CROSS COUNTRY
PARAGLIDING

SKYNOMAD

CROSS COUNTRY PARAGLIDING
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Cross country flying without an engine is the most difficult form of aviation, as it requires an extensive knowledge of aerodynamics and meteorology. At the same time, paragliders are the simplest aircraft to fly. There are top pilots and champions, who haven't read a single book about flying; they inspire, but they cannot teach you their intuition and feelings about the wind and the wing.

This book is an attempt to structure the complex matter of cross country flying and explain the major elements of this puzzle. It should help beginner cross country pilots to identify their mistakes and accelerate their progress. Advanced pilots might be challenged by some new ideas - or at least understand some techniques that, they've already been using subconsciously for years. This book may give comprehensive answers, but at the same time it may open a lot more questions. There is an entire universe of processes, even behind a simple wind gust, even behind a simple gliding flight. There is love and eternity when you merge with the wind and your wing. There is peace and humility when you let Nature be.

Understanding cross country paragliding takes time and experience. It is recommended to re-read this book several times and use it as a reference handbook throughout different stages of pilot's progression. Instead of complaining about the performance of their wings, pilots should first perform well themselves. There are so many techniques, tactics and strategies to practice before jumping to the next level wing. Be happy that cross country flying is so complex - it won't get boring soon!

Books are a form of one-way communication – from one side is the author with his experience – from the other are the thirsty readers. Nature is so mysterious, that it is impossible for a single person to reveal its secrets. We learn from each other through our flights, stories and even the photos we share. Let's move a step further and create a live book, where in a forum-based discussion readers can become authors and participate in the improvements and creation of future editions of this book: www.skynomad.com/forum

Search for knowledge and you will find beauty!

CONTENT

AKNOWLEDGEMENTS

I would like to apologize to my friends and relatives, who I neglected all these years chasing the wind.

I would like to thank my patient colleagues from SkyNomad Paragliding School (www.skynomad.com) and our partners – Godfrey Wennes from Australia (www.flymanilla.com), Advance paragliders (www.advance.ch), Mac Para (www.macpara.com) and Nest guest house in Sopot, Bulgaria (www.nest.bg)

Special thanks to a great teacher – Nikolay Tsarov, who inspired me with the power of knowledge, quietly observed my mistakes and encouraged me to think higher and further.

DONATE

This book took a lot of effort and years of experience. If you find it useful or if you want to support future work in the field of paragliding aerodynamics and meteorology, then you can donate whatever you like via PayPal to **nskynomad**@gmail.com

Donate

Nikolay Yotov

INTRODUCTION

Cross country flying (XC) is the eternal zeal to go higher and further. The lack of an engine sets natural limitations, which push us to learn more about the Sky, the Earth, and our wings. This opens an endless universe, full of invisible life and intriguing challenges.

Our dependency on the wind's capriciousness teaches us patience and humility. The studying, predicting, and participating in the game between the Earth and Sky gives us an aesthetic delight in their beauty, a triumph of the mind and feelings of freedom, happiness, and love from the merger with Nature.

Unpowered cross country flight starts with a simple ***gliding flight*** – a forward movement with slight descent, which covers a certain distance according to the initially gained height earned by climbing a hill, or pull by a winch. In order to extend the flight, the pilot needs to find and climb in rising air, before losing height and landing.

> Finding and catching rising air currents after take-off is often the most challenging part of the entire flight. That's why, the choice of takeoff location and timing are of prime importance. Sites with high, bare and sun-facing slopes are easier for the first climbs, unlike low, humid, vegetated, or shady ones. This doesn't mean that we should fly only easy places. Every site has its moment of glory, when elsewhere it doesn't work. Most record cross country flights are made in strong conditions when easy sites can be too windy and turbulent.

After finding the first lift and climbing in it, the goal of cross country flying is to cover some distance over the ground by a series of glides and climbs. Additionally, the goal of cross country paragliding can be specified by flying:
- As fast as possible;
- Along a certain route or passing near a landmark;
- Toward a certain landing place.

Sport flying distinguishes the fastest pilots by making them fly at the same time along the same route. Flying in the same conditions minimizes the role of luck, and reveals the pilot's knowledge, decisions, and skills.

The basic objective of fast cross country flying is the ability to fly greater distances in a limited time. The duration of the day and sun's energy limit:
- Visibility (*night flying is dangerous*);
- Presence and strength of air updrafts, used for gaining height (*they're too weak or absent at night*);
- The size of the playground, because of the daily expansion and night shrinkage of the atmospheric Boundary Layer. The Boundary Layer (BL) is where the terrain directly affects the atmosphere through convection, friction, turbulence, etc. Above the Boundary Layer is the Free Atmosphere.

Fast flying not only makes the flight longer, but can also help to pass through bad weather zones like wide shadows, thunderstorms, fronts, breezes, falling winds, etc. Of course, fast entry in random currents and vortices bears its risks – especially for hot sport wings that are more sensitive to turbulence and more unstable, because of their thinner profiles and higher aspect ratios.

Apart from flying fast in competitions, the paragliding community (*FAI/CIVL, Leonardo, XC contest and social media*) encourage flying greater distances along specific routes.

The most common type of flight is called ***Open Distance***, where the goal is to fly the farthest possible distance from take-off to landing. Such flights are usually done with the wind, which increases ground speed and distance flown over the ground during glides and even during climbs. *Open Distance* cross country flight is the easiest for beginner pilots, because flying downwind can extend the glide 2-3 times more, than in calm air. This gives a bigger area to search for the next updraft.

Open Distance is also the safest type of flight, because the paraglider enters the updrafts that have been tilted by the wind from their less turbulent upwind side - like surfing waves downstream.

Current *Open Distance* world record is more than 600 km and apart from stamina and a pilot' skills, it demonstrates a good knowledge of meteorology.

Open Distance cross country flying can have an additional requirement – the pilot declares the landing place before the flight – so called ***Open Distance to a Declared Goal***. This demonstrates that the pilot not only drifts with the wind, as far as possible, but he knows the terrain and conditions so well, that he can confidently predict what's possible and what isn't for the given day.

Another popular type of cross country flight is ***Out and Return***. The idea is to decrease the effect of the wind and highlight the pilot's skills in various conditions. It's easy to fly downwind, but much harder against it. The difficulties show who is the best. An additional stimulus is that there are no travel expenses for *Out and Return* flights.

After many *Out and Return* flights, it became clear that there are favorable terrains and conditions, which help the pilots. For example - flying over a long mountain range with wind along it for half of the day and then wind switches in the opposite direction for the second half of the day. So, in order to reduce the help from the conditions and show more of the pilot's skills, an ***FAI Triangle*** route has been introduced. The shortest side of the triangle should not be less than 28% of the entire perimeter.

Of course, even here can be found favorable terrains and conditions that mask a pilot's skills, but society won't give up its nature to compare one man with another, to make them compete and title them in a hierarchy. Competition and vanity are powerful motivators, but they're not obligatory for enlightened activities like flying, where one strives for knowledge, beauty, and harmony. One shouldn't neglect pre-existing knowledge, no matter how it was obtained. It is still useful to take part in classic contests like competitions and rank lists from time to time, in order to synchronize one's watch and check new equipment, flying theories and techniques.

The above-mentioned different flight types have something in common – they all consist of a series of three flying modes/stages:

Route Progress (RP)
Search for Lift (SL)
Climb in Lift (CL)

progress-search-climb-progress-search-climb-progress-search-climb… no matter if it's a 20 or 200 km flight; open distance, triangle or a competition task.

ROUTE PROGRESS

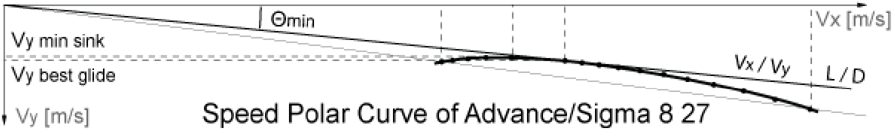
The *Route Progress* (RP) stage of cross country has the following goals:
- to travel as far as possible along the route ($S_{route\ max}$);
- for minimum time (t_{min});
- with minimum height loss (Δh_{min}).

GLIDE RATIO

The glide ratio of each specific wing determines who can cover a bigger distance with less height loss. The ***Glide Ratio*** (GR) is the ratio between the horizontal distance travelled and the height loss; between horizontal and vertical speed Vx/Vy; between Lift and Drag (L/D). Beginner's wings travel horizontally about 8 km per each 1 km of height loss. Top competition wings can have a glide ratio of about 11:1.

Glide ratio depends on wing profile, aspect ratio, airspeed (V), and drag of the lines, pilot's body and harness. A drag efficient pod harness can increase glide ratio by up to 1 unit compared to an open sitting harness.

Paragliders can change their airspeed by using their brakes and speed system, which change the *resultant aerodynamic force* (R), its *lift* (L) and *drag* (D) components and the entire glide ratio. This is best described by the speed polar curve:



Speed Polar Curve of Advance/Sigma 8 27

There are 4 specific speeds for the purposes of flight analysis – ***V min*** (*or stall speed*), ***V min sink***, ***V best glide***, ***V max***. Their values for Advance / Sigma 8 27 are respectively:

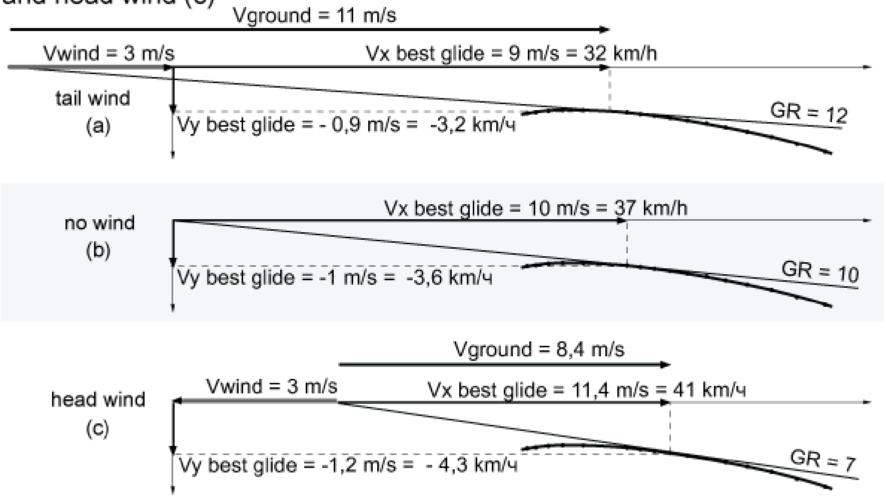
	x	y
V_{min}	30 km/h	1.1 m/s
$V_{\text{min sink}}$	34 km/h	1 m/s
$V_{\text{best glide}}$	39 km/h	1.1 m/s
V_{max}	55 km/h	2 m/s

The straight line from the origin of the coordinate system to the polar curve touches it at a point which gives the *best glide ratio* (*height/distance=max,* V_x/V_y*=max L/D=max*) and *minimum gliding trajectory angle* (Θ_{min}).

In calm air, *glide ratio in relation to the surrounding air* (GRA) is the same as *glide ratio in relation to the ground* (GRG). *Glide ratio to air* can be measured by an airspeed probe (V) and a variometer (Vy). *Glide ratio to ground* can be measured with a GPS ($V_{x\ \text{ground}}$ / $V_{y\ \text{ground}}$).

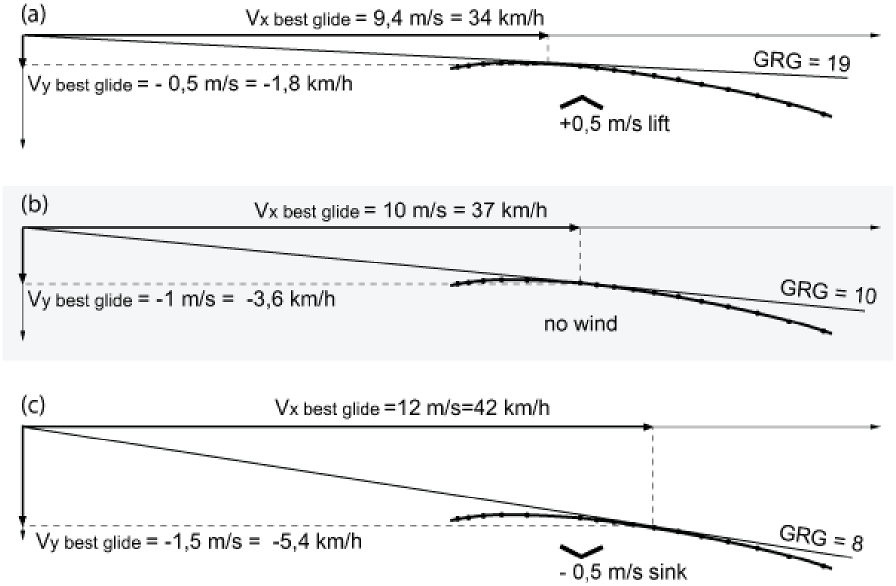
In windy conditions, when flying within horizontally or vertically moving air masses, *glide ratio to air* doesn't change, as airspeed, lift and drag stay the same, but *glide ratio to ground* changes, as ground speed changes (V_{ground}).

This can be visualized by shifting the polar curve left-right (*headwind-downwind*) or up-down (*lift-sink*):



Speed polars for best Glide Ratio in tail wind (a), no wind (b) and head wind (c)

Polar curve best Glide Ratio speed in lift (a), no lift (b) and sink (c)



The change of glide ratio in various winds gives us the basic cross country flying rule: **Fly faster in sink or headwind and slower in lift or tailwind!**

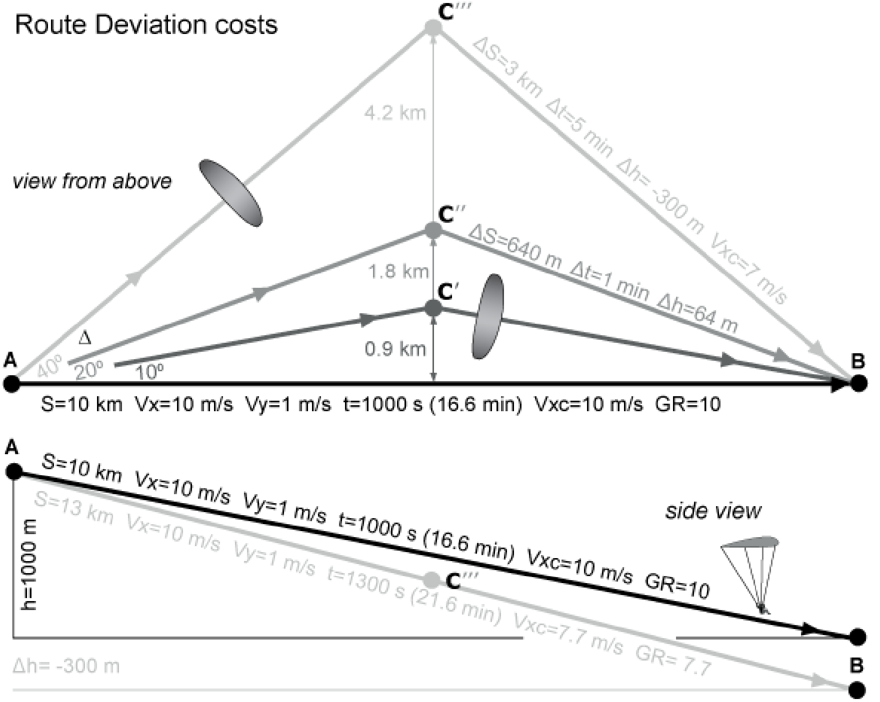
Even light lift can compensate glide ratio loss from a headwind.
Flying downwind can partly compensate glide ratio loss from sinking air.
The best is to fly downwind in lift. The worst is to fly in sink against the wind (*look for a landing spot soon*).

One of the simplest ways to fly cross country is to fly at *best glide ratio* (BGR) at all times in all kinds of conditions.
Modern GPS devices, flying instruments and applications show glide ratio to ground, so there is no need to re-calculate the *best glide airspeed* ($V_{\text{best glide}}$) each time when conditions change. Just increase or decrease your airspeed with the brakes or speed system to check if the glide ratio value increases. The GPS glide ratio value is not very precise and prompt, like the variometer values, but it helps you develop the instinct of when to fly faster and when to fly slower, adjusting your airspeed automatically, each time the vertical or horizontal ground speed changes. You can start adjusting your *best glide ratio flying mode* to predominating conditions, and then progress to transient conditions. In the beginning it’s not so important to be precise at chasing the best glide ratio – more important is to develop the instinct and react in the right direction. Be a pilot, not a passenger!

ROUTE DEVIATION

As in life, the *route line* (RL) is often surrounded by temptations. A big dilemma in cross country flying is: are these temptations worth a *route deviation* (RD)?

Such temptations can be: a good thermal, a convergence line nearby; or to avoid shade, rain, a strong head-wind, turbulence, a lack of landing spots along the route line, etc. It is difficult to predict the benefits of these temptations from a distance, before going to them. It is difficult even to judge the distance to those temptations.Here are some examples of route deviation costs, when flying from point A to point B via a third point C:

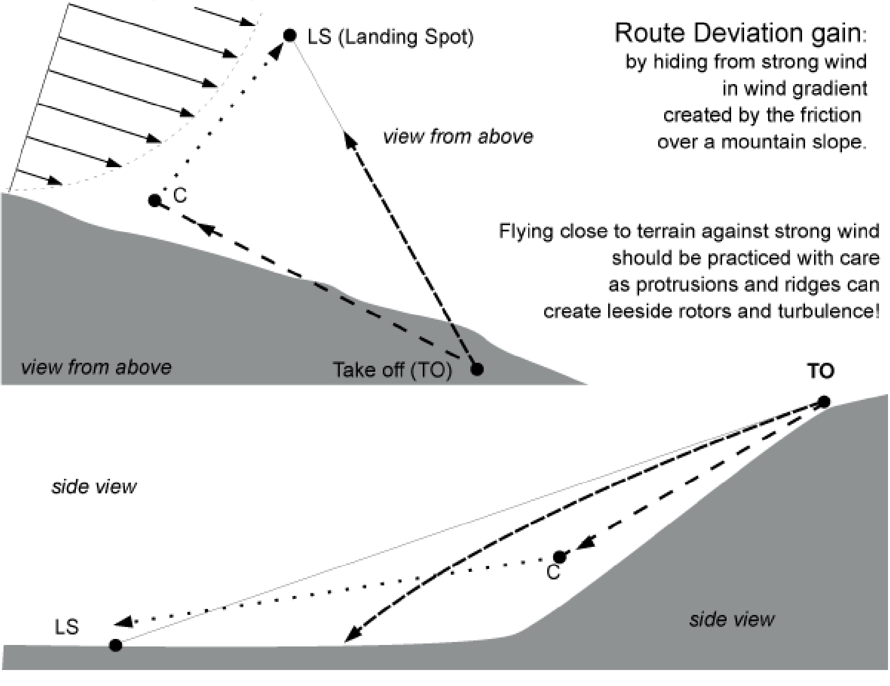


Route deviation losses of time (Δt) and height (Δh) are nonlinear (≈ *5% for 20˚RD; ≈ 30% for 40˚RD*). If the outermost route deviation point C and point B present equally strong lift, then route deviation cannot compensate for time loss and is worth it only to prevent a *bomb-out* – premature landing, when glide ratio is not enough to reach directly point B.

In reality, lift never rises at a uniform speed from the bottom to the top. A 40˚ route deviation saves time if we then avoid getting stuck low at point B, instead of staying high by flying through point C (*e.g. when the climb at B and C is 0.5 m/s between ground and 300 m, and 2 m/s between 300 and 1000 meters*). A smaller route deviation of 20˚ and less can save time in various situations (*e.g. 1 min time gain when the climb is 1 m/s between 0 and 300 m and 2 m/s between 300 and 1000 meters*). Also, don't forget the accumulative effect of several route deviation gains or losses along the route line.

The non-linear losses due to route deviation mean that we should think in advance, well ahead along the route, what comes next. In case of an inevitable Route Deviation, due to airspace, athermic or non-landing zone, we'll lose less, if we start the deviation earlier, than approaching it first and then going sideways for it.

Route deviation is beneficial not only in the case of using a good climb nearby, but also in cases when deviating from the direct line may reduce glide ratio harm caused by headwind or sink. For example, we can use the reduction of wind close to the slope of a mountain (*horizontal wind gradient*) to reach an upwind goal, which otherwise would be impossible to reach if we fly directly to it.



Route Deviation gain:
by hiding from strong wind
in wind gradient
created by the friction
over a mountain slope.

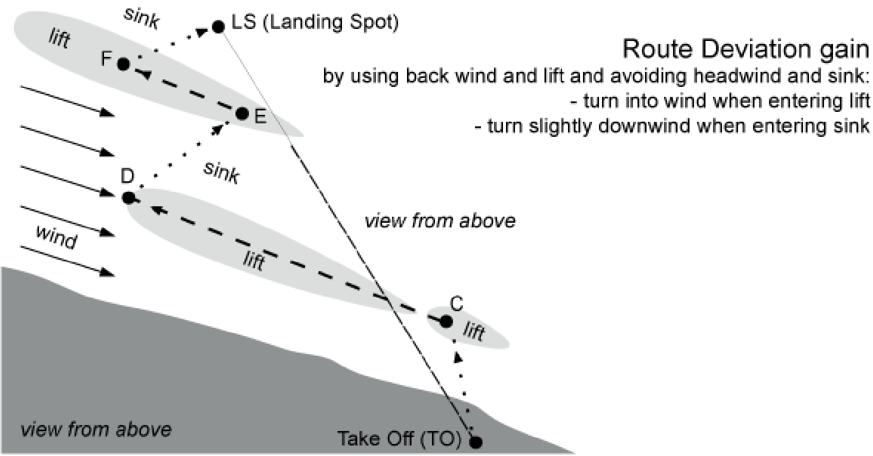
Flying close to terrain against strong wind
should be practiced with care
as protrusions and ridges can
create leeside rotors and turbulence!

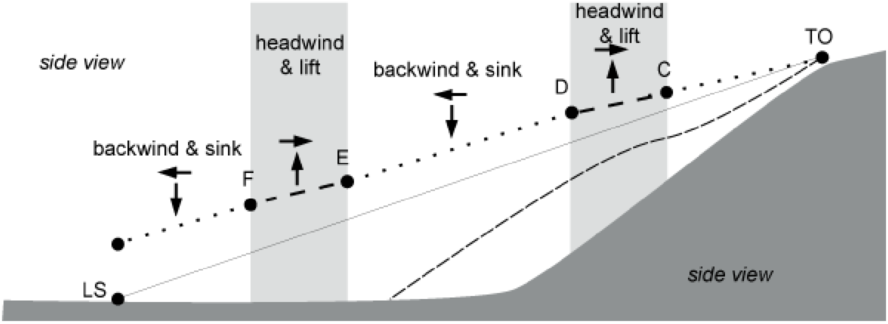
Using wind gradient by flying close to a mountain slope against the wind should be practiced with care, as terrain protrusions and ridges can create rotor and turbulence downwind!

How close to the terrain is it safe to fly? There is no straight answer, but there are a few basic principles:

- Steep terrains allow closer flying as there is more height for collapse recovery or moving away from the slope in case of sudden entry into sinking air;
- When flying against the wind, sharper ridges and protrusions ahead can be a source of turbulence, especially in strong winds. Smoother shapes are less turbulent but can produce big sink on their downwind side, which may ground you before reaching a landing field;
- Humid and unstable conditions smooth out rotors and turbulence, while dry and stable air keeps their energy for a longer time enabling them to travel further downwind;
- Being very close to terrain is rarely justified, as friction can slow down thermals or ridge lift. Better to play and explore the *invisible mountain* made of lively air drafts further away from the visible mountain;
- Very steep slopes, like those found in the Alps, allow very close fast flying, as pilots use the ridge soaring effect of thermic air to fly straight and don't waste time circling. It can also be surprisingly smooth, as the terrain is evening out the upslope breeze. It can be more turbulent 15-20 meters further away from the terrain, because of various air mixing, formation and triggering of thermals. In the long term, soaring straight along a steep ridge with plenty of weak lift can be faster, than periodic stopping to circle in strong concentrated lift.

Another classic example of route deviation gain is increasing glide ratio along a certain route with lift and sink streets by turning into wind when in lift and turning slightly downwind when in sink. This is often observed in flying areas like Dobrostan, Bulgaria, where even beginner pilots have to learn this technique in order to reach the official landing spot (LS), which is partly upwind from the takeoff (TO). A straight flight from takeoff toward the landing spot may not have enough glide ratio to reach the landing field, but turning upwind when in lift (*in order to reduce the glide ratio harm of the headwind*) and turning downwind when in sink (*in order to reduce the time, spent in sink*) can make the wing fly further than when it's just flown straight, without deviation. In other words, active piloting is a clever way to stretch the wing's glide ratio beyond its design limit. A straight line is not always the best!





Improving glide ratio by using lift streets:

- When you encounter lift, turn into wind! This will reduce the glide ratio loss from the headwind component;
- When you enter sink, turn *partly* downwind to reduce glide ratio loss. Partly, because you still need to cross and exit the sink street, not to fly along it.

In most cases, automatically turning into wind after each encounter of lift gives numerous benefits:

- It might be a lift street, which you can use;
- The initial lift you've encountered might be an old bubble that's drifting downwind from a strong thermal source. Flying upwind may bring you to fresher and stronger thermals from the same thermal source;

- Generally, the upwind side of a thermal is less turbulent than the downwind side. It’s less sinky, and it puts you in a better strategic position to track the thermal or to continue along the route;
- In times of uncertainty, turning into wind when entering lift is like saving money for rainy days i.e. it’s an investment in height and *position strength*.

Reducing sink or headwind’s glide-ratio-harm by using wind gradient or lift streets is often used to reach a potential lift zone with maximum possible height. At some sites and conditions, this technique is the only available way to reach the first thermal after take off.

HARVESTING THE MICRO COSMOS

Improving your glide in gusty air by minimizing losses and catching opportunities

During route progress in a straight flight, the paraglider often flies through various gusts coming from random directions. They’re usually too short lived and too small in size to be worth circling as in a classic thermal. For the pilot, gusts cause pitch, roll and yaw motions of the wing, but these are just the final visual result of different interconnected aerodynamic processes. Through specific control inputs, paragliding pilots can influence these processes and improve flight efficiency.

Every gust of wind changes the paraglider’s airspeed vector V, both in size and direction.

Each change of *angle of attack* (AoA - α) or *side slip angle* (SSA - β) moves the paraglider out of the best glide mode, which makes the wing fly inefficiently. Glider planes can even use their tail rudder for high sideslip angles to decrease glide ratio on landing, instead of airbrakes.

Any decrease of airspeed causes a direct loss of lift force and glide ratio.

Not every increase of airspeed is a gain – it must come within the working range of wing’s angle of attack ($5^\circ < \alpha < 25^\circ$). If the angle of attack increase is too high ($\alpha > 25^\circ$), then a *stall* occurs. The gust from below may still cause a temporary height gain, but the following loss of airspeed due to the stall leads to a drop, often bigger than the initial height gain.

If a wind gust causes too low angle of attack ($\alpha < 5^\circ$), then there is no gain in height as there is no gain in lift force.

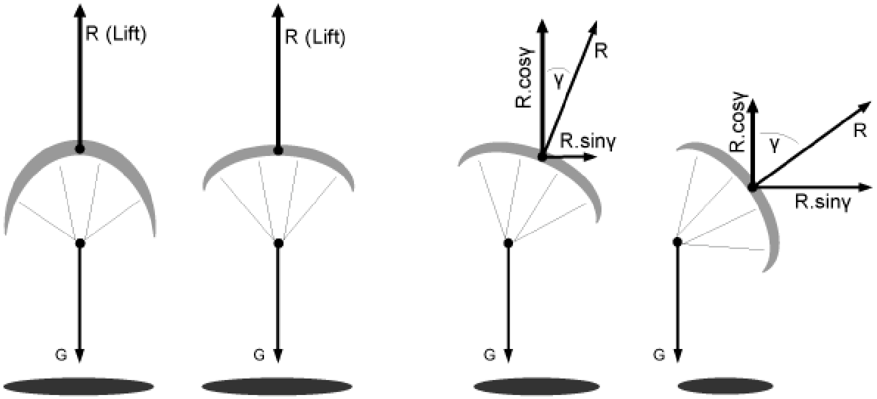
> The majority of pilots associate *stall* with airflow being disrupted and torn away from the wing's surface, when flying with too high angle of attack.
>
> ***Stall* means a disappearance of the lift force**.
>
> When the supporting the flight aerodynamic force is gone, we drop and fall downward accelerated by our weight force (G). Stall, or the disappearance of lift force, can happen either because of too high angle of attack, but also because of too low angle of attack!
>
> Each wing's profile has a certain *zero lift angle of attack* ($\alpha \approx 4^\circ$), where the airflow around the wing doesn't create a lift force. Further down ($\alpha < 4^\circ$), the lift force becomes negative. Of course, sail-made soft paragliders cannot stand too low or negative angles of attack with too much pressure from above; a collapse will occur. A collapse is when the wing folds and deforms downwards, from the leading edge toward the trailing edge. A stall may also cause the wing to deform, but it starts from the trailing edge toward the leading edge.

Harvesting the microcosmos of gusts and disturbances requires a good understanding of paragliding aerodynamics, which can be described in a separate book.

A basic rule is to keep the wing within the working range of the angle of attack ($5^\circ < \alpha < +25^\circ$), preferably at the best glide ratio angle of attack ($\alpha \approx 9^\circ$). As we cannot see the invisible wind gusts and the resultant change of airspeed and angle of attack, the simplest approach is:

Keep the wing above your head and promptly dampen pitch, roll, and yaw disturbances!

Wind gusts cause the wing to move away from a vertical position above the pilot, which changes its *angle of pitch* (θ) or its *bank angle* (γ). This reduces the horizontal projected surface area of the wing. The wing surface is the one, which creates lift and opposes gravity. Any pitch and roll increase paraglider's own descent rate through the air (V_y).



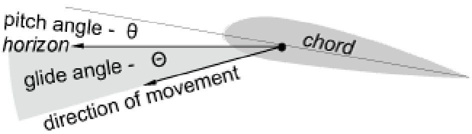
Decrease of lift and increase of sink
by reducing wing's surface horizontal projection
by changing Angle of Roll γ

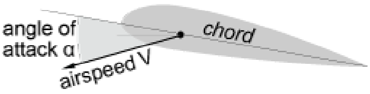
No matter if wing is high or low arc
(high or low ahedral angle) -
Its lift production depends on
wing's surface horizontal projection

Roll (and pitch too) reduce wing's surface
horizontal projection and thus its
aerodynamic force lift component R.cosγ

Experienced pilots are very keen to avoid unnecessary pitch or roll movements. They try to fly their wings like a skillful waiter, who carries a tray full with glasses, as flat as possible, trying not to drop a single one, despite his vigorous manoeuvres, among the impatient clientele.

Many pilots don't differentiate between angle of pitch and angle of attack. **Angle of pitch** is the angle between the wing's surface and the horizon, while **angle of attack** is the angle between the wing's surface and the airspeed vector V (*airflow direction*):





Brakes and the speed system first change the angle of pitch, and then the new orientation of the wing within the flow changes its angle of attack. This instantly changes the aerodynamic force and the paraglider changes its flying trajectory. The new trajectory means airflow, or airspeed, coming from a new direction and a new angle of attack. Then, after a transition process, the paraglider attains a new angles of pitch and attack, with a new airspeed and an aerodynamic force, which correspond to the new brake or speed system setting.

Wind gusts change airspeed in size and direction and also the resultant aerodynamic force. The new resultant magnitude and direction of the aerodynamic force makes the wing move. The light-weight wing rotates around the attached heavy body of the pilot, changing its pitch or roll angles. At the same time the change of the aerodynamic force plus the constantly acting weight force, accelerate the mass of the pilot's body and the whole paraglider in one direction or another. The new trajectory means airflow, or airspeed is coming from a new direction and again this means a new angle of attack. Again, after a transition process, the paraglider moves with the wind and recovers its initial airspeed, aerodynamic force, and angles of attack, pitch, and roll. Gliding angle, trajectory and glide ratio will be different, according to the moving air mass the paraglider flies within. If wind gusts last shorter than the transition process, then the paraglider adapts to the new (*old*) environment by gaining or losing height. Given the wide variety of gusts and the numerous combinations between those and the transitional processes of the paraglider, it is difficult for the pilot to understand what's going on and react adequately and promptly. The easiest course of action is to focus on negative outcomes and minimize their harm:

- Loss of airspeed
- Reduction of the wing's horizontal projected surface
- Oscillations

Airspeed loss can be reduced by less use of the brakes and by more frequent work with the speed system.

Most pilots pull their brakes when a gust hits their wing. It's a natural fear-driven instinct to go into the embryo pose - when a sudden force hits you. But with experience, pilots learn to trust their wing and let it meet gusts and turbulence with higher speed and internal pressure. Higher internal canopy pressure means higher resistance to collapses.

Another unnecessary reason to pull on the brakes is when the paraglider jumps up, and the pilot slows it down in attempt to stay longer in lift and gain more height. There might be different reasons for a wing to jump up - entering rising air like a thermal, the suction effect from wind gradient, or vortex, but also a simple horizontal headwind gust, which sharply increases airspeed and boosts lift production. A pull of brakes can enhance the climb, but the loss of airspeed afterwards can nullify the gain and even more height can be lost, than before the gust. So, **it's better not to touch the brakes, when a wind gust hits**! The best is to know and watch the outside conditions in order to react promptly and efficiently to them.

Most paragliding schools and instructors teach students to fly all the time with some tension on the brakes. Especially in turbulence, where the general advice is "*Keep tension on the brakes*". Constantly applied brakes make sense only:

- To save reaction time, when beginners have to recognize and stop the wing's forward surges, which prevents collapses or at least minimizes their development;
- To have bi-directional brake control i.e., not only to pull and slow the wing, but also to be able to release them and let the wing accelerate.

Constantly applied brakes technique is inefficient as it noticeably reduces the precious airspeed and glide ratio. It also increases wing profile curvature and wing's reactions to outside disturbances.

Experienced pilots don't fly with constantly applied brakes, because they understand a situation much earlier and also react quicker with the brakes, when needed. Modern wings, especially two liners, have an easy-going speed system, which adequately substitutes the release of the brakes for an increase of airspeed.

The constantly applied brakes technique has some advantages for climb in lift, or thermaling, but there is no reason to use it during route progress or search for lift stages of cross country flying.

So, to minimize loss of airspeed:

- **Use less brakes**! Brakes heat the universe and increase the entropy, the chaos;
- **Use speed bar more frequently**, when the wing pitches back or when you feel a decrease of wind in your face!

