The gliding characteristics of sailplanes as affected by the strength and direction of the wind

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Scope

The aim of the present study is to show how the gliding characteristics of sailplanes, and particularly the best glide ratio and the corresponding airspeed, are affected by the wind.

Glider pilots know that the presence of a head wind or of a cross wind along a given course increases the difficulty of their flight but, as far as I know, a quantitative evaluation of this effect has not yet been made.

The subject should be of interest, in my opinion, also to those who are charged with task setting in competitions, on the basis of meteorological forecast. In fact, it will be shown how the difficulty of a given task (for instance, a "goal and return" or a "triangular" flight) is affected by the orientation of the course with respect to the existing wind, of which the strength and direction are known.

Theory

Let us consider a sailplane flying from A to B in the presence of a wind (air moving at a constant horizontal speed W with respect to the ground and at an angle γ relative to the given course). If V is the sailplane airspeed, the sailplane ground speed is V_S and γ is the "angle of drift".

The angle γ is conventionally taken as $\gamma = 0^o$ for tail wind and $\gamma = 180^o$ for head wind.

We can write:

$$V^2 = V_S^2 + W^2 - 2\, V_S W \cos \gamma$$

The solution of this equation with respect to V_S yields:

$$(1) \qquad V_S = W \cos \gamma \pm \sqrt{V^2 - W^2 + W^2 \cos^2 \gamma}$$

If $V > W$, only one triangle may satisfy eq. 1: it corresponds to the sign $+$, the sign $-$ giving a negative V_S, i. e. directed from B to A, which is not in accord with the initial assumption.

If $W > V > W \operatorname{sen} \gamma$, we have two possible triangles, that is two values of V_S for a given V, but with two different angles of drift. It is easy to see, however, that only the greatest of the two values of V_S is of interest, as a better glide ratio relative to the ground corresponds to it.

We shall therefore write eq. 1 with the sign $+$.

If $V < W \operatorname{sen} \gamma$, eq. 1 yields no real solution.

The glide ratio of the sailplane relative to the air is given by $E = V/V_y$, where V_y is the sinking speed corresponding to the airspeed V. The glide ratio with respect to the ground is given by $E_W = V_S/V_y$. Dividing eq. 1 by V_y we obtain:

$$(2) \qquad E_W = \frac{V_s}{V_y} = \frac{W \cos \gamma + \sqrt{V^2 - W^2 + W^2 \cos^2 \gamma}}{V_y} =$$

$$= \frac{V}{V_y}\left(\frac{W}{V} \cos \gamma + \sqrt{1 - \left(\frac{W}{V}\right)^2 + \left(\frac{W}{V}\right)^2 \cos^2 \gamma}\right)$$

or

$$(3) \qquad r = \frac{E_W}{E} = \frac{V_s}{V} = \cos \gamma + \sqrt{1 - \left(\frac{W}{V}\right)^2 + \left(\frac{W}{V}\right)^2 \cos^2 \gamma}$$

Eq. 3 yields the ratio r between ground and air speed, or between the glide ratio relative to the ground and to the air respectively, as a function of W/V and of the angle γ. r is therefore independent from the particular sailplane considered.

Glide ratio is a characteristic of the given sailplane, as well as the corresponding airspeed. Both these characteristics, E_{max} and $V_{E\,max}$, are easily obtainable from the speed polar of the sailplane considered.

The function $r = r(\gamma)$, as defined by eq. 3, is represented graphically in fig. 1 for different values of W/V between 0 (no wind) and 2.

The use of this diagram for calculating the glide ratio relative to the ground of a given sailplane when a wind of known W and γ is present, is very simple.

Glide ratios relative to the air, corresponding to several values of the airspeed V, have to be calculated first according to the speed polar of the given sailplane.

