About the Instant Cross-country Speed

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Abstract

The instant cross-country-speed of gliders is defined and a formula given which is discussed in detail, explaining for instance why the classical theory is failing to provide suitable instantaneous results, why the instant cross-country speed may be regarded to be the shadow speed of the glider if the sun rays are inclined in the right manner and the shadow is cast on flat ground, or how energy is gained and transformed into cross-country speed. Igc-files of two flights are evaluated to test the formula, showing promising results suggesting its implementing into modern flight computers for the purpose of helping pilots to improve their cross-country-speed and flying performance.

Introduction

The average or cross-country speed is one of the most important entities in soaring: it determines the pilot's performance on his cross-country flight. Normally, it is the flown distance divided by the elapsed time. But, for small distances and times such as minutes or seconds this simple calculation doesn't work, it fails to provide the so called *instan*t cross-country speed with the side effect that pilots just do not know how fast they are really advancing at the moment – if, for instance, they spiral up to the cloud base at 5 m/sec or head to the next updraft with 200 km/h or if they have to deviate from the course line to catch a better thermal. Pilots would certainly appreciate any immediate feedback about the instant situation and its influence on the xc-speed.

Therefore, it is the intention of the paper to define and find the formula of the instant xc-speed which is able to display the instant proceeding of the glider. According to some considerations [4-7] and Fig. 1, this might be the instant speed of a virtual vehicle moving along the reference line from start to finish, reflecting in a suitable manner the glider's advancing.

Classical Theory

Let's see if the classical theory is able to provide said instant xc-speed or not. As the classical theory [1-3] is well known we restrict ourselves to essential issues only.

We start with the *basic xc-model* which considers a single glide/climb sequence shown in Fig. 2. For *constant* or *average* values of the speeds (with V = gliding speed, airsink = sink rate of the air, Vs = Vs(V) = polar sink rate of the glider, Vario = value of the vario during gliding = -(Vs + airsink), M = rate of climb in the thermal (m/s) or MacCready setting), the overall cross-country speed Vxc, achieved *at the end* of the sequence, is given by the formula:

$$Vxc = V*M / (M + Vs + airsink) = V*M / (M - Vario) \quad (1)$$

We note that Eq. (1) is only valid for negative vario values during gliding (Vario < 0). Vxc will be a maximum if the pilot flies with the best-speed-to-fly V_{opt} which can be found by the famous "*tangent construction*" (Fig. 3) or for $V = V_{opt}$ by the equation:

$$dVs(V) /dV = (M + airsink +Vs) /V = (M – Vario)/V \quad (2)$$

Normally, the sink rate of the air is *not constant* along the gliding path. Most assume, in this case, Eqs. (1, 2) and Fig. 3 to be valid also for the instant values of the parameters. But this is not self-evident as we will see in the following. To find the best-speed-to-fly in this case (see Fig. 4), we divide the gliding path in as many parts (X_i, with i = 1, 2, 3…n) as there are different values of the sink rate of the air ($airsink_i$) and the vario ($Vario_i$) at the gliding speed (V_i). Additionally, we create a *virtual* glider which at the end of each gliding part is climbing back to the reference line by a virtual thermal with M, the same climb rate the real glider is achieving in the real thermal at the end of the gliding path.

Analogue to Eq. (1, 2) and Fig. 3, the cross-country speed Vxc_i and the best-speed-to-fly $V_{opt\ i}$ of the *virtual* glider in each gliding part X_i is given by:

$$Vxc_i = V_i*M / (M - Vario_i) \quad (3)$$
$$dVs(V_i) / dV_i = (M - Vario_i) / V_i \quad (4)$$

Without going into details, the overall xc-speed Vxc of the real and virtual glider is the same and will be a maximum if the pilot is flying in each gliding part with the best-speed-to-fly of the *virtual* glider according to Eq. (4).

Now, because Eq. (3, 4) relate to the *virtual* glider, they can be used to find the best speed-to-fly also for *positive* values of $Vario_i$. However, the *virtual* glider will show in this case some remarkable features (see Fig. 4b). It will rise above the reference line and then, at the end of the gliding part, will spiral down in the virtual thermal back to the reference line. Of course, the coming *down* in an *up*draft is only possible for a virtual glider which is able to reverse the flow of time (a feature which we call "paranormal") - and to achieve by that a negative

(!) virtual thermalling time. This symbolizes the amount of time the achieved height gain in the gliding part X_i will reduce the total thermalling time of the real glider. The negative thermalling time of the virtual glider (for $Vario_i > 0$) has the effect that the xc-speed Vxc_i of the *virtual* glider will show now "paranormal" high values.

Example: if the glider climbs with M in straight flight, then the xc-speed of the virtual glider (according to Eq. (3)) will be *infinite* (e.g. $Vario_i = M$, $Vxc_i = V_i *M / (M – M) = V_i *M/0 = +/- \infty$), and if the glider climbs in straight flight faster than with M, then the xc-speed of the virtual glider will be even *negative* ($Vario_i > M$, $Vxc_i = V_i *M /(M – Vario_i) < 0$). This indicates that - as the glider is still moving forward in the positive direction – it is now moving in the opposite direction of time – from present into the past - achieving by this the negative elapsed time and negative xc-speed (*remark*: -speed = distance/-time). The virtual glider in this case is something like a time machine. If you would sit in such a glider the pointers of your watch would move in the anti-clock wise direction. You would get younger.

An additional *example* (Fig. 5) may demonstrate this feature. The real glider in this example is thermalling with M = 2 m/s, but climbs in the second gliding section in straight flight with $Vario_2$ = 3 m/s. Therefore, according to Eq. (3), the corresponding virtual glider moves in the second gliding section with the "paranormal" xc-speed $V'xc_2$ of minus (!) 160 km/h, passing by that the second gliding section of 10 km within a time of minus (!) 4 minutes and 45 seconds to achieve at the end of the flight the same overall xc-speed as the real glider of 126 km/h.

These examples show that Eq. (4) is able to provide the best-speed-to-fly if the glider is gaining height in straight flight ($Vario_i > 0$), but that the corresponding xc-speed Vxc_i of Eq. (3) will show "paranormal" speeds which our little human mind is not able to understand. A device which would display such xc-speeds to the pilot would be confusing.

