EHEST
Component of ESSI
European Helicopter Safety Team

Techniques for Helicopter Operations in Hilly and Mountainous Terrain

FOR HELICOPTER PILOTS AND INSTRUCTORS

TRAINING LEAFLET

HE 7

CONTENT

INTRODUCTION

The helicopters ability to transit through, manoeuvre, land and take off from hilly or mountainous terrain is one of the most demanding aspects of helicopter operations. Pilots at some stage are likely to experience this challenging environment and require an understanding of the basic principles, threats, errors and the possible undesirable aircraft states, in order to operate safely.

Whilst the terrain can vary in its topography, hazards, elevation and prevalent weather, the same basic techniques should be utilised. Flying in hilly or mountainous terrain is particularly demanding and has resulted in a number of helicopter accidents.

It should be noted that this leaflet only describes the basic techniques to be employed in hilly or mountainous terrain and a pilot who intends to operate in this environment is strongly recommended to receive a ground brief and flight training from an appropriate flight instructor before attempting to do so.

1. PLANNING AND PREPARATION

The basic principles of planning and preparation as outlined in the EHEST HE 3 Off Airfield Landing Site Operations leaflet still apply. However operating in hilly and mountainous terrain, requires extra planning considerations which are highlighted below in a 'MATED' brief.

Met - As the site is likely to be remote from an airfield with the associated met facilities, the pilot will be required to interpolate the information provided in the synoptic charts, TAFs and METARS. However, it must be noted that hills and mountainous terrain can create their own micro climates in which the weather may deteriorate rapidly. Wind speed and direction is influenced by the terrain and special attention should be paid to identifying the local wind conditions, especially for any sign of up-draughts and down-draughts. Clouds can form quickly on both hill tops and valley bottoms and pilots must learn to recognize the clues to weather given by cloud formations such as lenticular and rotor clouds.

Aircraft - Take-off mass, centre of gravity (CG), and performance calculations will be required for the arrival and departure from a landing site (LS), especially if there is a difference in elevation and cargo or passengers are been picked up or dropped off. It is essential to calculate the density altitude (DA) at which the aircraft will be operating as this will have an effect on aircraft performance; higher density altitudes can reduce the power margin dramatically. The Rotorcraft Flight Manual (RFM) will indicate the relevant power margins, hover in ground effect and hover out of ground effect ceilings, minimum and maximum speed and pitch settings. Helicopters operating at a high DA will generally be flown at higher pitch settings and therefore higher angles of attack. This will result in reduced control response consequently flying with reduced margins with regards to the dangers of retreating blade stall, vortex ring and Loss of Tail rotor Effectiveness (LTE).

ATC - Whilst any airfield information and NOTAMs for en-route/diversion/departure airfields will be available through the normal channels, information on LSs may need further research and landing permission. Radio communication in mountainous terrain may be difficult and/or intermittent and therefore consideration should be given to establishing a flight following system. Always file a flight plan whenever operating over inhospitable terrain or notify somebody of your intended route and operating area.

Exercises - A flight (regardless of an intended landing) into hilly and mountainous terrain will require the pilot to be proficient at the skills associated with off-airfield landing techniques, advanced transitions, limited power and out of wind operations. Knowledge of the special techniques for operating / transiting / landing in valleys, bowls, ridges and pinnacles outlined in this document is essential.

Duties - Although the flight can be conducted as a single pilot operation by a pilot experienced in hilly and mountainous terrain operations, it is strongly recommended for the inexperienced pilot to initially undertake dual training and wherever possible fly with a second crew member. This is especially important as the pilot may encounter negative physiological and psychological effects he has not encountered before, e.g.:

Hypoxia	–	a lack of oxygen, which is difficult to identify in oneself and can lead to over confidence and a lack of judgment.
Spatial Disorientation	–	being surrounded by high mountains and flying over deep valleys can disorientate a pilot.
Visual Illusions	–	lack of horizon, false horizon, white out and grey out, lack of depth perception which can lead to disorientation.
Apprehension	–	nervousness due to lack of experience in the environment can lead to nervousness indecision and over-controlling.
Fatigue	–	mountain flying can be very mentally and physically tiring.

Note 1: Survival equipment and or emergency supplies should be carried when flying over inhospitable terrain in the event of a precautionary or forced landing. Consideration should be given to a means of communication, water, warm clothes, fire-making, a means of attracting a search aircraft. It should not be assumed that a stranded aircraft and crew will be quickly or easily located.

Note 2: Be aware that a GPS is merely an aid to and not a replacement for your navigation skills. A route indicated by the GPS might be inappropriate in hilly or mountainous terrain as the GPS does not recognise areas of turbulence or an appropriate flight path.