To minimize a loss of lift - due to a reduction of the wing's horizontal projection surface area, promptly prevent or reduce big pitch and roll angles.

However, there are healthy forward surges which shouldn't be stopped as they are the result of the wing's self-accelerations. Self-accelerations are good as they restore and increase airspeed and lift. Self-accelerations are caused by the wing's *inductive ability* reaction to higher angles of attack (*e.g., when entering lift*). The *inductive ability* is explained in an extra chapter at the end of this book.

Self-accelerations are one of the major causes of collapses. Sometimes, surges can be quite aggressive and need a correspondingly aggressive response with the brakes, even beyond the stall position. It’s not so scary as the brake pull is only momentary, and not as long lasting as for a full stall. During aggressive surges, safety takes priority over efficiency! Even an innocent collapse can lead to an annoying loss of height and time.

So, the pilot has to actively filter which self-accelerations are good to feed the wing with speed, which are bad and cause collapses, and all those in between, which cause lift force loss due to a decrease in the wing’s horizontal projected surface area.

Remember that airspeed gain not only increases a wing’s lift production, but also its manoeuvrability. Brakes are aerodynamic controls which are more effective at higher speed. Investment in high manoeuvrability pays back in higher efficiency and safety.

Apart from timely stopping of aggressive surges with the brakes, the pilot can also preventatively reduce their severity. *Inductive ability* and resultant self-acceleration happen due to an increase of the angle of attack – e.g., when entering lift. Thus, prompt application of the speed system would not allow a big increase of the angle of attack and would dampen the inductive ability and aggressive self-accelerations. It may seem contradictory – why should I accelerate my wing forward when entering in rising air, if the entering of rising air would cause my wing to surge forward? Again, as in the case of the instinctive brake pull, prompt application of the speed system, when the pilot is hit by a gust of lift, requires lack of fear and trust in the equipment, environment, and knowledge. Practice and you will see that it’s not so dangerous and actually works for dampening surges and still gains airspeed.

The down side of a prompt application of the speed system, when entering lift, is that it dumbs part of the wing’s feedback about what the air looks like. Maybe it’s not just a momentary gust but a proper thermal which is worth thermalling? Or a monster vortex which will punish us with a collapse, after seducing us with lift first? New sharp-nosed profiles give speed and glide, but also castrate wing’s reactions on outside gusts. Some competition pilots are obsessed with flying on speed bar at all times, but they’re missing the beauty of the micro cosmos around us.

Again, it’s about experience and knowledge. Sourcing new information channels is not enough. Harvesting the micro cosmos is about understanding the dynamics, not just passively observing what’s happening.

A part of aerodynamics is describing a wing’s oscillations arising from single or multiple wind gusts. The paraglider is the most stable aircraft due to its great pendulum effect. It’s actually a pendulum with an actively moving pivot point. It has two pendulum effects – the upper and lower pendulum. The ***lower pendulum*** is obvious – any displacement from the vertical position makes the weight of the pilot swing back under the wing – the *centre of gravity* (CG) goes under the *centre of pressure* (CP). The ***upper pendulum*** represents the movement and acceleration of the centre of pressure when aerodynamic force changes magnitude and direction due to external or internal (*control*) inputs.

Oscillations, both due to upper and lower pendulums, cause a change of angle of attack and make the wing fly inefficiently, away from the best glide mode. They should be stopped quickly with minimum airspeed loss, adjusting the wing to the new environment.

Harvesting the microcosmos is a complex matter from within the aerodynamics universe, close to art. Learn first to reduce airspeed loss, projected surface area of the wing and parasitic oscillations. Then play with a boost of airspeed caused by wind gusts and the wing’s inductive ability. May the force be with you :)

SEARCH FOR LIFT

The *Search for Lift* (SF) stage of cross country starts even before take off. During flight it has the following goals:
- to find usable lift for minimum time t_{min});
- with minimum height loss ($-\Delta h_{min}$);
- with some progress along the route, if possible ($S_{r\ max}$).

UPDRAFTS, DOWNDRAFTS AND WIND

1. Updraft types:
   - 1.1 Large scale (*cyclone, trough*);
   - 1.2 Ridge lift from geostrophic wind (*the main wind over the country*);
   - 1.3 Ridge lift from anabatic wind;
   - 1.4 Ridge lift on a thermal slope (*cloud*);
   - 1.5 Wave;
   - 1.6 Convergence:
     - 1.6.1 From converging winds;
     - 1.6.2 From turn of the flow (*e.g., between surfaces with different friction*);
   - 1.7 Lift from suction from above (*wind gradient*);
   - 1.8 Lift from a vortex (*rotor*);
   - 1.9 Lift from a micro gust;
   - 1.10 Updraft, which compensates nearby downdrafts (*e.g. bouncing of falling winds*);
   - 1.11 Lift from winds pushing under an airmass (*cold front, sea breeze, katabatic wind, falling winds*);
   - 1.12 Thermal lift from air mass instability. Dry and wet thermals.

Lift used in cross country flying is mostly due to thermals, but almost always it is mixed with other types of updrafts or downdrafts. Some may enhance it; some may weaken it. For example, when wind is pushed up a slope, the ascending air mass additionally destabilizes the thermals within it and vice versa. To mix and blend different types of lift, it is important that interacting air masses have similar properties like temperature, humidity, density and viscosity. Otherwise, air masses can still ascend together, but with shear turbulence mixing along their borders - like a cold sea breeze, which enters a warm and dry airmass inland.

2. Downdraft types:
   - 2.1 Large scale sink (*anticyclone, ridge*);
   - 2.2 Sink at the lee (*downwind*) side behind an obstacle, from geostrophic wind;
   - 2.3 Sink at the lee side of a thermal;
   - 2.4 Downhill along a mountain slope, from katabatic wind (*this* is *different from falling geostrophic wind in terms of its range, profile and turbulence*);
   - 2.5 Wave downward phase;
   - 2.6 Divergence of air:
     - 2.6.1 From the splitting of wind flow;
     - 2.6.2 From the turning of wind flow;
   - 2.7 Sink from suction from below (*inverted wind gradient when flying above a mountain ridge*);
   - 2.8 Sink from vortex (*rotor*);
   - 2.9 Sink from micro-gusts;
   - 2.10 Sink, which compensates a nearby updraft (*thermal*);
   - 2.11 Sink from air mass instability, both dry and wet.

Understanding downdrafts is just as important as understanding updrafts. Downdrafts consume height and shorten the flight, but also often trigger, indicate and model the shape of nearby updrafts.

Knowing different types of lift and sink is important as behind the same variometer indication, there might be completely different processes and circulations. Ignoring them can lead to bad decisions and empty hopes. For example, a thermal enhanced by suction over a mountain ridge can give the wrong impression about the thermal strength for the day. This can cause you to waste time searching for something with a similar strength, further along the route, where the help of the suction effect is gone. Or the opposite – a thermal suppressed by sinking air can give the wrong impression that the next thermal is also going to be weak. The pilot may waste time circling in each weak lift he encounters, instead of filtering out the weak thermals and working the strong one only.

The variations of lift and sink are endless, while human adaptation to conditions is limited and inert!

3. Wind

Air is full of different circulations with different scales, which fight or help each other. Wind is the horizontal part of air movement in these circulations but it also reveals what happens in the vertical part of the circulation – what lift and sink look like.

Inside large-scale circulations like cyclones and anticyclones, wind seems like something independent from thermals, something which tilts, triggers, drifts and deforms them.

In small scale circulations, the wind at take-off might be part of a thermal circulation. That’s why, when searching for lift, first we should clarify the big picture – to identify all available circulations and their features. For example, a ground inversion may reduce the circulation section area from below and increase winds at higher altitude. Sometimes, a cloud development over a mountain ridge narrows the flow section area from above and also increases the wind.

It is important to understand different circulations, their engine, range and scale. There is a big difference between wind due to a jet stream at high altitude, or a sea breeze crawling over the ground. The height and the source of the wind are important, because they determine to what extent it will interact with the terrain. For example, a high level wind blowing over an inversion layer will interact only with the highest parts of the mountain and so the mountain can be seen as a low hill i.e., not achieving its full potential for creating updrafts and downdrafts by the wind. Another time, the overdevelopment of thermal cumulus congestus clouds over the mountain can double and triple its “height” and can become an effective obstacle, even for strong winds. Thus, the overall atmospheric instability enters the equation of unravelling the circulations’ scale and strength. Sometimes, the circulation’s engine is a vertical instability like a gust front from rain’s downdraft; another time it is the horizontal pressure difference between hot and cold zones. The variety is enormous and the meteorology is eternal :)

After identifying updrafts, downdrafts, winds, and the circulations connecting them, we shall build our route line so that it passes through:

- More zones of lift and fewer zones of sink;
- More backwind and less headwind;
- More zones with safe landing and fewer zones with turbulence or without landing.

Each time, *lift, sink, wind* and *landings* have a different impact on the search for lift decision making. Sometimes, we restrict ourselves to fly toward a certain direction, because of lack of landings. Another time we avoid flying over easy for landing fields, because of blue sky – a sign of sink. Yet another time we risk flying over difficult terrain for landing such as a forested zone, seduced by a fat cumulus cloud – a sign of good lift. We constantly work with these 4 factors (*lift, sink, wind and landings*) and constantly intuitively re-calculate their probabilities. Experience in flying, terrain and conditions is exceptionally important for the preliminary setting of a good route and minimizing the time spent searching for lift. Experienced pilots can fly more and risk less at the same time!

The big differences between experienced pilots and beginners are visual judgment of gliding range, wind awareness and evaluation of safe landing spots. Experienced pilots have played thousands of glides and approaches to random landings in various conditions and they know what is possible and what is risky. They recognize early and promptly how to avoid entering *traps of the terrain* like wind-blown zones, sink in deep valleys, etc. At the same time, experienced pilots can afford deeper entry over non-landable terrain, and they can scan bigger zones for lift.

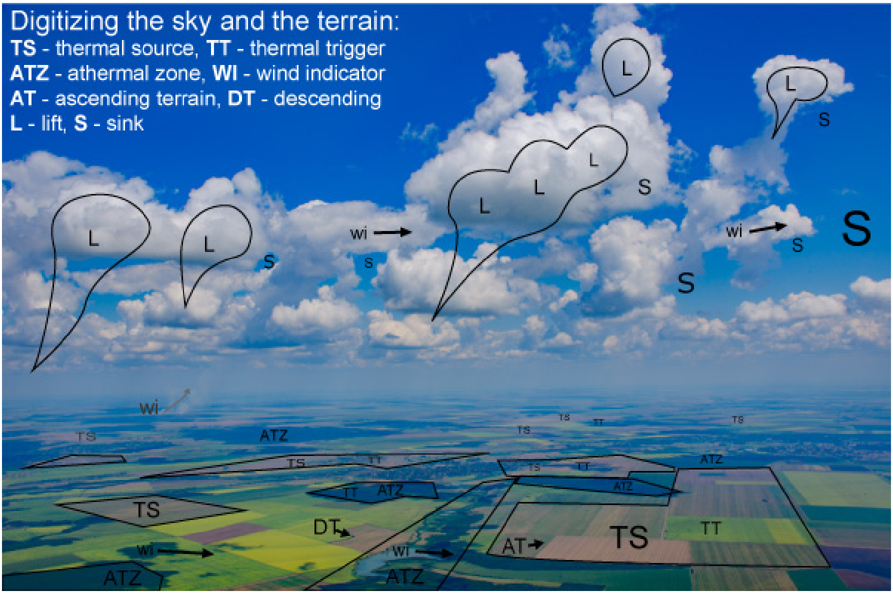
Another difference between experienced pilots and beginners is the time and scale of scanning the terrain and the conditions along the route. The attention of experienced pilots is almost constantly engaged with the search for the next lift, many kilometers ahead. Inexperienced pilots cannot trace the thermal trajectory easily, which consumes their concentration and their time for scanning the conditions and terrain ahead - especially, if they still have fear of sharp rocks, strong winds, turbulence and aggressive glider's reactions.

Apart from experience, knowledge and lack of fear, the successful search for lift and the whole cross country paragliding endeavor requires a certain psychological attitude – curiosity and love of knowledge, imagination, watchfulness, sensitivity, but also being free from earthly worries. The big paradox of flying is that it gives you freedom, but to obtain it you have to enter with a free mind the temple of flying i.e., freedom is given to the free one!

THE GRAND CHESSBOARD

The *search for lift* stage is the most difficult part of cross country flying. *Route progress* is relatively easy – fly straight in a given direction; *climb in lift* can also be mechanical by just chasing the strongest sound of the variometer. The search for lift requires vast knowledge of meteorology and the ability to „read“ surrounding air through the wing’s behaviour.

During the search for lift, the pilot transforms what he sees into a chessboard with lift, sink, winds and landings and tries to draw his optimal route line through them. This requires a good eye for details, without unnecessary gaze at them, but with fast and exact extraction of the abstract; digitizing the analogue picture - the climb is here, the sink is there, the landing is over there.



The analogy with a chess game can be simplified by dividing the elements into strong and weak, ours and theirs (*cloud streets and lonely clouds; lift and sink*).

The position of elements we work with is no less important than their strength. Sometimes, a pawn in a good position can be stronger than a queen in a bad position. For example, it is better to go for a weak climb, which is closer to other climbs than going to a distant strong climb surrounded by strong sink. The idea of ***position strength*** is also valid for the climb in lift stage of cross country flying.

One of the most reliable signs for a thermal is the logical sequence of its elements – first comes the *thermal source* (TS), then the *thermal trigger* (TT) and further downwind is the *cumulus cloud* (CC) visualizing the end of the thermal.

> A classic mistake, when searching for lift or thermalling next to a slope, is to be so hypnotized by the might of the mountain, that we constantly follow the terrain closely - to obey and join the stronger one. This way, we may lose the thermal, because we don't take into account that it lives its own life and rises independently, without blindly following the slope of the mountain. There is a similar

psychological and even philosophical problem and bias between the Materia and the Idea, between the real and the abstract.

Who to believe, who to obey – the hard surface of a sun baked mountain or the *invisible mountain* above, created by the wind's interaction with the terrain?

A similar problem, when searching for lift is being primitive and reacting impulsively to direct irritants/stimuli, instead of reacting to abstract ideas. For example, many pilots see a juicy cloud and rush for it without realizing that it will vanish before reaching it. A more successful approach is to see the juicy cloud as part of a bigger circulation and try to benefit from its next cycle, movement or transformation.

SEARCH FOR LIFT SUBSTAGES, INFO CHANNELS AND SCAN PATTERNS

The *search for lift* stage of cross country flying can be divided into 3 sub stages, similar to cross country flying (XC) stages, but on smaller scale:
- Identifying a *potential lift zone* (PLZ) ≈ Task setting (XC);
- Flying to the *potential lift zone* ≈ Route progress (XC);
- *Scanning the air* (SA) to *localize lift* (LL) ≈ Search for Lift (XC).

Scanning the air is easier for sensitive, observant, adaptive and open-minded pilots. Initially, it might be difficult for pilots with too much imagination, thinking and theories. Even experienced pilots can be surprisingly ignorant and slow to obvious signs of good lift, just because they suppose it should be somewhere else. Both, creating an idea and erasing an idea have inertia; adaptation takes time.

Good imagination, thinking and theories work well ahead, help the *search for lift* and reveal the big picture. But *scanning the air* requires a particular set of qualities, according to different outside conditions.

When flying, pilots are in three basic modes – *sensing*, *thinking*, and *acting*.

Sensing includes perception from all available information channels – visual, tactile (*wind in face or harness pressure on skin*), inner ear balance apparatus (*position in space and motion*), sound, smell, temperature.

Thinking includes the instinctive and cognitive (*knowledgeable*) processing of information. We are born with various self-preservation instincts, but our human cognitive ability allows us to suppress them and even develop counterintuitive behaviour; to react to ideas, not to irritants. In the beginning, the cognitive approach is infested by fears, but later we can master our mind and body and turn “instinctively” when we enter lift. Practice and experience optimize the thinking and polish it like a river stone. Intuition is like an oval river stone – it’s not good for masonry, but it shows quickly the flow.

Acting is the visible part of piloting – the work with controls.

The balance between *sensing*, *thinking*, and *acting* depends on conditions. Classic thermals require more action than thinking. Broken thermals require more filtering with less acting. Odd and twisted circulations require more sensing and thinking.

> ***Piloting*** is an awareful control. If the pilot doesn’t know that the pull of brakes changes the angle of pitch and attack, he is more like a passenger. Modern airline pilots are actually operators of autopilots, computers, and automatic systems. In their training, they are drilled to strictly follow a set of instructions and miss the freedom and the pilot progress opportunities, which we have in paragliding. A slow flying aircraft, like the paraglider, has constantly and greatly changing basic flying parameters like airspeed and angle of attack, because our airspeed is within the same range as wind gusts. This requires more frequent piloting with its sensing, thinking, and acting for maintaining efficient flying modes. There is also a difference if the pilot reacts on a change of a flying parameter, its speed of change or the sum or accumulation of changes with time (*integral*). There is one brake, but so many different ways to pull it! The better pilot is not the one who flies further or faster, but the one who is aware of what’s going on with his wing and the surrounding air. Kilometers and competition rankings are like gambling, which give short term satisfaction. Awareness and merging with wind and wing are like making love, which gives long lasting happiness.

Scanning of Air for Localizing Lift requires “reading” of different air circulation structures and their elements, through all available information channels:

- *Acceleration*. When a wind gust hits the wing, or when the wing enters a wind gust or a thermal, the wing with the pilot attached below accelerates in one direction or another. The pilot feels the acceleration, through the pressure of harness’s seat and risers, upon his skin and body. Fly thermals with your bum and cross country with your head!
- *Vertical and horizontal speed*. They are shown by a variometer, GPS device or smart phone application, using pressure, GPS or acceleration sensors. Horizontal speed is often neglected by obsessed with their variometer pilots, but it’s very important for revealing of surrounding air and circulations. If our speed increases - when flying against the wind, it’s often because a thermal is blocking the wind ahead of us;
- *Paraglider specific behaviour*. Unlike other aircrafts, paragliders have much much lower *wing loading*, which means a bigger surface carrying less weight. The relatively big surface of paragliding wings makes them great sensors of surrounding air motions. The paraglider is a big pendulum, which combines the aerodynamic force changes, the pilot’s body weight force and inertia into specific motions, unlike other aircraft;
- *Inner ear balance apparatus* detecting when the pilot is rotating, following paraglider specific movements;
- *Visual observation* of moving objects, clouds, etc. Visual observation is also used for reading changes of body rotations, when following pitch, roll and yaw motions. The human eye can detect a change of 1-2 degrees, so just by looking toward the horizon, a good pilot can detect quite small changes of the angle of pitch;
- *Wind feel* on face, noise in ears, smell of air and its temperature.

Scanning of air patterns for localizing lift have the following goals:

- to cover maximum area or check a specific spot or direction;
- with minimum height loss;
- for minimum time. Except, when struggling very low and we are trying to win time till the next thermic cycle.

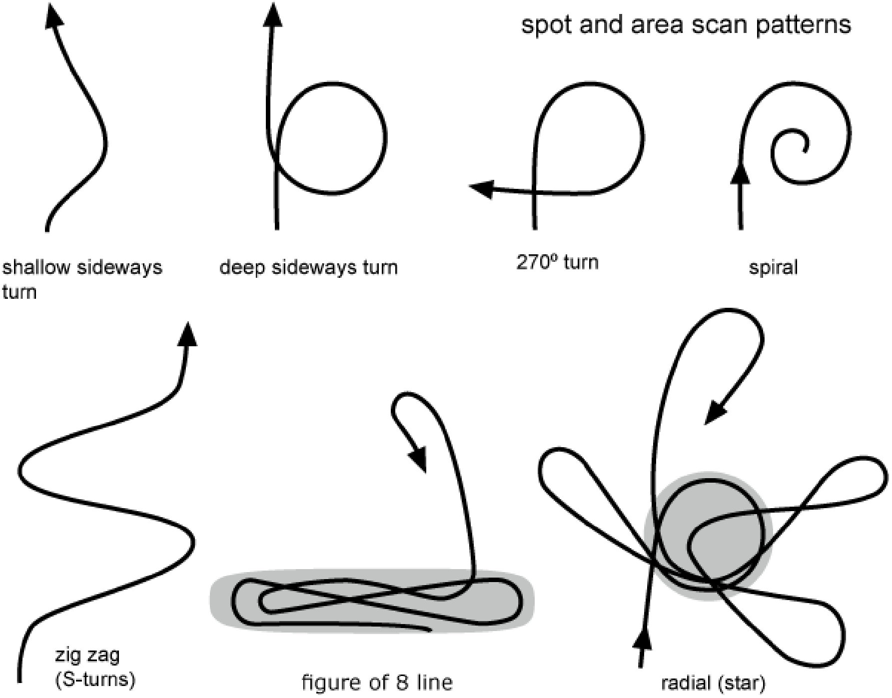
Scanning of air patterns can be divided into *spot* and *area*.

Spot scan patterns:

- *Shallow sideways turn* of up to 90° and turning back to original direction, if nothing has been found;

- *Deep sideways turn* of more than 90° and coming back to original direction by completing a 360° turn, as a change of direction consumes more height then keeping the same direction till completing a full circle;
- *270° turn*. In the absence of another search direction, this is a very efficient check of what’s happening in 3 different directions – forward, to one side and then to the other;
- *Spiral* - reducing the radius of a circle to localize a potential lift in the centre, to find the core;
- *Expanding spiral* – expanding the radius of a circle to localize a better lift around.

Area scan patterns:
- *Zig zag* - covers a big area with up to 90° turns;
- *Radial* or *star-like* scanning for better lift nearby and coming back to the main one if nothing has been found;
- *Figure of 8* - waiting in ridge lift for the next thermal cycle, checking what’s in front and coming back to the ridge.



spot and area scan patterns

shallow sideways turn

deep sideways turn

270° turn

spiral

zig zag (S-turns)

figure of 8 line

radial (star)

Some scan patterns are more efficient than others, who require bigger Route Deviation and even flying back. **Never search the same place twice**, unless you’re low and it’s bubbling promisingly!

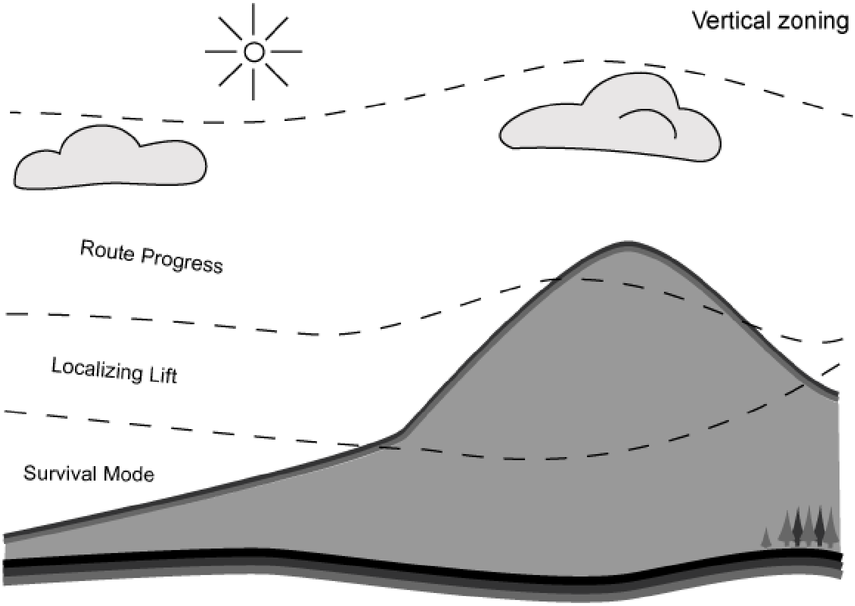
ZONING: HORIZONTAL, VERTICAL, TIME

The *search for lift* stage, and the entire cross country flight, can be understood better if the flying playground is divided into different zones. Apart from the horizontal zoning, where lift, sink, wind and landings are like figures on a giant chessboard, there is also vertical zoning, where the playground is divided into 3 height sub-zones.

The highest zone is where we finish the *climb in lift* and glide to the next lift, converting height into *route progress*.

The next zone below is dedicated to *localizing lift*, but we still can add some route progress while within it. Localizing lift is a part of the much bigger *search for lift* stage, when we search for the next lift during route progress, but also during *climb in lift*. About 80% of cross country focus is dedicated to the search for lift.

If we don’t find usable lift and lose more height, then we enter the ***survival mode** zone* (SMZ), where we desperately search for lift to prevent an early landing – a *bomb-out*. In survival mode we don’t care about route progress anymore and we can even fly back. Being able to walk is more important, than adding a step along the road.



Vertical zoning can be refined further, such that we have 5 instead of 3 zones. The lowest one, below the *survival mode* zone, is the ***landing approach*** zone, where we give up searching for lift and focus on our landing. The highest one, above the *route progress* zone is the ***extra lift*** zone, where we climb inside clouds or other exotic types of lift.

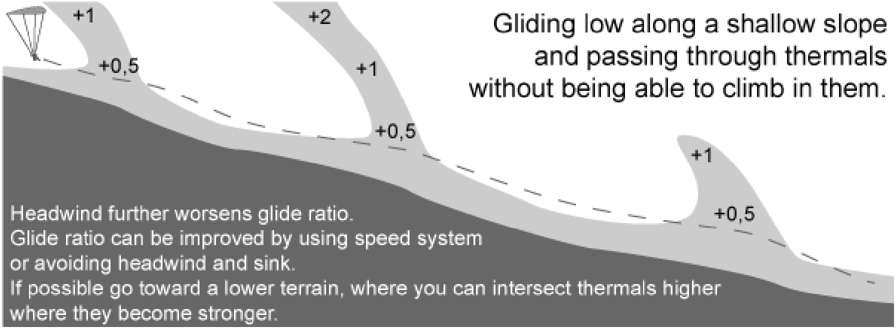
Route progress, *localizing lift* and *survival mode* zones are not equal, but determined and updated in accordance with the vertical and horizontal distribution of lift, sink, wind and available landings ahead.

The *Route progress* zone is wider than *localizing lift* and *survival mode* zones, when there are:
- Reliable high rising climbs starting from low altitude;
- Favourable lift distribution along the route line like lift streets, convergence lines and thermal clusters;
- Back winds drifting us along the route;
- High-performance paragliders;
- Plenty of landings;
- Good pilot' knowledge and skills in route progress, search for lift and climb in lift.

The *survival mode* zone is usually used to recover from mistakes and misfortunes during search for lift and localizing lift. *Survival mode* has two goals – often aligned, but sometimes not – to cover as great an area in search for lift, and to use even light lift to win time, even without gaining height. Downwind flying gives the best glide ratio and the maximum search for lift area. Going downwind does not always guarantee survival, as some streams fill a too big terrain vessel before transforming into a rising air. When you switch to *survival mode*, you should build a search for lift route line, which passes through 1-2 potential thermal triggers and a realistic landing within their range plus a safe margin in case of unexpected sink or headwind. The survival mode masters are sensitive and sensible pilots who not just listen, but actually hear, what the wind sings to the wing; they climb fast, and build efficient search-for-lift lines. Don't forget the landings and don't gamble too much with them. *Survival mode* in flying is also a life concept too. Try to play it longer :-)

The change of a zone, due to change of conditions, automatically changes the other zones. For example, when entering a difficult to read terrain, the rise of the localizing lift zone influence the survival mode zone underneath, which follows it as a backup height zone. And the opposite – when entering a terrain with limited landings, the rise of the survival mode zone changes the localizing lift zone above.

The pilot not only sets imaginary vertical zoning borders, but can physically alter them when entering different terrains. For example, the pilot may turn toward a descending terrain and expand the vertical heigh zones. The pilot should also be careful not to fall into *traps of terrain*, like flying low along a slightly descending slope, parallel to the gliding trajectory. It's a combination of slope angle, wind, and wing's glide ratio. It is frustrating to realize that the game is over when you still can glide far and find thermals, but all the time you're too low to catch them. Even in very unstable conditions thermals have a minimum usable height. They need time and space to organize and accelerate from flat warm layer to a vertical column or bubble. Low saves are great, but endless survival mode can turn flying into a prison. So, monitor your glide ratio and wind, but also watch what the terrain is doing below, in order to stay free in a comfortable height band.



During the search for lift stage, we should always look for the thermal *source-trigger-cloud* triad. At high altitudes, pilots care more about what clouds ahead are doing. At low altitudes, they look at thermal sources and triggers. But good pilots look for the *source-trigger-cloud* triad all the time, at all altitudes. This exercise for the mind helps to build experience, even when flying is easy, even when we're on the ground just watching the sky.

The thermal *source-trigger-cloud* triad is not only useful to guide us toward thermal areas, but also to localize, intersect or re-centre thermals quickly. It is very important to monitor precisely the tilt of our or other's thermaling trajectories. This will help to confirm or reject our *source-trigger-cloud* triad assumptions.

Thermal *source-trigger-cloud* triad should be modified in *force majeure* conditions, like vast overcasting with a few sunny holes. The sunlit areas become the only available thermal sources. Classic triggers lose their strength, replaced by the contrast sun-shadow borders. When high, we’re no longer chasing clouds, but blue holes and especially their upwind side.

A common beginner’s mistake is to focus too much toward a particular thermal source like a parking lot, a dry field etc. In reality, thermal sources are much bigger than we think. The whole ground layer can be covered with warm air, fed from various sub sources and brought by the wind from 5, 10 and even 20 km away. Then, thermal triggers become more important than thermal sources.

In strong winds, the location of a thermal source may lose its significance as wind drifts warm air far away and mixes it with surrounding air, creating a semi unstable ground layer. Sheltered areas, strong triggers or convergence lines may become more important when searching for lift.

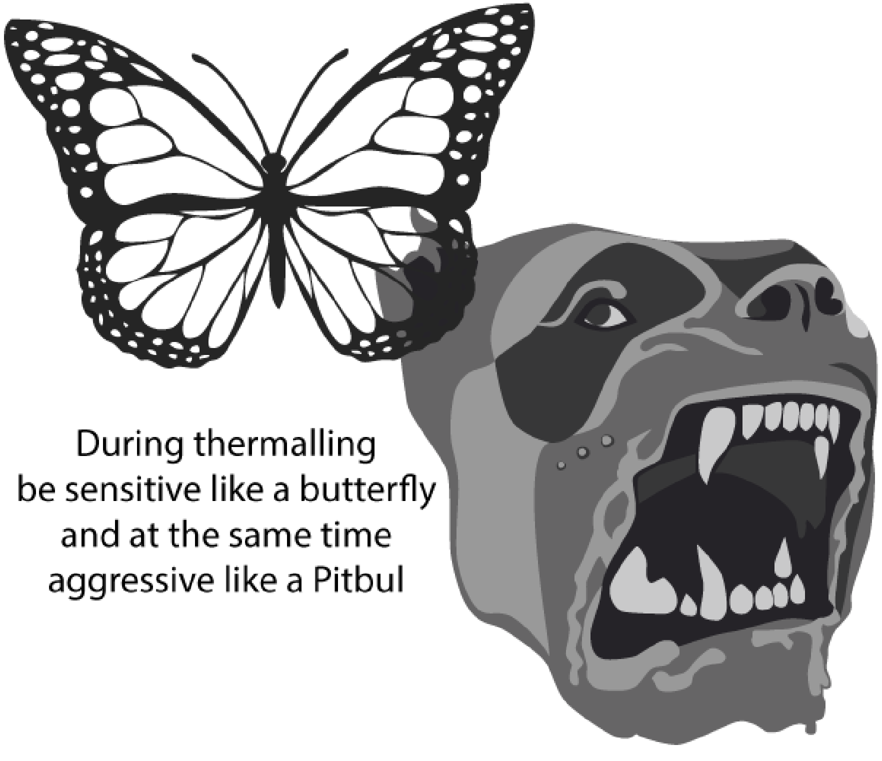
A good thermal trigger is usually combined with a *thermal collector*. It can be a terrain feature like a pyramidal slope, or a saddle, where two or more thermal flows meet. A *thermal collector* might be also an air circulation like a convergence, a wake behind an isolated hill, a line from a front wedge, wave, or bouncing of falling winds. The good thing of a *multi thermal trigger* is that its wedge or circular shaped zone is bigger, stronger and you have more spare options.

> The cross country flying playground is the so-called *boundary layer* – the lowest part of the atmosphere which is the most strongly influenced by the terrain through friction, turbulence and heat exchange. Thermal tops, including their clouds, set the top of the boundary layer. The main source of heat for the transparent air is the ground surface heated by the sun. The daytime, spring and summer addition of solar energy expands the boundary layer. Night, autumn and winter cooling shrinks it. The daily and seasonal variations of boundary layer hint that its moving ingredients, like updrafts, winds and circulations, have their own life cycles and flying becomes harmonious, if we tune into them.

The Pitbull and the Butterfly

Flying low in survival mode is the most dramatic part of cross country flying, when you want to fight like a gladiator, but you have to stay cool and open minded. You’re schizophrenically torn apart between two opposite mind states – being sensitive like a butterfly about little breaths of wind and at the same time ready to bite like a pitbull each decent lift, which can hold you up. It’s so frustrating when you want to shout, and kick, and grab, desperate not to sink further down, but your only option is to open your senses and feel where the lift is: Here it is … and you turn and bite it like a pitbull … Rrrrrh … Oh, no! It’s gone … and you’re sensitive like a butterfly again.

Tender and aggressive at the same time. It requires a specific mindset and after participating in the birth of many thermals, you can develop a character that will open new horizons in flying and life.



TIME ZONING

The only sure thing in life is change!

It’s difficult to comprehend the enormous variety of interacting meteorological elements like winds, clouds, inversions, waves. It’s even harder to use them for cross country flying due to their short-, mid- and long-term periodical oscillations. Additionally, the multi scale air circulations go in random directions, helping or opposing each other, pulsing with their own independent oscillations and life spans. To top it off, we’re moving in space and time, which further complicates our tuning into them.

How to be in the right spot at the right moment?

The easiest approach is from big to small, from the general to the detail. For example, for cross country flying we choose a suitable season or day with favorable conditions. Throughout the flying day we check what the tendencies are. Will the wind increase? Are there high clouds coming? Will local cloud development overcast the sky? Will stable air come in or is a local destabilization and overdevelopment more likely?

For a better prediction of the condition’s tendencies, it’s good to examine the previous and next day’s forecast. It’s good to know and recognize large scale air mass invasions and their local transformations by the terrain, season and daily influx of the sun’s energy.

Then, we need to know the life-cycle of separate elements we work with during the given day and environment. How much time does it take for the warm air to rise from the ground to the cloud base? How much time is the life-span of a cloud, which in turn hints at the life-span of a thermal? Is its growth faster than its decay? How much time might an overcast period last, before it kills the clouds making it?