The next step in our analysis is to increase the numbers of gliding parts of Fig. 4 to infinity ($i = 1, 2, 3… \infty$) shrinking the gliding parts and the virtual thermals to an infinitesimal small size (Fig. 6). This has the effect that the virtual glider now will move completely on the reference line. In addition to that we introduce the elapsed time t which enables the study of the movement of the real and virtual glider as a function of the time t. This finally turns the xc-model of Fig. 4 into the xc-model of Fig. 6 in which the discrete values of the speeds Vxc_i, V_i, Vs_i, $Vario_i$, $airsink_i$, are replaced by the corresponding instant values V'xc(t), V(t), Vs(t), airsink(t) at the position x(t), transforming Eqs. (3, 4) of the *virtual* glider into:

$$V'xc(t) = V(t)*M / (M – Vario(t)) \qquad (5)$$

$$dVs(t) /dV(t) = (M – Vario(t)) / V(t) \qquad (6)$$

V'xc(t) of Eq. (5) is now the instant xc-speed of the *virtual* glider at the position x(t) of the real glider (see Fig. 6). Eq. (6) enables calculation of the best speed-to-fly which is optimizing V'xc(t). Historically, Eq. (6) had been used to invent the MacCready ring and the modern speed-to-fly variometers.

Now, as V'xc(t) is regarded to be the instant xc-speed according to the classical theory[3], we want to know if it would be able to fulfill our set requirements. Unfortunately this is not the case, for the following reasons:

1) V'xc(t) according to Eq. (5) provides values of the instant xc-speed only during gliding and not during thermalling (as the climb rate is set to M) - in the same manner as the MacCready ring is only able to display the best-speed-to-fly during gliding and not during thermalling.

2) V'xc(t) will achieve "paranormal" values for positive vario values during gliding (Vario(t) > 0), a problem which we have discussed already in length (see Figs. 4b, 5).

3) There is another reason why the instant xc-speed of the *virtual* glider of the speed-to-fly theory cannot be used as the instant xc-speed of the *real* glider. We know from the foregoing considerations that the virtual and real gliders of Fig. 4 and Fig. 6 start and finish the flight at the same time. But, what happens in between? The real glider of Fig. 6 moves forward with the gliding speed V(t) whereas the virtual glider is moving on the reference line with the instant xc-speed which is normally less than the gliding speed V(t). Therefore, at the time t the virtual glider will be not at the position x(t) of the real glider, but on a position which we denote by x"(t). At this position x"(t) the *real* glider had experienced some time ago the gliding speed V"(t) and vario signal Vario"(t) (see Fig. 6) and therefore (analogue to Eq. (5)) the xc-speed of the *virtual* glider (which is at the time t at the position x"(t) and not at x(t)) is given by :

$$V"xc(t) = M*V"(t) / (M – Vario"(t)) \qquad (7)$$

This tells us that the virtual and the real glider in Fig. 4 and Fig. 6 experience the same conditions (the same gliding speed and vario signal) at the same position, but not at the same time. In other words: *both gliders correlate with regard to position, but not with regard to time* – an additional feature which we must require from the virtual glider (namely the correlation with regard to time) if it shall be able to display the proper instant xc-speed of the real glider.

To sum up: The classical theory is successful with regard to the calculation of the *total* xc-speed Vxc and the instant xc-speed V'xc(t) showing an optimum at the *best-speed-to-fly*, but not with regard to the *instant xc-speed* of the glider which would be able to display the instant proceeding of the glider by "normal" speeds even at positive vario values during gliding.

Finding the proper instant cross-country speed

As the classical theory is not able to provide the wanted instant xc-speed, we have to go new ways.

To solve the problem we study again a simple flight (Fig. 7) comprising two gliding parts. In the first we assume the glider to proceed with the average xc-speed Vxc of Eq. (1) and in the second with a value of the instant xc-speed V'xc(t) of Eq. (5) (*Remark:* this model should be actually equivalent to the classical xc-model of Fig. 6). We assume also that in the second part the glider is gaining height in straight flight. We study now the movement of the real and virtual glider which start and finish the flight at the same time. From time to time the positions are linked by a line. According to the classical theory the virtual glider in each gliding part has to come back to the reference line first before it can move on to the next gliding part (see also Fig. 4). This has the effect that the virtual glider is moving from point 2' to 3' *far to slow* with respect to the advancing of the real glider and therefore, has to *expedite enormously* (with "paranormal" speeds) in the next gliding part from 3' to 4' to catch up again with the real glider. We would actually expect the virtual glider to move from point 2' to 4' with constant speed (see Fig. 8), in the same manner as the real glider is moving with constant speed from 2 to 4. In this case both gliders would experience at the same time the same conditions - which in other words would establish the above required *correlation with regard to time.* As the xc-model of Fig. 8 is simple and, hence, easy to calculate we get for the instant xc-speed Vxc(t) of the new virtual glider:

$$Vxc(t) = V(t) + Vario(t)*k \quad \text{with} \qquad (8)$$

$$k = [V / (M - Vario)] = Vxc / M \qquad (9)$$

In the first gliding part of Fig. 7 we had assumed that the *virtual* glider is moving along the reference line with the average speed of Vxc. After the flying time t the position x* of this glider is given by (see Fig. 9):

$$x^* = t*Vxc = (x/Vxc + h/M)Vxc = x + h(Vxc/M) \qquad (10)$$

x being the position of the real glider and h its height. We see that the height of the glider has the value of a distance, the value being governed by the factor k = (Vxc/M). Assuming this factor to be *constant* and differentiating Eq. (10) with respect to the time, we get again our formula of the new xc-speed:

$$dx^*/dt = V(t) + Vario(t)[Vxc/M] = Vxc(t) \qquad (11)$$

Vxc(t) seems to be the instant xc-speed we have been searching for. It has the following advantages:

1) The instant xc-speeds show "normal" values even for positive vario signals during gliding.

2) It provides xc-speeds also during thermalling for V(t) =0

$$Vxc(t)_{therm} = Vario(t)_{therm}*k \qquad (12)$$

3) It correlates with regard to time, as mentioned above

4) and, because of its simple set up, it is easy to integrate to get the corresponding average values Vxc of the xc-speed.

Vxc(t), however, has one slight disadvantage: it does not necessarily show a maximum if the pilot flies with the best-speed-to-fly according to the classical theory – a feature which we will discuss later in detail.

Fig. 10 demonstrates the difference between the instant xc-speed V'xc(t) of the classical theory according to Eq. (5), and its analogue Eq. (7), and the new instant xc-speed Vxc(t).