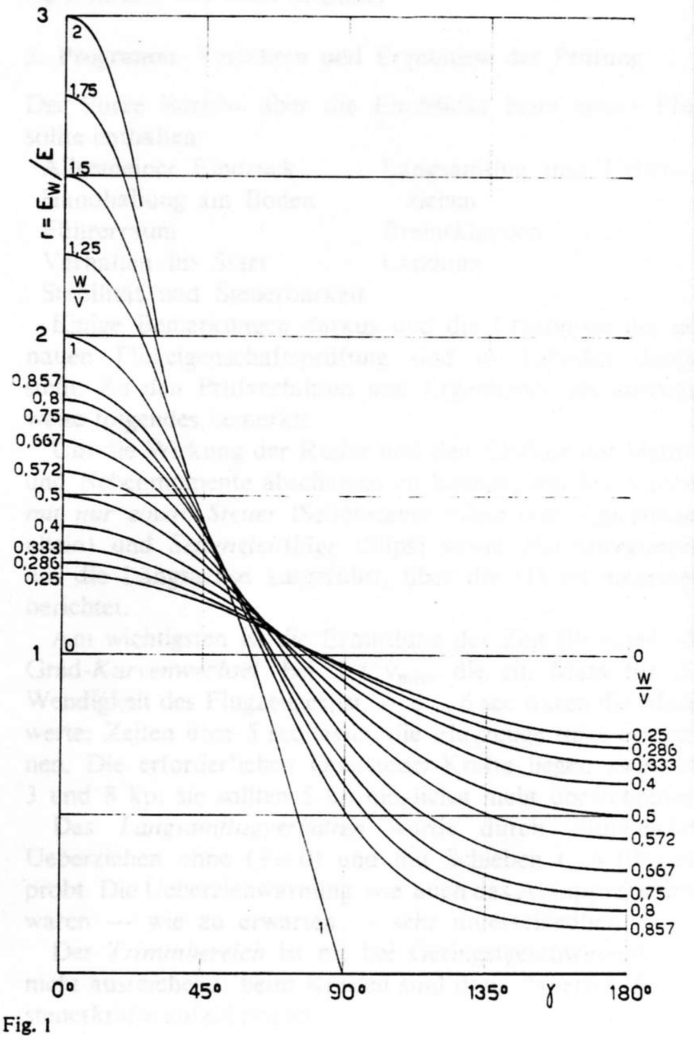

Fig. 1

The ratios W/V are calculated next for the given wind speed and for each of the chosen values of airspeed.

The diagram of fig. 1 (or eq. 3) gives the values of r for the various W/V and the known γ. Glide ratios relative to the ground will be given by $E_W = r\,E$.

Numerical example

Calculations have been carried out for a sailplane (A) having the following characteristics:

Wing span = 19.2 m, aspect ratio = 17, total weight Q = 480 kg, wing loading Q/S = 22.8 kg/m².

The speed polar of this sailplane is known by flight measurements and is shown in fig. 2.

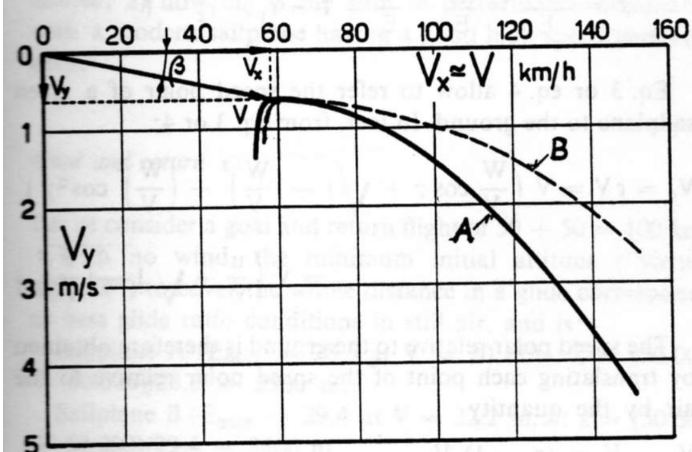

Fig. 2

With head wind (γ = 180°) and cross wind (γ = 90°) and for several wind speeds (W = 10, 20, 30 m/s), fig. 3 shows the glide ratio relative to the ground as a function of the airspeed V. "u" and "v" are the components of W, parallel and perpendicular to the course respectively.