At the end, we need to be aware of our own movement. How much time will it take to reach the cloud ahead of us? How much height loss would it take to check for lift 1 km upwind or 1 km downwind? Shall we reach the cloud before it stops working, if we’re 400 m above ground and climb with 2 m/s?

Even if we don’t manage to harmonize ourselves to the entire flight, it’s worth trying to adjust ourselves to its separate elements, like escaping an overcast area, catching young thermals and skipping the old one, or avoiding a local strong wind. Again, experienced pilots on sporty wings with high glide ratio and wider speed range have a clear advantage. By slowing down or speeding up, they can adjust themselves to the cycles of thermals, overcasting, winds, etc. Sometimes, intentional delay by working the final weakest part of a thermal can bring you just for the birth of the next thermal along the route, while blind rushing and over-filtering can bring you out of the next thermal’s cycle. ***Festina lente* - less haste, more speed**!

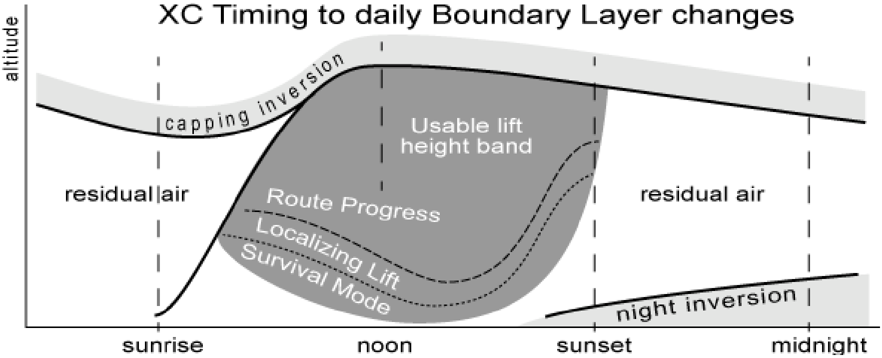
As a practical rule, if you see a good cloud within a gliding distance, in most cases, the thermal which causes it will be gone before you reach it. If the thermal source and trigger are strong and active, then a new cloud may appear at the same place, or slightly upwind. Beginner pilots are often disappointed when reaching a dying cloud, and then they are often pleasantly surprised by the next thermal cycle. Good pilots don’t waste emotions on temporary gains or losses. They’re happy in a bigger scale, when they find a good working zone with many thermals over a long period of time, not just one of their bubbles.

Good timing to the next climb is easier when you’re working with thermal zones like clusters and convergences, instead of individual thermals. Sometimes, focusing your timing on the second or even the third potential lift zone along the course line may help avoid arriving too late or too early at your next thermal. Poor timing on larger scale events like a broad shadow or a general airmass stabilization cause more harm than small scale misfortunes.

INTER CONNECTION BETWEEN BOUNDARY LAYER, TIME AND VERTICAL ZONING

With the rise of the sun, the first thermals start on the slope of the mountain. Flatlands are still calm, capped by the night inversion. As the day advances, thermals gradually increase their top and bottom range, which respectively increases potential route progress distances. With the approach of the peak of the day, the pilots can afford higher climbs and lower saves, which further increases route progress distances. During late afternoon, with the reduction in Earth’s heating, the boundary layer stabilizes, starting from below and expanding upwards. The pilot needs to stay higher, where there are still usable thermals.

The daily change of the instability profile - the strength and vertical range of thermals, modifies the vertical zoning: – route progress, localizing lift and survival mode zones.



The first thermals of the day are short-lived bubbles. In the afternoon, they become like a chimney or column type, solidly attached to their thermal triggers. So, it's not just the vertical range, but also the cyclicity of thermals, which determines our timing - when to hurry, when to slow down, what to take, what to ignore?

Some terrains and conditions make you fly harmoniously; some push you to work more to harmonize with them and it's not only because of their strength, but their structure too.

Time zoning becomes easier when you understand the short-, mid- and long-term oscillations of the cross country ingredients.

> The daily influx of the sun's energy leads to two contradictory events involving clouds and overcasting:
>
> Adding heat into the air decreases its relative humidity and there is less condensation and cloud formation. Daytime heat is known for melting cloud covers.
>
> On the other hand, part of the sun's energy goes into evaporatng moisture from vegetation and the rise of cloud-producing thermals. High and humid layers and blocking the cloud-rise inversions can easily cause massive overcasting – *horizontal overdevelopment*.
>
> Which one will prevail – sunshine or shadow production depends on the boundary layer temperature and humidity distribution. The

boundary layer profile doesn’t usually change rapidly; it stays quite the same for the given terrain, climate and season, unless there are fronts, advections or sensitive balances, which could cause significant transformations.

In mountains, at the beginning of the day, the winds are weak; climbs are further away in front of the slope and more vertical. A common mistake is when pilots, who are lazy to run, wait for winds that are easier for inflation and take off. Later, when winds increase at the launch site, stronger thermals pass through, but it becomes more difficult to distinguish them within stronger upslope winds and follow their tilted by the wind trajectories. In the afternoon, it might be just wind without usable thermals at launch. Then, good thermals are much deeper in the “heart” of the mountain. Be careful and don’t follow them low inside the mountain, unless you are ready to embrace it.

During thermic activity, a general rule is that calmer areas are often convergences, with better and more vertical lift. Windy areas are usually divergences, with poorer and more difficult to use lift.

CLIMB IN LIFT

Climb in Lift (CL) stage of cross country flying has the following goals:
- To climb fast ($V_{y\ max}$);
- To climb high ($+ \Delta h_{max}$);
- To make some route progress, if possible.

Before attempting their first cross country flight, beginner pilots should learn how to climb in lift well. Not just for the success of the cross country flight, but because of their safety. Losing lift and not climbing high enough means fewer safe landing options. Bad centring and frequent entering and exiting in and out of lift means more encounters with sink and turbulence around. Poor thermaling directly results in more collapses and scary experiences, which can psychologically damage the pilot, halt his progress, and even make him quit paragliding.

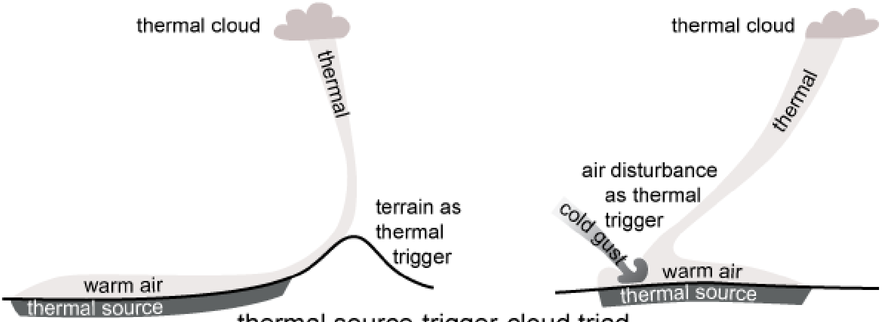
Start step by step. Go first to a flying place with big, easy and smooth thermals, preferably of the stationary column type, not short-lived pulsing bubbles. Climb in them and fly out. Come back and catch them lower. Climb up, fly out, come back, climb up…

Do the same at another place or in other conditions. Often, there are various updraft types used in the same cross country flight, so prepare for different thermal types and thermaling techniques.

Good pilots should be able to:
- Catch and climb in various types of lift, from the bottom to the top - from their lowest to their highest usable parts, when needed;
- Climb fast, as about half of the cross country flight time is spent on gaining height;
- Find time and concentration to observe the terrain and conditions ahead, while climbing. The decision, when and where to go next, should be taken before the current climb finishes. *Climb in lift* is the perfect sounding of the atmosphere's boundary layer, like professional meteorological balloons and mathematical forecasts. Use your first climbs to see the boundary layer structure: Are there inversions and at what height? How high is the cloud base? At what height band does the lift get stronger, or weaker? What's the wind strength and direction at different altitudes? Does it get more turbulent at a particular altitude and why?

Thermals are the main type of lift used in cross country flying. Thermals are a product of atmospheric instability (*temperature lapse rate*). Instability is created from below (*warm ground*) or above (*cold air*). In any case, thermals have three common elements:

- ***Thermal Source***. The place that is producing a warm layer of air, which has the potential to rise up, because it's lighter than surrounding air.
- ***Thermal Trigger***. A terrain feature or air disturbance, which transforms the horizontal warm air layer into a more drag-efficient vertical bubble or column.
- ***Thermal Cloud***. The highest end of the thermal, visualized by the condensation, if there is enough moisture.

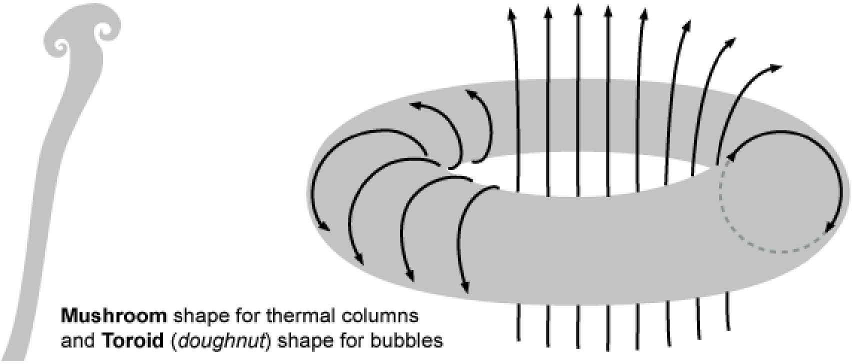


thermal source-trigger-cloud triad

When searching for lift, good pilots try to match these three elements and intersect the line connecting them, according to their altitude of arrival. When thermalling, it's easier for the pilot to follow the climb if he knows the trajectory of the thermal - where it comes from and where it goes to. A pilot who has spent more time in a thermal should understand it better and should have more efficient thermalling technique, than newly-arrived pilots.

The trajectory of a rising thermal can be quite snaky and difficult to follow. There are two major forces driving a thermal's motion – buoyancy and wind. Stronger buoyancy force, driven by temperature difference, and bigger volume and mass make thermals more resistant to wind.

The air drag, which opposes the upward motion of a thermal, models it into the more efficient *toroid circulation* – doughnut-shaped for thermal bubbles and mushroom-shaped for thermal columns:



Mushroom shape for thermal columns and **Toroid** (*doughnut*) shape for bubbles

How to use an invisible, oddly shaped thermal, rising along a wavy trajectory throughout the invisible air?

The simplest approach is **chasing the sound of the variometer** – go wherever it beeps louder.

The more intelligent approach, consciously or subconsciously used by experienced pilots, is to imagine and “see” a thermal’s shape and trajectory. Thus, pilots avoid reacting with a delay to what the variometer tells them, but also predict and prepare for the efficient use of changes in lift. The imagination requires knowledge and experience of different types of thermal. “Seeing” means reading, sensing and understanding all available sources of information - variometer, acceleration felt by the body, change of position in space through inner ear balance apparatus, paraglider specific behaviour, the feel of wind, noise, smell, and visual clues.

Before we learn how to deal with something that is difficult, strange and invisible, first, we need to understand its elements, structure, variations and parameters. We need a thermal classification according to paragliding specifics, parameters and abilities.

When you enter lift, you cannot stop, pull the handbrake and park in it, like a car. The paraglider needs to keep flying and working as a wing. Circling is the most efficient way to stay in an area of lift with minimum descent through the air. Modern paragliders descent with a vertical speed of V_y = 1-1.1 m/s while gliding and with V_y = 1.2 m/s or more while circling.

THERMAL CLASSIFICATION

THERMAL ELEMENTS

Lift Zone – an area where the variometer indicates a vertical speed V_y that is higher than the paraglider's trim sink speed. $V_y > -1.2$ m/s. Air is "lifty"; it's rising, but not fast enough to gain height with it.

Climb Zone – $V_y > 0$ m/s . There is a gain of height

Core – a distinct area with the strongest lift

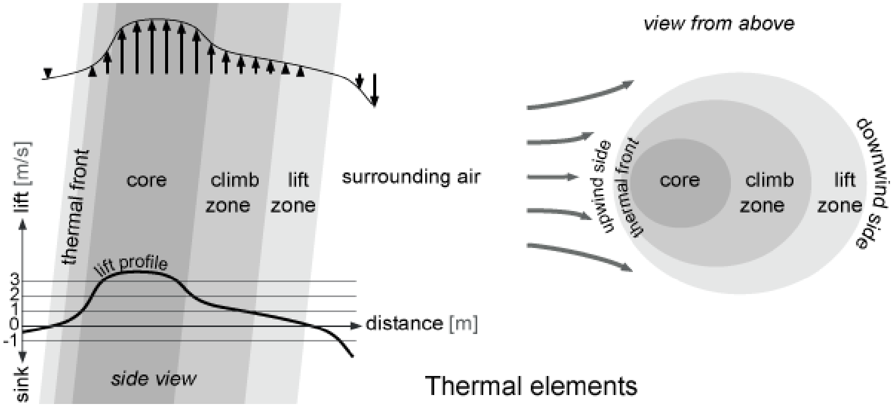
Surrounding Air – the air around the *lift zone*

Lift profile – horizontal distribution of updraft's vertical speed

Core Wall – the border between the *core* and the *lift zone*

Thermal Front – a distinct border between the *lift zone* and the *surrounding air*. The *thermal front* is usually found in asymmetrically shaped by the wind thermals, where the *core wall* is very close to the end of *lift zone.* A zone with steep horizontal wind gradient.

Thermal Top, Thermal Tail, Upwind side, Downwind side



Thermal elements

THERMAL TYPES

We classify thermals or parts of them according to different criteria like size, strength, shape, etc.

1. *SIZE* - according to the paraglider's ability to stay in it with 360° turns:
    1.1 ***Bubbles***: too small to stay in climb zone; losing height on average, when thermalling;
    1.2 ***Narrow***: difficult to stay the in the climb zone, but possible to gain height; require efforts and occasional small radius turns;
    1.3 ***Medium***: staying in the climb zone may require efforts and small radius turns;
    1.4 ***Wide***: easy to stay in the climb zone, using wide turns with minimum banking;
    1.5 ***Huge***: a sign of convergence or cloud suck.

2. *STRENGTH* - according to paraglider's ability to maintain and gain height with 360° turns:
    2.1 ***Subzero***: $-1.2 < V_y < 0$ m/s; the thermal rise is less than paraglider's own sink rate, so typical circling, even if it's very flat, still leads to height loss;
    2.2 ***Zero***: $V_y \approx 0$ m/s; the thermal rise is close to paraglider's own sink rate, so it can be used to maintain height, but requires efficient circling;
    2.3 ***Weak***: $0 < V_y < 1$ m/s; the weak thermal requires efficient turning with skillful tracking and staying inside, as it may disappear suddenly and be lost easily;
    2.4 ***Moderate*****:** $1 < V_y < 2.5$ m/s; the moderate thermal can still be lost, but it's more stable and usually the whole circle is in climb;
    2.5 ***Strong*****:** $2.5 < V_y < 5.5$ m/s; it's well shaped and it's easy to track and stay in it;
    2.6 ***Very strong*****:** $V_y > 5.5$ m/s; If a very strong thermal is small in size, then it may cause long-lasting loss of airspeed and manoeuvrability, which can make it difficult to turn within it.

3. *LIFT PROFILE* - according to the distribution profile of upward velocities; a horizontal wind gradient:
    3.1 ***Arc*;**
    3.2 ***Bell shaped*;**
    3.3 ***Peak***;
    3.4 ***Plateau*;**
    3.5 ***Multicore, compound, cluster***:
        3.5.1 ***Equal cores***;
        3.5.2 ***Subordinate cores***;
        3.5.3 ***Random cores***.
    3.6 ***Asymmetric***.

4. *HORIZONTAL SHAPE OF A CROSS SECTION* – usually modelled by the wind:
    4.1 ***Circular***: usually in calm conditions;
    4.2 ***Doughnut***: toroidal elements;
    4.3 ***Elliptical***: elongated by the wind with stronger lift at the upwind side;
    4.4 ***Water drop***: more pronounced elongation by the wind;
    4.5 ***Streeting***: greatly stretched horizontally due to strong wind and weak instability; a lift street by a single or multiple thermals.

5. WIND DRIFT
    5.1 ***Vertical***: no drift;
    5.2 ***Drifted*** (*for bubbles*);
    5.3 ***Tilted*** (*for columns*);
    5.4 ***House thermal***: a thermal well-known by local pilots, which triggers regularly from the same spot, usually close to the take-off; it is usually strong, reliable and less dependent by the wind;
        5.5 ***Wandering thermal***: unlike thermals drifted by the wind, which have been triggered from a static trigger point, wandering thermals have a moving trigger point or mechanism - usually an air disturbance like strong sink, a gust or cold front; wandering thermals are more typical for uniform flatlands without strong ground features.

6. *TRAJECTORY*
   6.1 ***Straight***;
   6.2 ***Exponential***;
   6.3 ***Oscillating***;
   6.4 ***Sneaky***.

7. *VORTICITY*
   7.1 ***Vertical axis of rotation***;
   7.2 ***Horizontal axis of rotation***;
   7.3 ***Toroidal circulation***.

8. *WARM AIR SUPPLY*
   8.1 ***Bubble***: limited warm air supply by the thermal source or trigger;
   8.2 ***Column*** long lasting warm air supply by a given thermal source, usually delivered by a few thermal sources; it's observed mainly in the afternoon when uniting the warm air circulations start and when there is an accumulation of daily heat;
   8.3 ***Pulsing column***: Periodical change in updraft's flow rate due to the irregular work of the thermal source or trigger.

9. *MOISTURE*
   9.1 ***Dry***: thermals made of dry air; usually bumpier and more turbulent;
   9.2 ***Wet*:** humid air, still invisible and usually smoother;
   9.3 ***Saturated***: condensed moisture inside a cloud;
   9.4 ***Blue***: a thermal which never creates a cloud.

10. *INSTABILITY PROFILE*
   10.1 ***Low level stable***: no usable connection with terrain thermal sources; thermal soaring is possible at higher altitudes, above the stable ground layer;
   10.2 ***Low level quasi stable***: good overall temperature gradient, but with hidden blocking inversions; possible dust devil formation due to abrupt release of thermals in dry conditions; very weak and shapeless climbs in humid conditions;
   10.3 ***Low level unstable***: easy and frequent triggering of thermals in super adiabatic temperature gradient, especially in highlands;
   10.4 ***Cloud connected***: the last part of the thermal is visualized by moisture condensation;
   10.5 ***Cloud sucked***: the last part of the thermal is boosted by the cloud suck above;

- 10.6 ***Cloud disconnected***: the thermal has no usable connection with the cloud above and usually ends a few hundred meters below it;
- 10.7 ***Stopped by inversion***: the thermal can be completely stopped, but sometimes its core may penetrate the inversion, stripping its other parts; there is a lot of turbulence; the surrounding sink zones might be amplified by the inversion's elasticity and the updraft's ricochets; the core which manages to go through is influenced by the winds above the inversion;
- 10.8 ***Finishing due to shortage of warm light air***: both because the thermal source provided only a small amount of warm air, or because of too much mixing and dissolution into surrounding air;
- 10.9 ***Finishing due to buoyancy deficit***: thermal air still might be warmer than surrounding air, but the temperature gradient is not enough for the thermal to overcome air drag and friction.

11. *TURBULENCE* – thermals which cause pitch, roll, yaw, airspeed and aerodynamic force changes; possible collapses and stalls:
    - 11.1 ***Smooth***: no spontaneous reactions by the wing;
    - 11.2 ***Solid***: climbing in the thermal causes moderate and predictable changes of pitch, roll and yaw, which need to be controlled by the pilot – especially the pitch, which can cause overshooting and collapses;
    - 11.3 ***Bumpy***: energetic kicks of lift cause considerable changes of pitch, roll, yaw, airspeed and aerodynamic force; active flying is needed to prevent asymmetric and frontal collapses; there might be long-lasting losses of airspeed and lift force;
    - 11.4 ***Choppy***: frequent and sudden, but short-lasting losses of airspeed and lift force; sudden drops; the pilot's reactions are usually slow and do not help;
    - 11.5 ***Wild***: the stronger version of bumpy thermals with larger kicks from any direction; the pilot's body is being thrashed and accelerated in random directions; possible long-lasting stalls and collapses.

12. EMBEDDED / NESTED in other types of lift or air circulations
    12.1 ***Ridge lift***: thermals are often triggered by the ridge lift zone, in front of the ridge, but you can also find them within the ridge lift or rising along the slope; in stronger winds, the thermals can trigger abruptly and be deformed and turbulent;
    12.2 ***Anabatic***: the lower part of thermals is embedded in the anabatic flow; unlike ridge lift thermals, anabatic thermals can be partly or entirely fed by the anabatic flow and are also less turbulent;
    12.3 ***Wave***: upward wave zones improve instability and thermal rise, often better than in other places;
    12.4 ***Convergence***: convergence zones not only increase instability but can also mechanically enhance thermal rise and cluster it with other thermals;
    12.5 ***Virgin***: usually the first thermals for the day in a certain area, which may be turbulent as they penetrate through inversions and residual air;
    12.6 ***Lubricated***: thermals, which follow the path of other thermals, including their inversion punctures; thermals aided by other types of lift;
    12.7 ***Suction thermal*****:** the acceleration of wind flow over a ridge creates a zone with lower pressure, which can greatly increase instability and can even mechanically suck air from underneath. The same for vertical positive wind gradient areas, especially under local jet streams;
    12.8 ***Rotor thermal:*** Similar to a suction thermal, but here the thermal is part of a pronounced lee side vertical vortex (rotor) or is enhanced by it. Apart from lee-side suction and vorticity, there are also other mechanisms for vortex creation.

THERMALING STAGES AND TECHNIQUES

Once we find a thermal, we switch to *climb in lift* mode, which has 4 sub stages:
- Entering lift;
- Scanning and mapping;
- Climbing and tracking;
- Exiting lift.

The search for lift may bring us into a thermal unexpectedly, but often there are preceding signs, which give us time to prepare and enter the thermal efficiently.

ENTERING LIFT

The main goal of entering lift is to prepare us for the next stage – *scanning and mapping* of lift. The secondary goal is to gain maximum height during the thermal entry. In some occasions - e.g. when being desperately low, rapid height gain may have priority.

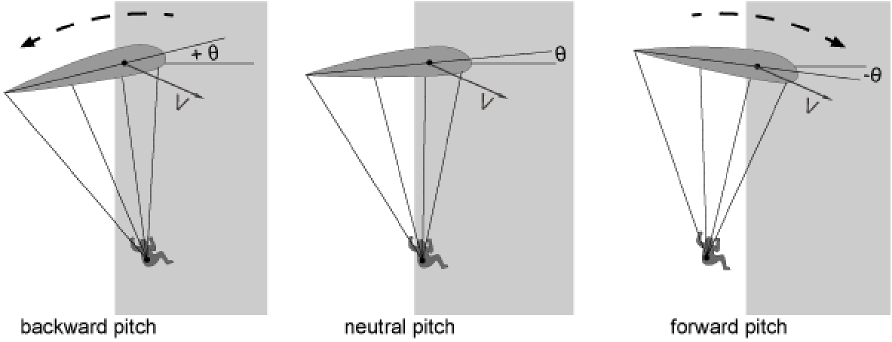
Scanning and mapping require manoeuvrability. Maneuverability requires airspeed. So, the main goal when entering lift is to preserve airspeed, and even increase it, if possible.

Paragliders have 3 possible reactions, when entering a thermal: *pitch-up* backward motion, *pitch-neutral*, *pitch-down* forward motion. Which one will happen, depends on the wing design's profile, on airspeed of entry, and on the thermal's strength and profile – horizontal wind gradient.

> Classic wing profiles are aerodynamically unstable. This is because a gust from below increases their angle of attack, which moves forward their *centre of pressure*, where the entire aerodynamic force is being applied. This creates a pitch-up momentum, which rotates the profile, and additionally increases the angle of attack. The great paragliding pendulum compensates for the wing's aerodynamic instability and restores the pitch-up effect.

Other wing profiles, like S-shaped or also called “*reflex*” profiles, are aerodynamically stable as their *centre of pressure* doesn’t move toward a creation of a pitch-up moment and rotation. The price is reduced performance, or glide ratio, and they’re popular among paramotor pilots, who want minimum discomfort from thermals and wind gusts.

Modern high performance wings have flatter and thinner profiles with sharper noses. These, plus the arrangement of line attachment points, make them less pitch-up active, when entering lift.



Thermal entry scenarios

Whether the wing will pitch-up, pitch neutral or pitch-down depends on:
- *Lift profile* – the horizontal gradient of vertical wind. This works in combination with the other factors;
- *Speed of entry*;
- *Wing profile*. When high camber wings and thicker profiles hit lift, they react like hitting a wall and pitch-up backward. Thinner and flatter profiles cut deeper into the thermal’s flesh and stay more pitch-neutral;
- *Wing loading*. More heavily loaded wings have milder reactions to outside disturbances like thermals;
- *Aspect ratio*. High aspect ratio wings are more reactive to outside disturbances (*steeper* c_y^{α} *characteristic*) – an increase of angle of attack boosts lift force and makes wings “jump up”. The big upward acceleration promptly reduces and restores the angle of attack and gives less time for pitch-up motion. It should be reminded that high aspect ratio wings are usually made with thinner and flatter profiles, sharper and less reactive noses, shorter chords and higher wing loadings.

The *pitch-up* entry is the worst, as it may consume the entire airspeed. For beginner cross country pilots it is a pleasant kick from below, the feel of lift and height gain. Many pilots even amplify it by an instant pull of brakes during the entry: some pull them subconsciously, because of fear when something hits them, others pull consciously to gain more height.

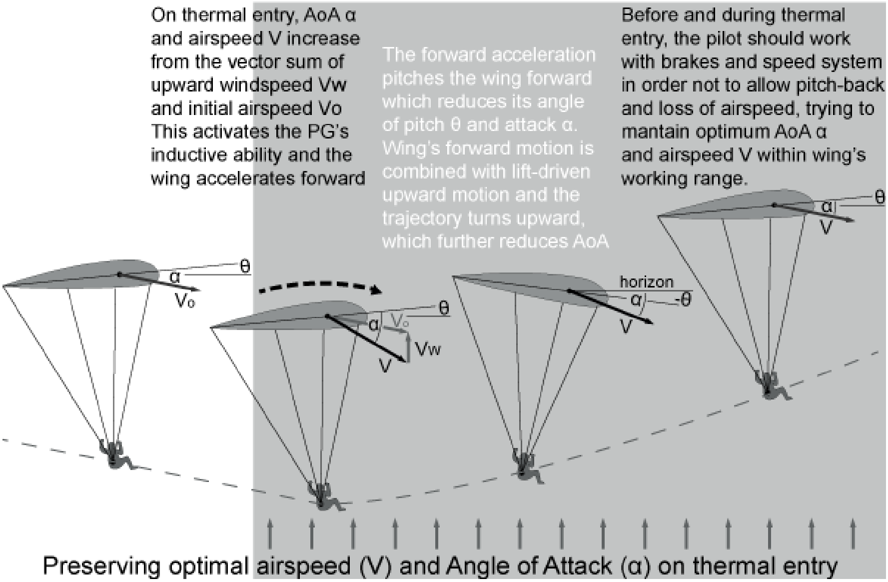
But what is the profit of man, if he gains some height, but loses his speed - the soul of his wing? The paraglider will partially stall and fall to recover airspeed, which may cause a height loss - bigger than the initial height gain. Even, without net height loss, the process of airspeed recovery causes parasitic motions, and is mainly a waste of time. This time is better used for exploring what's ahead.

The *pitch-neutral* entry is fine. There is no lift force harm as the wing keeps its maximum horizontal projected surface area. Still, the transition process will be accompanied by angle of attack changes, away from the *best glide ratio flying mode*.

Instead of chasing temporary height gains with pitch-up or pitch-neutral entries, it's better to work toward an airspeed gain, which also brings height and glide ratio gains. Remember that the lift force depends on the square of airspeed (V^2).

When a wing enters an updraft, the vector sum of their velocities increases the wing's airspeed. Angle of attack also increases and this activates the wing's *inductive ability*, which self-accelerates the wing forward. Use it, let it happen, don't pull breaks to make the wing gain height or to keep it comfortably horizontal. Of course, the forward self-acceleration makes the paraglider pitch forward and beyond a certain angle of attack the flight becomes inefficient again. We should stop too big forward surges, not only because they cause inefficiency and resulting parasitic oscillations, but also to prevent collapses from negative angles of attack.

And here comes experience. We cannot see the angle of attack, but we can feel this healthy surge forward, combined with an upward acceleration. It's a specific movement, which we learn to recognize and achieve. We learn to "squeeze" the kick from underneath to obtain lift, but mostly to maintain and even increase the wing's airspeed. We cannot control the thermal strength, but through our speed system and brakes, we can control our airspeed and angle of attack throughout the entire transition process of thermal entry.



On thermal entry, AoA α and airspeed V increase from the vector sum of upward windspeed Vw and initial airspeed Vo This activates the PG's inductive ability and the wing accelerates forward

The forward acceleration pitches the wing forward which reduces its angle of pitch θ and attack α. Wing's forward motion is combined with lift-driven upward motion and the trajectory turns upward, which further reduces AoA

Before and during thermal entry, the pilot should work with brakes and speed system in order not to allow pitch-back and loss of airspeed, trying to mantain optimum AoA α and airspeed V within wing's working range.

Preserving optimal airspeed (V) and Angle of Attack (α) on thermal entry

As pitch behaviour depends not only on the wing we're flying, but also on the type of lift we're entering, and as we don't know what's ahead of us, it's good to enter thermals with higher airspeed, pursuing the more favourable *pitch-down* entry. Preparing for a thermal entry by applying the speed system also improves our glide through the sink, which often surrounds lift and compensates for its rise.

When pilots search for lift and feel its first signs, they usually slow down by releasing the speed system and even apply brakes. Some pilots, even with a lot of airtime, slow down to stiffen their wings, to prepare them for the battle with the thermal, because for them the thermal is first a source of turbulence and then a source of lift. They should do more SIV and acro to erase their fears and embrace thermals as friends. Other pilots intuitively slow down their wing to increase their sensitivity and precision for localizing lift. Both are wrong for efficient thermal entry. It should be fast! There is a high probability that the slowing during the first signs of lift, coincides with the thermal entry, which guarantees an inefficient pitch-up backward motion and a loss of airspeed. An efficient entry is to cut deep through the thermal's flesh with your sharp wing, like a butcher with a chopper. This requires a lot of pitch control experience and working with the speed system.

> A good exercise is to practice swings by applying and releasing the speed bar in calm air. It should produce good swings, similar to the pitch control exercise with brakes.
>
> The pilot can exercise further by flying on half speed bar in lively air, keeping the wing horizontally above - by dampening pitch angle changes, only by applying more or less speed bar, without touching the brakes at all. Newer model wings are pretty solid and collapse resistant with their rigid elements and construction, so this exercise can be extended further with the pilot letting the brakes off and spreading their arms like a bird, while working only with the speed system in various kinds of air.
>
> By their worn out speed system lines you will know them :-)

After a thermal entry, the speed system should be released when reaching the good lift, which increases airspeed and replaces the pilot's duty to keep the airspeed high. Then, the pilot harvests this naturally increased speed to turn and catch the best lift.

If, during thermal entry, there is a need to turn to localize lift better, then the pilot should keep the speed and control direction with weight shift and rear risers, not with brakes.

In theory, a well-done search for lift stage of a cross country flight should bring us straight into a thermal. Then we enter it and quickly scan and map the lift nearby, and start climbing in it in the most efficient way.

In reality, the search for lift brings us into lifty air, which we scan and map, looking for its thermal. We find it and continue scanning and mapping, looking for its strongest lift, or the core. We start circling, focused on efficient climbing, but there is often wind, which blows the lift away and we lose it. Then, we scan and map the air again, to see where lift has gone. We find it, concentrate on it, trying not to lose it, and continue climbing in it, as efficiently as possible. But then, we see another pilot, who is climbing faster with his own circles, very close to us. Is he a better pilot? No, his thermalling technique is similar to ours. His lift is obviously better. Probably a branch from our lift, or another core in our thermal. How did we miss it?

This real-life situation shows that *scanning and mapping* is a continuous process throughout the whole *climb in lift* stage of cross country flying, no matter how much we're focused on fast climbing, no matter how much we look ahead for the next thermal and no matter how busy we are thinking about where to go next. Sometimes, we need to sacrifice efficiency for knowledge. The fruits will come later!

SCANNING AND MAPPING

Scanning is finding what's around. ***Mapping*** is remembering its position. Good scanning requires the use of all available informational channels and understanding their message. Mapping requires a good 3D imagination and memory, including our own movement in space.

> There are 2 viewpoints – inner and outer. The inner is the pilot's view point during flight. The outer viewpoint is again us, but in the role of an observer - watching a nearby paraglider, or examining a track log visualization during post-flight analysis. Seeing yourself from outside expands your horizons. The difference between these two viewpoints is that, when we're playing the role of pilot, we have all available information channels, and when we're playing an observer, we have only the visual. It's good to have both viewpoints and easily switch between them in order to see the detail, but also the big picture.

Scanning of air during the search for lift stage of cross country flying is similar to scanning during thermalling. The main difference is that, during thermalling, we have a limited scan range, as we need to stay in the thermal we're engaged with. Search for lift scanning has more freedom in space and time, and the focus there is toward various types of lift and circulations, not just a single thermal. But both use the same search patterns and information channels - variometer, the feel of acceleration on our body, the change of position in space through our inner ear balance apparatus, the paraglider's specific behavior, our senses on wind, noise, smell, and sight.

Beginner cross country pilots should be exposed to all available information channels, even without knowing their meaning. Some are easy, like the beeping sound of a variometer; others are difficult – like the *paraglider's specific behaviour*. Beginners can use the easier signs of lift to learn the difficult ones - e.g. the kick of lift acceleration precedes this variometer beeping, which is followed by that *specific paraglider's behaviour*.

Later, beginner pilots can shut down some of the information channels in order to sharpen others, and also to be more independent. Some pilots feel helpless and land, if their variometer stops working - because of flat batteries.

Switching off the variometer sound is a great exercise, which sharpens your attention toward feeling the accelerations and the *paraglider's specific behavior*. Instead of blindly following the variometer's sound, you can improve not only your senses, but also your imagination, skills and knowledge. It helps you recognize different thermal shapes and filter better the usable lift.