Interpretation of Vxc(t) to be the shadow speed

If we set the reference line on flat ground and the Sun in the right position (Fig. 11), then the shadow of the glider being cast on flat ground can be described by the following formula:

$$V(t)\ shadow = V(t) + Vario(t)*ks \qquad (13)$$

ks being responsible for the inclination of the rays.

Comparing this formula for the shadow speed (Eq. (13)) with the formula of the instant cross-country speed (Eqs. (8, 9)) we see that the instant cross-country speed Vxc(t) can be regarded to be the shadow speed of the glider if

$$ks = k \qquad (14)$$

The interpretation as shadow speed surely helps to get a better understanding of the instant cross-country speed Vxc(t).

Features of the instant cross- country speed Vxc(t)

Maximum and optimum instant xc-speed

Fig. 12 shows the instant xc-speed Vxc(t) of the Ventus cM 17,6m during gliding in dependence of the gliding speed V(t). It is assumed that the glider is thermalling with M = 2 m/s and that the k-factor is set to k(2) = 47. Curves of instant xc-speed are drawn for different values of the sink rate of the air (-airsink = -2, -1, 0, 1, 2 m/sec). To be able to compare Vxc(t) with the instant xc-speed V'xc(t) of the classical theory (according to Eq. (5)) the corresponding values of V'xc(t) are shown in Fig. 13.

The curves of the instant xc-speed Vxc(t) of Fig. 12 show a maximum at the gliding speed V(2) = 162 km/h which according to the classical speed-to-fly theory is the optimum gliding speed for the MacCready-setting M = 2 m/s and for zero sink rate of the air (airsink = 0 m/s). This is quite remarkable, because the pilot achieves the maximum instant xc-speed Vxc(t)max if the pilot sticks to the gliding speed of V(2) = 162 km/h independent of flying through updrafts or downdrafts. This seems to stand in conflict with the classical speed-to-fly theory according to which you should fly slower in rising and faster in sinking air. But, this is not the case. Vxc(t) is only able to display the correct instant xc-speed. To get the best speed-to-fly we would have to combine both Vxc(t) during gliding and Vxc(t) during thermalling, similar to V'xc(t) which is continuously combining gliding and thermalling and therefore is able to provide the best speed-to-fly. As a consequence of this, the pilot should follow the command of the speed-to-fly-instruments to achieve the highest overall xc-speed at the end of the flight. Vxc(t), in this case, will not necessarily show the maximum, but at least the optimum (best) instant xc-speed Vxc(t)opt marked by dots in Figs. 12 and 13.

Instant cross country speed for different values of the climb rate M and k-factor

Fig. 14 shows the instant cross-country speed Vxc(t), during gliding, dependence on the gliding speed V(t) for different values of the climb rate (or MacCready setting) M = 0/ 0,5 / 1,0 /…5 m/sec and k(M)-factor = 166, 95, 69,…27. It is *assumed* here that the sink rate of the air is zero. We note that deviations from the optimum speed will cause a lowering of Vxc(t). Interesting to see that this is also the case for M = 0 and k(0) = 166.

Fig. 15 shows the corresponding instant xc-speed V'xc(t) of the classical theory dependence on the gliding speed V(t) for different values of M, airsink = 0.

The instant cross-country speed dependence on the vario signal

Fig. 16 shows the instant xc-speed Vxc(t) dependence on the vario signal during gliding Vario(t)glide which gives a nearly linear curve. Also the instant xc-speed V'xc(t) due to the classical theory is shown which is approaching infinity at Vario(t)glide = 2 m/s. During thermalling the instant xc-speed Vxc(t) is depending completely linear on the vario signal Vario(t)therm. However, no information about the instant xc-speed V'xc(t) according to the classical theory (Eq. (5)) is available in the thermalling mode.

Converting energy into cross-country speed

The new theory and its formula for the instant xc-speed Vxc(t) of Eq. (8 and 12) enable us to study how the glider is picking up energy and transforming it into xc-speed.

During thermalling

The energy of the glider is given by the sum of the potential and kinetic energy. If we use total energy compensated altimeters and variometers we are able to express the energy and power (energy gain per time unit) in the short form:

energy(t) = height(t)*weight (15)
power(t)therm = Vario(t)therm*weight (16)

Vario(t)therm being the climb rate of the glider during thermalling.

At the same time, because of Eq. (12), the glider will achieve by thermalling the following instant xc-speed (shadow speed):

Vxc(t)therm = Vario(t)therm*k (17)

We note that during thermalling (see Fig. 17) two things are happening at the same time: the gaining of energy (by power(t)therm) and achieving of instant xc-speed (Vxc(t)therm).

During interthermal cruising

To keep it simple we start with a special case. We assume that the sink /climb rate of the air is zero. A netto vario would show zero (nettoVario(t) = 0). This has the effect that the vario signal during gliding is only influenced by the polar sink rate of the glider Vs(t):

Vario(t)glide = - Vs(t) (18)

Because of our foregoing considerations (see Eq. (16)) the energy loss of the glider per time unit is given by:

power(t)glide = -Vs(t)*weight (19)

The interpretation of this is as follows. The glider stores energy in form of height and weight. This is comparable to the fuel cars are storing in their tank. Now, similar to a car that burns fuel in its engine to overcome drag and to produce forward speed, the glider "burns" height in its invisible engine to produce the gliding speed V(t) and (according to Eq. (8)) the instant cross-country speed:

Vxc(t)glide = V(t) – Vs(t)*k (20)

To control the power and, therefore, speed of the car the gas pedal (throttle) is used. In gliding the pilot controls the gliding speed V(t) which via the polar sinking rate Vs(t) determines the energy and power transfer into the instant cross-country speed Vxc(t)gliding. Calculating the instant cross-country speed, for different values of M and k(M)b, dependence on V(t) displays the features of the glider's invisible engine which works best if the pilot flies with the MacCready speed (see Figs. 14 and 18).

We are now fit to study the common case in which the vario signal is determined by the polar sink rate of the glider Vs(t) and the sink rate of the air airsink(t). For a better understanding we use now instead of airsink(t) the signal of the netto variometer which we indicate by nettoVario(t). It is therefore

Vario(t)glide = -Vs(t) + nettoVario(t) (21)

and the power transfer during gliding:

Power(t)glide = -Vs(t)*weight + nettoVario(t)*weight (22)

accompanied by the instant xc-speed according to Eq. (8):

Vxc(t)glide =[V(t)-Vs(t)*k] + [nettoVario(t)*k] (23)

Influence of the netto vario on the instant xc-speed

We see from Eq. (23) that an additional xc-speed [nettoVario(t)*k] is achieved, if the glider is flying through rising air, and from Eq. (22) that at the same time the glider is picking up additional energy determined by nettoVario(t)*****weight. These effects are independent from the gliding speed V(t). See also Fig. 12 and 18.