2. WEATHER

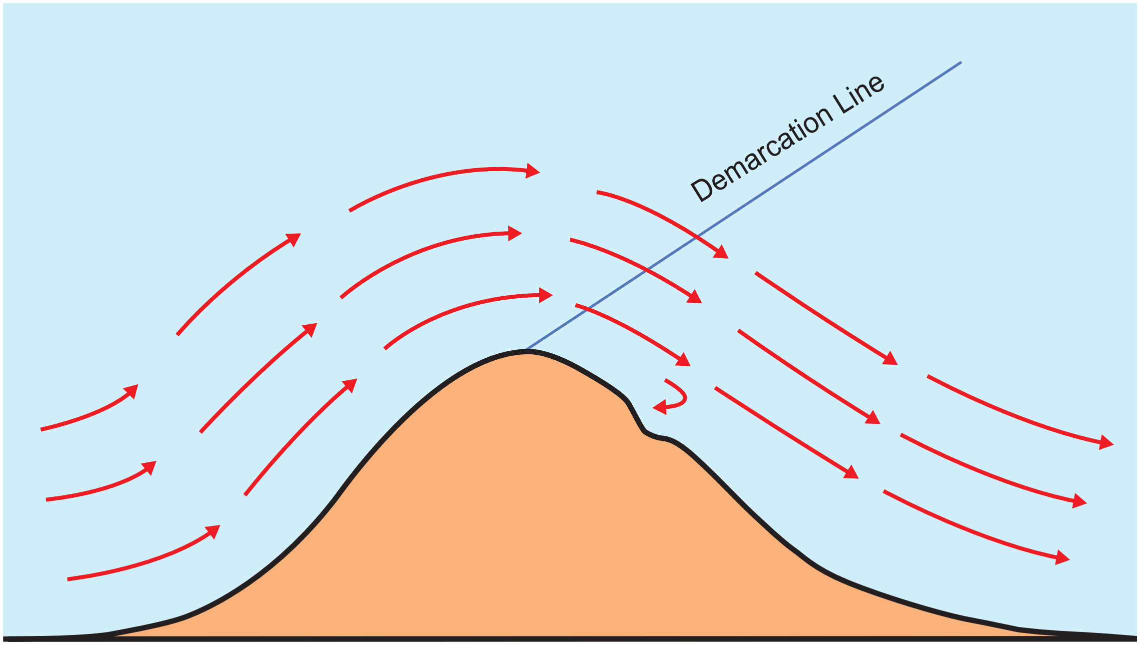
2.1 Wind

An awareness of the wind speed and direction is critical in the hills and mountainous terrain because it follows the surface. If the ground rises, the wind flows upward on a slope and it is referred to as the 'windward' side. If the ground slopes away from the wind direction, the wind flows downwards and is referred to as the 'leeward' side. When wind flows over smooth hills and mountains it tends to flow smoothly. When it flows over a cliff it tends to tumble over the edge in a turbulent manner. When it is forced through a gap i.e. along a valley then the speed is increased due to the Venturi effect.

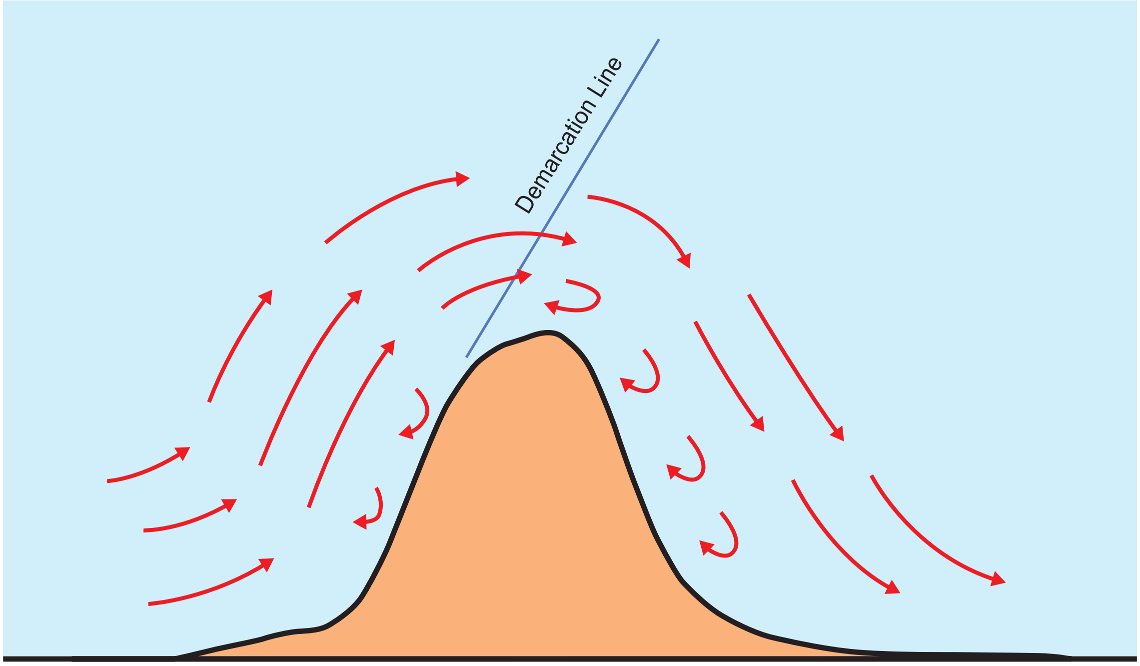
On a windward slope turbulence rarely exists and the resulting up-draughts can be beneficial in producing lift and therefore requiring less power to manoeuvre. As a result the windward slope with up-draughts is preferable to operate in whenever possible.

On a leeward slope there is generally turbulence and down-draughts that can make flight hazardous and should be avoided.

The area where the up-draught turns to a down-draught is referred to as the 'demarcation line'. The demarcation line between up-draughting and down-draughting air will, typically, become steeper and move towards the windward edge of the feature as wind speed increases.