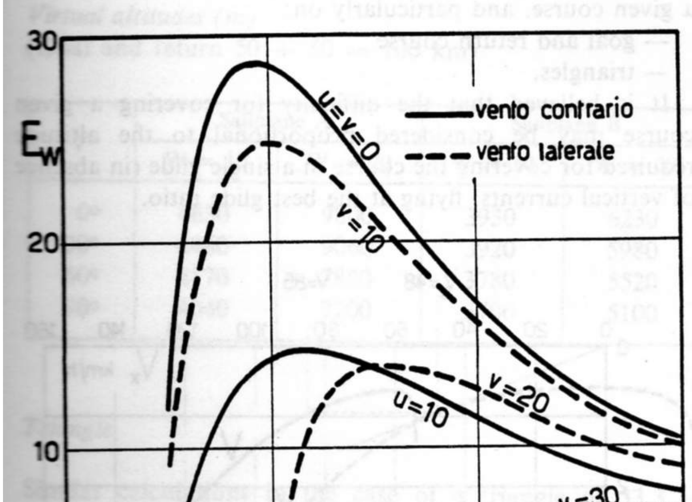

Fig. 3

The curve W = O (u = v = O) showes the glide ratios relative to the air, or relative to the ground when there is no wind.

It is evident the strong reduction of glide ratio with head wind and also with cross wind. With a W = 20 m/s head wind, E_{max} is one fifth of the E_{max} in still air, and with a 20 m/s cross wind it becomes about one half. It is also evident the corresponding variation of the airspeed for best glide ratio.

Fig. 4 shows, for the same sailplane and a wind speed W = 20, the curves giving glide ratios as a function of γ for different values of the airspeed V, and the envelope of these curves which gives the best glide ratios and the corresponding airspeeds.

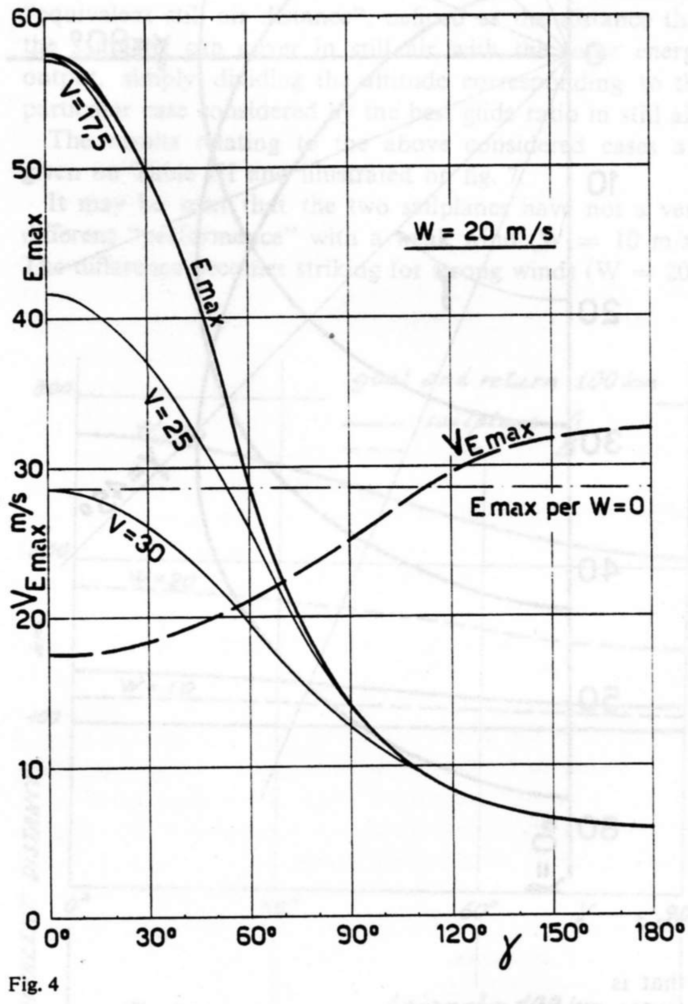

Fig. 4

A different representation of the same functions is shown in fig. 5, which is a polar diagram where E_{max} is the radius and γ is the angle, for W = 0, 10, 20 m/s.