An *example* may demonstrate the effect. If the netto-vario shows a climb rate of 1 m/s in straight flight and if the k-factor is at M = 2 m/s for instance k(2) = 50 , then we get an additional cross-country speed of Vxc(t) = 1x50 = 50km/h. In case of a rising air of 2 m/s we get additionally 2x50 = 100km/h. On the other hand, if we fly in sinking air of minus 1m/s then our instant xc-speed will be reduced by -1x50 = -50km/h, and at a sink rate of – 2m/s by -2x50 = -100km/h.

Examples

To test the formula of the instant cross-country speed, the igc-files of two flights were evaluated. They can be downloaded from the OLC-home page.[9] Both flights were flown from *Wr. Neustadt*, Austria on the 30th of April 2004 by Herbert and Martin Pirker [9, 10]. See Fig. 19. The two igc-files of the flights were optimized by the cross-country evaluation program "SeeYou"[8] and afterwards the appropriate data (1 set of data for each minute of the flight) were transferred from the SeeYou parameter list (Fig. 19) to an Excel-table (not shown). In the following, with the help of this Excel-table, the instant xc-speed which we designate here with Vxc(t)1min was calculated. Instead of the gliding speed the "task speed"[8] was used which is also sensitive against deviation from the course line. To smooth the function Vxc(t)1min, the data were integrated by a time constant of Tc = 10min, Tc = 30min and designated as Vxc(t)10min, Vxc(t)30min. For the integration the so called RC-integration (used normally to integrate the vario meter signals) was applied.

In the Excel-table also the cross-country speed Vxc(t)SeeYou,30min is added which SeeYou[8] is calling "Vt,t=30min" and which you get if you divide the distance flown in the last half an hour by 0,5h and which is also displayed in the "list of parameters" of Fig. 19. This enables to compare Vxc(t)30min with "Vt,t=30min" of SeeYou and to discuss the difference (see Fig. 21).

Also, the following cross-country-speed was calculated:

$$\text{Vxc(t)total} = \text{Taskdistance(t)} / t \qquad (23)$$

Taskdistance(t) being the distance of the task flown since crossing the start line, t being the elapsed time. This enables the drawing of *diagrams* and *barograms* of the cross-country-speeds and height dependence on the elapsed time t.

Flight by Herbert Pirker (30. 4. 2004)

Fig. 20 shows the height (barogram) and the xc-speeds of this flight. It indicates in detail:

White: Height (barogram). The scale on the left side (ordinate) must be multiplied by 10 to get the proper meters.

Grey, thin line: Vxc(t)1min shows the instant xc-speed for GPS-fixes taken at intervals of 1 minute. The curve of this speed *varies extremely* according to the *meteorological conditions* and *inaccuracies* of the used data (1 fix per minute instead of every second, height stored in the logger by meters instead of cm, height also not total energy compensated).

Black: Vxc(t)10min shows the xc-speed integrated by the time constant of 10 minutes. The smoothed curve provides the pilot with quite valuable information on the xc-speed.

Grey, thick line: Vxc(t)total indicating the already achieved total xc-speed at the elapsed time t. The curve shows that with increasing flying time t the function becomes quite insensitive against changes of the instant cross-country speed.

Short description of the flight

Start in *Wr. Neustadt*. Poor rate of climb at the hill "*Hohe Wand*". Therefore, low xc-speed (40km/h) at the beginning. In the following, ridge lift and high xc-speeds (about 140 km/h) up to "*Dachstein*" (task distance about 200 km). After that, low cross-country speed again (down to 40 km/h) because of missing ridge lift, poor lift and some zigzag in the course. At the turn point (*Schmittenhöhe*, Zell am See, app. 270km) a 4 m/sec thermal causes a peak in the black curve of the xc-speed (110km/h). Flying back to the mountain area "*Dachstein*" and the eastern turn point (*Küb*, task distance 500km) and back again to "*Dachstein*" (task distance 700km) enables high speed racing (up to 150km/h) due to ridge lift. Turning back towards the east to fly home shows some reduction in the xc-speed due to rain and strong downdrafts before arriving at the ridges of "*Hochschwab*", and the exploiting of the last updraft at the eastern end of the mountain "*Rax*" followed by landing in *Wr. Neustadt*. The variation and changes of the xc-speed are demonstrated quite well by the black curve Vxc(t)10min which avoids exaggerated peaks at an acceptable retardation.

Fig. 21 enables a comparison of the instant xc-speeds Vxc(t)10min, Vxc(t)30min and Vxc(t)SeeYou,30min. The difference between the black curve of Vxc(t)30min and the white one Vxc(t)SeeYou,30min (= cross-country speed according to "Vt,t=30min" of the evaluation program SeeYou[8]) seems to be not big. Yet, Vxc(t)SeeYou,30min (white line) shows, not quite correct, an inadequate decrease of its values during thermalling and inadequate increase during gliding. Both functions Vxc(t)30min and Vxc(t)SeeYou,30min, integrated by the same time constant of Tc = 30 min, show in comparison to Vxc(t)10min a far better smoothing of the curves, but at the expense of an extremely delayed response to changes in the cross-country-speed.

Flight by Martin Pirker (30. 4. 2004)

In Fig. 22, displayed are the same functions (height(t), Vxc(t)1min, Vxc(t)10min, Vxc(t)total) as in the foregoing Fig. 20. With regard to the height (white line) the numbers on the ordinate have to be multiplied by (3/4)x10 to get the height in meters.

Short description of the flight

Start in *Wr. Neustadt*. Ridge lift up to mountain region "*Dachstein*" (200km), afterwards use of thermals up to the turn point at "*Gerlos*" (330km) and back again to "*Dachstein*". In the following, more or less ridge lift until the end of the flight.

