley given how many there are! One must be prepared for the worst, as adequate emergency landing spots are few and far between on such uneven terrain. As you approach the pass, do so at a 45-degree angle if it allows so that you have the option of more easily reversing course back to the side of the pass you came from. You should always keep your airplane in a position to easily turn towards lower terrain. Ensure that you are always at least 1000ft AGL during the crossing (2000ft+ recommended).

Alternate Airports and Escape Routes

Always plan for alternates and escape routes. Make note of key points in valleys with sufficient width where you would be able to comfortably turn around in case this is needed. Familiarize yourself with en-route terrain and airspace restrictions to avoid becoming trapped in deteriorating conditions. You should be able to visualise the route you plan to fly and the terrain you'll see outside the cockpit prior to your flight.

Valley navigation

Navigating valleys demands precision, especially when weather or terrain limits visibility. Many accidents occur when pilots push into deteriorating weather without a clear escape route.

Key techniques:

- In narrow valleys in Switzerland, always fly on the right-hand side (following standard valley circulation patterns) to maintain visibility of oncoming traffic. Avoid flying too low to allow room for maneuvering – remember that a valley gets wider the higher you are.
- Maintain visual contact with the valley exit or next key position where you are able to turn around. Remember that this should always be a left-hand turn.
- Avoid valleys where the terrain rises faster than your aircraft's climb rate unless at sufficient altitude. Ideally, already enter the valley at sufficient altitude to exit on the other side.

Turns in a valley

All turns in a valley must be left-hand turns. Consider your airspeed and ground speed – higher airspeeds result in larger turn diameters at the same bank angle. For example, at 100 knots with a 30-degree bank angle, the turn diameter is about 0.5 NM, while reducing the bank to 15-degrees doubles the diameter to approximately 1 NM.

Slowing down reduces the turn radius but make sure to maintain a safe margin above stall speed, noting that stall speed increases with bank angle. Wind also affects turn size: turning into the wind decreases the diameter, while turning downwind increases it, which can bring you closer to terrain.

Before and during manoeuvring in a terrain confined area, ensure you have:

- Adequate airspeed
- Safe separation between the aircraft and terrain (position yourself to the very right of the valley prior to commencing the turn)
- Slip ball central, avoiding too much 'into turn' rudder

We all love wingviews… but you've got to be careful in the mountains!

When manually controlling the aircraft, looking out to the side instead of forward can lead some pilots to instinctively level the wings parallel to the sloping terrain, as they might over flat land. This instinct can be dangerous, especially when flying in a valley where maintaining proper bank and alignment with the valley axis is critical. Stay focused and aware!

Avoid over-reliance on 'moving maps' – a danger but also tool if used wisely!

Flight simulation software like *Navigraph* or *Volanta* encourages reliance on 'moving maps'. While useful, these tools can create dangerous habits in mountain flying. If you lose situational awareness, excessive map reference delays decision-making, increasing the risk of CFIT (controlled flight into terrain), particularly in marginally adequate visibility or with unfamiliar visual approach procedures.

Knowing where you are on a 'moving map' ≠ adequate situational awareness for safe VFR.

Nevertheless, if your aircraft is equipped with GPS and a terrain radar, these can be incredibly useful as being a secondary tool to confirm whether what you think you're seeing outside is indeed the case and keep track of the terrain around you for situational awareness.

Switching between IFR/VFR mid-flight

While most scenic mountain flying occurs under VFR, you might wish to switch to IFR mid-flight (obviously, only if the aircraft is IFR-equipped) for a variety of reasons such as deteriorating weather conditions. In such cases, the pilot should contact ATC, request an IFR clearance, and follow the assigned routing and altitudes. Pilots should remain in VMC until the flight has been changed to IFR conditions and the IFR clearance is issued to ensure safety.

Similarly, when departing from an uncontrolled airport without ATC services under VMC, a pilot with a filed IFR flight plan can take off under VFR and contact ATC once airborne to activate the IFR clearance. The pilot must ensure they remain in VMC before their IFR routing starts.

Below is an example of phraseology for a VFR to IFR transition:

HB-ABC	SWISS RADAR, HB-ABC, REQUEST IFR CLEARANCE TO (destination) DUE TO WEATHER. CURRENTLY AT (location), (altitude), VFR.
ATC	HB-ABC, SWISS RADAR. PROCEED (direction (significant waypoint/landmark)/(cardinal direction)/along (river/highway/railroad)], [REMAIN (OUTSIDE/BELOW) TMA], REMAIN VMC, SQUAWK (TRANSPONDER CODE).
HB-ABC	– *READBACK* –
ATC	HB-ABC, IDENTIFIED, CLEARED TO (destination) VIA (waypoint/navaid/radar vectors), CLIMB TO (altitude/flight level), IFR STARTS (WHEN PASSING (altitude/flight level)/AT [(distance) NAUTICAL MILES TO/FROM] (waypoint/navaid)/IN (distance) NAUTICAL MILES).
HB-ABC	– *READBACK* –

Note that ATC might not have the time in high traffic situations to find you a valid routing. It is then your responsibility to find a valid route and coordinate with the ATCO to get a clearance for it.