Another exercise is to listen to music while flying. This switches off the sound of wind in your ears and also part of your focus is diverted. Good music can also bring you into super performing trance-like state or can enlighten you about obvious things you haven't realized before. Use music just to break the routine and learn new things. Don't go too much in this direction. Even the "harmless" marijuana is too demanding and can over-exaggerate some senses and thoughts, without practical benefits. Not to mention the risks of flying high :-) Flying is like a drug, so don't mix it with other drugs. If you get bored of it, other drugs won't help you enjoy it much longer. Don't just consume sensations, but work hard and go deeper into this beautiful universe. Enjoy the silence and the song of the wind.

A very good 3D memory exercise is to thermal with closed eyes, when far from the terrain and others, of course. It's the same as thermalling inside a cloud. Follow the sound of the variometer and try to remember the position of thermal elements. Later, switch off the variometer and try to thermal only by the feeling of acceleration and the paraglider's specific behavior. This exercise can be done on the ground with a friend's help. On tarmac, draw several circles inside each other, resembling a thermal cross section with different layers of lift strength. Then walk around with closed eyes and practice mapping and centring the thermal, directed only by the imitated variometer sounds from your friend nearby.

CLIMBING AND TRACKING

During thermalling, we are constantly *scanning and mapping*. The information we obtain from them is being applied into *climbing and tracking*.

Climbing is flying in lifty air, which is rising faster than our own descent rate. Its goal is to gain height, as fast as possible – *fast climbing*.

Tracking is following thermal's trajectory, no matter how tricky and twisted it can be.

Tracking usually has priority over *fast climbing*, because it provides long-term height gain and helps us to avoid dead-end lift branches.

In classic conditions with uninterrupted thermals, *fast climbing* keeps you in the strongest and continuous lift, which naturally combines *climbing* with *tracking*.

Scanning, mapping, climbing and *tracking* have a common requirement – to preserve the paraglider's airspeed and manoeuvrability.

In classic thermals, *fast climbing* is achieved by circling around the strongest lift, as close as possible. Closer means smaller circling radius. But small circling radius are achieved by big bank angles, which reduce the wing's horizontal projected surface and increase its descent rate. Even strong thermals can be wasted with too tight circling, with too high banking and descending. Sometimes, flat circling, further away from the centre of the strongest lift, can produce faster climbs.

Fast climbing depends on:
- Thermal strength;
- Thermal size;
- Radius of circling, bank angle and the paraglider's gliding descent rate.

Additionally, fast climbing depends on the thermal's profile and vorticity, but more on this later.

How flat or tight to circle?

It depends on many factors, so a simple approach is to tighten or widen your circles, from time to time, and check your variometer, to see which one gives a faster climb. Also, a good rule of thumb is to **circle as flat as possible, whenever possible, but stay in lift and closer to the core**. Every moment of flatness in lift is a gain. Multiply it!

A popular thermalling technique among paragliding and hang-gliding pilots is: **Tighten your turns when lift decreases and widen them when lift increases!**

This helps you to return back to lift when you start exiting it, and flatten and harvest it when you start entering it. This rule is suitable for wide and straight vertical thermals. It also helps beginner pilots for *mapping* the lift.

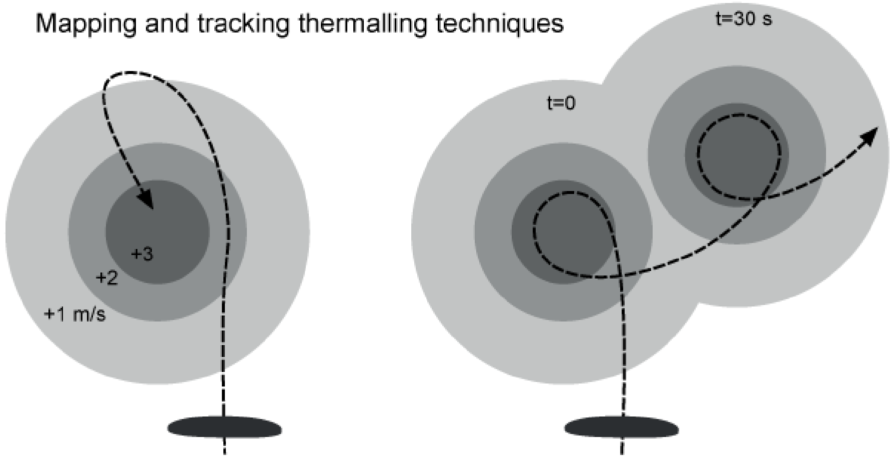
There is a completely opposite technique, which is more suitable for *climbing* and *tracking* tight thermals with tricky trajectories: **Tighten your turns when lift increases and widen them when lift decreases!**

The widening of turns doesn't mean flying straight. You keep the circle, but with a bigger radius, so that you *scan* a bigger area to see where lift is gone. The tightening part, when lift increases, is like "hooking" the core – the closer you get to the strongest lift, the tighter you turn, the longer you stay in the core.

Bigger sink from tighter turns with higher banking angle is compensated for the strong climb in the core. In the previous technique of tightening when lift decreases, the goal is to "go back into lift", but this is height expensive, as the tight turn is already in weak climb, which cannot compensate for the tight turn descent.

The first technique might be called the *mapping technique* as it works mostly for mapping lift. It might be also called *sink avoiding technique*.

The second technique might be called the *tracking technique*, as it works best for tracking thermals with tricky trajectories. Another descriptive name of the second technique would be "*the hooking technique*" because of its specific "hooking" of the core, similar to the stroke of a swimmer's hand.



Mapping and tracking thermalling techniques

Tighten the turn when lift decreases, widen the turn when lift increases.
Good for beginners for mapping lift.

Tighten the turn when lift increases, widen the turn when lift decreases.
Tighten the turn = "hooking" the core.
Good for tracking sneaky and drifted thermals.

Both the *mapping* and *tracking* techniques can provide *fast climb*, depending on the conditions in which they're being used.

The main fast climb advantage of the *mapping technique* is the temporary *flat passage* through the strongest lift, with minimum sink and the wing's projected surface area fully exposed to the strong thermal flow coming from below.

The main fast climb advantage of the *tracking technique* is the extra time spent in the strongest lift, despite the higher bank angle and descent from the tight turning.

Some thermal types, which are not too small in size, allow adding a *flat passage* section to the *tracking technique* for maximum harvesting of the core. Other exceptions of the *tracking technique* rule "to tighten the turn when lift increases…" is to **tighten the turn to avoid an obvious sink** or to **tighten the downwind half of the turn to avoid dropping behind a tilted by the wind thermal**.

Both *mapping* and *tracking* techniques require working with the tendencies of the variometer, which is a step further toward an wakeful piloting than just reacting to what's happening at the moment. **Whether the lift is increasing or decreasing is more important than how strong it is!**

Working with the variometer *tendencies* brings us closer to working with *acceleration* and helps us match them both. It helps with scanning and mapping what's happening around us.

> The rate of change of distance is speed. The rate of change of speed is acceleration. The variometer shows vertical speed. The rate of change of vertical speed corresponds to the vertical acceleration, which is felt instantly by the pilot's body, when a thermal hits the wing.

Perhaps, it is best is to use the *tracking technique*, but if you feel that you're often dropping out of the thermal, then use the *mapping technique* to tighten the turn when lift decreases. With experience, the dropping out of the thermal becomes pretty obvious for the pilot and he turns back instinctively, without much care for efficiency. **Poor thermalling in strong lift is better, than efficient thermalling in weak lift**!

Always suspect and keep on checking for better lift around, if your current lift is below the expected strength for the given place and conditions.

It's easier for beginners to see thermalling from the pilot's perspective. The pilot has three weapons – inner brake, outer brake and weight shifting.

Inner brake is used for:
- Setting the turn around the strongest lift;
- Tightening for hooking into the core or returning back into lift. The extra pull of the inner brake is combined with a release of the outer brake;
- Loosening, widening, and expanding the circle to scan a bigger area, to see where lift has gone.

Outer brake is used for:
- Stopping forward surges of the outer half of the wing, which may cause extra pitch-down sink and collapses;
- Releasing quickly to let the outer half of the wing to self-accelerate and produce tight flat turns, like a spin. Good pilots apply the outer brake more frequently and work with higher sensitivity and precision than inner brake inputs. Their outer-hand movements look like drawing a picture and right-handed pilots should thermal better to the left.

Weight shift is used for:
- Helping the inner brake achieve quicker and tighter turning by rolling the wing;

- Opposing inner brake to prevent excessive inside rolling or to maintain flat turning;
- Damping oscillations.

> In modern two liners, both brakes are pulled simultaneously only for landing or to prevent collapses. Turning is made by inner brake and outer “B” riser. Straight flight corrections are made only with “B” risers, which have specific handles, while brake handles stay around hand’s wrists.

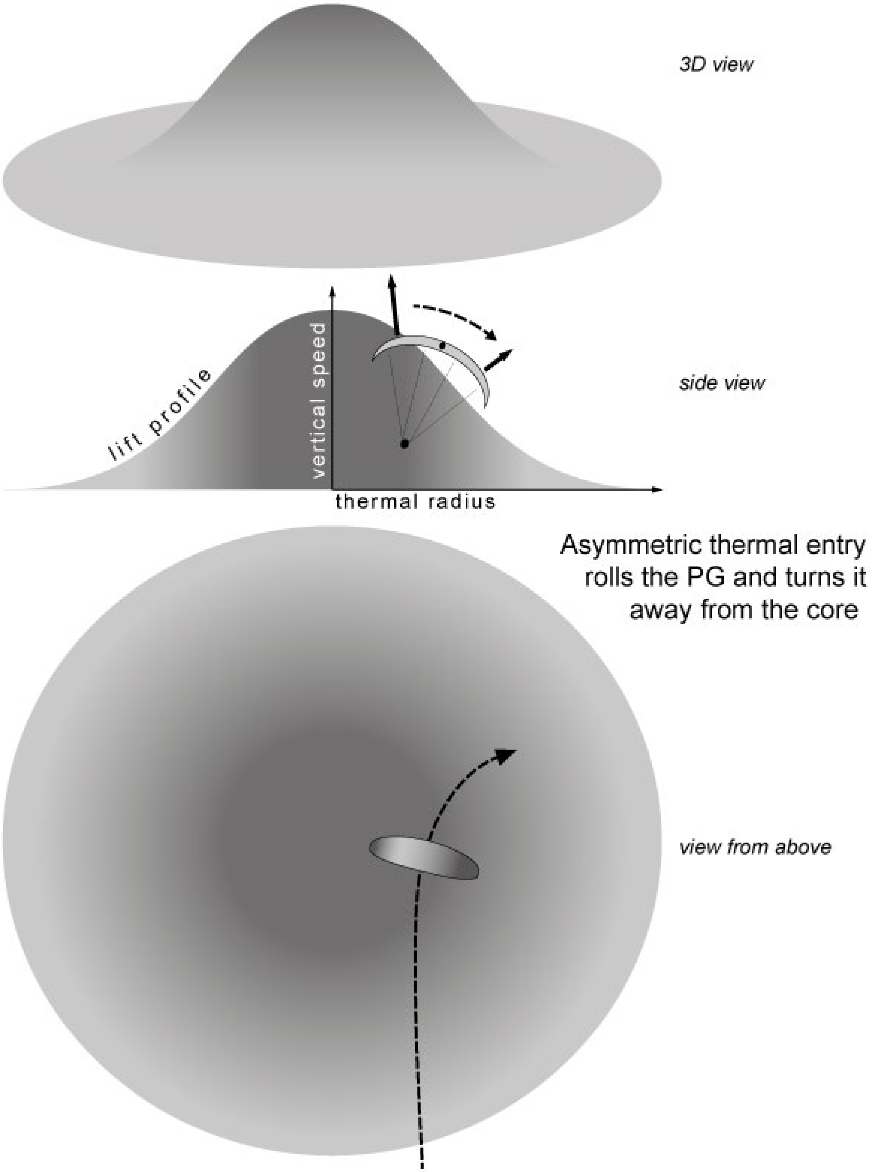
MILKING THE LIFT

Or *fast climb* optimizing techniques

When thermalling, if you notice that part of your circle enters a weakening lift, or even sink, then offset your next circles away from it. **Never fly through the same bad air twice** is valid not only when searching for lift, but also when thermalling.

Make constant corrections to your turns. The thermal is alive and there is always something to improve. This “constant corrections” approach helps you track thermals more easily and react quicker on sudden changes. Efficient thermalling is accurate and precise thermalling - as tight and as flat as possible.

The rise through different layers of thermals is modelled into the common bell-shape (*the lift profile curve is proportional to the cube of thermal’s radius -* r^3).



Asymmetric thermal entry rolls the PG and turns it away from the core

When the paraglider enters a thermal asymmetrically, then the half of the wing which is closer to the core is being lifted, and the whole paraglider is being rolled and turned away from the thermal. It looks like the rising air is pushing objects away, to clear its way up. Another simplistic view of this natural process is seeing objects *sliding down* on a tilted surface, like surfboards do. In the case of paragliders, the *turn-away effect* from the rising thermal is caused by a sideways roll from unequal lift between inner and outer wing sections. This tilts the resultant aerodynamic force R and its sideways component makes the paraglider turn.

The natural *turn-away* effect from an asymmetric thermal entry should be opposed, not with force, but with finesse.

> The philosophy of the martial art aikido is not to oppose the enemy with brutal force, but to use and even amplify the energy of his attack, by moving away from it, then pinning and throwing the opponent tangentially away.

It is inefficient to oppose and fight too strong roll and *turn-away* effects. The pilot instead should obey them and use them for a 270° turn to re-enter the thermal perpendicularly.

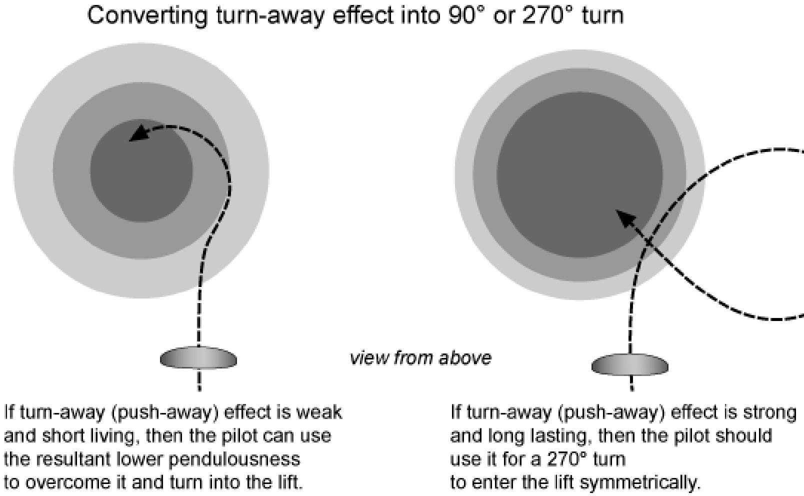
If roll and *turn-away* effect are not too strong, then the pilot can apply a micro trick, using the paraglider's specific behavior. The asymmetric lift hits the wing more from one side and rolls it to the other. This activates the paraglider's *lower pendulum*, which tries to bring the heavy pilot (CG) under the wing (CP). In this moment, the pilot can amplify the pendulum recovery motion, by weight shifting and breaking to turn back into the thermal.

The success of this technique depends on the thermal size and lift profile.

If they're too big and long-lasting, then the paraglider may continue rolling and tilting away, minimizing the pendulum recovery motion. Then, it's better to obey the turn-away effect and transform it into a 270° turn for a thermal re-entry.

If thermal size and lift profile cause a short-lived roll-away impulse, then it can be used for a direct turn into the thermal.

In both cases, as well as in live, a sign of efficient reaction is the elegant transformation of pushing and aggression into something beautiful.



Apart from the *turn-away* (*push-away*) effect, there can be an opposite *turn-in* (*suck-in*) effect, as every strong concentrated flow or stream creates lower pressure around itself and sucks objects toward it. This explains why light objects like straws, leaves, debris, rubbish, etc. rise quite high, sucked in and lifted by strong thermals. There might be a specific vortex air motion which initially lifts them from the ground, but the later long climbs, sometimes even to the cloud base, are due to the thermal *suck-in* effect.

There are several factors, which in combination determine if the paraglider will be pushed away or sucked into the thermal:

- Lift size, strength and profile. A strong concentrated stream has a bigger suction effect. The width of the horizontal gradient of the vertical flow (*the width of the zone where vertical speed changes*) should be of similar dimension to the paraglider's wingspan;
- Angle of entry, from the direction of symmetrical entry. More perpendicular entry – more *suck-in* effect. Less symmetrical entry – more *push-away* effect;
- Wing's backswept and anhedral angles. Flatter wings or positive backswept angle – more *turn-away* effect. High-arc wings or negative backswept angle – more *suck-in* effect;
- Wing's profile and loading. Thicker, more curved profiles – more *suck-in* effect. Thinner and flatter profiles – more *turn-away* effect. Higher loading – less *suck-in* effect. Excessive loading – neither *suck-in* or *turn-away* effect;
- Speed of entry.

As there are various combinations and interactions of the fore-mentioned factors, it is difficult to predict how the wing will react on the given conditions, which way the wing will turn. But this is not as important as to know whether the lift is left or right of us? Shall we turn left, or right? How long shall we let the wing lead us into something and when shall we take control?

The easiest approach is to monitor the wing's *self-turning behavior* and match it with other signs like "Is it preceded or accompanied by rolling? How big and fast is this roll? What are the lift tendencies, indicated by the variometer?".

This *self-turning behavior* is part of the paraglider's stability aerodynamics, determining how the paraglider reacts to outside disturbances.

Here is the place to mention differences between wings. Even wings within the same class (*EN A, B, C, D, CCC*), or with the same glide ratio can have completely different behavior in the same conditions, because of their design. Some turn naturally, sucked into strong thermals, others drop off pushed away from lift, third are more efficient in weak lift, forth "speak" more about what's around, fifth don't bother you much in turbulence, etc., etc.

> Life and flying are quite complex. It's possible to understand yourself or your wing, but it's hard to comprehend everything else around. It's possible to control yourself or your wing, but it's expensive to try to control others or Nature. That's why a good common rule in life and in flying is **Direct, but let be directed!**

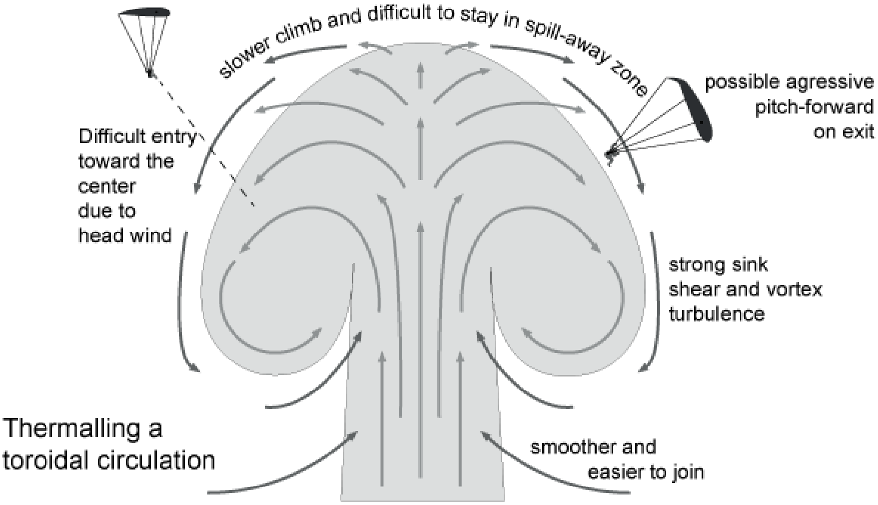
We shouldn't forget the classic toroidal circulation during the thermal rise. It causes an air spill-away effect at the top, sink around and entrainment somewhere lower, toward the centre. The toroidal circulation has a few effects on thermalling:

- The pilots at the top of the thermal may not climb as fast as a pilot coming from below. This is because the overall upward motion of the entire rolling toroidal vortex is slower than the airflow speed within the vortex;
- The air *spill-away* effect makes it difficult to stay at the top. This, plus the slower overall rise of the entire vortex, misleads the pilots that lift has finished, and they may leave it prematurely. Sometimes, the thermal top might be slowed down to zero by an inversion, but the toroid is still rolling, there is still more warm air coming from below. Then, after a

short slowdown, the thermal resurrects and those who patiently stayed in it continue climbing higher. Lower pilots may even not notice the pause happening at the top;

- The air *spill-away (divergence) effect* may cause an aggressive pitch-down forward surges during the thermal exit or when flying near its edges;
- There might be stronger than usual sink and turbulence around the toroidal vortex;
- The reverse entraining zone, or the convergence part of the vortex might be rougher, but helpful for joining the thermal;
- The thermal tail, following the toroid vortex is usually weak but smooth, as surrounding non-thermic air is also lifty, enhanced by the vorticity above.

Sometimes, nearby thermalling pilots may have completely different experience, simply because they are at different positions relative to the toroidal vortex circulation.



THERMALS AND WIND

The wind affects thermals. Thermals affect the wind.

In the beginning of the day, it's quiet on the ground, because the night ground inversion seals it from higher winds and because the stability blocks the vertical part of various circulations. There still might be katabatic winds, coming from the cold highlands, which flood the lowlands, downstream of rivers and their basins.

After sunrise, the more exposed highlands get their first doses of the sun's energy, but they're still too cold themselves and still busy sucking and draining cold air from above. Even if the first sun rays manage to heat a favorable sheltered area, even if it forms a thermal bubble, it quickly dissolves in the surrounding cold air.

> Similar dissolving is typical for spring and arctic areas. Despite that, cold air and instability are the main engines for a thermal's rise; good thermals prefer it not too cold outside and much warmer from below, like in summer, for long steady climbs. Good ambient temperatures lubricate the thermal's rise, smoothen the flow and keep the warm air supply from below. There is an optimum ratio between thermal and surrounding air temperature for high steady climbs with minimum dissolving, mixing, friction and air drag.

After few hours of the sun's heating, the first usable thermals start to form. In mountain areas, these are the easterly facing slopes, which rapidly "melt" the neighboring contact inversions and later even benefit from the warmed air trapped and stockpiled underneath. In flatlands, thermals rise within the lower layers, destabilized by sun's heating of ground surfaces – higher climbs are possible when inversion layers melt, or in some higher and stronger places, which puncture and thin out the inversions. In both mountains and flatlands, the start of the thermals can be accelerated by an extra humidity or cold air advection (*horizontal transportation*), which destabilize the airmass. Stronger winds, vortexes, and turbulence may prevent the night stratification and formation of inversion layers, or to destroy higher or lower inversion layers in the morning and to accelerate the beginning of the thermic activity.

With the development of the day, thermals rise higher and higher, where they get more exposed to *geostrophic* winds aloft (*the main winds blowing over the country*). Higher winds accelerate thermals at higher altitudes and when they lose buoyancy and become colder and heavier than the surrounding air, the gravity pulls them down. These downdrafts re-organize for reduced air drag and efficiency, and accelerate further downward. The countless thermals and their resultant downdrafts multiply this effect on a massive scale. Imagine a massive bombardment of countless air parcels, first accelerated horizontally by the high wind aloft and then vertically downward by gravity, along a ballistic trajectory. This is how higher winds "come down" during the day. Winds at higher altitude also weaken, because the whole wind flow blows through a larger section area – not only above the higher inversion, but also inside the expanding boundary layer underneath.

Another mechanism for weakening of higher winds is convection (*thermals*). Convection amplifies the roughness of the terrain and increases its friction with winds above. Water bodies are working like *wind conductors* with their smooth and thermically inactive surfaces. Vast water bodies or terrain depressions can work like *wind accelerators* as they attract and collect accelerated by the higher winds and gravity cold downdrafts.

Updrafts (*thermals*) and downdrafts influence wind in two ways – working like a conductor of higher winds on a large scale, and like an obstacle during their rise on an individual scale.

Wind influences individual thermals by:
- Mechanical drifting, tilting and rotating of rising thermals;
- Deforming their shape;
- Mixing thermals with surrounding air;
- Dispersing, accumulating or concentrating warm air from thermal ground sources in combination of terrain features, like sheltered or windy places;
- Establishing thermal trigger mechanisms with or without help from the terrain.

For the purpose of the *climb in lift* stage of cross country flying, we need to know more about the effects of thermals working like an obstacle, about the mechanical deforming, tilting and rotating of thermals by the wind.

Any rising thermal works like an obstacle to the wind, just as any hill or mountain does. Thermals have tons of invisible air and their enormous mass is being accelerated by buoyancy. Thermals have inertia and resist change. A thermal's different temperature, viscosity and layered structure keeps it relatively insulated from mixing with surrounding air, even if it's made of the same air itself.

When a thermal rises into stronger winds above, or when a wind gust hits a thermal, the wind tries to deform it and push it downwind.

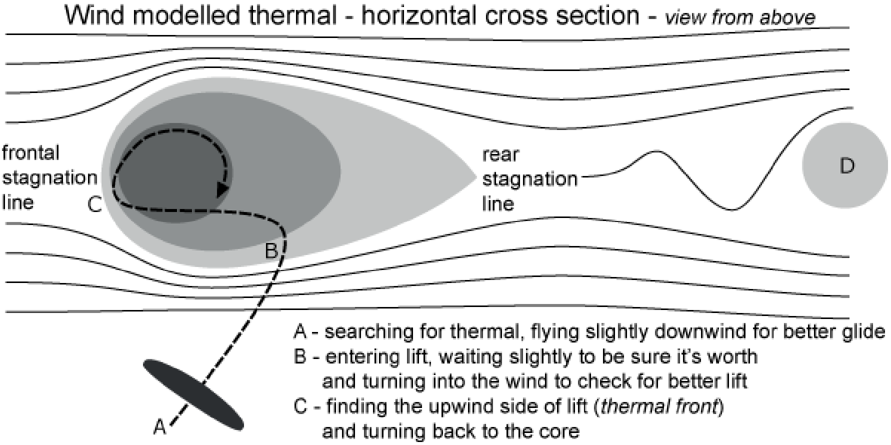
A rising thermal has been self-modelled for vertical upward air drag efficiency, but now it needs to re-transform again for horizontal air drag efficiency when it enters windier zones. From being circular, the thermal's horizontal cross section becomes more elliptical, like a water droplet. The thermal core stays concentrated at the upwind side, because the stronger the lift, the stronger is its momentum (m.V) and inertia, and the more resistant to change it is. That's why when searching or tracking lift, we should keep in mind that **weak thermals or thermal parts have more drift; strong thermals have less drift and tilt**.

Wind tilts thermal columns, because their upper parts are being exposed to stronger winds for a longer time. A wind-pushed thermal column has been tilted, but hasn't been weakened, because its buoyancy force is still there. The thermal column acts like a solid body. It has a slope, like a hill, and subsequent portions of wind may climb it and create an additional ridge soaring type of lift. The visible parts of thermals – cumulus clouds - usually have stronger buoyancy. These clouds are often fed by multiple thermals for a longer period of time, which makes their volume, mass and inertia even bigger. Thermal clouds often form around an inversion layer, which separates weaker winds below from strong winds above. All these allow for interesting and spectacular cloud soaring experiences.

Another effect of wind on thermals is found on their downwind side. We expect sink and turbulence, but often it's not that bad, if the thermal managed to obtain the streamlined shape of a water droplet at its horizontal cross section. This smoothens the flow behind the thermal, provides a shelter and promotes the nesting of other thermals, from the same or from neighboring thermal sources. A thermal may get old and stop rising, but it still can show the way to the youngsters, it still can assist the creation of a convergence and unite thermal clusters.

The interaction of wind with a thermal is very similar to wind interactions with an isolated conical hill: not much lift in front, not too bad sink and turbulence behind, but possible good thermals embedded in its wake.

All thermals have a *frontal* and a *rear stagnation point or line*, like all aerodynamic profiles or bodies. Pilots can recognize them by the weaker winds there - watch for increase or decrease of GPS ground speed in combination of your flying direction in relative to the wind direction! If you fly with cross wind and your ground speed increases, then you’re approaching the stagnation lines (*the frontal is smoother, the rear is bumpier*) or lift itself. Learn to make a difference between ground and airspeed and the different mechanisms which change them. Add your heading, wind direction, the feel of acceleration and variometer indications and you will “see” the invisible thermal.



A general rule in paragliding, hang gliding and gliding suggests to wait 4 seconds after entering lift to see if it’s big enough to circle in. **Count 1001, 1002, 1003, 1004 after entering lift and then turn**.

Good pilots recognize usable lift earlier and as they can climb tight and efficiently, so they need 1-2 seconds to decide if it’s worth circling in.

If you remember the *route progress* and *search for lift* rule to **turn into wind when hitting lift**, then there is no need to wait 4 or 2 seconds. Even if your lift is an old or a secondary thermal (*point D*), nested downwind from the main one, by turning into wind, you should be able to reach the main thermal. You can recognize that there is something better upwind by the relative calmness and increased ground speed along the *rear stagnation line*.

If you enter directly a proper thermal (*point B*) and turn into wind, then you should reach its upwind side (*point C*). It is generally easy to recognize the upwind end of the thermal, or the *thermal front*, by the paraglider’s specific reaction to strong horizontal wind gradient and concentrated lift there. The specific paraglider's reaction there is mostly a boost of lift and manoeuvrability (*even yaw instability*), but there might be other nuances like a pitch-up, roll, loss of airspeed or pitch-down.

Depending on the wing's design, wind strength, lift profile and thermal tilt angle, there might be a smooth exit from the upwind side. The wind still might be weaker around the *frontal stagnation line*, which pilots may confuse for the *rear stagnation line* and continue fruitlessly searching further upwind for a better climb. Understanding the thermals for the day, their properties and the wing's reactions should help with identifying the upwind end of the thermals.

After identifying the upwind end of the thermal, the pilot turns immediately and starts circling in lift. There is no need to identify the downwind side of the thermal as lift weakens and dilutes there. The best lift is encountered by each upwind check during the circling. The boost of force and *jump-up effect* on each turn into the wind has two causes:

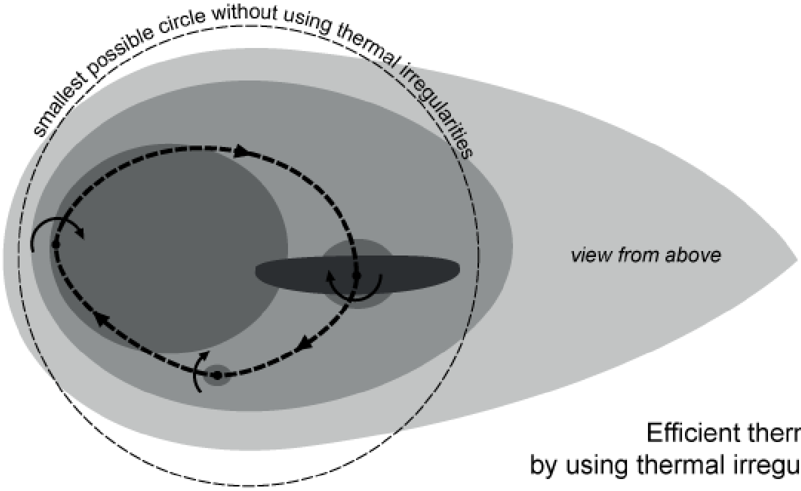
- The strongest lift is concentrated near the upwind side; next to the thermal front;
- During the downwind stage of circling, the paraglider gains inertial ground speed and when it turns quickly against the wind, then it hits against the wind-driven flow and increases its airspeed much more than usual. The aerodynamic lift force is very sensitive to airspeed changes, as it depends on the square of airspeed: if airspeed doubles, lift force will quadruple. The *jump-up effect* when turning quickly from downwind to upwind flying is noticed even in plain wind, without thermals. It is mastered by some birds like albatrosses, which use the vertical wind gradient for *dynamic soaring* for hundreds of kilometers – no exhausting flapping with wings – just elegant control of the direction of flight.

The *jump-up effect* when turning into wind can be further exploited, not only for extra height gain, but also for airspeed gain and manoeuvrability for further thermalling. At least, the pilot should not allow pitch-up and airspeed loss. So, **after each turning into the wind - hands up and no brakes**. A slight push of the speed bar may also help for simultaneous airspeed and lift force gain.

The steep lift profile, at the upwind side of the thermal, often helps to prevent the pitch-up backward motion after the *jump-up effect* when turning into wind. It can even surge the wing forward, sliding along the steep upwind thermal's slope, like wave surfing. The surge is mainly due to wing's induction ability, when passing through the strongest lift. This is a good moment to use the airspeed gain and turn quickly downwind back to the strongest lift in the core. **Learn to use wind, lift and gradients to efficiently convert the speed into a turn and the turn into a speed**.

Sometimes, at the centre of the core in calmer conditions, but more often at the windward side in windy conditions, there might be a specific *lift peak* with a diameter close to the paraglider's wingspan dimensions. The concentrated push of air from below makes the wing unstable for a moment – it can slide in any direction, like on the top of a sharp icy conical hill. The pilot can harvest this "instability", and add it to his thermalling circles. This easiness to turning "on heel", might be accompanied by pitch and roll changes. The pilot can use just their beginning, their self-initiation, for efficient turning, without allowing further increases in pitch and roll. *Lift peak* encounters usually allow for quite flat and narrow turning, spinning like a helicopter blade.

On a micro scale, there are more *lift peak* effects, not just the one found at the thermal front or at the centre of the core. Even in a smooth thermal, there are upward micro gusts, which can be harvested by an experienced pilot to circle flatter with a smaller radius. The pilot usually circles with a slightly applied outside brake and when he encounters these *micro lift peaks,* he quickly releases the outside brake to produce *micro flat turns*, or spins, which he adds to the main circle. Thermalling is not just circling by applying weight shift and inner brake. Efficient thermalling requires more work with the outside brake.



Efficient thermalling
by using thermal irregularities

Efficient thermalling is fast climbing by reacting on thermal's big and small-scale irregularities and textures, to circle as flat and as tight as possible, by constant work with inner and outer weight shifting and breaking.

Higher-loaded wings with a flatter profile chamber, like high performance competition wings, are less sensitive to a thermal's irregularities and textures and are poorer for harvesting them. Also, the lower speed of beginner's wings allows them to circle with a smaller radius and stay closer to the strongest lift.