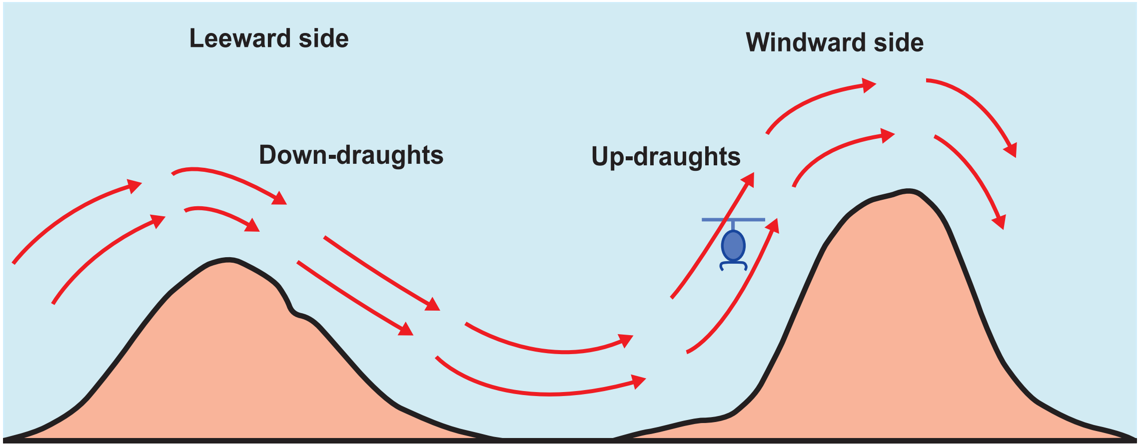


Light Wind Flow



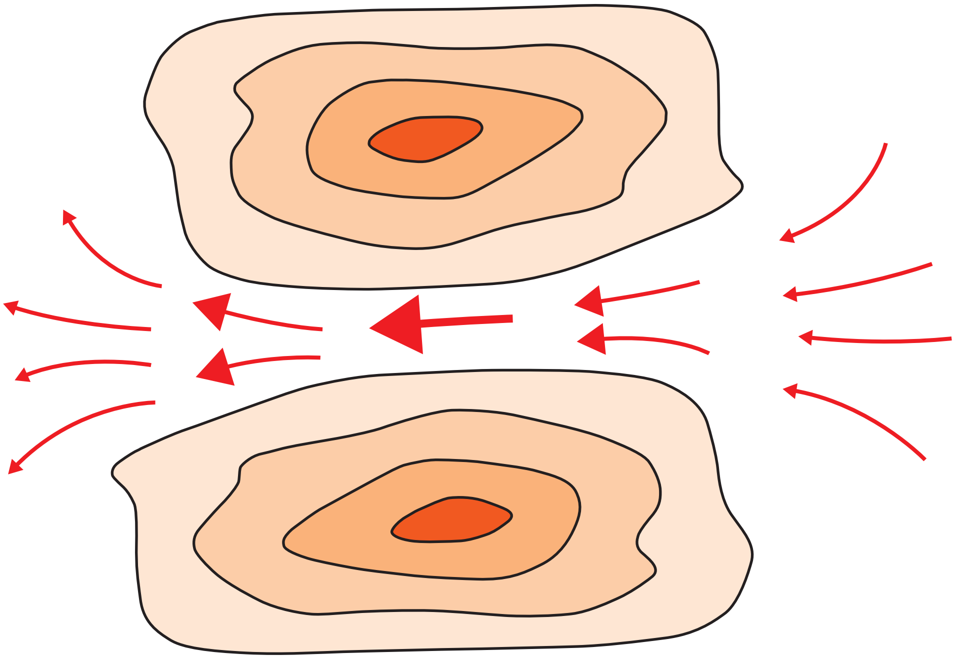
Strong Wind Flow Across Craggy Obstacle

When flying along a valley it is preferable to fly closer to the windward slope to take advantage of the up-draughts, rather than down the centre of the valley. The leeward slope should be avoided because of down-draughts and potential loss of lift.



Flying along a valley

The Venturi effect in valleys can cause a significant increase in wind speed possibly doubling the normal wind speed. This phenomenon is also accompanied by a decrease in pressure, which can cause the altimeter to over read the altitude at which the aircraft is flying.



Wind Venturi effect

Estimating the local wind speed and direction in hilly and mountainous terrain is difficult, however is essential and can be achieved by using the following techniques:

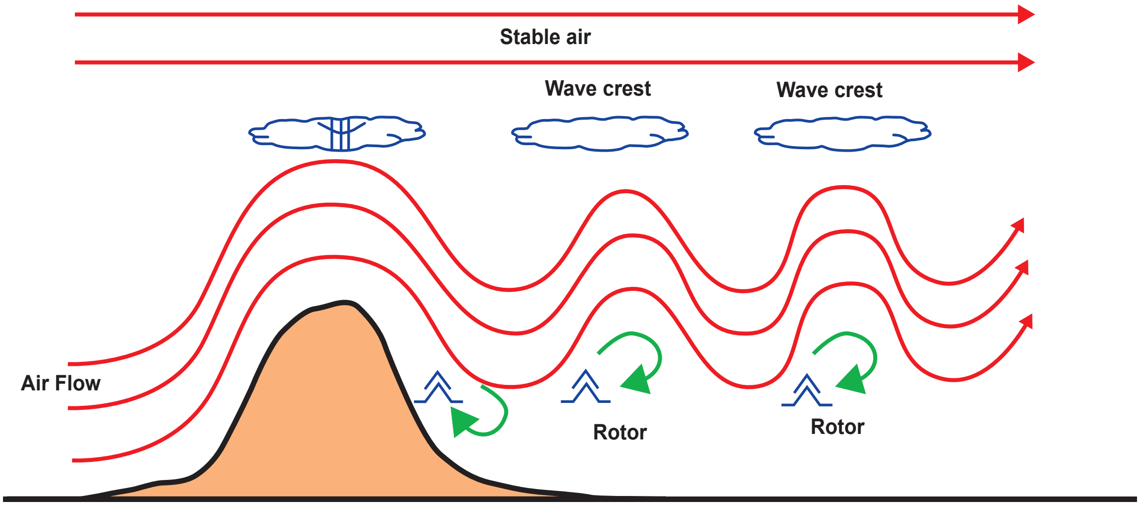
- Smoke
- Wind farms
- Wind lanes on lakes (smooth surface on the up-wind side of the lake and waves on the down-wind side)
- Vegetation, long grass, tree movement
- Cloud movement
- Fly a 360° turn around a ground reference at a safe height whilst maintaining a constant angle of bank and speed. The resultant drift will indicate the wind direction and strength.
- Comparing groundspeed to airspeed, visually over the ground or by use of GPS.

2.2 Clouds and Mountain Wave

Mountain Waves are defined as oscillations to the lee side (downwind) of a mountain caused by the disturbance in the horizontal air flow caused by the high ground. The wavelength and amplitude of the oscillations depends on many factors including the height of the high ground above the surrounding terrain, the wind speed, and the instability of the atmosphere. Formation of mountain waves can occur in the following conditions:

1. Wind direction within 30 degrees of the perpendicular to the ridge of high ground and no change in direction with height.
2. Wind speeds at the crest of the ridge in excess of 15 kts, increasing with height.
3. Stable air above the crest of the ridge with less stable air above and below that stable layer.