The areas enclosed by the curves are practically the locus of the points that the sailplane can reach in a glide in the various directions starting from an altitude equal to one on the vertical of the pole 0.

It is interesting to note from fig. 4 and 5 that, when a wind exists, a glide ratio equal to the best glide ratio in still air is obtainable for $\gamma = \sim 60°$ at W = 20 and $\gamma = \sim 70°$ at W = 10 m/s. Independently from the sailplane considered, we obtain from eq. 3, imposing r = 1:

$W/V = 2 \cos \gamma \qquad \gamma = \arccos \frac{1}{2} (W/V)$

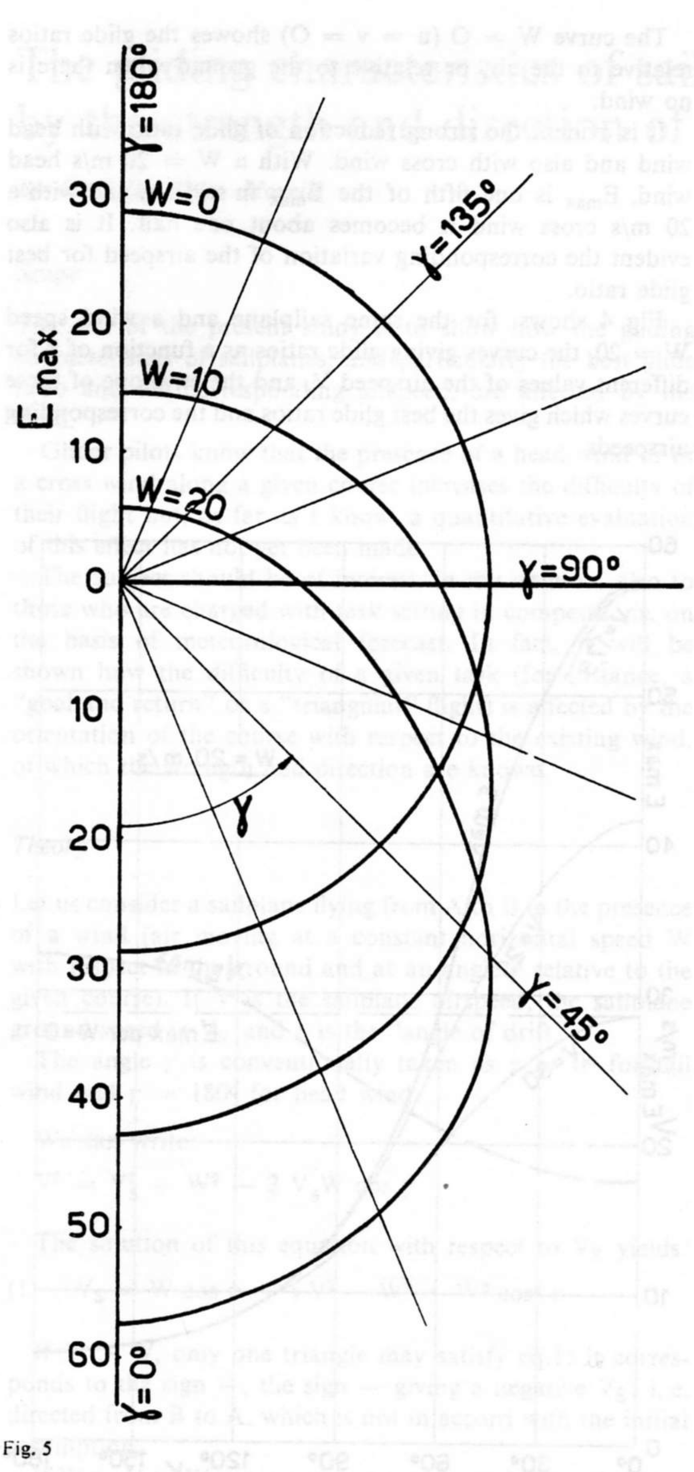

Fig. 5

that is

$W/V = 0{,}25 \quad 0{,}5 \quad 1{,}0$

$\gamma\; r = 1 = 82^o{,}8 \quad 75^o{,}5 \quad 60^o$

as may also be checked in fig. 1.

It is also interesting to note from fig. 5 that the maximum projection of E_{max} in a direction perpendicular to the wind direction, whatever is the wind speed, is always equal to the E_{max} in still air, and is obtained for $\gamma = 45^o$ at $W = 20$ and for $\gamma = 60^o$ at $W = 10$.

Particular cases

Eq. 3 may be written as a function of u and v, the components of W parallel and perpendicular to the course respectively, instead of W and γ:

$$W = \sqrt{u^2 + v^2} \qquad \cos\gamma = u/W = u/\sqrt{u^2 + v^2}$$

$$(4) \qquad = \frac{E_w}{E} = \frac{E_{u,v}}{E} = \frac{V_s}{V} = \frac{u}{V} + \sqrt{1 - \left(\frac{v}{V}\right)^2}$$

Wind along the course:

$$(5) \qquad r_1 = \frac{E_u}{E} = \frac{V_s}{V} = 1 + \frac{u}{V} \quad \text{(u positive for tail wind).}$$

Cross wind:

$$(6) \qquad r_2 = \frac{E_v}{E} = \frac{V_s}{V} = \sqrt{1 - \left(\frac{v}{V}\right)^2}$$

From eq. 4, 5 and 6 we obtain:

$$r = \frac{E_{u,v}}{E} = \frac{E_u}{E} + \frac{E_v}{E} - 1 = r_1 + r_2 - 1$$

Eq. 3 or eq. 4 allow to refer the speed polar of a given sailplane to the ground. In fact, from eq. 3 or 4:

$$V_s = rV = V\left(\frac{W}{V}\cos\gamma + \sqrt{1 - \left(\frac{W}{V}\right)^2 + \left(\frac{W}{V}\right)^2 \cos^2\gamma}\right)$$

$$= V\left(\frac{u}{V} + \sqrt{1 - \left(\frac{v}{V}\right)^2}\right)$$

The speed polar relative to the ground is therefore obtained by translating each point of the speed polar relative to the air by the quantity

$$V_s - V = (r - 1)\,V$$

where the values of r are read on fig. 1 as a function of the various values of W/V and γ, or calculated by eq. 3 or 4.

Fig. 6 shows such a construction for $u = -5$ m/s, $v = 15$ m/s (corresponding to $W = 15{,}8$ m/s. $\gamma = \sim 108^o$).

Effect of the wind on "Goal and Return" or "Triangular" courses

These results may be used to study the effect of the wind on a given course, and particularly on:

— goal and return course
— triangles.

It is believed that the difficulty for covering a given course may be considered proportional to the altitude required for covering the course in a single glide (in absence of vertical currents) flying at the best glide ratio.

