A Proposal for a New Variometer System

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INTRODUCTION

There are usually two things of great importance to the cross-country flying pilot: (1) the effective range of his glider, which should enable him to reach the next thermal or his goal at the end of his flight, and (2) the cross-country speed, which determines to a large extent his cross-country performance. Accordingly, the intention of this paper is to work out basic principles for an electronic variometer system which is able to measure, perform and display to the pilot continuously during flight the effective gliding and cross-country performance, in addition to the well known functions such as rate of climb and descent, speed-to-fly, etc.

A) The Effective Gliding Performance

On interthermal cruise the pilot has to control first of all his effective range, which depends strongly on the meteorological conditions (up and downdraft distributions), the actual performance of the glider (the polar) and the chosen speed. The range depends on the effective glide ratio $\overline{glr}(t)$, which we could measure by using the average values of the variometer signal $\overline{Vario}(t)$ and the true air speed $\overline{V}(t)$:

$$\overline{glr}(t) = \frac{\text{flown distance}}{\text{loss of height}} \approx \frac{\overline{V}(t)}{-\overline{Vario}(t)} \qquad (1)$$

To obtain the mean values of the air speed and the rate of descent we could use running integrators (low pass filters) according to Ref. 1:

$$\overline{V}(t) = \frac{1}{T_V} \int_{t_o}^{t} (V(t) - \overline{V}(t))dt + \overline{V}(t_o) \qquad (2)$$

$$\overline{Vario}(t) = \frac{1}{T_{Vario}} \int_{to}^{t} (Vario(t) - \overline{Vario}(t))dt + \overline{Vario}(to) \qquad (3)$$

The time constants T_V and T_{Vario} determine the time periods for which the averaging is performed. If we use very short time constants ($\overline{V}(t) \rightarrow V(t)$ for $T_V \rightarrow 0$ and $\overline{Vario}(t) \rightarrow Vario(t)$ for $T_{Vario} \rightarrow 0$, we get the instantaneous glide ratio:

$$glr(t) \approx \frac{V(t)}{-Vario(t)} \qquad (4)$$

Unfortunately the glide ratio glr(t) is not very practicable for dolphin-flying, as for Vario(t) = 0 the glide ratio will be infinite [$glr(t) = \infty$]. See Fig. 1. For this reason, we should use the slope of the glide path as an expression for the actual gliding performance which is defined by:

$$\overline{glp}(t) = \frac{\text{gain of height}}{\text{flown distance}} \approx \frac{\overline{Vario}(t)}{\overline{V}(t)} \qquad (5)$$

$$glp(t) \approx \frac{Vario(t)}{V(t)} \qquad (6)$$

The function (6) for the gliding performance works like a variometer, where the scale factor is varied by the reverse function of the true air speed 1/V(t). See also Fig. 2.

B. The Cross-Country Performance

A measure of the cross-country performance is normally (1) the distance the pilot was able to fly, or (2) the time the pilot had to spend for a given speed task. In both cases, the total average