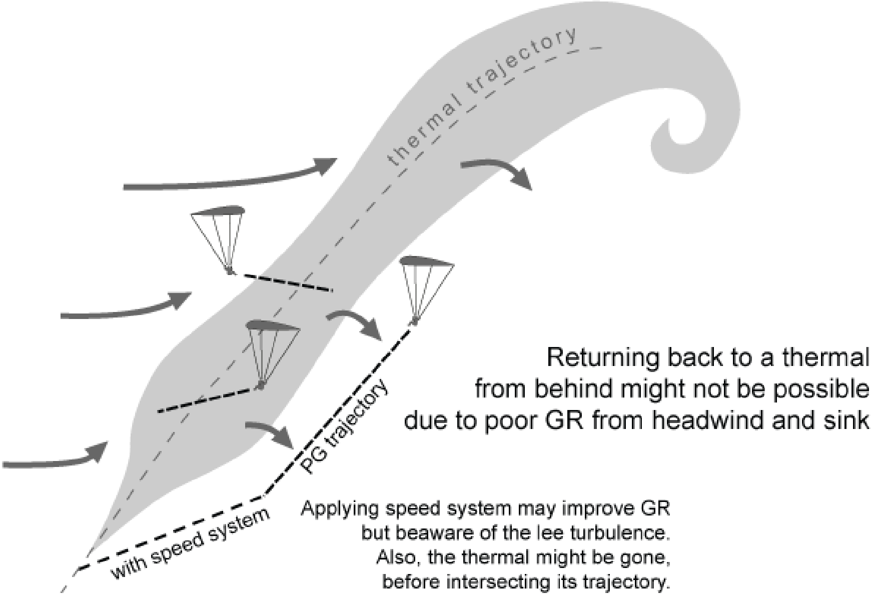
On the other hand, faster and high glide ratio competition wings can quickly and with minimum height loss scan wide multicore and cluster thermals. This gives them more cores on the menu to choose from, or to consume them all, if they're close enough. In some conditions, some wings are better, in others – others. It depends on how wing properties match the thermal's properties.

Active thermalling is reacting on a thermal' large and small-scale irregularities and changes, but not only toward efficient flat and small radius circling, but also toward avoiding height and airspeed losses, and safety issues like collapses, spins and collisions.

Using *lift peaks* might become obligatory for efficient thermalling, not only because they help for flatter turning with a smaller radius, but because they are like islands for airspeed re-fueling. If you miss them, especially the windward one, then you may enter painful periods of loss of airspeed, lift force, glide ratio and maneuverability. It may take quite some time to regain airspeed and maneuverability to re-enter the thermal again, which meanwhile may leak up through you. Panta rhei. **Airspeed conservation and gains might be of higher priority than chasing the strongest lift**.

Like the *search for lift* stage of cross country flying, where the flying playground is seen as a chess board, in the *climb in lift* stage of cross country, the chess game concept can be used on a micro scale. It is not only the strength of your pieces, but their position too. There might be a ticket to heaven, just 100 meters in front of you, but you will never reach it, because you've dropped behind a tilted thermal and you sink like a brick, when flying back to it against the wind.

Falling behind a thermal in strong wind is times worse than falling upwind of a thermal. When you're upwind, you can quickly return back to the thermal with the help of the wind, but when you're downwind, the way back has a very poor glide ratio, because of the head wind. The glide ratio is further worsened by the lee side sink, which compensates the thermal rise. A headwind with sink is really bad! Your gliding trajectory may be parallel or even stepper than the rising thermal trajectory. It is very frustrating to see others climbing well in strong lift in front of you and to know that you cannot reach them. You can apply full speed bar to break the vicious circle, but the lee of the thermal can be turbulent, and it still costs you time, so when you finally intersect the thermal trajectory, you may only find the unusable tail of the thermal while others continue to climb happily above you.

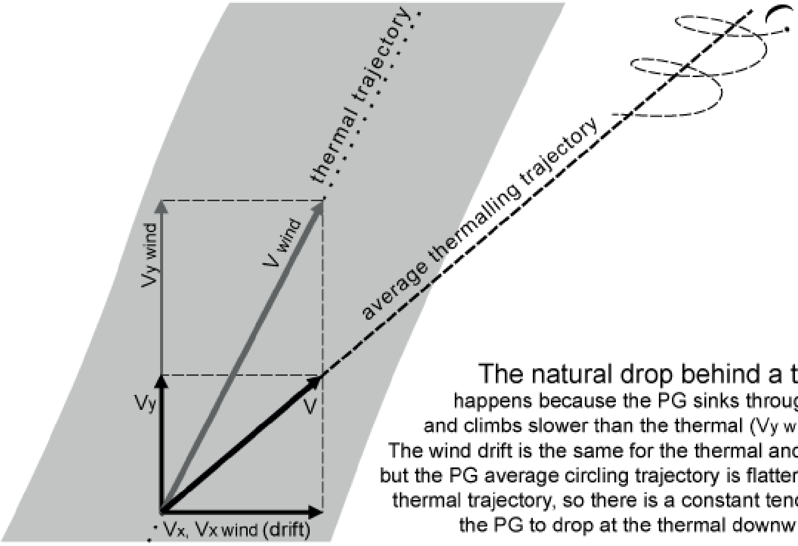


Experienced pilots recognize early that they're behind a tilted thermal and are faster and more aggressive with their speed system to get back into the thermal. They know their wings better and have less fear from turbulence and collapses, when attacking the thermal from its lee side.

Being in a good position gives you freedom. Freedom is not for free. You pay for it with efficiency, money, time, etc. If a beginner pilot often drops behind thermals and loses them, then he should do more frequent upwind checks, investing more in thermal tracking at the expense of thermal climbing efficiency.

Inside, or around a tilted or drifted thermal, you can achieve a better position by using some of the *route deviation* techniques used for the *route progress*, but on a micro scale, playing with the thermal's elements and irregularities. Again, the idea is to improve your glide ratio by avoiding strong headwind or sink, going around, or benefiting from micro zones of lift or wind gradient. High glide ratio and faster sporty paragliders are good not only for *route progress* and *search for lift*, but also for *climb in lift* stages of cross country flying!

Thermalling drifted bubbles or tilted columns shouldn't be done with simple uniform circles, as the paraglider inevitably drops downwind. The average circling trajectory has an inherent gliding sink, the paraglider climbs slower than the thermal and is more "vulnerable" to the wind drift.



The natural drop behind a thermal
happens because the PG sinks through the air and climbs slower than the thermal (Vy wind > Vy). The wind drift is the same for the thermal and the PG, but the PG average circling trajectory is flatter than the thermal trajectory, so there is a constant tendency for the PG to drop at the thermal downwind side.

Circling a drifted thermal requires upwind checks. On almost each circle, the pilot should flatten and fly straight against the wind for a while, to return closer to the upwind side of the thermal. The pilot can use the flattening to pass directly through the strongest lift and gain some extra height.

The pilot should constantly and precisely monitor the tilt and drift of his thermalling trajectory and match it to other thermal indicators like the probable source and trigger, other flyers, debris, thermal clouds, etc.

Successful matching of thermal's climb/drift ratio to paraglider's climb/drift ratio produces ***stable orbit*** – consecutive circles with steady flight parameters and minimum control inputs. A mismatch of a thermal's and a paraglider's climb/drift ratio results in frequent thermal exiting and entering. The wind gradient at thermal's walls constantly changes flight parameters and requires a lot of brake inputs to return the paraglider back into the thermal. Except inefficiency, frequent exiting and entering increase chance for collapses due to shear turbulence near thermal's walls. Being able to stay inside thermals makes experienced pilots fly better and safer than beginners.

Sometimes, *upwind checks* require a change of turning direction. Imagine, after reaching the upwind lift peak, the pilot starts turning it, but at the same moment he recognizes that there is better lift further upwind. Then, it's better to stop the turn and quickly change the turning direction for further checking upwind.

Zigzag changes of direction for an upwind check also scan a bigger area than a straight line upwind check.

Changing of turning direction is also used for finding and staying in good lift, while avoiding fighting with headwinds, gusts and sink.

> Of course, a quick change of turning direction should be avoided when there are other pilots nearby. Efficient thermalling is not very friendly, because circling is not symmetrical and because it requires surprising maneuvers. Like in life, don't expect others to understand what you feel. Despite the handy lift visualization, group flying might be confusing and oppressive to your ideas and even slow down your development in paragliding. Sensing and thinking are more efficient when you're alone.

Most pilots usually have a favorite turning direction, which gives them a feeling of precision and security, but limits their searching and climbing potential. They should practice flying in various conditions and **learn to turn equally well to the left or to the right**!

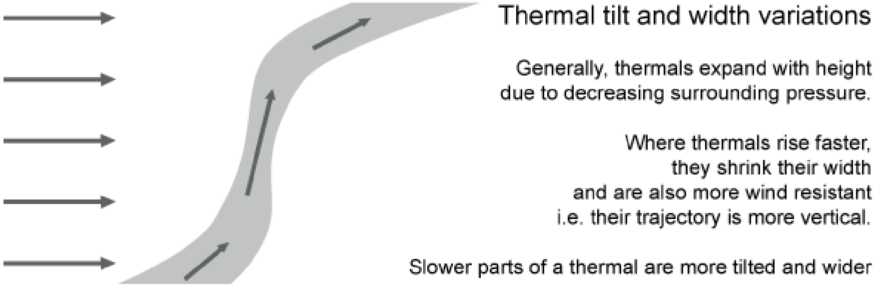
During upwind checks, pilots often turn too early, misled by a *fake lift kick*, or a *jump-up* effect. The boost of wing's force might be due to an increase of airspeed by a horizontal wind gust without any rising air around. The turn for thermalling decision should be based not only on the lift kick, felt on the bum and confirmed by the variometer, but also what the air feels like before and after the lift kick. What's the shape of the air? Any sideways drifts and rolls? How does the air and ground speed change before, during and after the lift entry?

With experience, pilots learn to recognize how wind, buoyancy and inertia influence a thermal's trajectory.

Stronger lift is more resistant to wind. There is less drift and less tendency to drop behind the thermal. Strong lift also has a strong *suck-in* effect. Strong lift means less upwind checks. It is more likely to develop toroidal circulations.

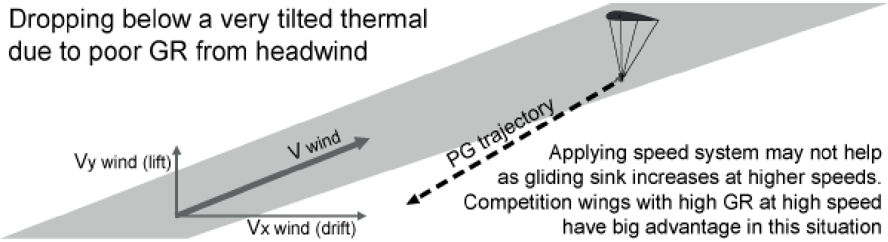
Weaker lift has more wind drift, a higher tendency to drop behind and thus it requires more frequent upwind checks.

Rising thermals gradually expand, because surrounding air pressure decreases with height. From the other side, when a rising thermal speeds up, it needs a narrower cross-section to go through and shrinks its width. And vice versa – slower flow needs a wider cross-section to go through. As a result, thermal width, and required-to-stay-in circling radius, may vary, depending on flow speed. It is the same air, from the same thermal source, but during its rise, it may speed up or slow down, depending on the boundary layer instability profile. Where air speeds up, it may become narrower and may require a smaller circling radius. And vice versa, slow lift might be wider and require larger radius circles.



The *tracking thermalling technique* of tightening the turn when lift increases, is particularly good for adapting to changing thermal radius, not only for tracking tricky trajectories.

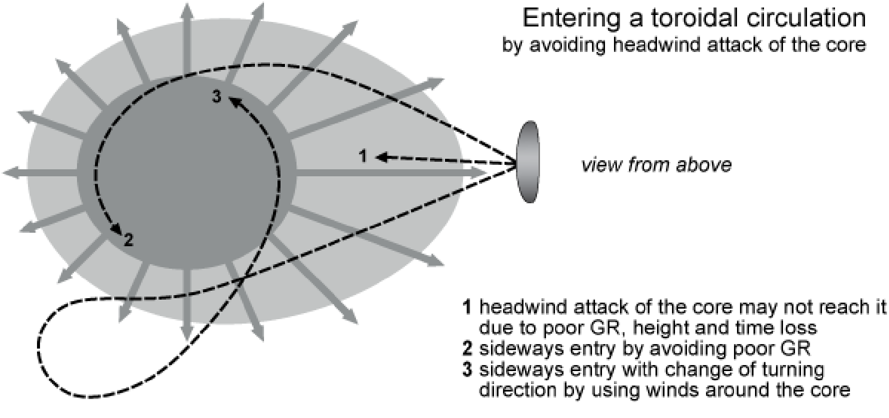
Another problem of weak drifted thermals is that upwind checks have poor glide ratio, even inside the climb, even when the variometer is beeping. Beyond some lift/drift ratio, it becomes impossible to check against the wind and stay in the climb. The paraglider can easily drop below a strongly tilted thermal trajectory, with no chance of returning back. So, upwind checks have limits and sometimes it's better to squeeze what's available and continue for the next thermal.



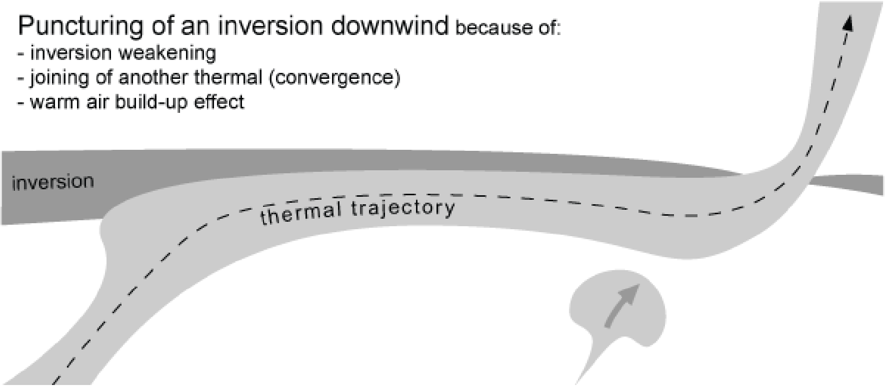
Keep in mind that the glide ratio also worsens when flying through turbulent air – e.g. at the wind shear near thermal borders.

An additional problem of weak drifted thermals is that upwind checks are time consuming, so even skillful tracking cannot prevent a short-lived bubble from leaking through you.

On a smaller scale, poor glide ratio can be a reason for difficult access to the thermal core, not only when there is wind, but also when the thermal has a pronounced toroidal circulation, where part of the air flows away from the centre (*diverges*). Direct attacks of the core, against the flow, cause extra height and time loss. It’s better to go around and look for sideways entries. A change of turning direction might be required for more efficient entries.

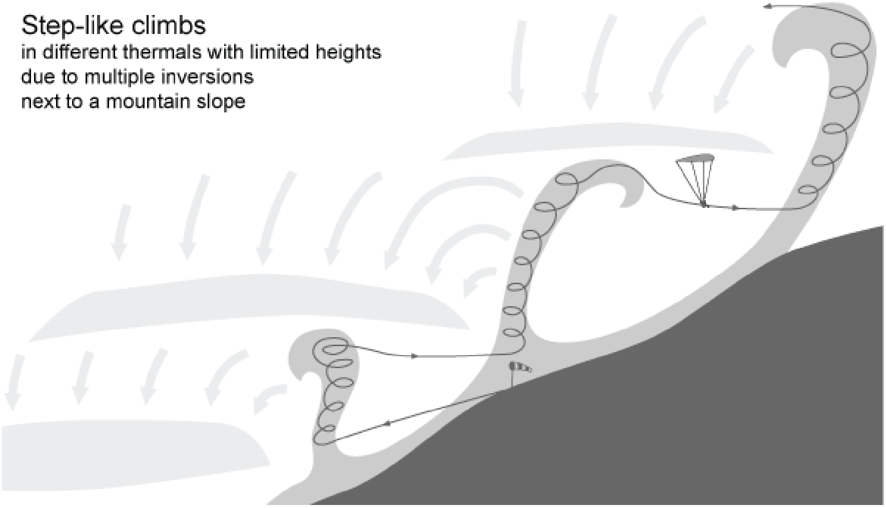


Despite difficulties with weak and tilted thermals, they can lead to better lift. Often, thermals weaken and tilt because they meet an invisible inversion layer. Then, they drift and spread downwind beneath it and later they can puncture it and go up strongly again. It might be because of an inversion weak point, or because of an accumulation of critical mass of light warm air. Also, wide thermal columns provide good conditions for the joining of other thermals in their wake.



Whether a thermal will be completely stopped by an inversion or will manage to go through depends on different factors, but here is a hint – **it makes sense to wait longer in weak but broad lift**, as quantity gains often lead to quality changes. Patience is strength, even when it doesn't pay back every time.

Thermals often rise through several inversion layers, especially near a large mountain slope, where step-like climbing pattern is quite common.



Of course, downwind checking and tracking by entering deeper into a mountain terrain should be practices with care! If we lose the thermal then coming out of the mountain against the wind and in the lee of other thermals upwind might be risky and even impossible. Landing inside the mountain, even in a forest, might be healthier, then dumbly pushing to come out. Embrace the mountain and she will accept you. **It's better to land in a smooth flow over rough terrain, than in a rough flow over smooth terrain**.

A tough dilemma during thermal tracking is what to do when the lift disappears?

Should we check upwind, in case we dropped behind, or should we check downwind, in case it reached an inversion and drifted downwind?

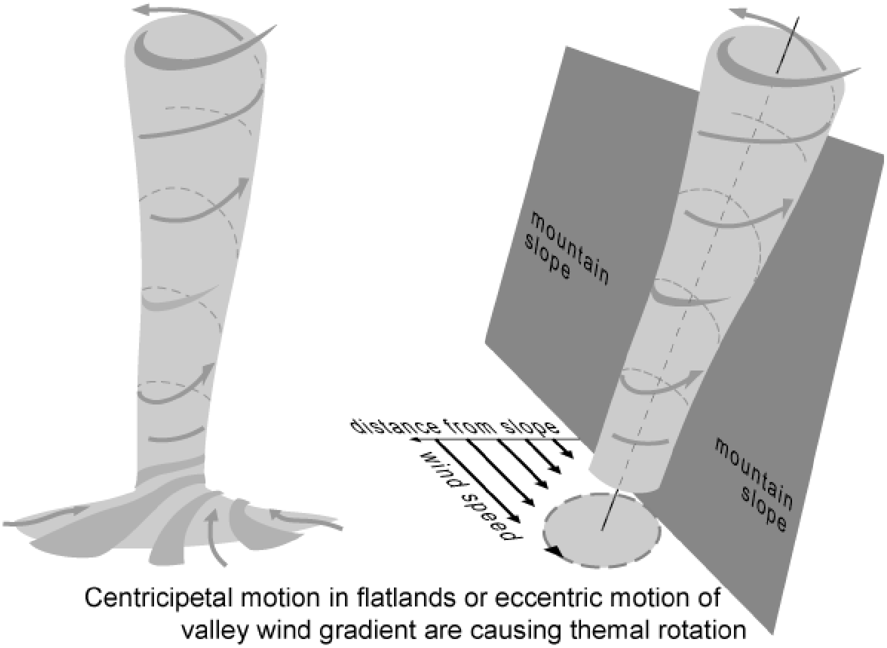
The main clue in this situation is to watch the tendencies. If the lift is gradually decreasing and if a slight upwind check shows no change, then it's probably the case of an inversion and downwind check is better option. If we only noticed an abrupt disappearance of lift, then it can be either upwind or downwind, or just gone, as inversions often have a messy shear turbulence. We should constantly monitor the lift tendencies all the time, as a background sense and thinking process, even when our main thoughts and vision are busy where to go next.

ROTATING THERMALS

When low, the pilot's approach to thermals should be "guilty, until proven innocent". Thermals should always be suspected of rotation, because they can be easily lost or used inefficiently, if turned in the wrong direction.

Vorticity is nature's answer to efficiency, as it preserves momentum. There is a zoo of air vortexes on micro (*eddies*), macro (*dust devils, tornadoes*) and mezzo scale (*cyclones*), with horizontal or vertical axes of rotation.

Vorticity is caused by *centricity* or *eccentricity*. Centricity is when air goes horizontally toward a centre, where it rises upward (*rotating thermals, dust devils, tornadoes, cyclones*). Eccentricity is when a force is acting eccentrically on a body. For example, when a thermal column is rising up along a steep mountain slope, the valley wind is rolling it, pushing it more on the side away from the slope and less from its inner side. The valley wind has a pronounced horizontal wind gradient, because friction weakens the wind closer to the slope.



Centricipetal motion in flatlands or eccentric motion of valley wind gradient are causing themal rotation

Air movement toward a centre is driven by a horizontal temperature and pressure difference, or because an updraft at the centre is sucking air from around. In the first case of temperature driven horizontal motion toward a centre, air builds up there, converges and causes a resultant upward motion. In the second case, the initial upward motion is driven by instability (*buoyancy*) and it sucks from below, causing the horizontal centripetal motion. Which is first, the egg or the chicken, the horizontal or the vertical engine, will help understand the particular circulation and its range. Also, there might be a combination of both engines – vertical instability with horizontal pressure difference.

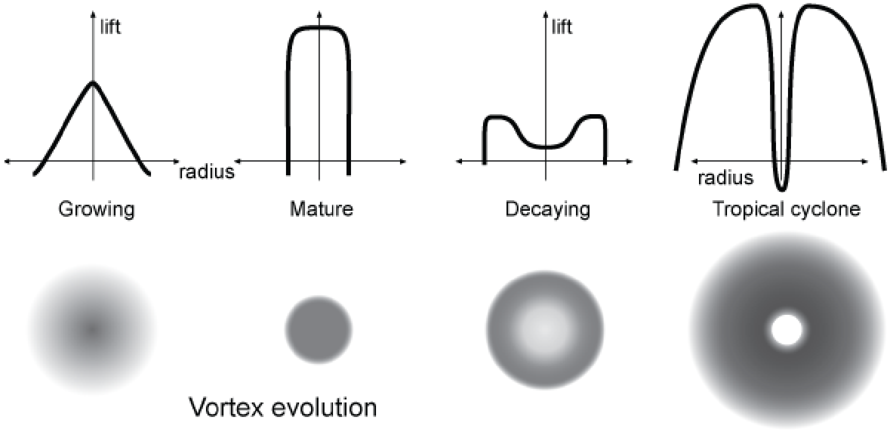
And again, on vorticity. Large scale air motions are influenced by the *Coriolis effect* from Earth's rotation (*turning to the right in the Northern hemisphere*). Large scale horizontal motion toward a centre and the Coriolis' turning to the right cause a cyclonic or counter-clockwise rotation in the northern hemisphere and clockwise in the southern hemisphere. And the opposite happens, when air diverges and moves radially away from a centre.

The Coriolis effect is negligible for small scale circulations like thermals, dust devils and even tornadoes. Small terrain irregularities or surrounding air disturbances are much stronger initiators of rotation. If instability is temporarily insufficient for easy transformation of converging horizontal motion toward a centre into a spontaneous vertical rise, then a rotation can engage its energy for a while. Imagine a gust of air going toward a centre and hitting head-on another gust of air also coming to the centre, but from the opposite direction. Imagine more gusts coming from all around and hitting each other head-on in the centre. And another one coming from behind. What a battle! Now imagine that something small, like a lonely torn tree, initiates a rotation, which elegantly deviates gusts from their brutal head-on collisions and invites them for a circular dance. And the more gusts join this circular orgy, the stronger it gets. Later, newcomers have no option, but to join the twist. "Make love, not war" is also valid for nature, not just for hippies.

This is how devils are born from the dust. Often, there is an inversion, which works like a lid and keeps the devils beneath. If it's strong, then the vortex will fatten and lose its attraction. Expanding bodies reduce their spinning; shrinking bodies - increase it. If the inversion is weak and the erected dusty devil penetrates through it, then there will be a second life for the old fag. It will get slimmer and spin faster, this time not fed by, but sucking into itself more surrounding warm air, transforming a horizontal motion into a vertical rise. And of course, when the warm surrounding air has been depleted, the feast is over. There is no point sucking in further cold, heavy air. It won't go up. This is how the devils die – from below, from the dust. Once the warm air supply has ceased, thermals and dust devils dissolve within the surrounding air. The decrease of pressure with height makes thermals and dust devils expand, which slows and eventually halts their rotation.

In the case of tornadoes, the initial air movement toward a centre happens at a higher altitude. The rotation is initiated by random air disturbances and is driven by the great instability inside the tornado thunderstorm cell. There are favorable conditions for the vortex to go downward from the cloud – unlimited sucking of warm air from beneath and an increase in spinning, because the vortex decreases its width, when going downward to higher surrounding pressure. The mechanisms of tornadoes and dust devils are the same, except that tornadoes can also go downward, while dust devils - only upward.

In the beginning of a vortex cycle, when horizontal centripetal motion prevails, there is a build-up of pressure in the centre. Later, when instability and vertical motion prevail, there is a drop in pressure in the middle of the vortex, while the periphery continues to suck-in air from the surface. Mega scale vortices, like tropical cyclones, can develop further and have a high-pressure zone with cloud killing downdrafts at the centre (*the eye of the cyclone*) and a low-pressure ring around it with strong updrafts and winds.



Vortex evolution

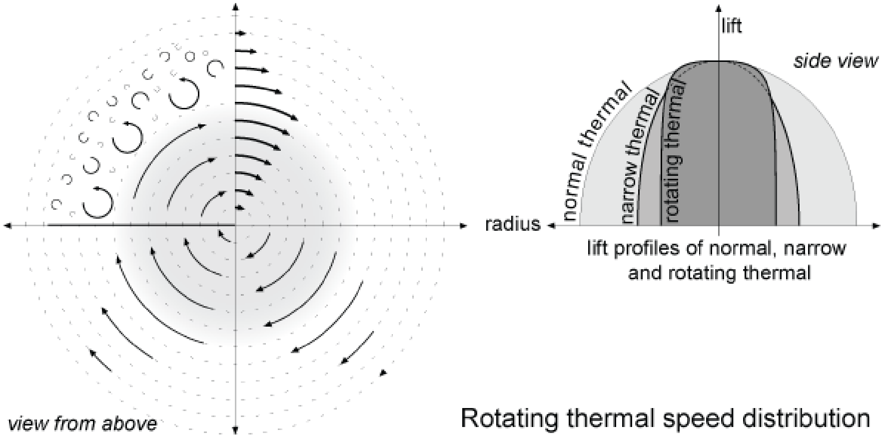
Thermal rotation makes soaring difficult. Flying is even more complicated by the vertical and time evolution of lift profile.

One good thing about rotation is that it makes the thermal core very distinct from surrounding air. It's like a perfect circle, as rotation smooths off irregularities. The rotation can even seal and isolate the core, like a layered onion, prolonging a thermal's life by reducing mixing with surrounding air.

Non-rotating thermals have a primary frontal toroidal circulation and sometimes older secondary toroidal circulations along their bodies, like a mushroom ring. These toroidal circulations drain warm air and bring in outside cold air, which reduces the thermal's size, strength and height. A toroidal rotation also promotes a curvier trajectory and branching.

Rotation around the vertical axis suppresses toroidal rotation with its leaks, entrainment, curving and branching. Rotating thermals are also more wind resistant, with straighter and more vertical trajectories, like rifled vs smooth-bore bullets.

The core of a rotating thermal is not only more distinct from surrounding air, but also has more uniform lift. It can be seen as a solid body, with the same angular rotation and sometimes surprisingly smooth air inside. Outside the core, air layers decrease their angular speed; outer layers lag behind inner layers. This transition, or horizontal gradient is sharp at the core's walls, causing a serious turbulence there. Sometimes, dust devils are surrounded by counter rotating smaller vortexes like planetary gear wheels.



lift profiles of normal, narrow and rotating thermal

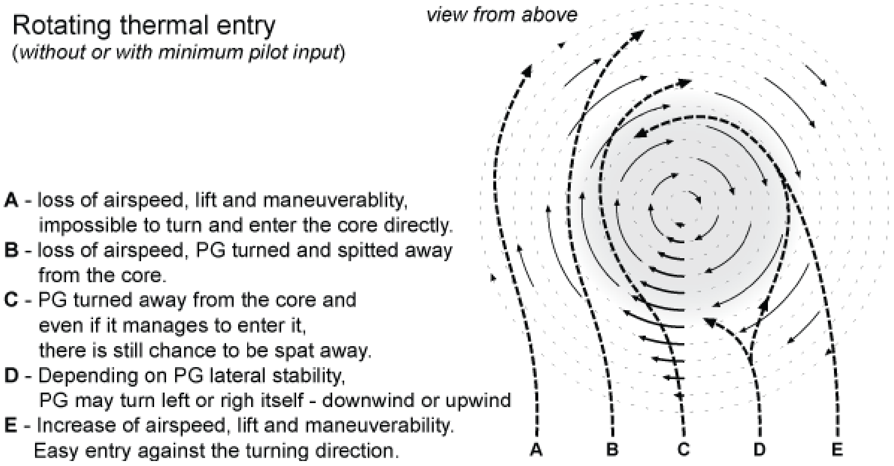
Rotating thermal speed distribution

Signs of thermal rotation:

- Unusually strong turbulence before entering the core;
- Depending on thermal entry direction, there are sudden sideways gusts, boosts of lift or loss of airspeed;
- The core is very distinct and often uniform and calmer inside compared to its surroundings;
- Turning in one direction provides a better rate of climb than the other;
- Turning in one direction makes the wing more manoeuvrable and easier to circle and stay in the core. Turning in the other direction makes the paraglider more difficult to control. It feels like the thermal is always spitting it out and often drops out of the lift.

The paraglider can enter and circle a rotating thermal in several ways, causing different processes and behaviors:

- *Entering a backwind gradient*: Loss of airspeed, lift and control;
- *Entering a crosswind gradient*: Rolling and turning away downwind;
- *Entering a headwind gradient*: Boost of airspeed, lift and control;
- *Entering strong lift*: Boost of lift, but possible pitch-up, too high angle of attack and temporary loss of airspeed;
- *Exiting strong lift*: Loss of lift and airspeed.
- *Circling against the rotation*: smaller radius and easy to stay in the core, which seems bigger; smoother and stronger climbs with peaks similar to the average;
- *Circling with the rotation*: bigger radius and difficult to stay in the core, which seems smaller; less uniform and weaker climbs with an average climb noticeably lower than peaks.

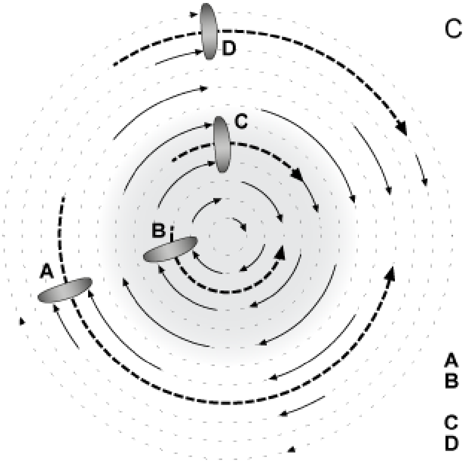

Rotating thermal entry
(*without or with minimum pilot input*)

A - loss of airspeed, lift and maneuverablity, impossible to turn and enter the core directly.
B - loss of airspeed, PG turned and spitted away from the core.
C - PG turned away from the core and even if it manages to enter it, there is still chance to be spat away.
D - Depending on PG lateral stability, PG may turn left or righ itself - downwind or upwind
E - Increase of airspeed, lift and maneuverability. Easy entry against the turning direction.

The thermal rotation has a constant angular velocity with linear velocities increasing further away from the centre. Once outside the core, linear velocities decrease to zero (*Rankine vortex*). Flying in a rotating thermal causes different airspeed between the inner and outer half of the wing. There are several different reactions when circling:

- *Inside the core, against the rotation*. The outer half of the wing has a stronger headwind and aerodynamic force than the inner one. This may roll-in, or make it easy for the pilot to roll the wing toward the centre. Circling the core is easy;
- *Inside the core, with the rotation*. The outer half of the wing has more backwind. This may roll-out the wing and turn it away from the centre, spitting out the glider from the core;
- *Outside the core, against the rotation*. Inner half of the wing experiences a stronger headwind and lift than outer one. This may roll the wing away from the centre, but at the same time the increased headwind may also slow the inside half wing and yaw it toward the centre. Whichever will prevail depends on the wing's characteristics and lift profile. Sometimes, the core wall is very distinct with a pronounced spit-out effect outside the core, which may suddenly change to easy circling and suck-in effect once inside the core;
- *Outside the core, with the rotation*. The inner half has a stronger backwind and less lift than the outer half. The drop of airspeed from the backwind may cause loss of lift force in the inner half wing and roll the whole wing toward the centre and help with joining the core.

Circling against and with the rotation



view from above

A - circling against the rotaion outside the core
B - circling against the rotation inside the core

C - circling with the rotation inside the core
D - circling with the rotation outside the core

Depending on thermal rotation direction, wing and lift profiles, thermalling might be with:

- ***Stable orbit***, which has a constant circling radius with minimum pilot input. Before Radio Controlled technologies, glider model plane designers were quite good at statically adjusting their aircraft for stable orbiting and impressively high climbs, without any control input during thermalling;
- ***Unstable orbit***, which has a changing circling radius itself requiring a lot of pilot' input.

Summary, circling against rotation gives a stable orbit and circling with the rotation – unstable. But sometimes, too good is not good, and too bad is not bad at all.

Sometimes, when circling against the rotation, the assistance of the thermal rotation for the turn may cause the wing to turn too sharp, like in a spin, and the paraglider may drop off or be spat out from the thermal.

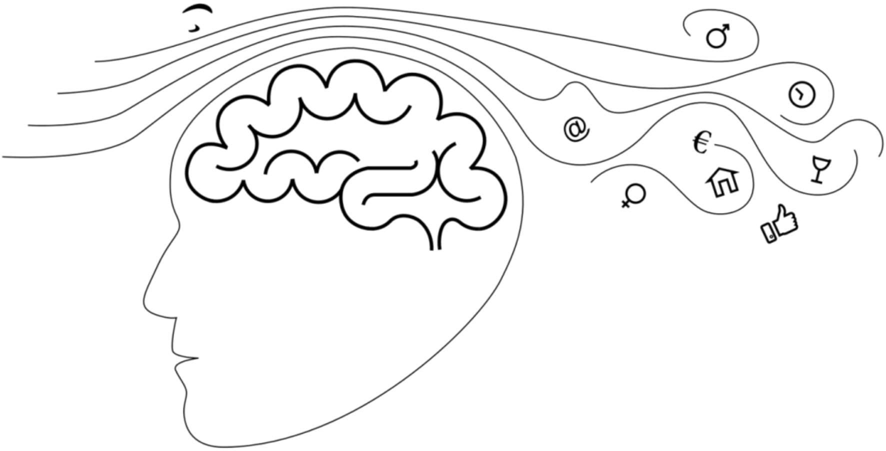
Sometimes, circling with the rotation might be with a weak climb but with a stable orbit. In other occasions, circling with the rotation may produce better climb. The air's textures and micro gusts also matter.

If there are no other pilots around, don't hesitate to change circling direction often, to check for fast climbs and stable orbits.

It is possible to climb well and freeze in the air for a long time with zero ground speed, when flying against a rotation, with lift and headwind, equal to your airspeed.