As you can see by the black curve of Vxc(t)10min, Martin manages to achieve in ridge lift as well as in thermals with heights up to 3000 m a relatively high and constant xc-speed, enabling him to fly 1027 km with his Standard Libelle.[10]

Conclusions

The instant cross-country-speed Vxc(t) of the glider has been defined which may be regarded to be the shadow speed of the glider, if the sun rays are inclined in the right manner and the shadow is cast on the reference line (or, for simplicity, on flat ground). Features of the instant cross-country speed Vxc(t) are discussed and the transforming of energy into cross-country speed revealed. Examples of two igc-files of flights show that the formulas provide reasonable results. However, the used data were not accurate. Better height and vario data, combined with a higher access rate, make it likely to get accurate values and smooth curves with a response time of seconds. This all suggests the implementing of the instant xc-speed into modern flight computers to enable fast and accurate flight analysis during and after flight.

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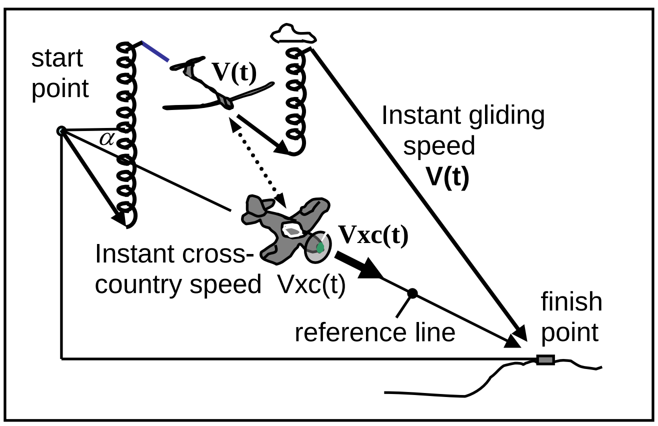


Figure 1 Definition of the instant xc-speed.

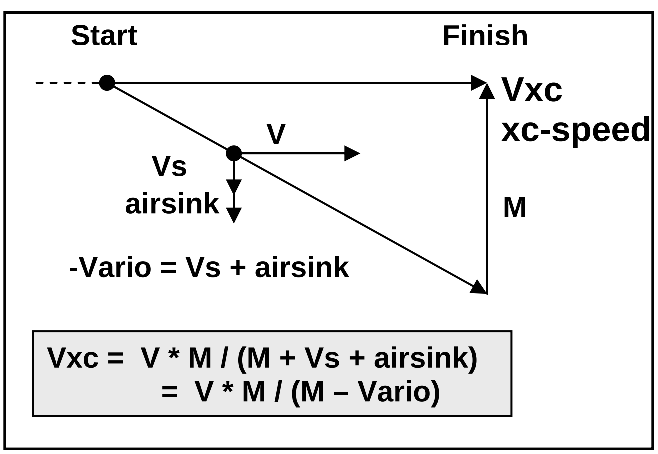


Figure 2 Basic xc-model.

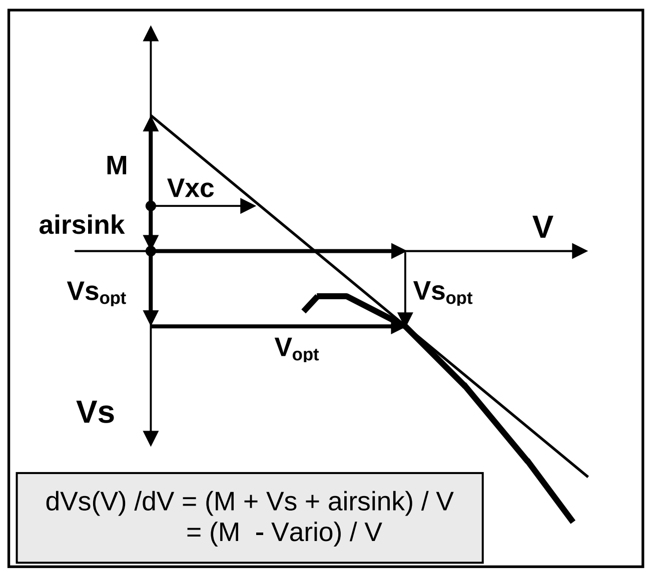


Figure 3 Tangent construction for finding optimum gliding speed (best speed).

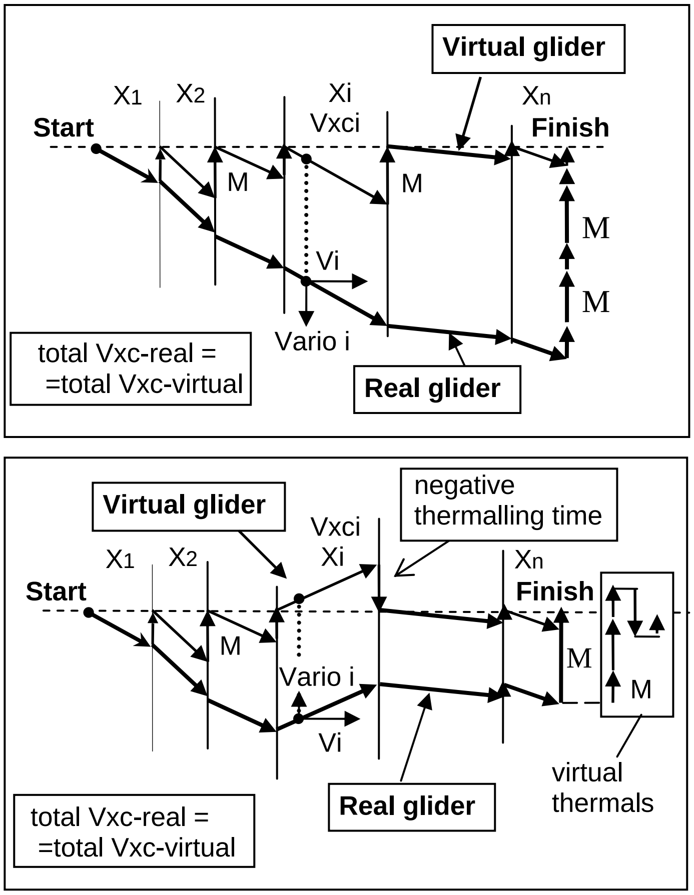


Figure 4 Advanced xc-model for *finite* numbers of gliding sections X_1, X_2, …X_n. **Figure 4a** (top) With height loss in each gliding section Xi. **Figure 4b** (bottom) With height gain in X_i ($Vario_i > 0$) causing a negative (!) thermalling time in the virtual thermal.