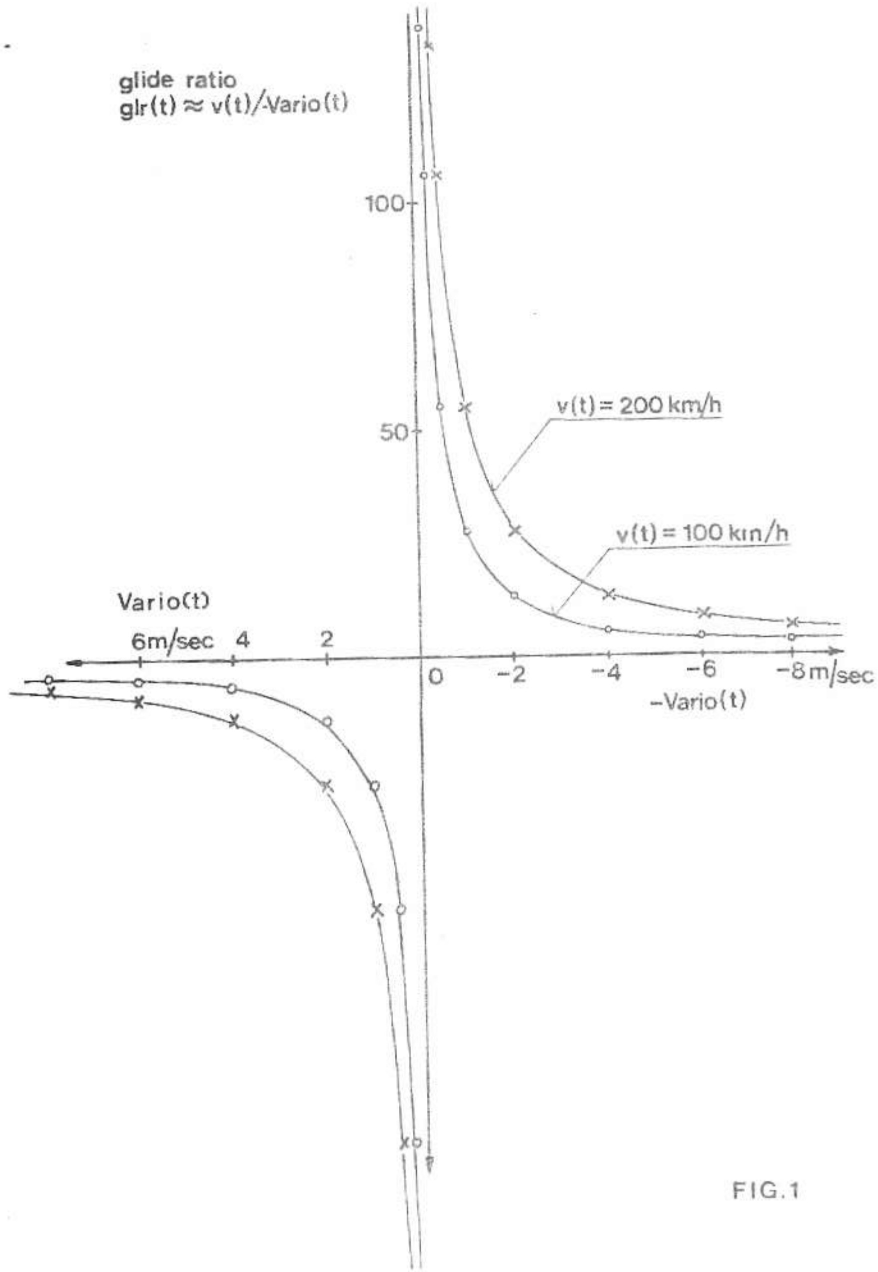

glide ratio
glr(t) ≈ v(t)/-Vario(t)
100
50
v(t) = 200 km/h
v(t) = 100 km/h
Vario(t)
6m/sec
4
2
0
-2
-4
-6
-8 m/sec
-Vario(t)