CLIMBING IN OTHER TYPES OF LIFT

Cross country paragliding is not only thermal flying. A single flight can use a lot of other types of lift, like ridge soaring lift, wave and convergence. Thermals themselves are often embedded within other types of lift.



RIDGE OR SLOPE SOARING

A common type of lift is when a terrain feature, like a ridge, shore, hill, or a mountain, is blocking wind and part of wind flow climbs over it, instead of going around. This creates a zone with constantly rising air, where birds and gliders can soar for long hours.

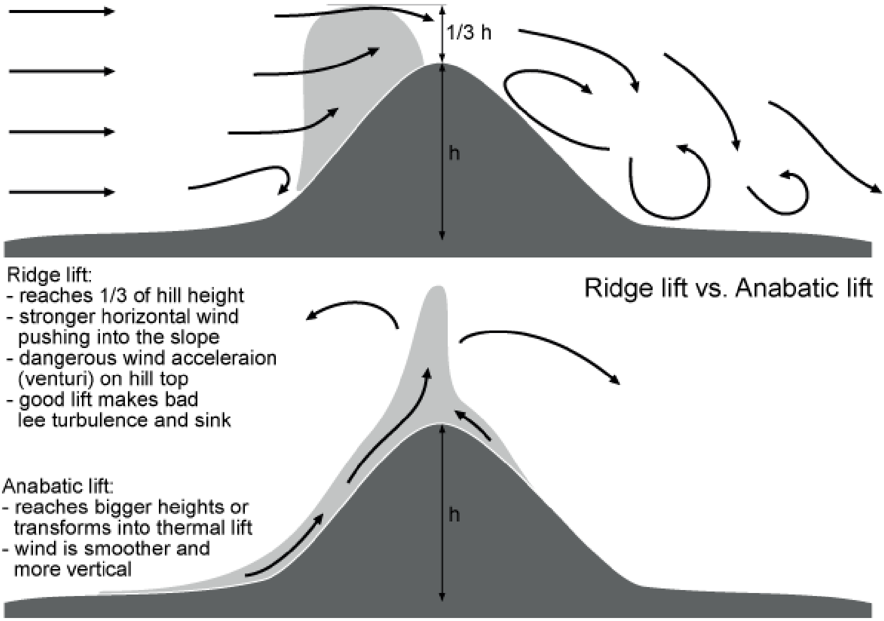
The size, strength and shape of the ridge lift zone depends on ridge size and shape, wind and instability profile. Bigger and stronger lift zones are made by:

- Big terrains with shapes that block the wind well;
- Strong winds at ground level or specific wind gradient profiles, matching the ridge properties;
- High boundary layer instability.

The main problem of cross country flying with ridge soaring lift is that it's fixed to the ridge which creates it. This limits our freedom of movement. Ridge soaring lift is mostly used for:

- Surviving premature landings. Often, when a pilot fails to find the next thermal, going to ridge lift is the only option to continue flight;
- Waiting (*time zoning*). Many cross country flights start from a soaring hill, where pilots wait in ridge lift for a thermal to pass through. Later, along the course line, pilots can use another ridge lift for waiting for another thermal;
- Searching and positioning. Pilots use ridge lift to search for a thermal within it or nearby. A common tactic is to gain maximum height, glide out, check for a thermal in front and return back into ridge lift, if nothing has been found. Ridge lift can allow good positioning in space, which otherwise might not be possible – e.g. intersecting thermals way in front of the hill at their beginning, not at their tail, which later touches the slope. It is also safer to catch thermals more in front of the ridge and gain maximum height, before going cross country downwind over the lee turbulence behind the hill;
- Route progress. There are terrains with long ridges, which allow tens of kilometers of cross country flying. They may occasionally require thermal lift for some transitions over deep gorges, but ridge lift prevails for most of the flight. Some Alps-like steep ridges provide long and fast lines for route progress.

Ridge lift soaring can be used to gain height, but shouldn't be mistaken with *anabatic lift slope* soaring, which can give much bigger heights. Ridge lift is more limited for height gain - usually 1/3rd of the height of the wind blocking obstacle (*hill, ridge, and mountain*). Ridge lift is caused by the mechanical upward deflection of (geostrophic) wind from a slope. Anabatic wind is driven by a mountain-valley temperature difference. It climbs the mountain slope for a much longer distance, without becoming too strong at altitude. Anabatic lift is smooth, and can allow pleasant and safe climbs from very low to very high. Anabatic flow can have thermals embedded inside it, but it can also become a thermal itself from an appropriate trigger point. Anabatic lift is soared with figures of 8, like ridge lift soaring, but can also allow full circles, without being pushed into the slope, like in windy ridge soaring conditions. Ridge racing along steep slopes in anabatic winds is safer than in geostrophic winds. Still, don't copy good pilots blindly!


Ridge lift vs. Anabatic lift

WAVE

Sailplane gliding pilots use waves not only for height gains (*sometimes to the end of the troposphere*) but also for proper cross country flights of 1-2000 kilometers.

Paragliders can’t fly so fast and it’s unsafe to fly in such strong winds, which are needed for wave creation. However, there are conditions, when strong winds are at higher altitudes, but lower, at take-off and landing altitudes, winds are manageable. With the help of thermals, paragliding pilots can contact wave lift and gain some extra height with it. But not as much as gliders, because the problem with strong winds remains and the height gain is only possible until the paraglider is blown back away from the lift.

Pure wave lift soaring is more of an exotic experience for paragliding pilots, than a real tool for cross country flying. But it’s good to study waves, because they influence what’s happening below.

The upward wave part increases instability and thermal lift beneath. The downward wave part stabilizes the air mass beneath, and can cause strong winds at ground level.

Wave motions also influence lift distribution below. In some conditions, especially in spring, the first half of the day might be with wave-based lift distribution and the second half can be classically thermic, with logically interconnected thermal sources, triggers, and clouds. In summer, when boundary layer instability increases, there are not many waves, because waves need a stable inversion layer to play their songs, like string of a guitar.

Waves give us an useful lesson about tracking thermal's trajectories. Good wave conditions occur when wind increases with height. Despite this, waves tilt against the wind with height. They start behind an obstacle, which initiates them, and tilt against the wind with altitude, because of hydraulic jump at critically-high flow speeds and because of suction and sink above the windy mountain ridge. In some conditions, like spring or morning, the remaining winter or night inversions promote small scale wave motions and make thermals tilt against the wind, surprising pilots, who would expect a standard downwind drift. This reminds us of the importance of *upwind checks*, when thermalling!

CONVERGENCE

Convergence means coming together. Convergence is *horizontal*, when opposite winds meet, or *vertical*, when updrafts join and rise together.

A horizontal meeting of winds creates an excess of air and a resultant vertical flow. Ground level convergence creates only an upward flow. High level convergences can be either up or downward.

Horizontal convergences do not always merge the meeting air masses into an uniform vertical flow. If they have different origin and properties, the airmasses do not mix easily, causing deformation and shear turbulences, and their resultant updrafts are difficult to follow. Short peaks of lift are observed, but the average one is weaker due to the lack of unification and pointless conflicts, like among people. On exit attempts, there are headwinds in all directions. They apparently meet in one zone, confirm the convergence, but the good lift happens at higher level of development, after overcoming the differences and the ego.

Horizontal convergences do not always merge the meeting air masses into a vertical flow. They may have different properties and viscosity and may travel together for a long time without mixing.

Vertical convergences are usually a result of horizontal convergences, but not always. There are circulations, where vertical motion prevails, and the horizontal convergence is resultant, secondary.

Convergence lift depends on:
- Speed and size of horizontally converging flows;
- Angle of collision. The more head on, the better;
- Airflow properties. The best lift is when two horizontally converging airflows have similar properties, otherwise one will wedge under the other. For example, in spring, a humid and cold inshore main wind meets a similarly humid and cold offshore sea breeze and both make a good convergence line along the coast. In summer, the sea breeze is like a miniature cold front, which triggers updrafts during its inland advancing, but cuts, cools and suppresses thermals behind it;
- Boundary layer instability or other types of lift, promoting the upward part of a convergence circulation.

Convergence is a pretty broad term for lift creating mechanisms, like cold fronts, when only one flow is moving, pushing under and lifting a semi-unstable air mass. In this case, there is no need for movement of two and more air flows, there is no need they to have equal scale and properties.

Other convergences are driven by lift distribution circulations and mechanisms, like lift lines, cloud streets, cluster thermals, wind-driven streets.

There are even convergences from the wind’s veering and backing, from wind passing over neighboring surfaces with different friction and properties.

There is a big variety of convergences with various scales, like the global Inter Tropical Convergence Zone; a midnight convergence, over the middle of a valley, caused by two opposite katabatic flows; or the convergence along the rear stagnation line behind a thermal or a hill. Some are quite predictable and chased by pilots, others come out of nowhere and have an undefined shape or properties.

There is nothing new about how to fly thermals embedded in a convergence lift, except to expect them to be stronger, smoother, more organized, easier to track and there are more of them nearby. Some convergences can be pretty bizarre – you can fly straight in decent lift for a long time, then turn back and fly through exactly the same air but find nothing (*one way lift*).

Convergence lift itself is usually big in size, but weak in strength. Gaining significant height is rare or limited. Maintaining height or improving glide ratio is a more realistic goal. Still, convergences are a powerful tool for cross country flying. Good pilots use them to regulate height, speed and time. *Don't think only of momentary gains; think more about the big picture*!

EXITING LIFT

Part of climbing efficiency is how to exit lift. Cross country goals determine how strong lift to take, for how much time and up to what height. Here, the focus is about efficient exiting from lift in general. A bad exit can nullify a lot of hard climbing work.

Lift exit goals are:

- Minimum height loss when leaving the lift zone and its surroundings. Any upward flow will cause a compensating downward flow nearby!
- Minimum time loss for continuing along the route line. Each climbing circle in lift gives us a snapshot view toward the route direction. By comparing it with the previous one, we can see the change of the figures at the chessboard along the route, we can interpolate and predict their development. During climb in lift, we have plenty of time for searching for lift ahead, so **we should always know our next goal before leaving lift**!

The answer, my friend, is blowing in the wind. The answer is knowledge!

It is not enough to "see" thermal sources or triggers, to understand the birth of thermals, their sneaky trajectories and cloudy hats. Take time to study death. The death of thermals.

The hard work of finding lift and climbing in it is not over yet. Study your enemy – sink. You cannot fight it, but only avoid it and minimize its harm.

In life, and in nature, **when something goes up, something else goes down**! There is no escape from the general balance law in the universe, but we can play little tricks, like avoiding flying at night or in winter, when sink prevails. The daily and seasonal expansion of the boundary layer gives us an abundance of lift. Sometimes in a summer afternoon, above a certain height, we can feel how everything goes up – not only thermals, but the whole atmosphere, even the last cripple lift goes up to worship the Sun.

Of course, these blissful moments are not enough to sustain a distant cross country flight, so studying sink is important.

Sink, like thermals, is a product of boundary layer instability and compensates a thermal's rise. At ground level, thermals need to reshape from flat warm air layers into drag-efficient rising bubbles or columns. Sink would do the same, if it has sufficient negative buoyancy, if it's cold enough. But still, sink is not so well organized like thermals for several reasons.

Sink sources and *sink triggers* are weaker than *thermal sources* and *thermal triggers*, which employ the mighty sun with all this terrain's variety of shapes and properties. Of course, rising thermals expand and cool, but sink never reaches such temperature differences as those between a hot brown soil and surrounding fresh air. Temperature contrast vertical drafts and surrounding air drives buoyancy.

There is also a lot of inertia, a lot of insulation. It takes time for warm thermic air to become cold sinking air. Thermals can turn into cold air sources only when they overpass their equilibrium altitude significantly, driven by inertia or other types of lift. This downward "bounce-back" motion might be enhanced by an "elastic" inversion above. If thermals gradually stop around their equilibrium altitude, where their inner air has the same temperature like surrounding air, then they will not be major sources of cold air and sink.

That's why the upper boundary layer instability profile (*temperature gradient*) is important for sink production. That's why unnoticeable changes at higher levels make next days with the same types of thermals, but with different types of sink or with different organization and distribution of sink.

Apart from thermals, other sources of high-altitude cold air and sink are cold terrain surfaces like shady or snowy mountain slopes. Even lowland cold surfaces, like lakes, can form circulations, which drain cold air from above. But these cold air sources have mostly a local effect; they participate mostly in local circulations.

More widespread and evenly distributed sources of cold air and sink triggers come from cold winds aloft disturbed by thermals coming from below, through shear turbulence and vortexes.

Cooling from evaporation of dying clouds is another source of cold air aloft.

And of course, a source of sink is the surrounding air itself, the airmass we fly in. It might be cold enough to form strong concentrated sink, especially in spring and cold air advections aloft. Very high instability may cause a spontaneous downward triggering within the airmass itself. The mammatus clouds within the thunderstorm anvil are spontaneous downdrafts meeting a stable layer bellow.

In most cases, sink is initiated by compensating for the thermal-rise's counter flow and circulations. Or by wind gusts and turbulence, with or without thermals.

As you can see, there is a big variety of sink mechanisms, which need more observation and studying. Still, there are few basic principles:

- Because of the higher temperature difference and stronger buoyancy force, lift is generally stronger and more concentrated than sink, especially at noon and in summer;
- In windy conditions, sink is often concentrated at the lee side of lift;
- Good convergence conditions combining more lift are also good for combining sink – cloud streets alternate with sink streets; cluster thermals go together with blue sink holes;
- Strong sink will slow down and stop before hitting a flat ground, while the end of lift is less defined, unless there is a strong inversion aloft.

Throughout a cross country flight, pilots should picture the profile of lift distribution and height bands with different strengths of lift. A sink profile might be useful too, or at least noticing at which altitudes sink is stronger and at which it is weaker. Is it at the thermal's top level, or perhaps at mid altitudes or lower?

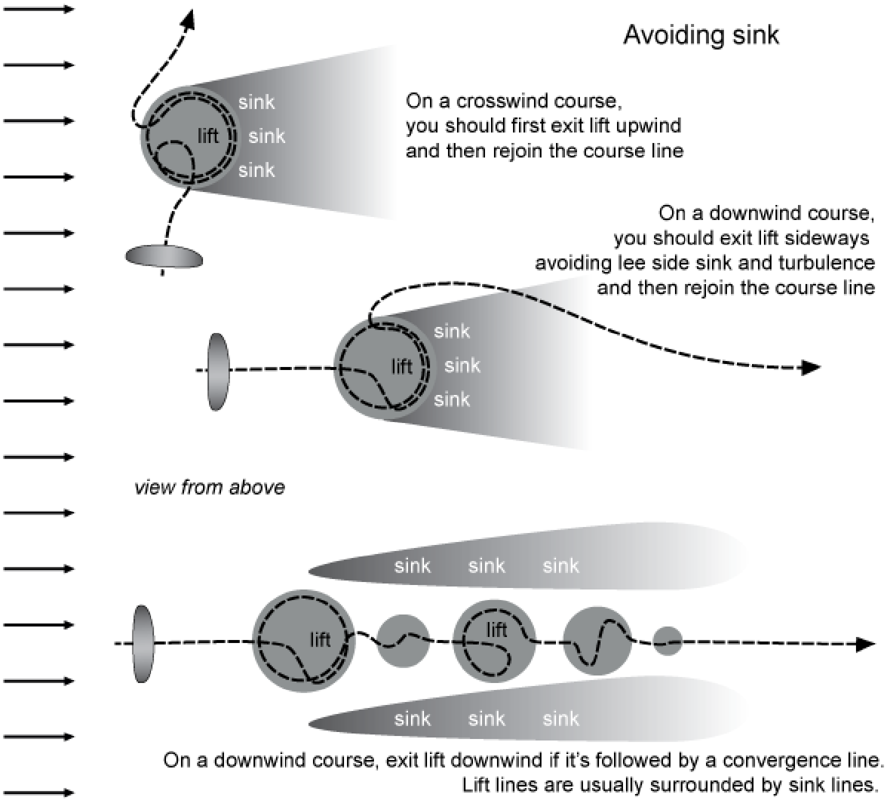
These can give some sink avoiding tips:

Exit lift sideways, if you expect strong sink downwind. Sometimes, wind gradient transforms thermal tops into horizontally rolling vortexes, enhancing the last part of the thermal lift, but also creating a stronger sink zone just behind. Exiting through it feels like long jump on a steep water slide, with the wing staying intact above the pilot, but without pressure and lift force.

Sideways exit can have an extra benefit from the lift's *V-shaped wake*, when fluid (*wind*) hits an obstacle (*thermal*). V-shaped wakes are classic behind stones in a river stream. Rafters know and use them. They're not so strong in the air, due to its much lower density, but they do exist and need to be explored more by pilots. A V-shaped wake form a strong thermal can initiate a lift distribution pattern farther downwind.

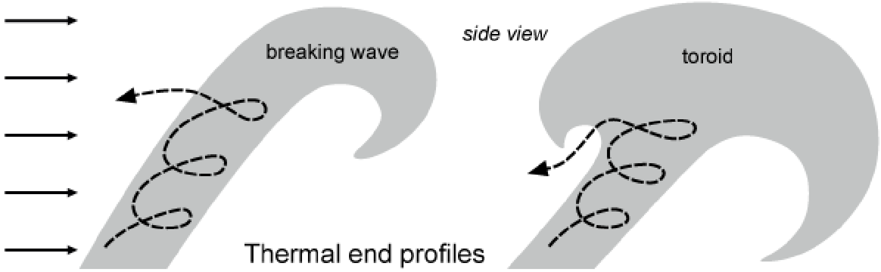
Climb some extra height, if possible, when you expect more sink during the following glide. Sometimes, thermals go through an inversion which is trapping stronger sink below, so extra patience and skills are often rewarded at the 2nd floor. Climbing inside clouds gives not only a plenty of height, but also decreases sink for the following glide. Cloud climbing benefits from the latent heat energy from condensation, and from the inertia of cold air production from evaporation. Of course, cloud flying is risky, unpleasantly wet for the pilot and not good for the equipment.

Flying straight downwind can be sink-avoiding, if there is a convergence lift line behind. As mentioned before, thermals are rarely isolated and the wake of one thermal can give a shelter for another one behind, or for few others, like in a lift street. Especially when the thermal is strong, big and blocks wind well, which creates a convergence along its rear stagnation line.



Often, the very end of the thermal is like a "breaking wave" due to stronger winds above and reduced buoyancy. This creates a lee side giant vortex and heavy sink which should be avoided by upwind or sideways thermal exit.

If the thermal top has a pronounced toroidal circulation, then upwind thermal exit can also pass through a vortex driven sink. Then a maximum climb to fly above the vortex and a straight downwind exit with higher speed and glide ratio would give more efficient and smoother exit from the thermal.



Lift exit decisions also depend on whether there are other types of lift, combined or embedded with the one we're currently using.

If the pilot cannot predict or avoid sink behind the lift he exits, then he should minimize its harm.

On lift exit, the paraglider jumps into no lift air, which is similar to a sudden entry from calm air to sinking air. Airspeed and lift force are decreased or entirely lost, possibly for a long time, until the paraglider starts descending faster than the surrounding air. Once air flow starts coming from below, the paraglider recovers its gliding mode. During the whole process, the paraglider travels along a ballistic trajectory. There is not much pitch motion – the wing stays above the pilot, except on final recovery, which may happen sharper and cause the wing to pitch-down forward.

The falling feeling is not pleasant, but if the pilot has managed to overcome fear from collapses, then he can even apply the speed system during the fall. This reduces angle of pitch and brings the angle of attack closer to more favorable values for quicker restoration of gliding mode. The application of the speed system should be reduced at the last moment, just before the wing self-acceleration starts, to avoid unnecessary height loss and inefficient oscillations.

So, we should practice using the speed system to enter and exit thermals with higher airspeed.

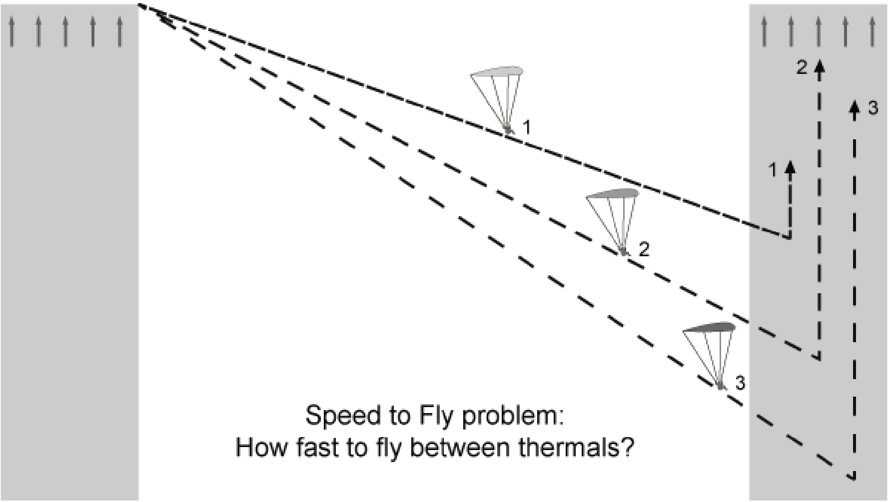
FAST CROSS COUNTRY FLYING

After learning and practicing the cross country stages – *route progress*, *search for lift* and *climb in lift*, let's see how we can combine them efficiently in order to fly along a certain route as fast as possible.

MACCREADY SPEED TO FLY

Let's first define the basic *speed to fly* problem.

Imagine three paragliders leaving a thermal at the same altitude and heading toward the next one. They glide at three different speeds – slow (1), optimum (2) and fast (3). The fastest (3) arrives first, but loses too much height, because of higher descent rate during his high-speed gliding mode. The slowest (1) arrives last with minimum height loss. The optimum pilot (2) arrives in between, but out climbs the fastest, because he started climbing from a higher position, and also out-climbs the slowest pilot, due to starting the climb earlier. The three pilots climb equally fast in the thermal.



Speed to Fly problem:
How fast to fly between thermals?

Speed to fly (*STF*) is the optimum airspeed we fly with, depending on the flight goal:

- Flying farthest from a given altitude (*V best GR*);
- Flying fastest from a given altitude (*V max*);
- Flying for the longest time from a given altitude (*V min sink*);
- Flying at *max XC speed* is usually used in competitions, when flying through a specific speed section lasts 2-3 hours and conditions are more or less uniform;
- Flying for *max XC distance* is usually used for chasing records by flying for long hours through changing conditions. Flying for *max XC distance* is also a race against time (Sun), like flying for max XC speed, but it has additional requirements like adapting to changing conditions (*daily evolution of the boundary layer*) in order to reduce the risk of premature landings. When chasing big flights, we look for long term profits and we tend to fly more conservatively, trading speed for less risks and more opportunities.

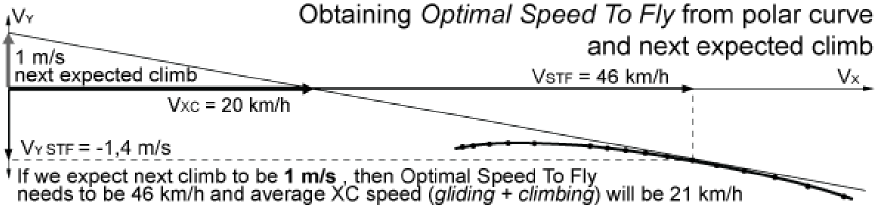
Again, on the question - what is the optimum speed for gliding between thermals? The answer requires knowing the speed polar curve, which is specific for each wing design, and the strength of the next expected thermal. It doesn't depend on the distance between thermals, because we assume that they're within the glide range and uniformly strong from the bottom to the top.

There is a mathematical solution used in flying instruments and applications, but modern pilots are allergic to formulas, so it's easier to visualize the *speed to fly* graphically. Again, we'll use the speed polar curve of an Advance/Sigma 8 27.

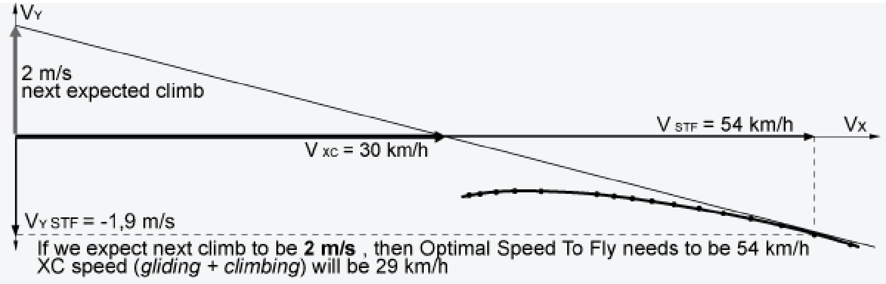
On the vertical axis we draw the speed vector of the next expected climb during circling, as shown on the variometer. Then, from the top of the climb speed vector, we draw a straight line toward the polar curve. The touching point gives us the optimum speed to fly between thermals.

If our glides between thermals pass through a sinking air mass, then we move the polar curve downward respectively and again build the line between the polar curve and the vector of the next expected climb speed.

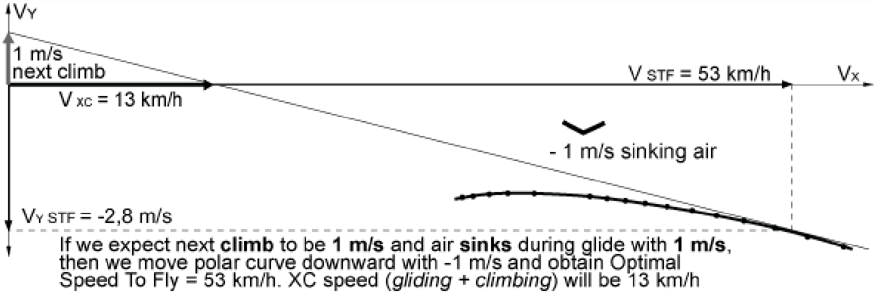
Strong thermals greatly increase *average XC speed*; sinking air between thermals greatly decreases it. The paraglider has a limited speed range, so in stronger lift or sink *optimal speed to fly* turns into flying on full speed bar with maximum airspeed V_{max}.


Obtaining *Optimal Speed To Fly* from polar curve and next expected climb

If we expect next climb to be **1 m/s** , then Optimal Speed To Fly needs to be 46 km/h and average XC speed (*gliding* + *climbing*) will be 21 km/h



If we expect next climb to be **2 m/s** , then Optimal Speed To Fly needs to be 54 km/h XC speed (*gliding* + *climbing*) will be 29 km/h



If we expect next **climb** to be **1 m/s** and air **sinks** during glide with **1 m/s**, then we move polar curve downward with -1 m/s and obtain Optimal Speed To Fly = 53 km/h. XC speed (*gliding* + *climbing*) will be 13 km/h

As a comparison, the following table shows the average XC speed, Speed To Fly, time spent in climbing and time spent gliding as a % of the entire XC flight duration for different climb speeds:

Climb speed (*m/s*)	Climb time (*% of XC*)	Glide time (*% of XC*)	V_{XC} (*km/h*)	V_{STF} (*km/h*)
1	67	33	20	46
2	50	50	30	54
3	40	60	36	V_{max}
4	33	67	40	V_{max}

> Speed to fly theory was developed by Paul MacCready, who applied it and became a world gliding champion in 1956. In paragliding, speed to fly theory doesn't have a significant use, due to the limited speed range: 25-60 km/h in paragliding, compared to 30-120 km/h in hang-gliding, and 60–220 km/h in gliding.

If you look back at polar curves in the *route progress* chapter, you'll see how glide ratio varies when flying through sink, lift, headwind, backwind. Some improve it; others worsen it.

Easy speed to fly (ESTF) gives the optimum speed we should fly within a mix of lift, sink and wind. It's just for the gliding stages, not for the entire cross country flight, with its series of gliding and climbing.

1. The input values are your momentary vertical speed V_y in m/s (*sink is with minus sign*) and your momentary ground (*GPS*) speed $V_{x\ ground}$ in km/h.
2. $x=V_{x\ ground} + 10*V_y$
3. If $x \geq 30$, then speed to fly = trim speed
4. If $x \leq 0$, then speed to fly = full speed
5. If "x" is between 0 and 30, then we transform "x" as a % between 0 and 30. Then, we should apply (100-x)% speed system. If x=20, which is 66% between 0 and 30, then we apply 33% speed system.

Examples:

- V_x=47 km/h, V_y= -1.5 m/s; x=47–10*1.5=32 ; thus STF=V_{trim}
- V_x=35 km/h, V_y= -2.3 m/s; x=35–10*2.3=12; 12 is 40% between 30 and 0. So, STF=60% speed system
- V_x=23 km/h, V_y= -2.5 m/s; x=23–10*2.5=-2; thus STF=Vmax
- V_x=10 km/h, V_y= +0.5 m/s; x=10+10*0.5=15; thus STF=50% speed system
- V_x=50 km/h, V_y=-3 m/s; x=50-10*3=20; thus STF=33% speed system

Easy speed to fly in a moving air mass is easy to calculate, but an even easier approach is just to use the glide ratio function, shown on most flying instruments and applications.

In the case of a negative event, like increased sink or decreased ground speed, the pilot accelerates the paraglider by applying the speed bar until the glide ratio reaches its maximum for the given conditions.

In the case of a positive event, like decreased sink or increased speed, the pilot slows the paraglider until the glide ratio reaches its maximum.

The above two rules, plus the conclusion from the *MacCready speed to fly* for gliding between climbs, should be enough for most paragliding pilots for their cross country efficiency, even for competitions and records. In other words, in most cases: **Fly at the airspeed, which gives you maximum glide ratio. Fly at full speed, if the next expected reachable climb is 2+ m/s**

Of course, the speed to fly should be adapted when there is a chance of *bomb-out* - premature landing, due to long transitions, or flying through difficult and changing conditions.

Many pilots think of *Macready's speed to fly* as a magic spell, which will solve their fast cross country flying problems. Probably, because *speed to fly* theory seems complicated and has the word *speed* in it. Pilots are right. *Speed to fly* is complicated, but luckily it has limited use, because of a paraglider's limited speed range, which allows us to simplify it. So, let's use the power of the weakness and work on other fruitful and practical ways to fly fast.

ATTITUDE

"I've got a strong urge to fly.
But I got nowhere to fly to, fly to, fly to…"
Pink Floyd, The Wall, Nobody home

Indecisiveness is cross country's fast flying enemy number one. Indecisiveness can be more expensive, than inefficient decisions. A boat, an airship or an army have one captain, one commander. There is no time for doubt or democracy when action is needed.

"Should I leave lift now? Oh, no! There is too much sink around. Let's go back and climb a little more".

Fight your fears! Don't be afraid to make wrong decisions. Learn from mistakes. There will be another summer, another day, another flight, when you'll make it better.

Be a seeker! Be an explorer in this invisible wonderland! Don't be satisfied with your current climb. Try another place. Try another technique. Avoid routine. Be happy when you find something new: this is more important than kilometers, or high ranking in competitions.

Be a student forever! It’s better to sacrifice performance now, but gain knowledge for tomorrow. Knowledge is not stockpiling information and experiences. Knowledge is a way of thinking, which gives you access to new knowledge. Knowledge is a weapon. Use it wisely.

Fly thermals with your bum and XC with your head! Be smart, but stay sensitive. Don’t let your intellect make you cynical. Fly like a tender pink butterfly, hypnotized by the aroma of all these beautiful flowers.

HEIGHT BANDS. WHEN TO LEAVE CLIMB?

Don’t leave lift if you don’t know where to go! It’s even better to have 2-3 potential lift zones ahead, before going on a glide.

Don’t forget landings! They’re more important than finding next lift. Climbing in lift expands your landing options, but descending in while gliding will reduce them again. Think of possible landings and next climbs together while climbing, rather than while gliding, when it might be too late.

Glider pilots have a rule to **leave the current lift when it gets weaker than the next one** expected ahead.

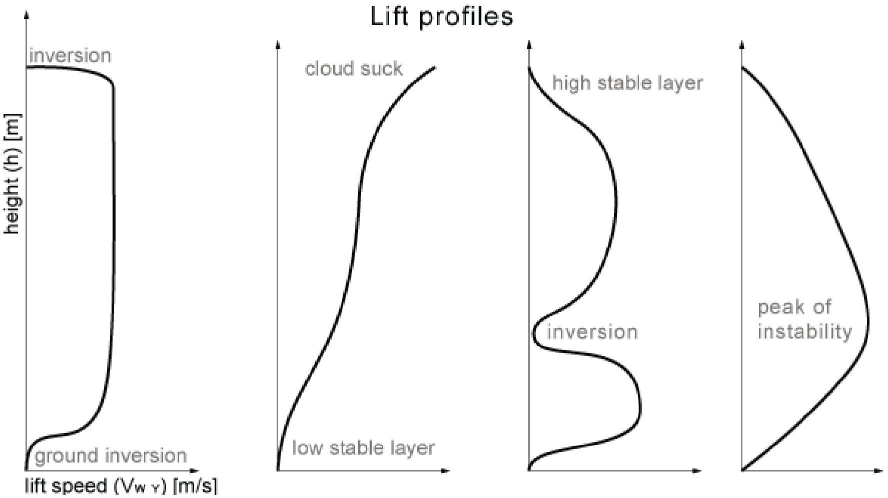
Of course, gliders are very fast at going to the next climb. As paragliding pilots cannot teleport themselves horizontally to the next climb, they have to adjust the above rule with their height loss on glide, which depends on the distance to the next lift and wind. Obviously, with tail winds and shorter distances, paragliding pilots stay closer to above rule. In headwinds and bigger distances, they should be more conservative.

Thermal lift usually starts rising slowly, speeds up and slows down again. As about half of the flight time is spent on climbing, cross country flying can be made faster, if we use more from the stronger lift and less from the weaker.

A common beginner’s mistake is to waste time in the weakest top part of the climb. This waste can be multiplied if we arrive high at the next lift and again climb in weak lift, just for the sake of being higher than others.

The opposite mistake is to be impatient, when climb decreases, and leave it too early or too low, instead of when waiting and checking for lift improvement. Then, we’ll arrive low at the weak bottom part of next lift, trapped on the 1st floor and constantly risking a bomb-out. A common reason for impatience is being in a racing mode when others overfly us from above. At some point, we have to accept being left behind, stop rushing and patiently climb to the 2nd floor. The earlier we recognize this situation, the better. A race is not over when we've been stuck low once or twice. It happens to top pilots too; there are too many chances and probabilities in this game. But if we leave a climb prematurely, unable to find something stronger, due to poor thermalling skills, knowledge or patience, then we cannot blame bad luck or others.

It's very useful to invest in the first lift after take off and climb it from the bottom to the top. This is a sounding of the atmosphere, like a meteorological balloon; drawing the picture of vertical wind and lift profiles.