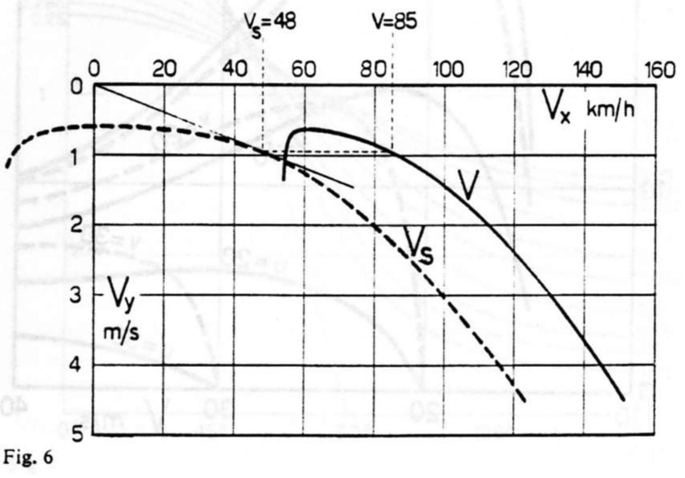

Fig. 6

In fact, the amount of energy required to equal the work done by the sailplane drag along the whole course, is practically proportional to this altitude. The difference between the kinetic energy at the starting and finishing points (due to the different corresponding airspeeds) is certainly negligible.

Calculations have been carried out for two different sailplanes:

Sailplane A: The same previously considered (good low speed characteristics but poor performance at high speed). The speed polar is shown in fig. 2.

Sailplane B: A modern "standard" sailplane ($Q/S = 23\ kg/m^2$) (good high speed performance). The speed polar is shown by the dotted line in fig. 2.

The results are intended to show: 1) a quantitative evaluation of the difficulty introduced by the wind on a given course; 2) how big is the gain in performance obtainable with a modern sailplane having a good high speed performance.

Goal and return

Let us consider a goal and return flight of 50 + 50 = 100 km.

With no wind, the minimum initial altitude ("virtual altitude") to cover the whole distance in a glide corresponds to best glide ratio conditions in still air, and is:

Sailplane A ($E_{max} = 28{,}6$ at $V = 20$ m/s): $z = (50\,000 + 50\,000)/28{,}6 = 3500$ m.

Sailplane B ($E_{max} = 29{,}4$ at $V = 22{,}2$ m/s): $z = (50\,000 + 50\,000)/29{,}4 = 3400$ m.

With a wind of 10 and 20 m/s at various directions relative to the given course ($\gamma = 0°$, axial wind; $\gamma = 30°$; $\gamma = 60°$; $\gamma = 90°$, cross wind), the "virtual altitude" is calculated supposing that the sailplane glides on each leg at the best glide ratio relative to the ground. The results are shown on Table I.

Table I

Virtual altitudes (m)
(Goal and return 50 + 50 = 100 km)

γ	Sailplane A		Sailplane B	
	W = 10	W = 20	W = 10	W = 20
0°	4630	9800	3930	6230
30°	4460	9060	3920	5980
60°	4170	7850	3780	5520
90°	4040	7200	3700	5100

Triangle

Similar calculations in the case of a triangle of 33,3 + 33,3 + 33,3 = 100 km yield the results shown on Table II. γ is measured with respect to one side of the triangle.

It should be remarked again that the variations of kinetic energy due to the different airspeeds of the glider on the various legs of the triangle are neglected, as they are considered to be small. There would be no difficulty, however, on taking them into account, if desired.

Table II

Virtual altitudes (m)
(Triangle 33,3 + 33,3 + 33,3 = 100 km)

γ	Sailplane A		Sailplane B	
	W = 10	W = 20	W = 10	W = 20
0°	4375	8625	3810	5890
30°	4325	8210	3845	5680
60°	4270	8080	3880	5600
90°	4325	8210	3845	5680

On the basis of these results it may be introduced an "equivalent still air distance", defined as the distance that the sailplane can cover in still air with the same energy output, simply dividing the altitude corresponding to the particular case considered by the best glide ratio in still air.

The results relating to the above considered cases are given on Table III and illustrated on fig. 7.

It may be seen that the two sailplanes have not a very different "performance" with a weak wind (W = 10 m/s). The difference becomes striking for strong winds (W = 20).