The reverse principle applies when transitioning from IFR to VFR. For instance, if landing at an airport without instrument procedures, the pilot must cancel IFR once the flight is in VMC and continue visually. Note: on VATSIM, you can file an IFR flight plan to a visual airfield so long as the change to VFR occurs before the last filed waypoint on the IFR route. This transition must be coordinated with ATC, ensuring separation from other air traffic and compliance with local airspace requirements.

Below is an example of phraseology for an IFR to VFR transition:

HB-ABC	SWISS RADAR, HB-ABC, REQUEST CANCELLATION OF IFR. CONTINUING VFR [TO (destination)].
ATC	HB-ABC, SWISS RADAR. IFR CANCELLED AT TIME (GMT TIME), [PROCEED VFR (DIRECTION (significant waypoint/landmark)/(cardinal direction)/ALONG (river/highway/railroad))], [DESCEND (BELOW TMA) APPROVED].
HB-ABC	– *READBACK* –
ATC	HB-ABC, RADAR SERVICE TERMINATED, SQUAWK (VFR/7000), FREQUENCY CHANGE APPROVED.
HB-ABC	– *READBACK* –

Note that you might be sent over to a frequency with flight information services.

When and how to abort a flight

A particularly difficult situation for most pilots to deal with is weather that deteriorates enroute in an aircraft which is not IFR-equipped. The urge to continue is very strong, with the thought that it will get better if we just continue a little farther. However, continuing is often the worst thing you can do. If inside a valley, you should never proceed further than the next safe key turnaround point where the weather is still adequate. Therefore, if you have followed this rule, you should be able to safely divert by making a left-hand 180-degree turn and tracking your path backwards. Evaluate your options early. Flight planning should have included alternate routes or airports; divert to one of these or return to your departure airport. If there is a sudden loss of visibility or formation of low cloud cover at the bottom of a valley, evaluate whether you can climb to cross a ridge into a neighbouring valley with better conditions. If no other options remain, consider making an off-airport landing while still having enough visibility to choose a safe site. Landing under control is always safer than continuing into poor weather and risking a crash into unseen terrain.

Dealing with an engine failure

In the event of an engine failure, the primary goal is to maintain control of the aircraft. Immediately lower the nose to establish the best glide speed and keep the wings level to prevent a stall. Always prioritize flying the aircraft. If you are high up, use your altitude to your advantage – you have a great gliding distance relative to the base of the valley. Once stable, turn towards lower terrain to increase your chances of a safe landing, ideally selecting a site at the base of the valley near open fields, roads, or any clearings. If unable, consider landing on a slope; landing uphill can reduce ground roll and minimize the risk of falling off an embankment or cliff. If you're near forested areas, avoid the dense treetops; a clearing or less densely vegetated area is preferable. Although on VATSIM, ATC may not be able to assist, it's still worth trying and broadcasting your intentions. Beware that you might be asked to disconnect from the network. Prepare for a controlled landing, adjusting your aircraft's configuration as necessary. Always be aware of the terrain and prevailing winds and approach the landing site cautiously. Do not extend flaps (and gear if applicable) prematurely to avoid added drag unless absolutely required. Remember, aircraft-specific procedures for engine failure are crucial, so it's important to know your aircraft's emergency procedures and be prepared to adapt to the terrain and conditions. Each situation is different. Pre-flight planning should include identifying potential forced landing sites in the event of an engine failure. Throughout your flight, also look out for potential landing sites.

5. Operational techniques for runway challenges

Landing and takeoff on icy runways

Winter operations in mountainous regions often involve icy or snow-covered runways, reducing braking and directional control. Beware of black ice, which can be difficult to spot. Apply brakes gently and use rudder rather than the nose wheel (if able) for directional control.

Flying ski-equipped aircraft

Landing on snow in special mountain landing sites requires special considerations for pilots interested in ski-equipped operations.

Tips for snow landings:

- Perform a low pass over the landing area to inspect snow conditions and identify obstacles.
- Land with minimal vertical speed and pull slightly back on the yoke once contact with the snow has been made to ensure the skis stay above the surface.
- Be prepared for reduced acceleration during takeoff due to the drag from snow.

Fly prepared, fly safe, and let the mountains inspire you.

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