What should we do with wind and lift vertical profiles?

First, we should check if they match the forecast. If there are puzzling differences - find the reason. Things doesn't come out of nothing and disappear into nothing. From your previous experience, you should already know how reliable the forecasting model for your flying site is. Forecasting services like meteoblue.com and skysight.io are getting better at taking into account the local terrain and its features. There is much less thinking nowadays and too many resources. It's better to master the practical implementation of one or two forecasting services, than to drown in confusion by flooding yourself with too many models, charts and pictograms. Control your information flow and you'll have more quality with better decisions. Previously, forecasts required a lot of meteorological knowledge and interpretation through local experience. Pilots still flew big cross country flights before the age of internet and smart phones.

If the forecasts are generally correct and there is still a difference with your in-flight sounding and observations, then remember the problem as homework for later and keep flying. Soon, you may find out what's going on. Just keep your eyes open.

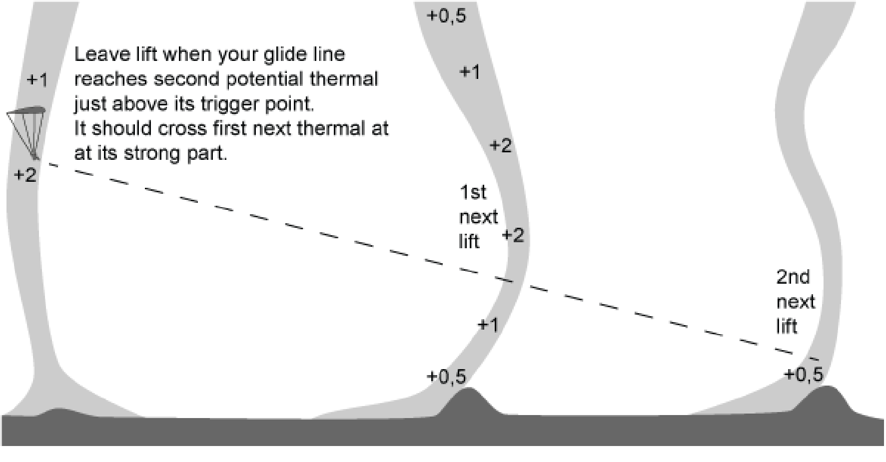
Everything happens for a reason. Often, especially in mountains, it's a local effect, like a giant vortex modelling the winds, time delaying inversion, humidity affecting meteorological elements, etc.

After sounding the atmosphere and comparing it with the forecast, the next step is to set up the vertical zoning – to ration how much height will go for *route progress*, for *localize lift* and for *survival mode*. The building of vertical zoning needs foundations. The basic one, in terms of fast cross country flying, is:

Make your glides arrive at the beginning of the next climb's improvement, or higher, but not lower**.** A derivative rule is:

Avoid being stuck low in *survival mode* as it consumes a lot of time. The survival penalty is so high, that it might be the end of the race for a competitor, even if he makes the goal eventually.

In most conditions, a safe and fruitful approach is to **aim to reach the next two climbs with one glide**. One shot, two goals. The pilot leaves the current climb when he sees that his glide line would take him just above the second trigger point, but intersects the first potential lift higher, at its stronger part. So, even if he misjudges the next lift, or it's just out of cycle, he still has a chance of catching the second potential lift and stay in the game.

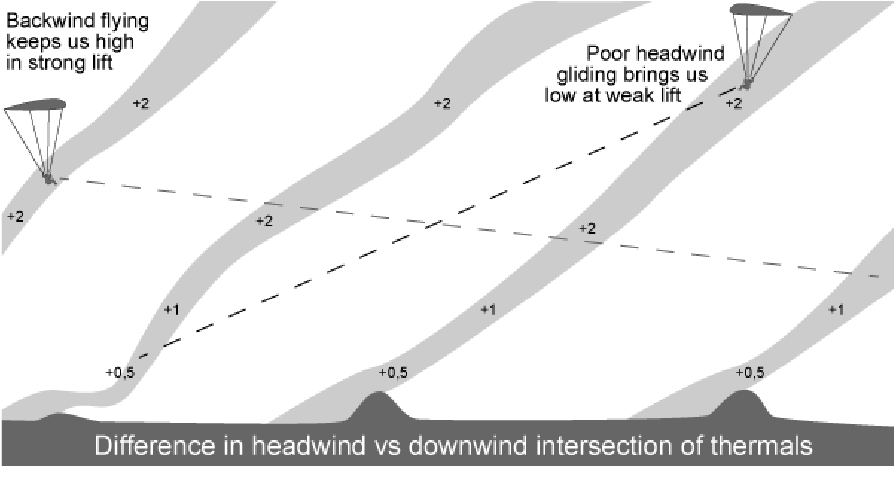


The next two potential climbs should be as closely aligned as possible, otherwise a *route deviation* for the first one may consume the height needed for reaching the second one. Also, both climbs should be as close to the *route line* as possible. The second one can be a little further away, as it is a backup for the first one, so it shouldn't cause a *route deviation* penalty, if finding the first climbs goes well.

Here comes another tip: **the backup option could be less efficient**, even further away from *route line*, but not too inefficient, like flying back.

Of course, there are always exceptions. Cross country flying with a tailwind is easy and fast, not only because of fast ground speeds and high glide ratio, but because the smaller height loss during glides makes us arrive higher - at a stronger part of the next lift. Also, the tilting of thermals by the wind makes the next downwind lift closer, than the next upwind lift.

On the contrary, flying into headwind is difficult and slow, not only because of slow ground speed and poor glide ratio, but because of the significant height loss between thermals, which make us arrive too low, at a weaker and unreliable part of the next lift.

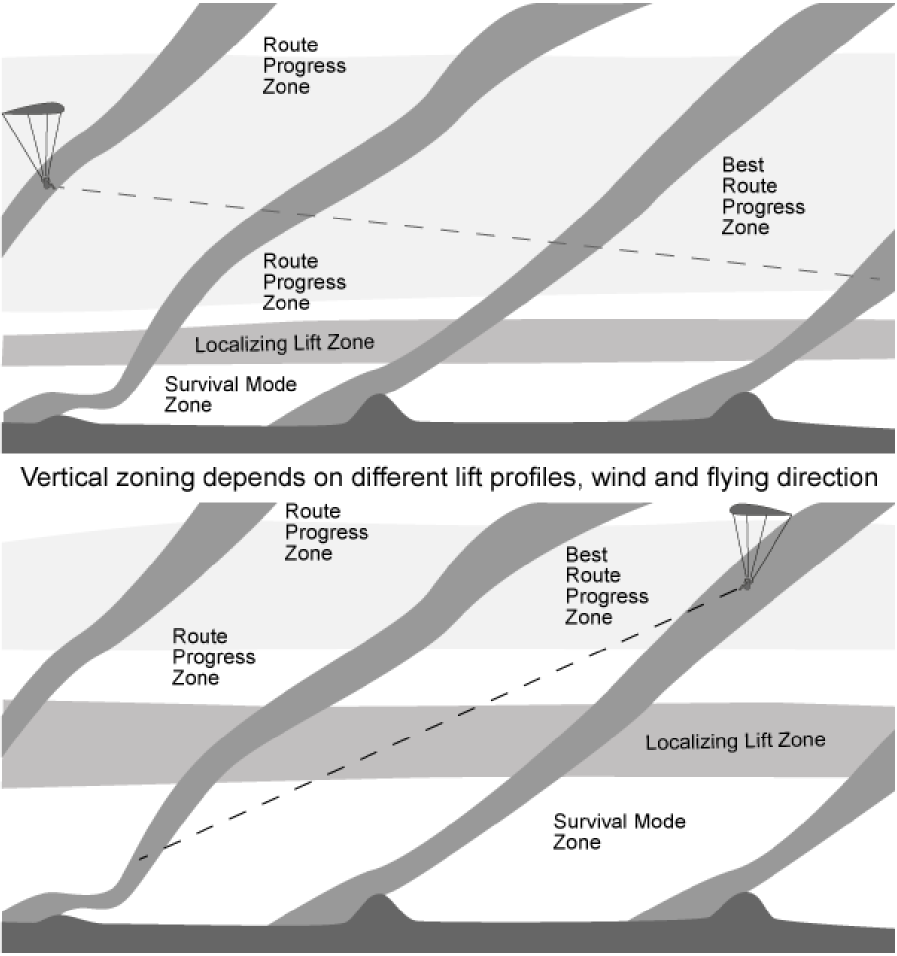


In headwind cross country flying, there is no subsequent lift as a backup! The only option is flying back to the lift we just left. It's very frustrating to get stuck against strong wind and weak drifted/tilted thermals. Climbing, drifting back, gliding against the wind, losing a lot of height, returning back to the same lift to avoid bomb-out, climbing again etc. Cycling like in a washing machine! In some conditions, only high-performance competition wings can break the vicious circle with their high glide ratio at high airspeeds. But sometimes, even they're helpless.

The best cure for *headwind cycling* is prevention:
Avoid areas with a stronger headwind and weaker thermals.

Despite strong wind, route progress may continue by hiding in the lee of obstacles or strong thermals, by using cloud streets, or going to the 2nd floor if the conditions there are more favorable, etc.

There are different *vertical zonings*, depending on lift profiles, wind and our cross-country flying direction.



Vertical zoning depends on different lift profiles, wind and flying direction

When flying against the wind, some pilots notice that they have more thermals to work with. Of course, the upwind progress is slow, but isn't it strange to encounter thermals more frequently? If you look at the last two pictures, you can see that, when flying against the wind, the gliding trajectory is closer to the thermal's trajectory. So, if you approach a hill, or any other thermal trigger, then you first encounter some of the old bubbles it has released. You may use them and continue upwind, encountering a younger bubble. You gain some height and push further against the wind. You lose height, but manage to reach the thermal trigger, where you find the latest thermal triggered from it. You take the lift, but also the drift and finish your climb somewhere behind the trigger point. The perception of having more thermals while flying against the wind is false. You really work with more thermals, but this is just in the vicinity of the same thermal trigger. A 50 km distance has exactly the same number of thermals, no matter if it's flown with or against the wind. Upwind cross country flying requires to spend more time in thermals than downwind flying, during which a few can be skipped due to the improved glide ratio and ground speed.

At higher altitudes, pilots often encounter wider areas of lift with less sink in between. Thermals expand with height, due to a decrease in surrounding pressure, but it's not enough to explain these high wide zones of lift. It might be because *high makes you free*. Once disconnected from the ground, thermals break their chains and are free to align with the wind and unite with other thermals. Also, the natural expansion of thermals with height makes their inner air more uniform and easier to merge with other types of lift. Height promotes similarity. Similarity promotes unity. Unity makes strength.

High, wide lift with weak sink in between may set a new vertical zoning and speed to fly. Climb strength may become a secondary factor, compared to the benefits of long flying within a height band with wide lift and weak sink.

The vertical profile of *sink distribution* is also a determining factor for vertical zoning and speed to fly, as well as lift and wind.

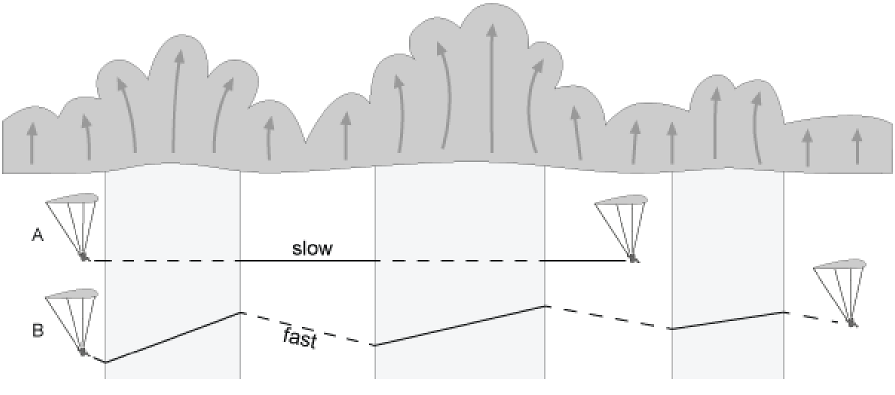
THINK BIG! CLOUD STREETS

Fast cross country flying is also achieved by using single large-scale lift, like convergence, lift streets and cloud suck, instead of the time-consuming work with many individual thermals. The abundance of lift saves us time while making some distance along the route line.

Lifty lines form downwind from obstacles or form parallel to terrain ridges, slopes or mountain ranges. According to the wind direction, they're usually:
- Along the wind (*convergence behind a conical hill*)
- Perpendicular to the wind (*wave*)
- At a 40-60° angle (*V shape wake behind an obstacle*)

When flying under a cloud street, or a cloud mass with live and dead cells, we can use *dolphin flying* under it, by **slowing in lift and speeding up in sink** or weaker lift.

Every use of big ears to escape cloud suck is a loss which indicates bad thermal exit timing. Using full speed bar for escaping cloud suck can also be a loss too, because the wing's force is working partly downward, against the flow coming from below, at the expense of the rest, which adds to cross country speed. This inefficiency is even more noticeable when there is also a headwind.



Pilot **B** is ***dolphining*** - slowing down in stronger lift and speeding up in weaker lift or sink. Pilot **A** is trying to keep the same altitude and distance from the cloud, so he needs to apply speed bar to descent, where lift is stronger and fly slower, where lift is weaker. His XC speed is slower, because he flies against the basic rule in XC: fly slow in lift and fast in sink!

During our trajectory's ups and downs, we should monitor our average trajectory and check if we gain height and get closer to the cloud, or we gradually lose height.

Dolphin flying can be combined with additional thermalling if:

- We gradually lose height;
- We're approaching the end of the cloud street and next lift is too far, or there is a blue hole ahead;
- There are signs of cloud street deterioration or interruptions;
- We've encountered a distinct better lift than what's been typical under the cloud street.

In zones of better lift, the pilot can gain extra height with a few swift S-turns, instead of time-consuming circling, where half of the turn is returning back from the route direction.

S-turning is also used when flying against the wind, and when working tilted thermals, trying to stay at their strongest upwind side and avoiding being drifted downwind. Birds often soar isolated thermals with a few S-turns, instead of full circles.

Cloud street soaring might be a combination of straight dolphin flying, S-turns and full circles.

There is an optimal height when flying under a cloud street.

If we're too high, we'll waste time fighting cloud suck.

If we're too low, we still might be in constant cloud street lift, but we're too slow – we cannot afford to speed up fully when lift weakens and we also have to stop and circle to climb more often. Losing our speed-range weapon makes us vulnerable and inefficient.

At the end of the cloud street, need for speed gives way to need for height. Concentrated areas of lift like cloud streets are often surrounded by concentrated areas of sink, so we should leave the cloud street at maximum height to prepare for the likely long transitions and heavy sink afterwards.

During dolphin flying, we consider not only lift strength but also its size and distance from the route line, and the wind too.

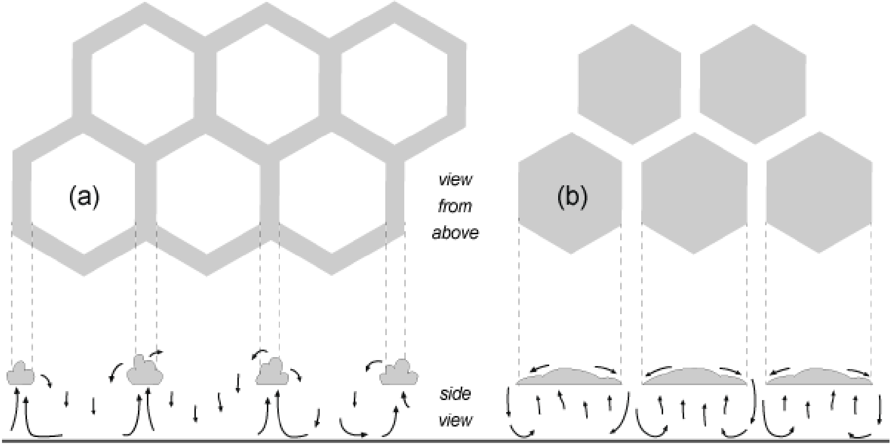
The dolphin flying technique can be applied on a micro scale for optimizing glides during route progress stages.

LIFT AND SINK DISTRIBUTION

A common practical rule says that the distance between thermals is 2.5 times their height. This is valid for a uniform terrain, but even in the flatlands there is an irregular lift distribution along the route line.

The more difficult is the question about the thermal's distribution in space. During his studies of convection, the French physicist Henri Benard found hexagonal distribution of rising fluid over a heated plate. No matter how uniform is the plate; there is always a zone which is warmer than its surroundings. It gives its heat to the fluid it contacts with. This creates a rising flow, which upward motion is compensated by a surrounding sinking flow. The most natural and uninterrupted link between lift and sink is the toroid circulation, similar to the rising of atomic mushroom. Thus, sink encircles and forms ring-like circulation around the lift which causes it.

When there are many rising currents above a heated plate surrounded by rings of sink, then the most efficient usage of space is when the mesh of rings turns into mesh of hexagons, similar to the beehive cells. Thus, the simplest distribution is a mesh of lift in the middle of the cells and the compensating sink at the hexagon walls. These are the so called **closed cells**. The satellite images of cloud distribution of cold air advection over a warm sea reveal the opposite case of the so called **open cells**, where clouds (*lift*) are at the hexagon walls with blue sky and sink in the middle.



Hexagonal lift and sink distribution: Open (a) and closed (b) convection cells

The satellite images also show the simultaneous existence of two neighboring zones of *open* and *closed cells*. Both occur after a cold front, but the *open cells* are further north (*in the Northern hemisphere*), where instability is higher and convection is deeper (*stronger thermals which rise higher, including their cloudy parts*). The strongest cloud development is at hexagon corners where the circulations of 3 neighboring cells meet. There are clearly defined cloudless blue holes at the centers of the hexagons – a sign of concentrated sink.

The *closed cells* are observed further south where the vertical temperature gradient is weaker, the convection boundary layers is shallower, and a there is a wide cloud layer with hexagonal contours of sink cut through which surrounds the cloudy zones of instability and lift.

One of the explanations for the simultaneous existence of completely opposite hexagonal circulations is that the *open cells* area is closer to the cold front effect with the pronounced descending airmass behind, while *closed cells* are observed more within an ascending airmass further away. At first glance there is a contradiction: how updrafts in *open cells* are stronger and rise higher within a descending airmass? The airmass speed of descent is times slower than speed of thermal's rise and its main role is toward a general airmass stabilization, which leads to concentration and individualizing of updrafts, driven by a strong temperature gradient. The general airmass ascent observed near *closed cells* leads toward an airmass destabilization (*everything wants to go upward*), despite the weaker temperature gradient. That's why updrafts occupy the wider area inside the hexagons and sink concentrates at their walls. The overall destabilizing of a shallower convective boundary layer creates cloud layer with instability areas, instead of concentrated clouds with high vertical development.

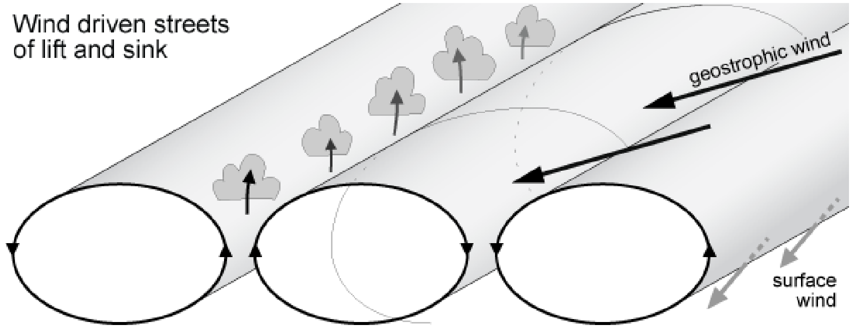
Another approach toward solving the simultaneous existence of *open* and *closed cells* goes through the question: Which is first – the egg or the chicken? The lift or the sink?

As *open cells* are closer to the cold front effect and the following cold air advection, then it is possible that the initial engine of cell convection is cold downdrafts, which fall toward the warm water surface. The airmass instability means both updrafts and downdrafts. Thus, the overall sinking airmass promotes wide downdraft zones which toroidally push surrounding warm air upward, along hexagon walls. Imagine an atomic mushroom which grows downward, similar to mammatus clouds. And the opposite – in the *closed cells* case, the initial circulation engine is the lift, compensated by the sink along the hexagon walls.

The analysis of *open* and *closed cells* should also include the latent heat of liquid-gas phase transitions of water. In open cells, updrafts are concentrated at hexagon walls and the release of heat from condensation enhances vertical development. In closed cells, the wide spread updrafts also release heat during condensation, but because updrafts occupy a wide zone inside the hexagon this extra energy goes mainly for sustaining cloud's life and horizontal overdevelopment, instead of vertical overdevelopment. The cold air production by evaporation from cloud's surface enhances sink at hexagon's walls in closed cells or concentrates in the middle of hexagon in the case of open cells.

The terrain we fly over is never flat, uniform and featureless. In cross-country paragliding, we rarely see a hexagonal distribution of lift and sink, but we should still keep it in mind when other logic doesn't work. It is possible to have a semi stable air layer close to the ground, which is less affected by terrain's thermal sources and triggers. Then, the entire ground layer becomes a thermal source and at a certain altitude there is a spontaneous formation and triggering of updrafts which may have hexagonal distribution. Similar effect is noticed in windy days after a cold front, when ground layer is so mixed by the turbulence, that the separate thermal sources don't work independently, but heat the entire ground layer of air.

In windy days ***wind lift streets*** may form. The ground surface friction of the moving airmass reduces the Coriolis effect from the Earth's rotation and forms a specific wind gradient – a wind veering or turning of wind direction with height. Air particles don't move linearly carried by the wind, but along a prolonged spiral trajectory (*Ekman spiral*). Thus wind creates cylindrical circulations with lifting and sinking parts. Wind driven lift streets might be further enhanced by airmass instability.



CROSS COUNTRY FLIGHT ANALYSIS

Premature landings, or *bomb-outs*, are often commented by pilots like "I should have climbed a little more in the last thermal", "my mistake was that I didn't check for another climb there", "the thermal cycle came later", "my landing triggered the thermal for others following behind", etc.

The painful puzzling of bombing-out, while others continue flying happily above can be solved with one word – learning. You may lose the battle, but still can win the war, if you learn more than others. A short flight might be more educational than a long one if you chase knowledge, not kilometers or rankings. It's a long-term gain; a life-long race.

Don't be afraid to make mistakes, to check this or that. In science, there is no experiment with a negative outcome if the result is knowledge. Don't just follow classic routes, but draw your own. Fly as many different places and conditions as possible, and you'll see the same universal principles of Nature everywhere.

Improving in cross country flying doesn't come just from flying or reading theories. They should be combined with good *post flight analysis*.

A good flight analysis needs a good set of criteria.

What was the goal of the flight? - Never fly without a goal!

Did cross country sub stages like *route progress*, *search for lift* and *climb in lift* meet their specific goals? Were they combined efficiently for achieving fast average cross country speed?

Additionally, flight analysis improves our understanding of cross country weather. Paragliding is the best and the cheapest way to understand micrometeorology - better than most professional meteorologists or commercial airline pilots.

Were the soaring conditions like the forecasted one? Did they match the theory? Were they evolving smoothly during the day? Where there any surprises or interesting meteorological phenomena?

Modern technologies, like smart phone GPS live tracking, are good not only for pilot's safety, but also for extracting flight's parameters from the paraglider's position change:

- *Horizontal Ground Speed* (V_x);
- *Vertical Ground Speed* (V_y);
- *Altitude* (h);
- *Time Duration of Flight* (t_{max});
- *Type of Flight* – Open Distance, Out and Return, Triangle;
- *Linear Distance* between start and end ($S_{l\ xc}$);
- *Route Distance* ($S_{r\ xc}$). Total distance via turn points in case of O*ut and Return* or T*riangle* flights;
- *Cross Country Speed* (V_{xc}).

There are even more flight statistics extracted, just from recording flight positions in space like Total Height Gain, Number of Climbs, Maximum Ground Speed, Maximum Vertical Speed, Maximum Sink, Maximum and Minimum Altitude, etc.

So, what can we do with all this information? How can we improve our flying with it?

Flight parameters and statistics are used in two interconnected directions – *piloting* and *weather evaluation*.

Weather evaluation is important for pilot's improvement. Even pilots, who cannot go flying, can still make a forecast for a given day and compare it with the information delivered through other pilots' flights. There is a lot of learning, just by watching the sky or flights of others.

Was the cloud base height as forecasted? Was the day with strong thermals? Were the flatlands working? Was there a convergence? Etc.

An accurate weather evaluation can be derived from tracklogs of good pilots with a predictable behavior.

Piloting evaluation is difficult to be separated from *weather evaluation*. Did someone climbed that high and flew that far because he is a good pilot or because conditions were good for cross country? The best pilot evaluation is when it's based on comparison with nearby pilots, like in competitions, where pilots fly the same route at the same time. A less accurate pilot evaluation can be achieved by comparing a certain flight with flights of other pilots done in the past from the same site and along the same route - the case of site records. Or comparing a certain flight with the same site, route and pilot flights but done with different wings. In both competitions and in record chasing, the better pilots with better wings fly with higher average cross country speed V_{xc}.

High *Cross Country Speed* V_{xc} means that the pilot flew well during *route progress*, *search for lift* and *climb in lift* stages of a cross country flight, and also combined them efficiently. A crazy pilot can fly in crazy winds and achieve an impressive average cross country speed, but except big balls it doesn't prove that this pilot is better than others. That's why we have to compare tracklogs and extract answers like: What's the advantage of this pilot? Why? What's the mistake of the other pilot? Is it a single mistake, perhaps a bad luck, or there are series of mistakes of the same type?

Route Distance is an important indicator, as it shows pilot's consistency throughout different terrains and conditions. A gambling pilot can achieve high cross country speed for a while, but premature landing in the middle of nowhere is a sign of long-term mistakes, of a failure to reach a flight's goal or even lack of a goal.

Time Duration of a flight also reveals pilot's consistency and performance, despite his growing tiredness.

Type of Flight is important, because flying downwind is easy, with high cross country speed, but flying against the wind or with cross wind is much more difficult and slower. That's why Out and Return or Triangle flight distances are valued higher at online contests and rankings.

Launch Site, Route Line and Landing matter as some sites and routes are "experts only", because of difficult launch, house thermals, limited landings, turbulence, etc.

After examine of the above general flight parameters, the post-flight analysis can go into deeper details. Let's first remind the goals of cross country sub stages:

- *Route progress* - travelling longer distance along the route ($S_{route\ max}$) for minimum time ($t_{route\ min}$) with minimum height loss (Δh_{min});
- *Search for lift* - localizing next lift quickly ($t_{LL\ min}$);
- *Climb in lift* - climbing fast ($V_{y\ avg\ max}$);

Good pilots achieve higher *Cross Country Speeds* V_{xc}, because of:

- *Fast climbing*. Higher *Average* ($V_{y\ avg}$) and *Maximum* ($V_{y\ max}$) *Vertical Speeds* show that better pilots can extract more from a certain lift or from all climbs on average. In case of slow climbing, pilots should check their *Average Circle Time*. Good pilots usually circle tighter and quicker.

Inexperienced pilots lose lift and re-centre it more often. *Left or Right Circling Time* show if the pilot is flexible and can turn equally well to the left or to the right. Obviously, terrain, conditions and other pilots around restrict random circling directions but there is always an optimal circling direction when encountering a thermal;

- *Fast localizing of lift* - t_{LL} . Better pilots waste minimum time zigzagging and roaming, before steady circling and climbing, which can be clearly seen and extracted from a tracklog. Again, remember that *localizing lift* is a sub stage of long-lasting *search for lift* stage of cross country, so f*ast localizing of lift* is an indirect indicator of *search for lift* efficiency. Too much time spend in too many scan patterns might be due to difficult conditions, but also poor sensitivity, not knowing what the wing says, initially wrong search for lift decisions, or poor understanding and imagination of what lift looks like. Pilots search for lift all the time, during climbing and gliding. *Search for lif*t efficiency is indirectly evaluated through *Number of Climbs*, *Route Distance* and *Cross Country Speed*;
- Low *Average Descent* during glides ($V_{y\ avg\ gl}$) and *Maximum Sink* ($V_{y\ min}$) reveal the ability to use lifty lines and avoid sink;
- High *Average Glide Ratio* during glides ($GR_{avg\ gl}$) shows good *route progress* efficiency and small *route deviation* losses.

The efficiency of combining climbs and glides can be examined by the usage of *height bands*:

- *Height Band Margins:*
    - *Average Top Altitude* when leaving a climb*;*
    - *Average Bottom Altitude* when starting a climb*;*
    - *Average Route Progress Width*;
- *Vertical Speed Before Exiting Lift;*
- *Vertical Speed After Entering lift.*

When needed, good pilots can switch between wide or narrow, high or low *height bands*. This requires good *low saving* and *lift tracking* skills:

- *Maximum Altitude* (h_{max}) – good climbing and tracking skills help pilots follow weak and broken thermals through inversions. Good pilots can go higher, when needed, to expand their height band;
- *Number of Low Saves* under 300 m above terrain;
- *Average Height of Low Low Saves*. The *Lowest Save Height*. The lower the harder.

> A high number of very *low saves*, combined with high cross country speed, indicates good search for lift skills. Pilots, who're good at finding the next lift low, can afford longer glides and *height band flexibility* for their *speed to fly*. Pilots should regularly practice their *height band flexibility*, so they can naturally follow boundary layer daily evolution or adapt quickly to any change of conditions.

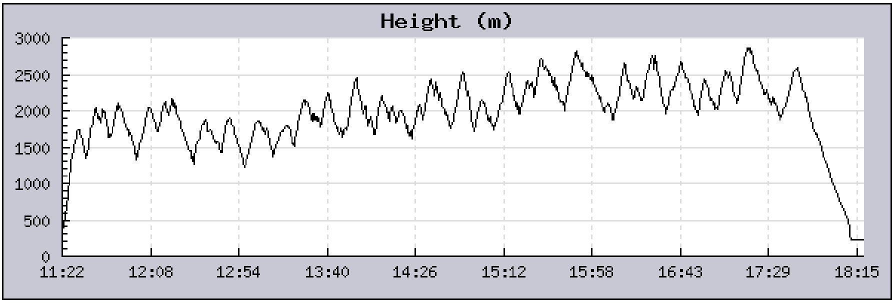
In future, more and more flight parameters and statistics will be extracted from flights' tracklogs. But they will probably have limited use about *piloting evaluation* as they may confuse and overload pilots with unclear digits, mathematical models and probabilities. More work needs to be done toward finding and selecting high-quality flight parameters, which can really help pilot's development. Be efficient when you try to improve efficiency!

The big potential of our flight tracklogs is toward *weather evaluation*. The flying characteristics of our wings are well known, so it's easy to extract horizontal and vertical wind speeds and identify air circulations. We can use temperature sensors to obtain the temperature atmosphere profile from our climbs. All these can be transmitted in real-time and go for improvements of weather forecasting models.

EXAMPLES

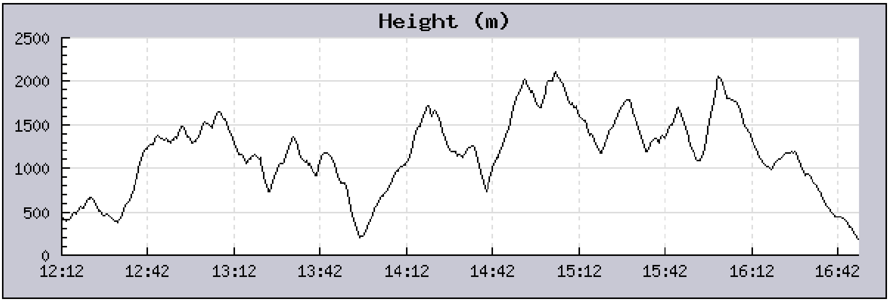
From Leonardo Fligh Data Base @ paraglidingforum.com

Glide ratio matters! Speed range matters! Aspect ratio matters!



A 560 km Out and Return flight with a glider plane with Vxc=81 km/h. The wide speed range allow for a very fast *route progress* between climbs. High glide ratio and long glides easing the finding of next thermal at higher altitude without excessive *route deviations*. The flying height band is mostly in the upper part of the boundary layer (*notice it's daily rise*), comfortably high above survival mode zone. Strongest climbs are also the highest one, probably helped by cloud suck.

Never give up!

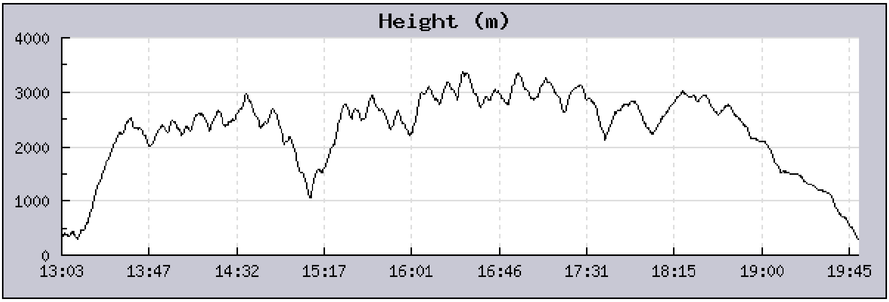


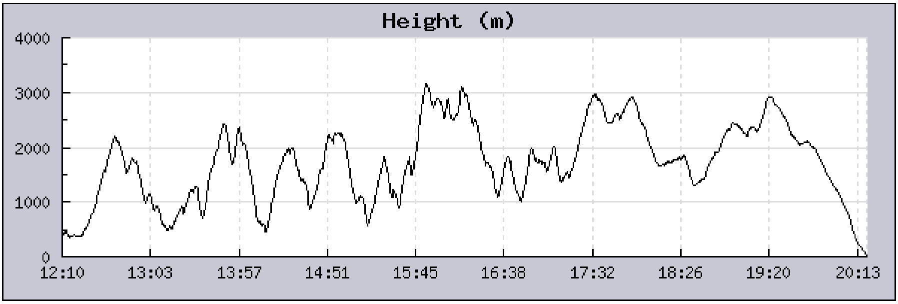
A 100 km Open Distance flight with a low save from only 14 meters above flat ground! Our wing span is about 11 meters. 14 meters are two paragliders above each other.

Switching to survival mode reduces average XC speed because low altitude climbs are weaker and time consuming and because search for lift often requires a route deviation. Also lower winds are often different than higher winds.

Still, never give up! Low saves are possible even during a landing approach.

Staying high doesn't give the best cross country speed V_{xc}!





These two Open Distance flights above are done in the same conditions and direction, starting from the same take off.