Vertical currents within the oscillations can reach 2,000 ft/min. The combination of these strong vertical currents and surface friction may cause 'rotors' to form beneath the mountain waves, resulting in severe turbulence.



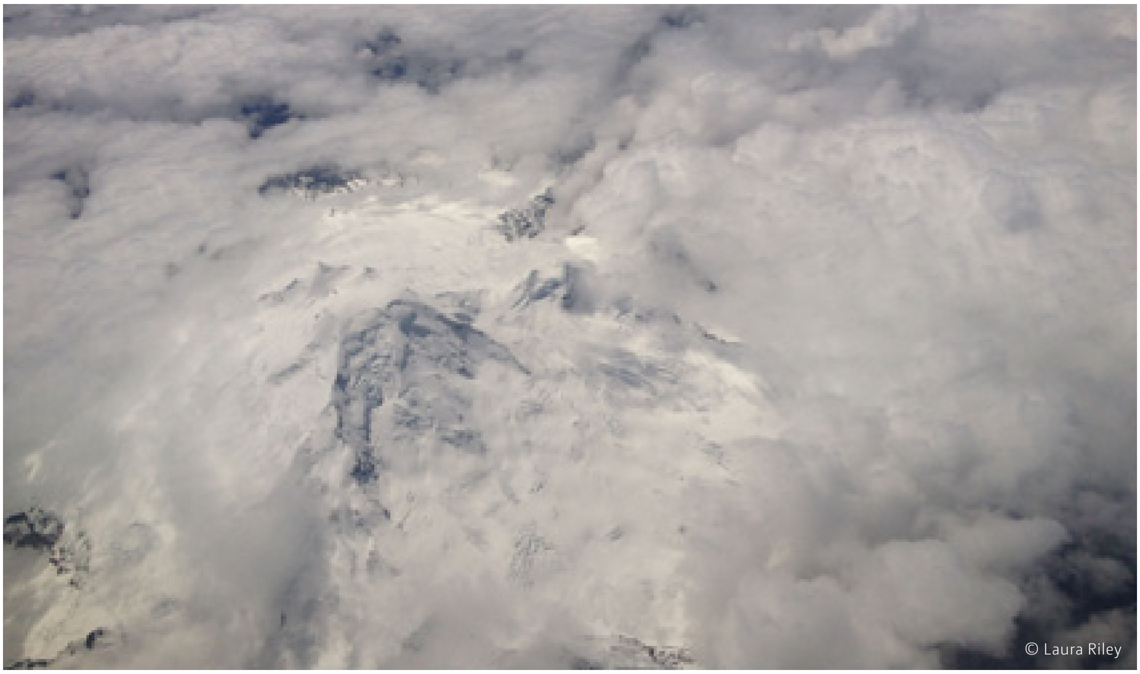
Rotor effects and mountain waves

Mountain Waves are associated with severe turbulence, strong vertical currents, and icing. The vertical currents in the waves can cause significant fluctuations in airspeed potentially leading, in extremes, to loss of control. Loss of Control can also occur near to the ground prior to landing or after take-off with a risk of terrain contact or a hard landing if crew corrective response to a down-draught is not prompt.

Severe icing can be experienced within the clouds associated with the wave peaks.

Local knowledge of the conditions which tend to cause the formation of mountain waves enables forecasting of potential wave propagation. Lenticular Clouds (lens shaped clouds) can form in the crest of the mountain waves if the air is moist. Roll Clouds can also occur in the rotors below the waves if the air is moist. These clouds are a good indication of the presence of mountain waves but, if the air is dry, then there may not be any cloud to see.

Cloud formations



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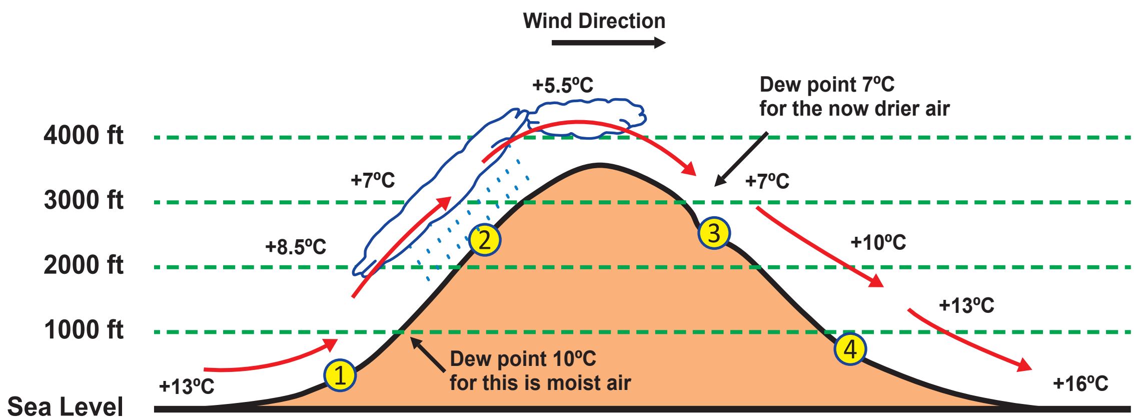
2.3 Föhn Effect

Föhn Effect is a warm dry wind that blows down the lee side of a mountain. When a large air mass is forced up and over a mountain range (Orographic Lift), clouds and precipitation form as the air rises and cools adiabatically. When the air mass reaches the top of the mountain it has lost a significant amount of its water content and so has a much lower dew point. As the air then begins to descend down the lee slope of the mountain, and the air pressure increases, it warms adiabatically. The resultant wind is dry and warm giving clear conditions at airfields on the lee side of the mountain range. As well as creating a warmer climate, these dry winds can be a cause of wild fires during the summer months which may affect flying operations.

Another effect is that a pilot approaching from the leeward side of a mountain can only see the silhouette of the top of a cloud, but he cannot see the full extent of the cloud on the windward side.