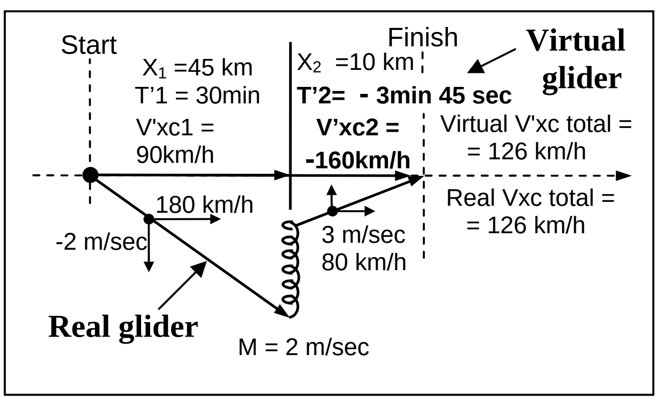


Figure 5 Example demonstrating "paranormal" xc-speeds of the virtual glider in case of positive vario signals during gliding.

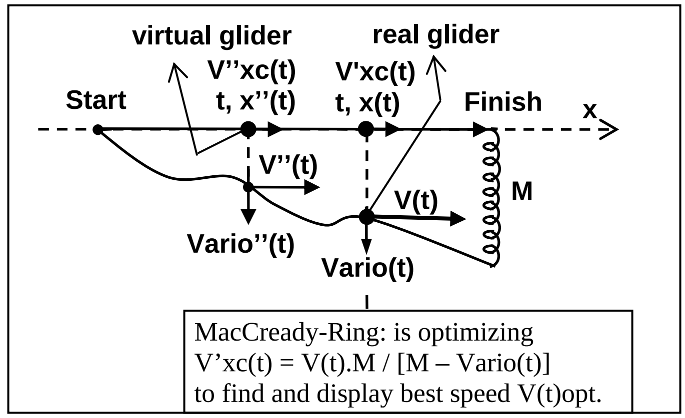
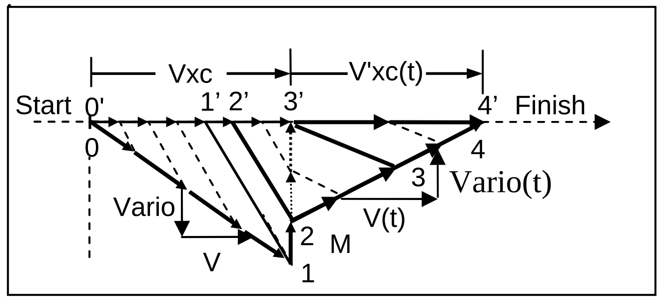


Figure 6 Xc-model analogue to Figure 4 with an *infinite* number of gliding sections (cannot be shown), the positions and speeds being defined as a function of time t.



Figures 7 Movement study of the virtual and real glider according to the classical theory.

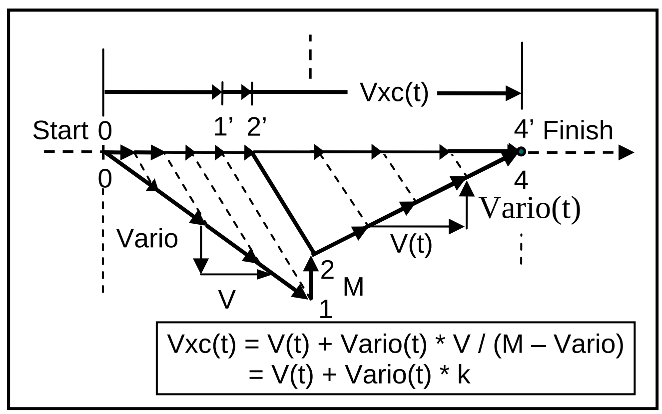


Figure 8 The new virtual glider moving from 2' to 4' in the same manner as the real glider from 2 to 4.

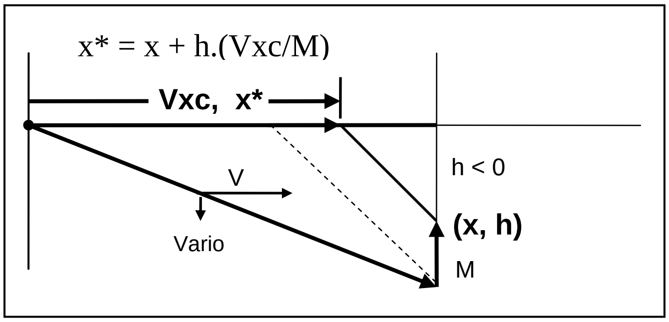


Figure 9 Moving in average with Vxc along the reference line by gliding with (V, Vario) and thermalling with M.

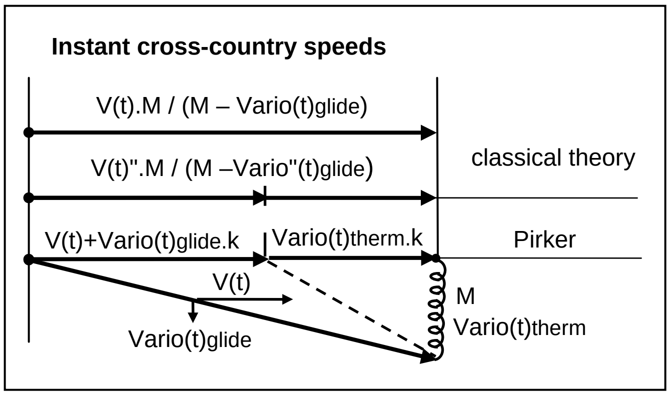


Figure 10 The instant xc-speeds of the virtual gliders in comparison (V'xc(t), V"xc(t), Vxc(t)).