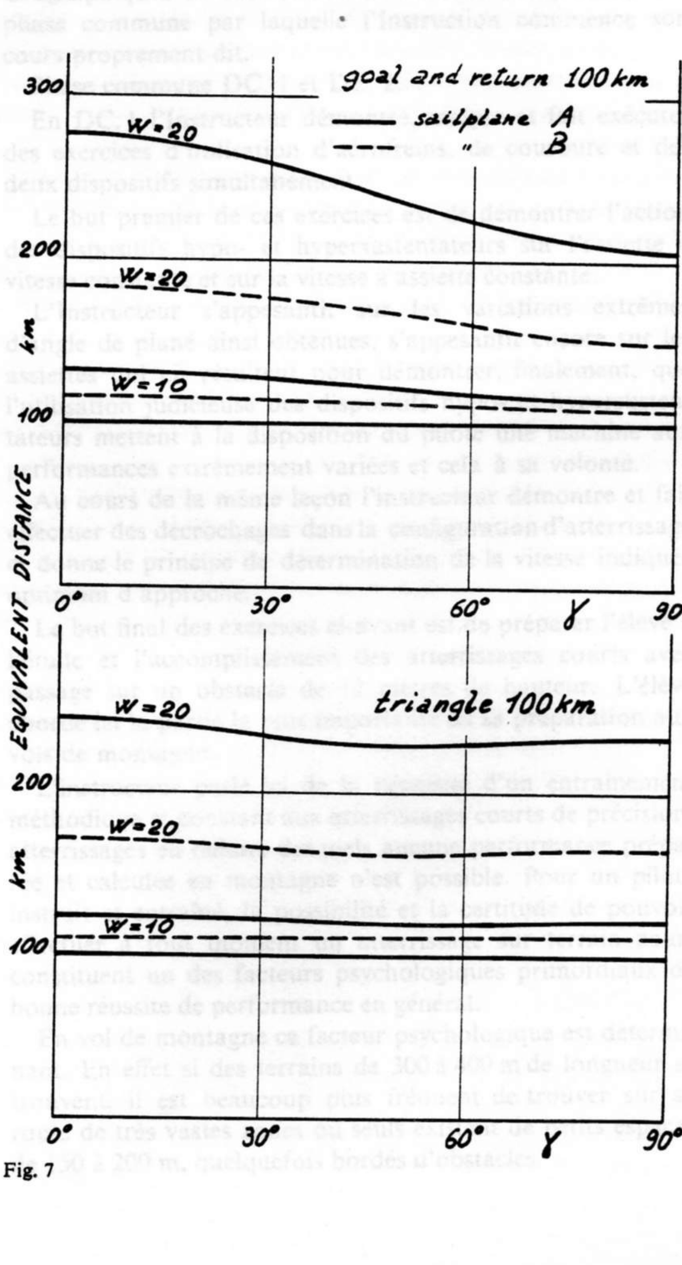

Fig. 7

In some competitions where different types of sailplanes are admitted, a system of handicaps is imposed. In the light of the results here obtained, it seems to be very difficult indeed to determine the right handicap if the strength of the wind is also to be taken into account! On the other hand, it would not be right that the handicap does not take into account the effect of the wind, if a considerable wind is present. If, moreover, the difficulty of forecasting wind speed and direction (both variable with the altitude!) is considered, it should be concluded that no satisfactory system of handicapping may be applicable to gliding competitions.

It may also be interesting to remark, from fig. 7, that the effect of the wind varies considerably with the wind direction. This effect becomes particularly evident for strong winds and does exist also for triangular courses, a case in which it might be unexpected.

Table III
Equivalent distance (km)

γ	100 km goal and return W = 10	100 km goal and return W = 20	100 km triangle W = 10	100 km triangle W = 20
Sailplane A				
0°	132	280	125	246
30°	127	259	124	235
60°	119	224	122	231
90°	115	206	124	235
Sailplane B				
0°	116	183	112	173
30°	115	176	113	167
60°	111	162	114	165
90°	109	150	113	167

(Swiss Aero-Revue 4/1965)