Föhn effect

1. Air cools at 3ºC / 1000 ft until saturated, then cools at 1.5ºC / 1000 ft[1] until the top of the mountain is reached

2. Precipitation removes moisture from the air

3. Air warms, quickly becoming unsaturated, at rate of 3ºC / 1000 ft

4. Air on leeward of mountain is drier than the windward side and has a lower dew point

[1] The Saturated Adiabatic Lapse Rate (SALR) is a variable but typically falls between 1.5 and 1.8 °C/1000 ft.

2.4 Cumulonimbus Cloud

Cumulonimbus clouds and other clouds of vertical development typically produce heavy rain and thunderstorms, especially when the air is forced up due to Orographic Lifting. The cumulonimbus convection currents produce strong and unpredictable winds particularly up-draughts and down-draughts which are extremely dangerous and aircraft should avoid flying in the vicinity of a cumulonimbus cloud.

2.5 Turbulence

In mountainous areas turbulence is often encountered. This can either be mechanical turbulence (due to the friction of the air over uneven ground at low levels), or thermal turbulence (due an air temperature instability at mid levels). Turbulence affects the behaviour of the aircraft in flight and increases the threat of retreating blade stall, vortex ring and LTE as the ground and air speed fluctuates. For helicopters equipped with teetering rotor systems there is the additional danger of main rotor mast bumping and rotor / tail strike.

Severity of turbulence:

- Light turbulence:
  is the least severe, with slight, erratic changes in attitude and/or altitude.
- Moderate turbulence:
  is similar to light turbulence, but of greater intensity - variations in speed as well as altitude and attitude may occur but the aircraft remains in control all the time.
- Severe turbulence:
  is characterised by large, abrupt changes in attitude and altitude with large variations in airspeed. There may be brief periods where effective control of the aircraft is impossible. Loose objects may move around the cabin and damage to aircraft structures may occur.

- Extreme turbulence:
  is capable of causing structural damage and resulting directly in prolonged, possible terminal loss of control of the aircraft.

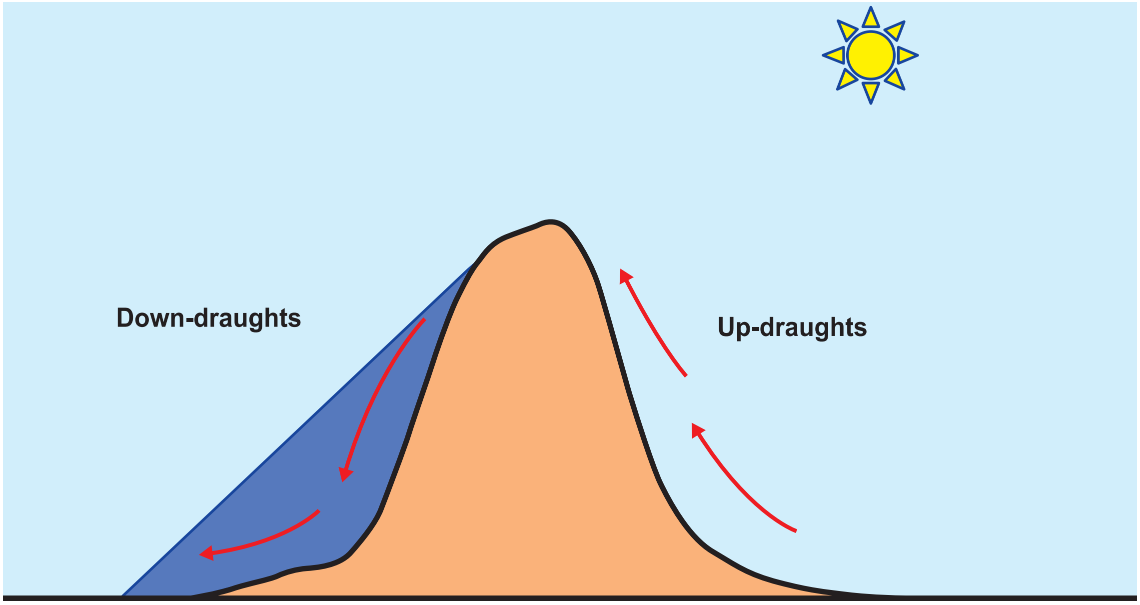
Turbulence can be experienced anywhere and without warning, therefore it should always be anticipated, especially in hilly and mountainous terrain. Pilots should always be prepared for turbulence by keeping a positive grip on the flying controls and reducing the airspeed to the recommended RFM 'turbulent airspeed'.

2.6 Solar Heating, Anabatic and Katabatic Winds

In days with no or little winds, orographic up-draughts or down-draughts are not very significant; therefore the effect of heating the ground by the sun can produce an inversion with associated up-draughts on the sun-side and down-draughts on the shadow-side of a mountain.

The same effect can be experience by day and night. During the day, the air heated by the ground creates an ascending air mass (anabatic wind). This breeze can be apparent from about a half hour after sunrise. At night, the air close to ground cools creating a down-draught (katabatic wind). This night breeze can start an hour before sunset and can continue throughout the night.

Note: where there is rising air, there will also be descending air!



Solar heating, Anabatic and Katabatic winds

2.7 Snow

Snow is particularly hazardous, especially when encountered in mountainous terrain. Flight in falling snow with the associated threat of icing and DVE shall be avoided. In snow covered areas it is advisable to wear appropriate eye protection as glare makes it difficult to assess speed, terrain, wind and height.

Due to recirculation and 'white out' landing on snow in mountainous terrain is extremely hazardous. Therefore this should only be undertaken by pilots using the zero speed/zero rate of descent landing technique who have conducted appropriate training!

3. FLYING TECHNIQUES

3.1 Speed Management

Maintaining an appropriate airspeed can be very challenging in mountainous terrain. Pilots need to be aware of the speed limitations from the RFM especially in relation to turbulence speed and VNE. It is advisable to maintain Vy whenever possible, thereby allowing maximum power margin for manoeuvring.