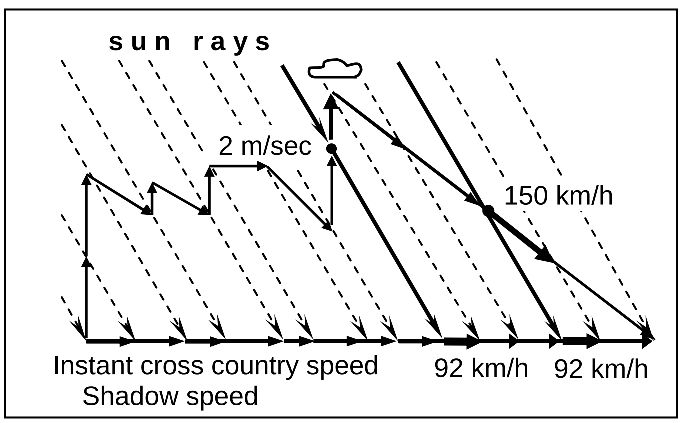
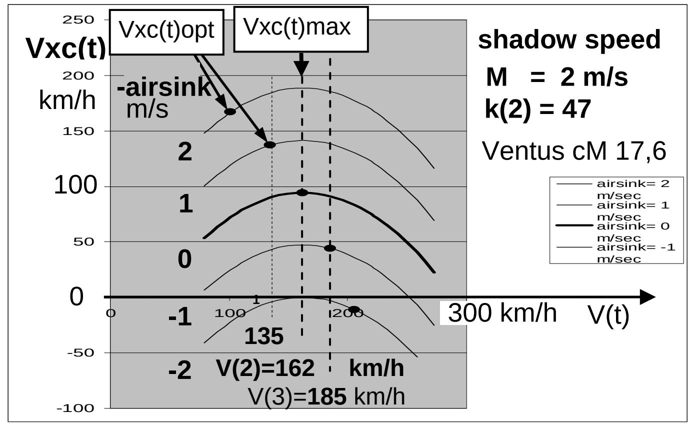
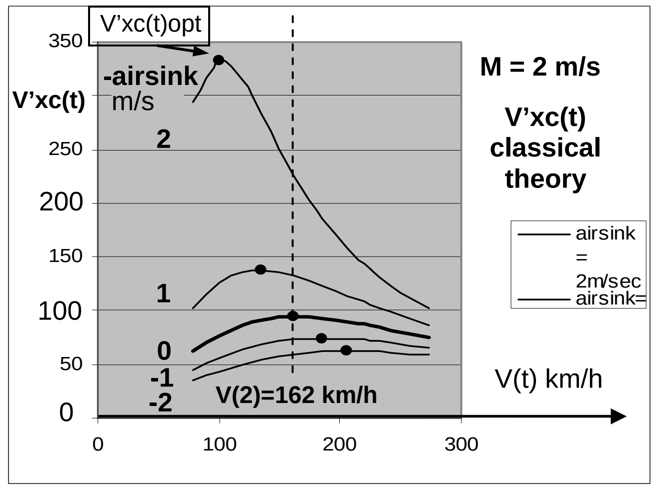
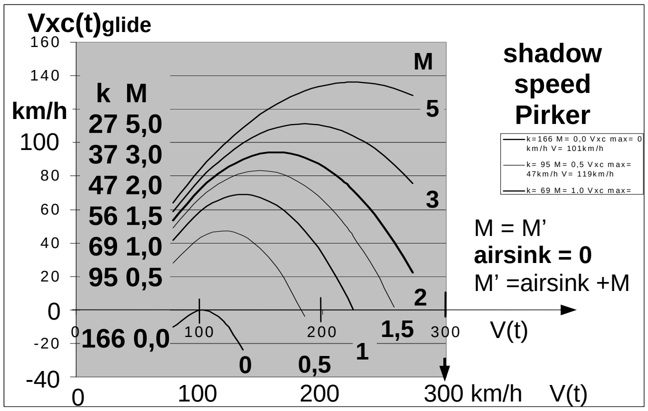


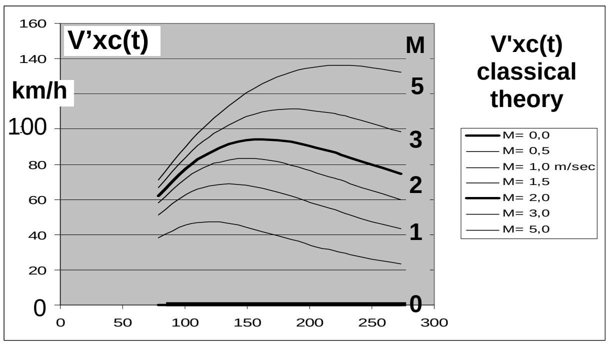
Figure 11 Shadow speed of the glider on flat ground.





Figures 12 (top) **and 13** (bottom) The shadow speed Vxc(t) during gliding (Fig. 12) in comparison to the instant xc-speed V'xc(t)according to the classical theory (Fig. 13) dependence on the gliding speed V(t) for different values of the sink rate of the air during gliding (airsink = -2, -1, 0, 1, 2 m/sec) and climb rate in thermals of M = 2 m/sec.





Figures 14 (top) **and 15** (bottom) Shadow speed Vxc(t) during gliding (Fig.14) in comparison to the instant xc-speed V'xc(t) according to the classical theory (Fig. 15) dependence on the gliding speed V(t) for different values of the thermalling climb rate M and corresponding k-factor at zero sink rates of the air during gliding, calculated for Ventus 17,6 cM.

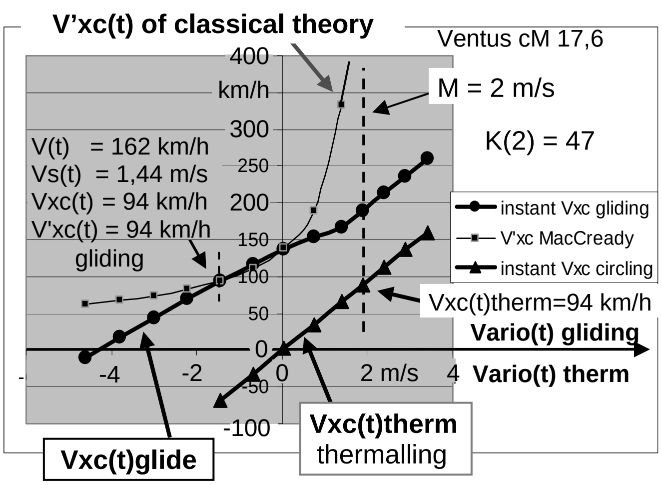


Figure 16 displays dependence of the vario signal during gliding, the shadow speed Vxc(t)glide and the instant xc-speed V'xc(t) according to the classical theory, and during thermalling the shadow speed Vxc(t)therm (for M = 2 m/s and k(2) = 47).

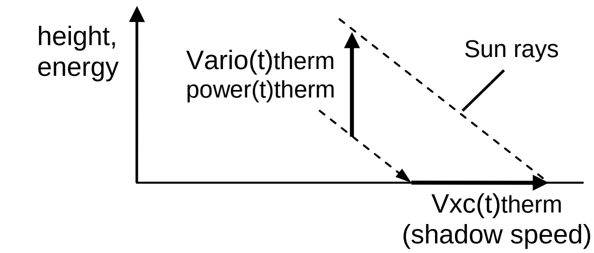


Figure 17 Thermalling climb rate Vario(t)therm causing energy gain and shadow speed at the same time.