In the first one, the pilot flies conservatively slow by continuing to climb, even when lift weakens at altitude. For downwind flying with 25 km/h winds this is OK, as the pilot progress along the route, even when circling in weak lift. Often, there is less sink between climbs at high altitude. Staying high also helps avoiding survival mode bomb-out risks and time losses. He flies 250 km with V_{xc}=36 km/h.

On contrary, the second pilot leaves thermals when they weaken. On glide, he doesn't bother with weak lift, below a certain threshold value. He often risks going low, close to survival mode. But at the same time, he expands his route progress height band for fast long glides. This, combined with his good searching and climbing skills, makes him fly faster (*V_{xc}=44 km/h*) and longer (*350 km*). The second pilot is known for his appetite and aggressive style. He "eats" much more air, both horizontally and vertically, by faster gliding and climbing.

So, fast cross country flying means *cutting* through the air, not just *floating* in the air, using wind. Only a dead fish goes with the flow. "A carp was swimming against the stream. It swam and swam… until it became a dragon" – Chinese proverb.

CONCLUSION

Cross country paragliding can be both simple and complex. You can go with the flow and fly easy places and conditions, doing what others are doing. Later, you should hit the road and fly various places and conditions, discovering the same universal principles everywhere. And then, before becoming saturated from consuming this big big paragliding world, you can go deeper in the microcosmos of aerodynamics and meteorology. You can pioneer new places and cross country routes. You can test new flying prototypes and techniques. Or you can just humbly clean a take-off or a landing site, replace an old windsock, give lift, or support new pilots. Remember, that we can enjoy flying, not because of our hard-earned money spent on flying equipment and holidays, but because of all these dreamers before us.

This book attempts an analytical approach, where cross country flying is broken into *Route Progress*, *Search for Lift* and *Climb in Lift* stages and their substages. Classification of thermals, thermalling techniques, micro gains, horizontal and vertical zoning, speed to fly and post flight analyses are just the basics. There is still a lot of work to be done and a lot of flights to be flown to validate the theory. Let the Nature speak.

In the hierarchy of sports and human activities, cross country paragliding is somewhere at the top. It does not only feed your senses, but it gives lessons to our non-flying life. It makes you patient, observant, tolerant… Cross country teaches you efficiency, because we're dealing with limited resources. The same in life. How to play our cards the best possible way? Still, remember that sometimes we need to sacrifice the moment to win the future. Sometimes we need to abandon a tempting flow to gain a better position with more choices. Freedom always comes at a price. We need to play the efficiency game, without becoming cold machines. We need gains, which we can spend on pleasure, experiments, mistakes, and further knowledge. Then flying can become an art.

At the end, life and cross country flying are beautiful quests, where the way is more important, than the goal. Having a meaningful perspective is important for the comfort of the mind, but the way is what shapes us. The way is where we grow, where we live.

EXTRAS

INDUCTIVE ABILITY

The term *inductive ability* was first introduced by Nikolay Tsarov in 2008. It is used to describe paragliding aerodynamics.

General aviation aerodynamics deals with *lift*, *drag*, *thrust* and *weight* forces, but they cannot explain forward motion, stability and other important questions in paragliding and flying without an engine. Also, lift and drag don't exist in nature as independent forces. They are artificially invented by humans, for convenient understanding of principles of flight.

Every object, which moves through the air, interacts with it by creating a single force – the **aerodynamic force**.

Some call it the **resultant aerodynamic force (R)**, because it is considered as a sum of many small aerodynamic forces produces by different surfaces of a flying body. In nature, a body produces only one force with the environment which it interacts with. One body, one air, one force. One love.

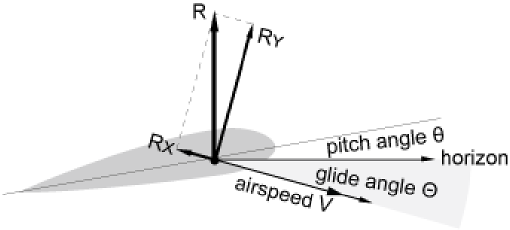
This force can be divided into whatever components we like. Depending on the pursued task, we chose a reference coordinate system for easier calculations, visual understanding, etc.

The most popular aerodynamic force components are *lift* and *drag components* in relative to the *speed coordinate system* (*OX is along the speed vector V, OY lays in aircraft's plane of symmetry and is perpendicular to OX, OZ is perpendicular to the plane of symmetry*). **Lift component** (R_y) is perpendicular to the airspeed vector V. **Drag component** (R_x) is in the opposite direction to airspeed vector. Lift and drag components are popular in classic aerodynamics, where a motor trust force T overcomes drag D, and moves the airplane through the air creating lift L, which overcomes downward weight force G.

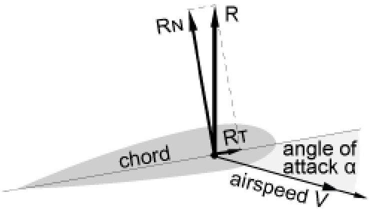
In gliding, where there is no motor, the thrust force, which moves the wing forward, is created by the wing itself. This contradicts the idea of an independent drag force from classic aerodynamics – how can a wing create a forward thrust force and a backward drag force at the same time?

Wing’s thrust force nature in gliding can be described by the **tangential component of aerodynamic force R_T**. As with seeing lift Ry and drag Rx components along the speed coordinate system, the aerodynamic force can be seen in a coordinate system in relative to wing’s surface. All forces, accelerations and velocities acting along the wing’s surface are called *tangential* and those acting perpendicularly to the wing’s surface are called *normal*.

Lift R_Y and drag R_X as components
of the full aerodynamical force R
in relative to the airflow (airspeed)



Tangential R_T and normal R_N components
of the full aerodynamical force R
in relative to the profile surface



The **inductive ability** is the wing’s ability to transform normal airspeed component (V_N) to tangential aerodynamic force component (R_T), or shortly said – normal speed to tangential force. Simply said, the inductive ability is transforming a flow coming from below, perpendicularly to wing’s surface, into a forward force and motion.

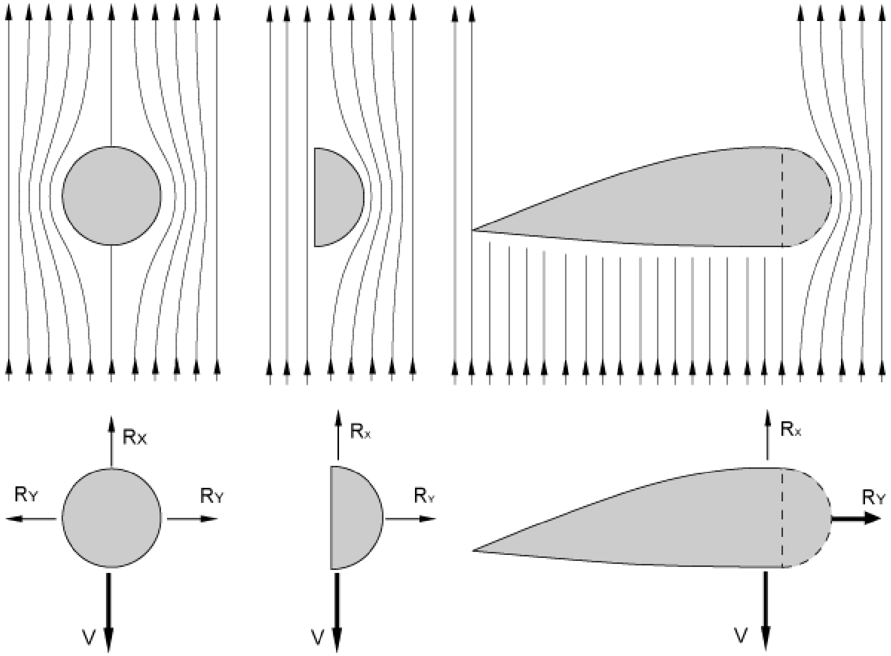
In physics, *induction* means “indirect influence”. Direct influence is when a body moves in the same direction as the force acting upon it. In paragliding, the gravity pulls the wing in one direction and it react by going in another, almost perpendicular direction.

This is how the inductive ability works:

If we place a body that has a circular symmetrical profile in an airflow, the acceleration of the flow around the sides will produce zones with decreased pressure and two self-balancing sideways forces: $R_{y\ left} = R_{y\ right}$.

If we put a body with an asymmetric semicircular profile, then the sideways force R_y will be unbalanced i.e. the downward motion will create a sideways force and motion.

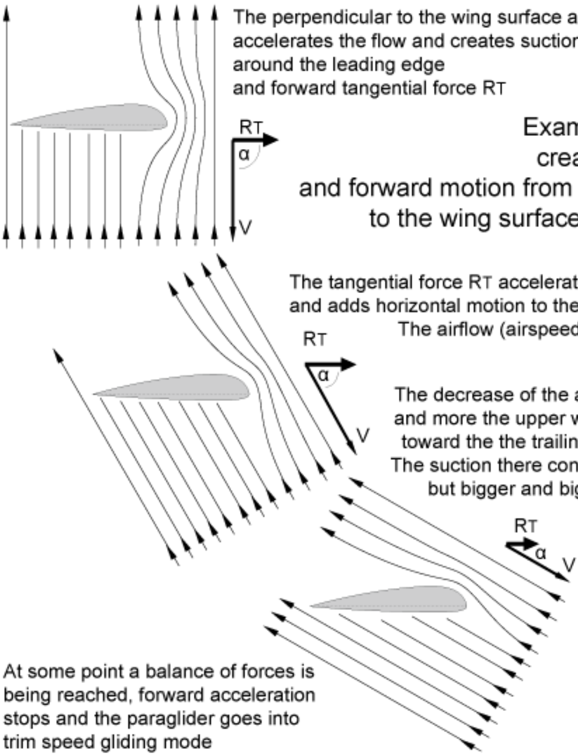
The same analogy is valid for a classic wing profile, where the roundness at the leading edge creates a “forward suction”.



Transformation of downward motion V into a sideways force RY

If we drop a paraglider in the air, it will accelerate downward by gravity. The airflow coming from below will create a suction around the roundness of the leading edge, which will accelerate the wing forward. The tangential force R_T (*tangential component of aerodynamic force*) will add a horizontal motion to the vertical fall. The initial 90° angle of attack will decrease, but due to the convex shape of the top surface after the leading edge (*camber*), there will be more accelerated flow and suction there. The tangential force will add more forward motion, which will further reduce the angle of attack, but will engage more and more the top surface adding an airflow from the nose toward the tail. At certain angle of attack, the tangential aerodynamic force component will start to decrease, but its normal component will continue to increase. The upward normal component, perpendicular to the wing's surface opposes the downward weight force and slows down the fall of the paraglider. At some moment a gliding flight balance is being reached:

Example of inductive ability: creation of tangential force and forward motion from normal (perpendicular) to the wing surface airspeed (component)



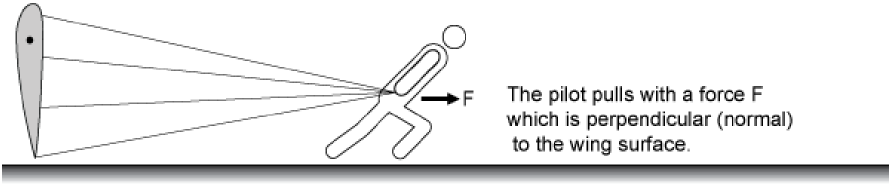
The perpendicular to the wing surface airspeed
accelerates the flow and creates suction
around the leading edge
and forward tangential force RT

The tangential force RT accelerates the wing horizontaly
and adds horizontal motion to the initial vertical descent.
The airflow (airspeed) changes its direction.

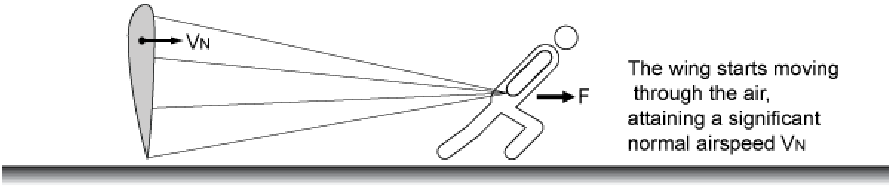
The decrease of the angle of attack engages more
and more the upper wing surface from the leading
toward the the trailing edge, accelerating the flow.
The suction there continues the forward force (RT)
but bigger and bigger part of the upper surface
works for lift production.

At some point a balance of forces is
being reached, forward acceleration
stops and the paraglider goes into
trim speed gliding mode

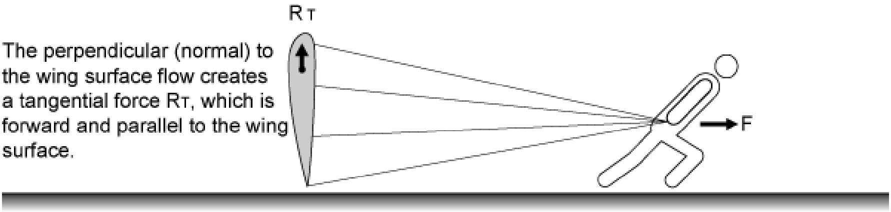
Another example of inductive ability shows that a forward, tangential to the wing surface, force and motion are created, even when the wing is not horizontal:



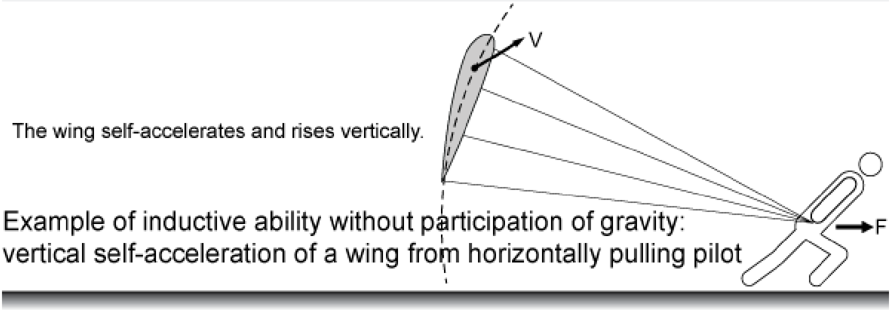
The pilot pulls with a force F which is perpendicular (normal) to the wing surface.



The wing starts moving through the air, attaining a significant normal airspeed V_N



The perpendicular (normal) to the wing surface flow creates a tangential force R_T, which is forward and parallel to the wing surface.



The wing self-accelerates and rises vertically.

Example of inductive ability without participation of gravity: vertical self-acceleration of a wing from horizontally pulling pilot

The inductive ability explains a lot in paragliding:

- Why a wing surges forward, when beginners sit prematurely and suddenly overload the wing on take-off, or when exiting a full stall, or when entering a thermal, or when taking off from a cliff, or D-bag;
- How a winch-driven pull force lifts the paraglider high;
- Spiral and tumbling auto rotations and other acrobatic manoeuvres;
- Paragliding stability and control.

The classic aerodynamics uses the experimental lift force formula:

$$\boldsymbol{R_y = \frac{\rho . V^2}{2} . S . c_y}$$

ρ – air density [kg/m^3] ,
V – airspeed [m/s] ,
S – wing surface area [m^2],
c_y – lift coefficient depending on the angle of attack at which airflow interacts with wing's profile

The other aerodynamic force components like R_x, R_T and R_N use the above formula, but with their own specific coefficient – c_x, c_T, c_N

Nikolay Tsarov has developed a method for transforming a speed polar curve (L/D, c_y/c_x) to a force polar curve (N/T, c_N/c_T).

From the speed polar curve of Advance/Sigma 8 27, the resultant force polar curve showed that $c_T < 0$ for $\alpha<6°$ and $c_T > 0$ for $\alpha>6°$. This means that the tangential component R_T is working backward, slowing the wing below $\alpha<6°$, and R_T is working forward as a thrust force for $\alpha>6°$.

> Nikolay Tsarov graduated as an avionics engineer at the Bulgarian Air Force School near Pleven, where he later worked as a teacher. His self-studies of aerodynamics and physics evolved to the complete theory of hang gliding and its practical implementation in designing and building of an award-winning moto hang glider. He wrote challenging the status quo papers about Energy, Gyroscope, Coriolis effect, Magnetic field, Electrostatic field, etc.
>
> His work in paragliding was not only an innovative description of aerodynamic theory, but also a practical test of ideas, by building various flying prototypes and instruments: The invertor, Two Directional Balanced Differential Control system, 3 sector wing, AoA and Sideslip indicator, angular speed sensor and indicator, instant airspeed meter, etc.

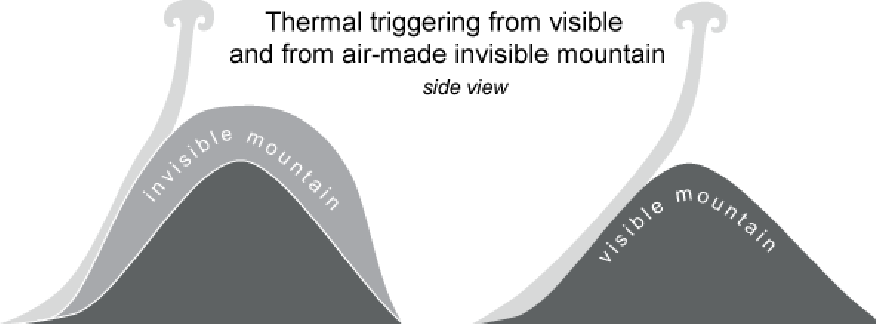
THE INVISIBLE MOUNTAIN

The idea about the *invisible mountain* came in 2008 during a night swim at Bayron Bay, after a daily trip to Nimbin, Australia:

„*I was trying to go inside and play with the breaking waves, but the mighty current didn't let me in. I explored the shore line to the left and to the right, and eventually succeeded, discovering and using an underwater terrain, carved in the sand bed by the ocean currents. My feet felt ridges and valleys which resembled the mountain slopes I fly at home, at Sopot. I realized that, as the fluid models the sandy terrain, the terrain also models the fluid*."

This gave me an instant answer to many old questions like "why a good slope doesn't always make good lift?", "why thermals sometimes rise far in front from the slope?", "why a thermal triggers at the base of a deep valley, where there should be only sink?", etc.

There is an invisible mountain, made of air, covering the visible terrain. The invisible mountain works like the visible solid mountain with winds, thermals, lee turbulence, etc.



The invisible mountain is a living creature, a child born from the flirt between Earth and Sky. The invisible mountain depends on:

- Terrain shape, size and skin (*friction*);
- Wind's strength, direction and profile (*wind gradient*);
- Atmospheric instability (*temperature gradient*);
- Sun's energy and angle.

There are several mechanisms for creating an invisible mountain. The most common is:

WIND AND TERRAIN INTERACTIONS

If you blow air into a cup, then you'll receive a quite strong counter blow, back into your face.

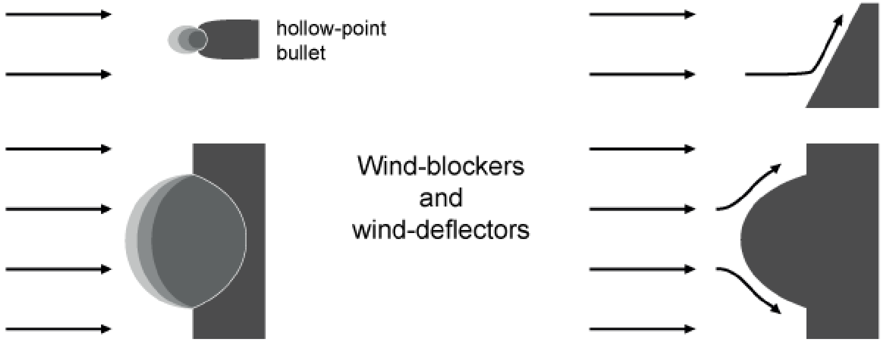
Alpha male pilots flying with pod harness, have developed an in-flight peeing technique, by standing up in the harness and opening its lower part against the flow. This creates an air bubble, which opposes the airspeed flow and allows the urine to go forward on a ballistic trajectory, keeping the pilot's legs and harness quite dry. This is an exception against the common rule "don't pee against the wind".

At high velocities, a hollow-point bullet creates a compressed air bubble in front of the projectile, which can do an explosion type of damage, when hitting someone.

The above examples show that a solid body or a terrain feature can significantly change the air flow upwind, not only the classic turbulence downwind behind. The better a terrain blocks the wind, the more it will contribute for the invisible mountain creation.

Apart from wind-blocking, the terrain also causes wind-deflecting effect. The wind-blocking pumps and inflates the invisible mountain, the wind-deflecting deforms its shape.

Good wind-blocking is done by surfaces, perpendicular to the wind direction, like steep mountain walls. Surfaces that are close to perpendicular to the wind direction work as ***wind-blockers***. The best wind-blockers are concave shapes or wind-captures like deep gullies. Surfaces, which are facing wind at a sharp angle, work more like ***wind-deflectors***.



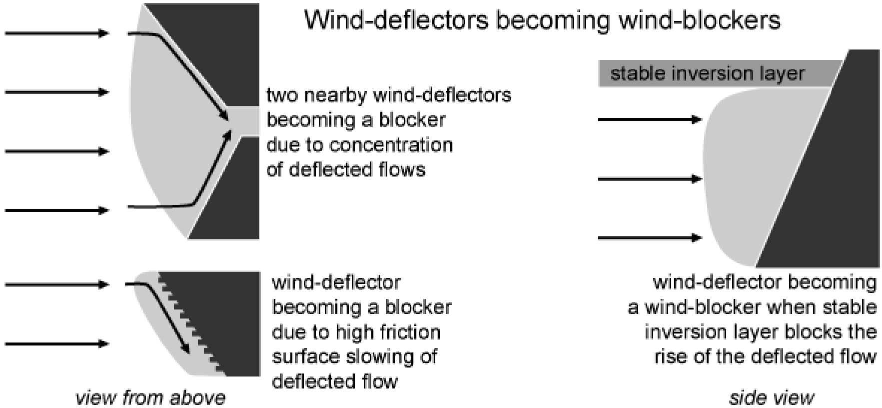
Protruding parts of terrain, which deflect wind in opposite directions act as ***wind-splitters***.

Two wind-deflectors can become a good wind-blocker, if their deflected flows interact with each other e.g., when are being concentrated in a small zone – a focus.

A single wind-deflecting surface can become a wind-blocker, when exposed to a flow with an asymmetric profile, like horizontal or vertical wind gradients.

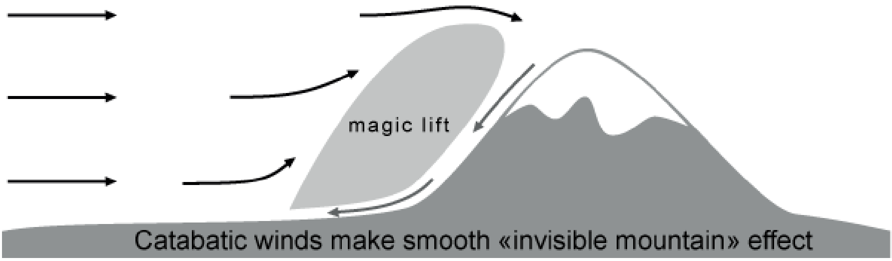
A single wind-deflecting surface can become a wind-blocker, when the deflected flow is being slowed down or turned by surface friction, from vegetation or terrain roughness.

A single upward wind-deflecting surface can become a wind-blocker, if a stable atmospheric layer (inversion) opposes the ascent of deflected flow. And vice versa – an atmospheric instability may increase the deflection effect and drain air out of the invisible mountain.



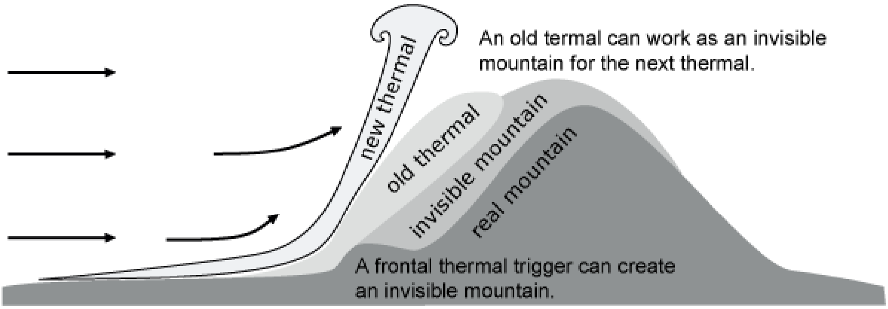
Wind-blockers might be enhanced by snowy or shady slopes, which produce cold air and a counter flow, against the main wind.

For example, in late summer afternoons, shady north-east facing slopes produce a catabatic flow, against the prevailing north-easterly wind, which like a cold front, crawls over the ground triggering lift upwind. This smooth and vast “magic lift” zone works like a mild wind-blocker.



Instability and vertical motions also participate in shaping the invisible mountain and its elements like wind-blockers.

For example, an isolated strong thermal, triggered in front of the main slope, also works like a wind-blocker, during its life span. The triggering might be due to a small hill in front of the big mountain, the upslope destabilization, catabatic winds or the invisible mountain "slope":



The invisible mountain can have a layered structure, like an onion.

The invisible mountain is thicker in front of wind-blockers and thinner in front of wind-deflectors and wind-splitters.

Taking off from wind-blocking parts of terrain, like the end of a valley, is not good because thermals are too far upwind ahead.

Taking off from wind-splitters, like protruding ridges, is better as it is closer to the thermals, rising along the invisible mountain surface. Also, taking off from protruding ridges provides better glide ratio and bigger area for searching for thermals and landing places.

Understanding the invisible mountain is important because:

- Thermals often trigger and follow its surface, well away from the solid mountain underneath;
- Surfing the invisible mountain surface gives better airspeed, manoeuvrability and glide ratio. You get more lift and landing options there;
- The invisible mountain explains why some zones are turbulent and some smoother.

> Kerio valley in Kenya is a classic example of the invisible mountain effects. The 1300 m steep bank of Rift Valley blocks well the prevailing easterly winds. This creates plenty of lift, with smooth sunrise ridge soaring conditions, which become turbulent at midday, due to the abrupt thermal triggering within the compressed onto the slope air. This "pillow" of compressed by strong winds air is the body of the invisible mountain. The smoothest and safest thermals are along its surface and further upwind. There are also thermals within the compressed air, which can be stronger than their buoyancy factor for their triggering, rise, deformations and turbulence. Thermal bodies are like the slippery soap which you try to squeeze in your hand. They can accelerate suddenly and stop suddenly, not only vertically, but also sideways. The very nature of compressed air promotes spontaneous and chaotic air movements. Thermal trajectories rarely follow the classic wind drift. Upwind checks are usually more productive than downwind checks. Going close to the slope often surprises you with sink and even back wind. The sink formation and distribution are also quite freaky. Sink shouldn't be seen just as a descending airmass, but more like an independent sink producing circulation, which with the help of surrounding headwinds can trap you and eat your height.

The invisible mountain constantly changes its shape due to thermal blocking, air stockpiling and draining. For example, the wind may fill a valley with air to the point of making an air bubble at its entry, which can even trigger a thermal there. Then, another thermal's rise at the end of the valley may drain air from it, transforming the valley from an air "bubble" to an air "hole".

There is a difference how anabatic and geostrophic winds shape the invisible mountain. Anabatic is more engaged with draining and inflating, while geostrophic wind's pushing into the terrain is the main factor for the blocking effects.

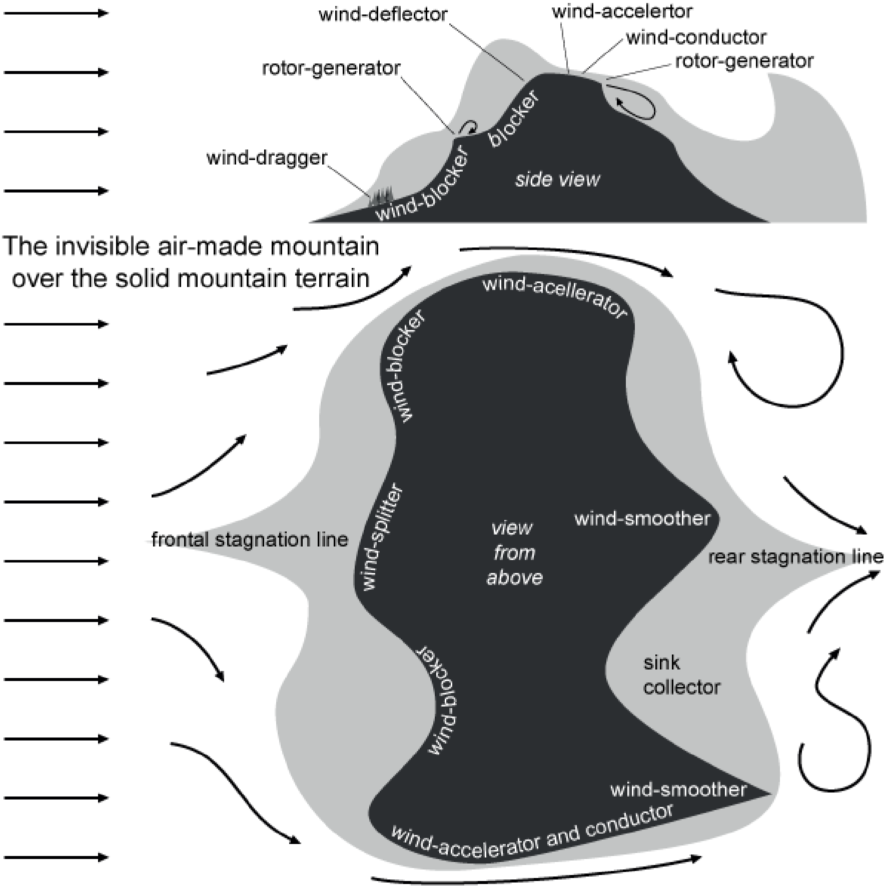
Solar heating and atmospheric instability influence the terrain's conductivity, deflection and blocking toward thinning or thickening of the invisible mountain.

The combination and the dimensions of terrain blockers, deflectors, splitters, air pillows, thermals, clouds, etc., also determine the size and shape of the invisible mountain.

The invisible mountain doesn't necessarily need a solid physical mountain, to be built over it. Cold frontal surfaces, terrain-like inversion layers with smooth hills and depressions, clouds and thermals can replace the solid mountains with their mass and inertia.

The most important parts, when evaluating an invisible mountain are:
- *Wind-blockers* like concave shapes, thickening the flesh of the invisible mountain;
- *Wind-deflectors* like convex shapes, thinning the invisible mountain;
- *Wind-accelerators* like the top or the sides of the original mountain, which accelerate the wind (*venturi*) and suck air from their surroundings and from above;
- *Wind-conductors* like low-friction naked surfaces, or cold snowy or shady slopes. Water surfaces like lakes, big rivers or seas are classic wind conductors, because of their low mechanical and convective (*thermal*) friction. Wind-conductors are areas, which don't resist or transform wind flow, but help it keep its properties;
- *Wind-feeders* – vast surfaces which feed and expand the flow by warming it for thermals and anabatic winds or cooling it for sink and catabatic winds;
- *Wind-draggers* like rough, high-friction surfaces;
- *Wind-splitters* like ridges and convex shapes;
- *Frontal stagnation line*. Unlike local wind-splitters, the frontal stagnation line splits the flow for the entire original mountain. The frontal stagnation line (*zone*) not only splits the flow, but also has the slowest winds. It can be considered as a general wind blocker, compared to local wind blockers from separate concave shapes. The frontal stagnation line is often a thermal trigger. It also provides the weakest winds for safe landing, when wind elsewhere becomes too strong. Still, keep in mind that individual wind-blockers, splitters and the frontal stagnation line can produce variable and even back winds. They should be avoided for landing, if steady wind direction is more important than low wind strength;

- *Rear stagnation line*, where flow meets again after being split by the entire original mountain. Meeting flows form a convergence, so it’s a good place to search for thermals, but beware of changeable winds and turbulence;
- *Wind-smothers*. Lee side terrain protrusions, which create, promote and direct isolated streams that smooth out the turbulent lee side air. Wind-smoothers work like a comb for the messy turbulent lee side air. Narrow valleys which channel the wind are also “combing” the turbulent air by their uniform streams of air;
- *Sink-collectors* like lee side deep wide valleys;
- *Rotor-generators* like sharp edges.



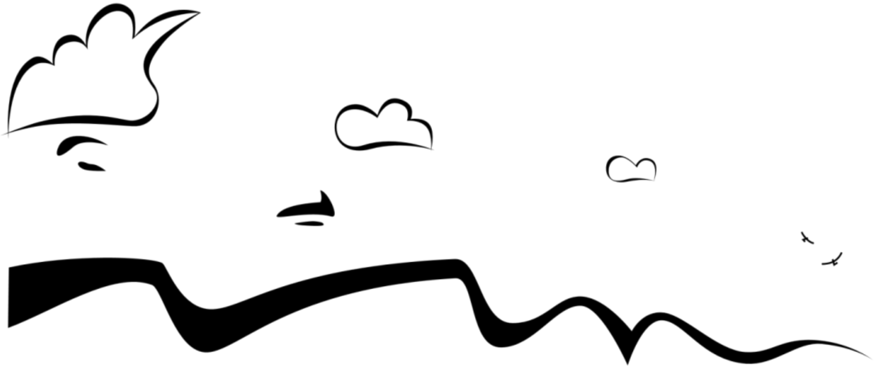
The frontal and rear stagnation lines of a mountain can stretch for many kilometers upwind and downwind. They can promote convergences and other types of lift, but even sensing them is a valuable information about how a mountain interacts with the wind.

Apart from the main stagnation lines of the entire object, there are local *mini stagnation lines*, due to terrain irregularities. The frontal ones are useful when searching for lift or take off. The rear ones are useful for lee flying, when searching for lift or just escaping bad sink and turbulence.

Wing profiles are very sensitive to the angle of attack. Even a 1º change immediately changes lift force and airflow picture around the wing. Wing profiles have pretty smooth and streamlined shapes. From the other side, mountains have more complex shapes and are even more sensitive about changes of wind direction and speed.

The invisible mountain concept is vitally important for the most difficult form of cross country paragliding – *vol bivouac* mountain flying, with its enormous variety of take offs and top landings. *Vol biv* is travelling through a mountain terrain by series of flights and bivouacs. This is the ultimate freedom in flying – just you, your wing and the mountain.

Being a skynomad is being a child of Earth and Sky. You learn their powers and elements, their quarrels and love affairs. In order to survive and grow up, you need to see the Invisible Mountain. Merge with her and more secrets will come. The mountain belongs to the one who loves her, not to the one who tries to control. The more you love her, the more she'll give you. And perhaps, one day you may realize that you don't need a wing, because all these years have taught your thoughts to fly.



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