3.2 Attitude Management

When operating in hills or mountains the 'real' horizon can be difficult to identify from the slopes of the surrounding terrain. When this happens, vertical and horizontal references can be lost and it is difficult to establish whether the aircraft is climbing, descending or is in straight and level flight. Frequent reference to the aircraft altimeter, ASI, VSI and attitude indicator should be made.

3.3 Height Management

If the aircraft encounters a wind-shear or a severe down-draught and it is not possible to maintain height using power, the pilot should turn toward a clear area, adopt wings level, set maximum power and the pitch attitude for Vy in order to maintain or achieve a safe flight condition.

3.4 Transit Flying

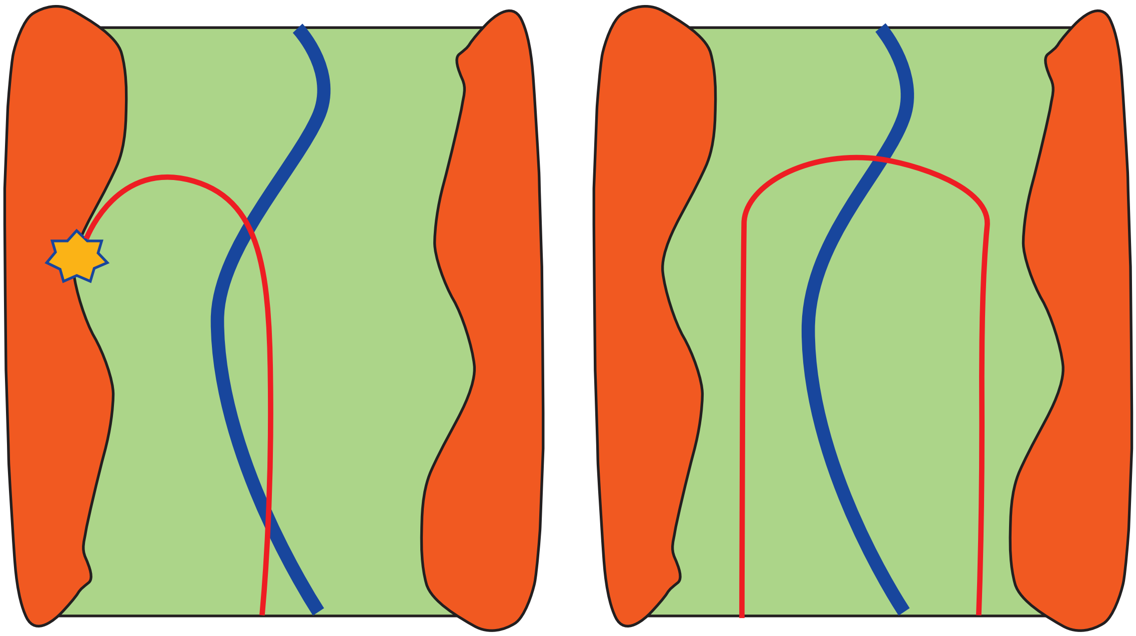
When flying through hilly or mountainous terrain, the route should be planned taking the local meteorological conditions into account avoiding adverse weather as described earlier. When crossing mountains, especially in strong winds, you should clear the top of the mountain by at least 500 ft. If you are unable to achieve a safe clearance, consider an alternative route or a diversion.

When crossing a range of hills or mountains with cloud on the top, it is better to approach parallel to the top of the range in order to see the extent of the cloud. If the cloud cover appears to be extensive beyond the high ground, consider an alternative route or a diversion.

If flying along a valley it is preferable to fly closer to the windward slope rather than along the centre of the valley. The leeward slope should be avoided for transiting because of down-draughts and potential loss of lift. If it is necessary to fly on the leeward side, it is advisable to fly at Vy in order to optimise the power margin.

Special consideration should be given to the threat of power/cable car wires, logging wires etc. which are often strung across valleys sometimes without any notice to pilots.

The escape route when flying along a valley is normally to perform a 180° turn. Therefore if continued flight along the valley is deemed inappropriate, e.g. due to low clouds, DVE or obstacles, an early decision to turn back is essential to ensure a successful turn.



180º turn in a valley

Valley in Mountainous terrain

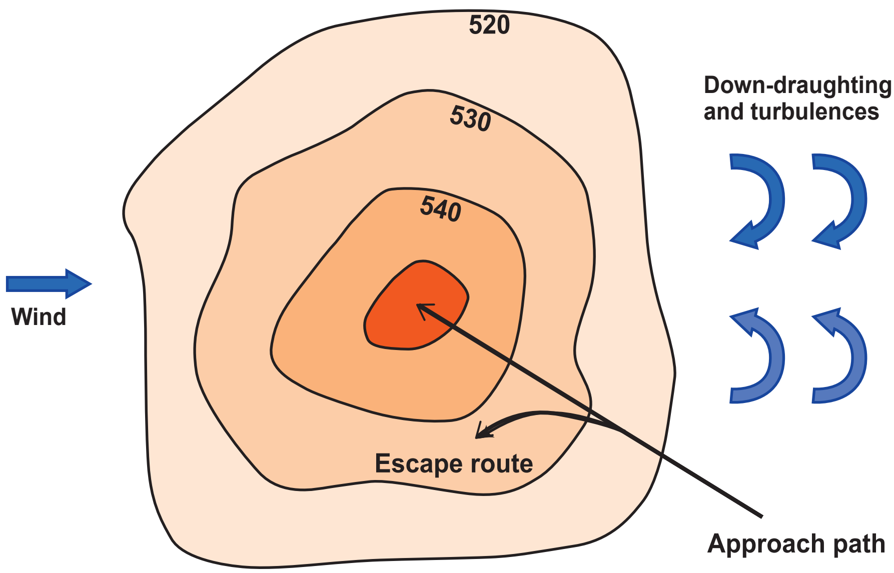
3.5 Landing Site Recce, Circuit and Approach

Before landing at any remote site a recce has to take place to identify the wind speed and direction, obstacles, an approach/departure path, potential escape routes and to assess the elevation and suitability of the LS. Techniques for LS recce including the 5 'S' elements and the conduct of power checks are described in HE 3 Off Airfield Landing Site Operations.