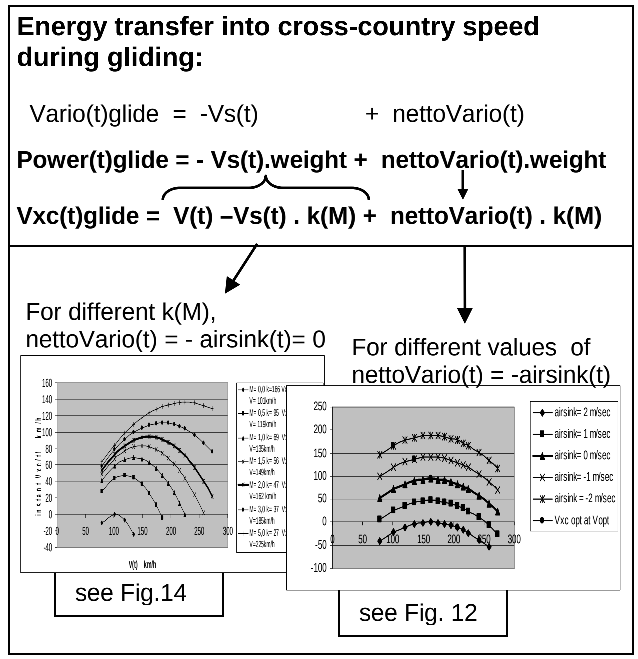


Figure 18 Energy transfer into xc-speed during gliding.

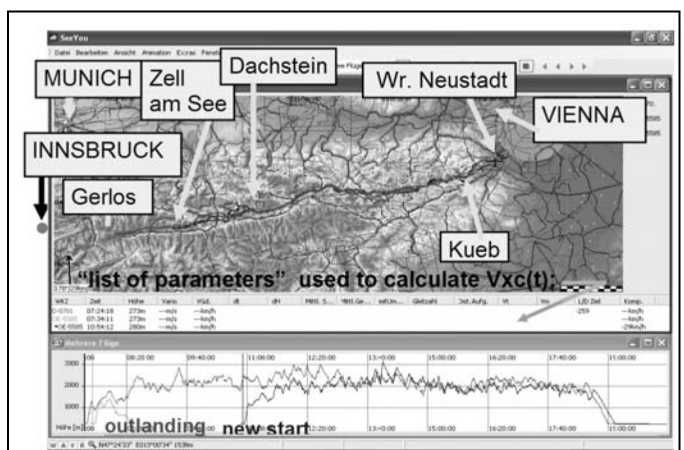


Figure 19 Flights of Herbert and Martin Pirker displayed by the evaluation program of SeeYou.

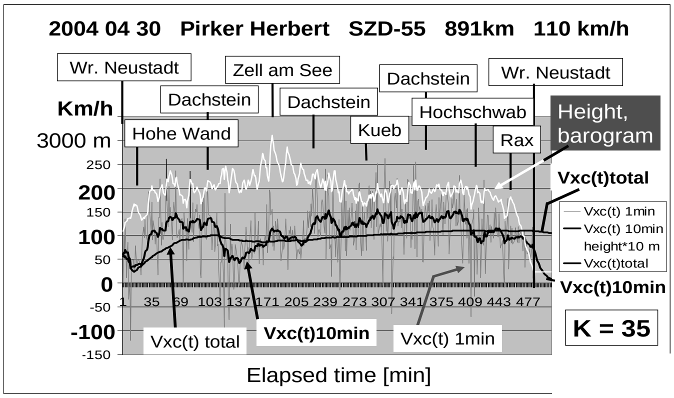


Figure 20 Barogram (white) and the instant xc-speeds with the time constants of 1 minute (grey), 10 minutes (black) and the total xc-speed (grey, thick line) achieved by Herbert Pirker on his flight.

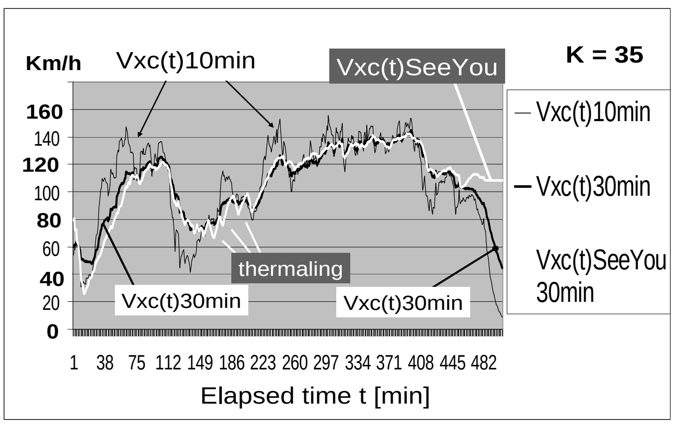


Figure 21 Instant xc-speeds with the time constant of 10 minutes (grey) and 30 minutes (black) in comparison to the instant xc-speed calculated by SeeYou (white).

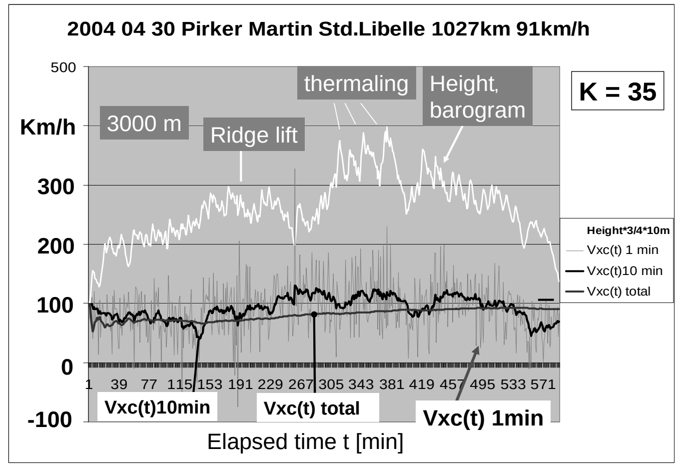


Figure 22 Barogram (white) and instant xc-speeds achieved by Martin Pirker on his flight.