3.6 Approach to a Ridge or Pinnacle

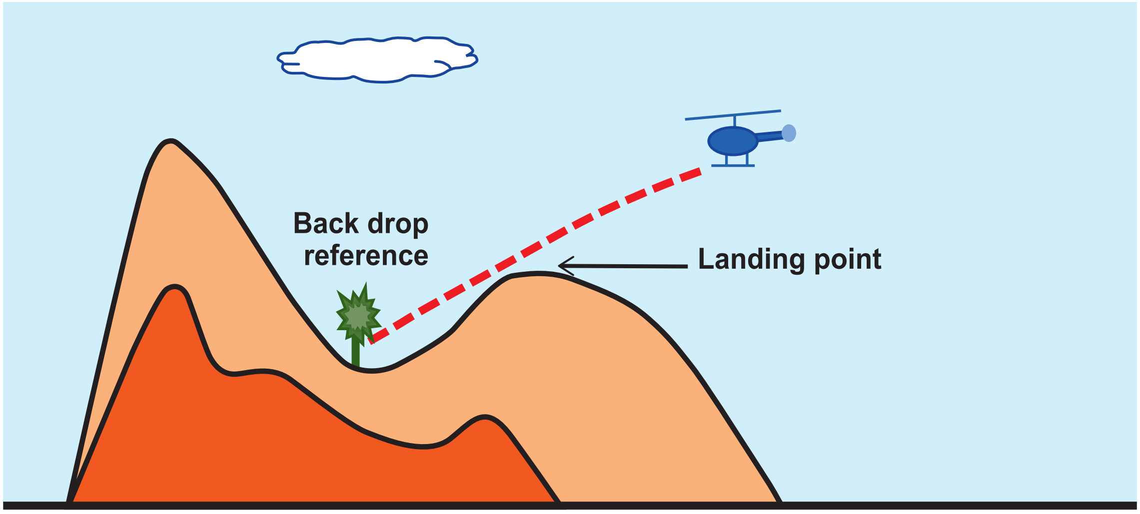
The absence of obstacles and the opportunities for an 'escape route' make ridges and pinnacles a good choice for a landing site. However, as previously described, these sites are often affected by a turbulent rising and descending airflow over the top, the demarcation line has to be identified.

A normal circuit should be flown above the elevation of the LS. For the final approach, if possible, rather than flying directly into wind towards the feature, the final approach may be flown at an offset angle (up to 45°) and out of wind to keep the aircraft out of the descending air and allow an escape route away from the feature. If there is little or no wind, the approach angle can be normal, however, it is essential to avoid reducing the speed too early and loose translational lift before gaining ground effect. If the wind is moderate or strong, an approach with a normal to steep angle can be flown as the wind will maintain translational lift until entering in ground effect (avoiding flight through turbulent areas upwind of the LS).



Ridge or pinnacle approach

To maintain a constant angle approach the 'backdrop technique' can be employed by choosing an additional reference beyond the LS. If on the final approach the reference point appears to go UP or DOWN, in relation to the LS it indicates an overshoot or undershoot situation and should be corrected (see below)



Approach to a pinnacle

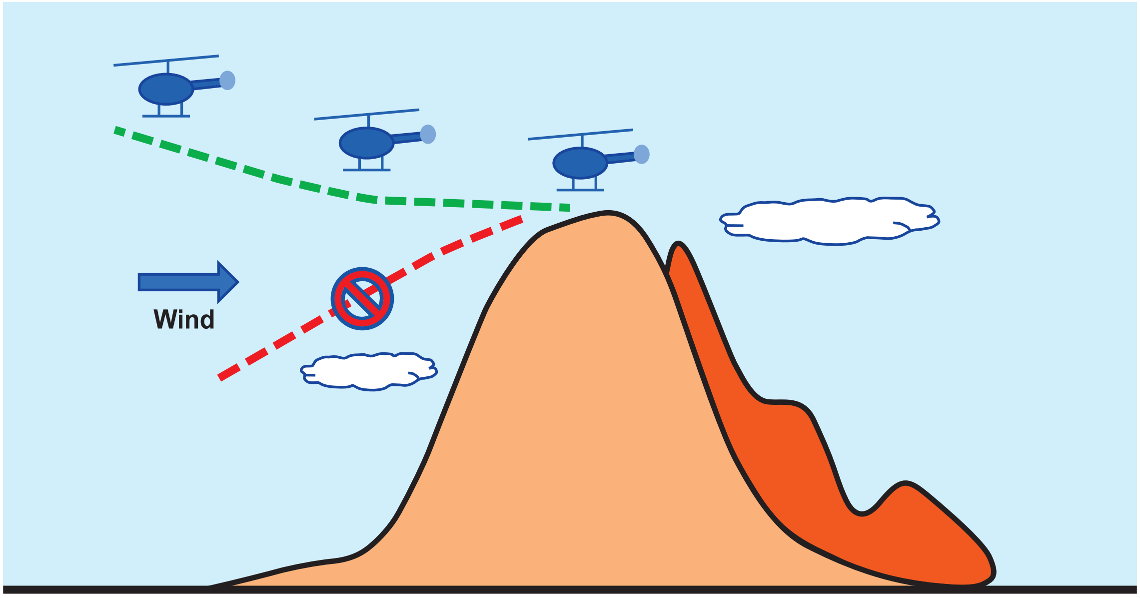
The escape route for an approach to a ridge or a pinnacle should be a planned turn away from the feature, which should not require abrupt or excessive manoeuvring, into an obstacle free area previously identified during the recce phase.

3.7 Take-off from Ridge or Pinnacle

The take-off from a ridge or pinnacle uses the same technique. Where possible the take off point should be an area closest to the windward edge of the feature to utilise the up-draught. In the hover and prior to transition, a power check should take place to ensure there is a sufficient power available for a transition away from the LS. Wherever possible a normal transition should be performed gaining forward speed whilst maintaining sufficient height to clear any obstacle until Vy is achieved. If obstacles are present, consideration should be given to performing either a vertical climb prior to transition, or using the appropriate aircraft elevated heli-pad technique.

On transition to the climb frequent reference should be made to instruments especially the ASI, VSI, altimeter and the power being used. It can be hazardous to attempt to 'fly down the hill' and this should not normally be considered as an appropriate take off path.

If it is not possible to land back on the feature, an escape route should be planned to fly the aircraft into a clear area.



Take-off from a ridge

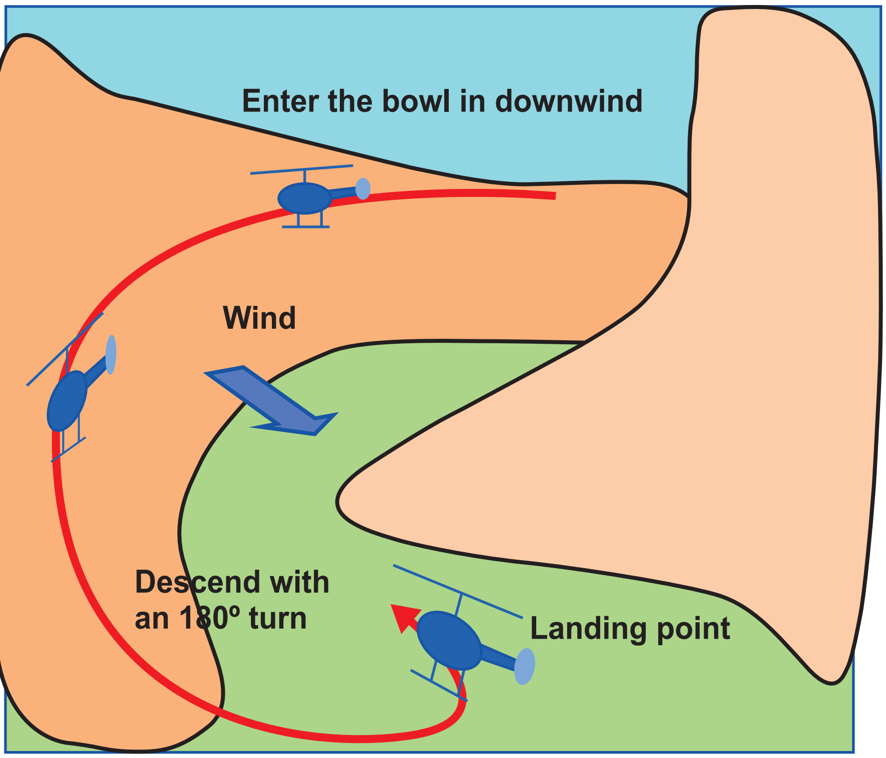
3.8 Bowl Approaches and Departures

A 'bowl' is where mountains surround a confined area (often formed by a small lake or stream) with an open access on one side of it into a valley. The surrounding 'walls' can be steep and high with limited escape options and therefore this technique requires a high degree of skill and should only be undertaken by a proficient pilot.

An approach can normally be made by entering the bowl, flying around the sides of the bowl and then making a descending approach into wind to a flat area close to the exit to the bowl.

An orbital recce is normally flown around the inside of the bowl, entering from the open area, initially as high as possible and as close as safely possible to the sides of the bowl. Vy is recommended to ensure maximum power margin and the power required to main level flight should be constantly monitored in order to identify areas of up-draughts and down-draughts. The aircraft may then depart the bowl through the open area flying over the proposed LS. If necessary, further lower recces can be conducted until a safe orbit can be achieved at which a final descending approach can be made. The landing is similar to that employed for the pinnacle and ridge. The take-off, ideally, is to exit into a clear area through the open access. However, it may be necessary to climb within the bowl in order to achieve the required obstacle clearance.

The escape route once inside a bowl would normally to fly the aircraft away from the bowl walls, initially towards to centre of the bowl and then exit through the open area. Once flying inside the bowl there are few outside references, it is therefore essential that frequent references are made to the relevant aircraft instruments.



4. THREAT AND ERROR MANAGEMENT

Before undertaking flight in hilly or mountainous terrain a risk analysis should be conducted in which the Threats, Errors and Undesired Aircraft States are identified and Managed with the appropriate mitigating actions.

A **Threat** is defined as an, event or errors which occur beyond the influence of the flight crew, increase operational complexity and which have to be managed to maintain safety margins.

Errors are defined as actions or inactions by the flight crew that lead to deviations from organisational or flight crew intentions or expectations.

Undesired Aircraft States are defined as flight crew induced aircraft positions or speed deviations, misapplication of flight controls or incorrect system configuration, associated with a reduction in safety margins.

Example:

Threat: Turbulence, wind-shear, up- and down-draughts

Error: Flying at inappropriate speeds

Undesired aircraft state: Retreating blade stall, LTE, Vortex Ring, mast bumping, momentary loss of control

Mitigating Action: Fly at appropriate turbulence speed / Vy

5. SUMMARY

If you wish to ensure a safe and enjoyable flight in, around, or over hills or mountains, you must develop the skills, collect the knowledge and appreciate the factors involved. Above all, know your own limitations and those of the aircraft and stick to them.

When conducting operations in hilly or mountainous terrain consider the following:

- Be aware of aircraft performance and limitations
- File a flight plan or notify someone of your intentions.
- Study the navigational charts carefully – do not rely on GPS
- Get up to date weather information for a go no-go decision
- Don't go when winds are stronger than 25 knots.
- Fly at a safe altitude
- Be aware of the wind direction and speed
- Monitor for sign of change in weather
- Be aware of the psychological and physiological effects of mountain flying
- Always plan an escape route
- Be aware of wind-shear and recovery actions to be taken
- **Before undertaking flight in hilly or mountainous terrain receive appropriate training from a qualified flight instructor who is experienced in mountain flying techniques.**

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Component of ESSI
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