FIG.1

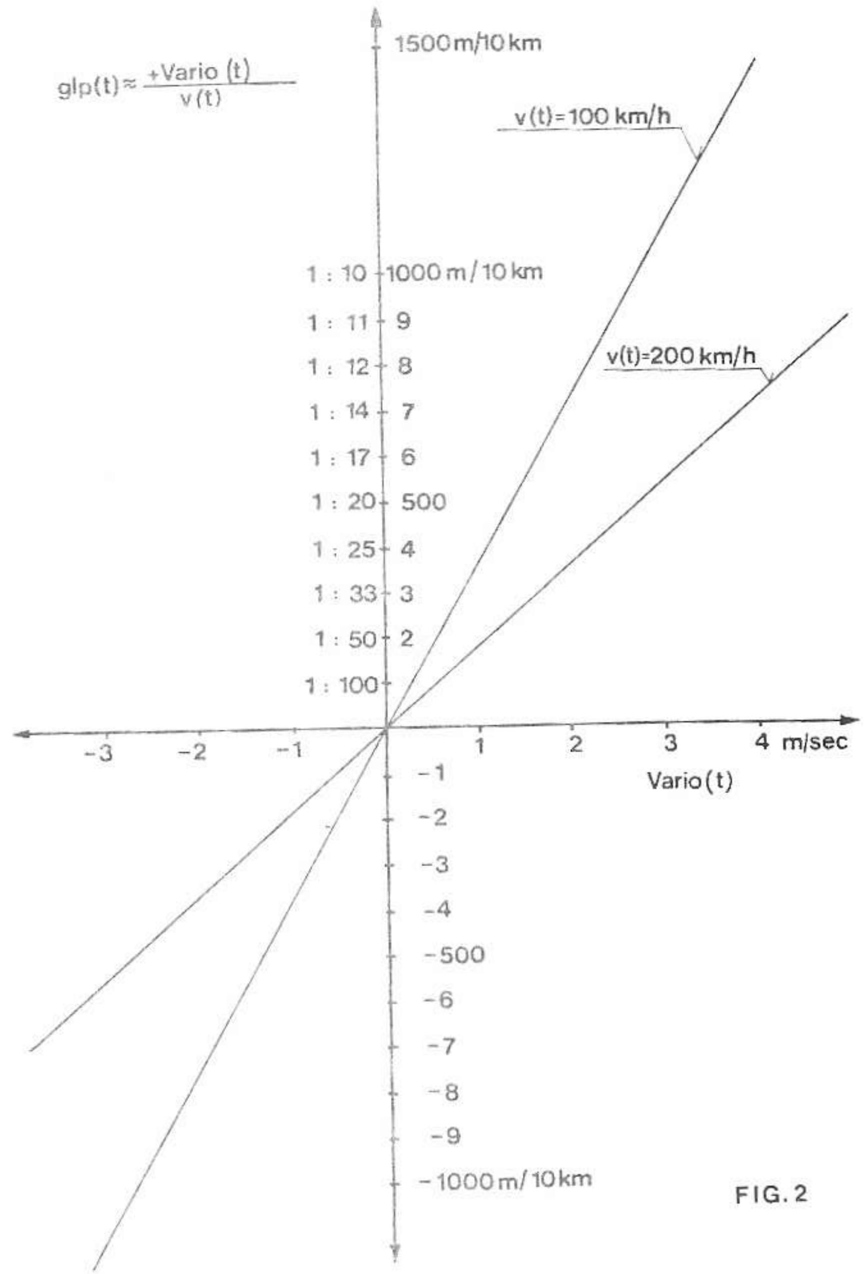

glp(t) ≈ +Vario (t) / v(t)
1500 m/10 km
v(t)=100 km/h
v(t)=200 km/h
1 : 10
1000 m / 10 km
1 : 11
9
1 : 12
8
1 : 14
7
1 : 17
6
1 : 20
500
1 : 25
4
1 : 33
3
1 : 50
2
1 : 100
-3
-2
-1
1
2
3
4 m/sec
Vario (t)
-1
-2
-3
-4
-500
-6
-7
-8
-9
-1000 m/10 km

FIG. 2

cross-country speed, defined by

$$\overline{VR}(t)\text{total} = \text{flown distance/durance of flight} \quad (7)$$

plays a dominant role. According to the relation:

$$\text{distance} = VR(t)\text{total} \cdot \text{time of flight} \quad (8)$$

the distance is higher for (1) higher cross-country speeds and (2) for longer flights, and the time of flight according to :

$$\text{time of flight} = \text{distance of task} / \overline{VR}(t)\text{total} \quad (6)$$

is less, the higher the cross-country speed of the pilot is.

Due to these relations (8 and 9) the cross-country speed (7) is often used as a measure for the cross-country performance. Yet the relation (7) only shows the performance of the whole flight. To gain further insight, consider the average and instant cross-country speeds (which will be defined in detail below) which are much more interesting to the pilot as they give him a chance to see where he is doing well or where he is losing time. They deliver immediate quantitative information on the pilot's situation and give him the possibility of quick and better analysis of his flying techniques.

For better understanding, imagine a glider and a motorplane flying the same task with the same cross-country speed. According to this assumption they cross the starting line at the same time, fly along as a team and also finish the task in the same total time. Although they have by presumption the same cross-country speed, their maneuvers are quite different. The motorplane flies along the straight line from the starting to the finishing point, which we might call the reference line. So, to keep up with the motorplane the glider pilot has to be in front. If he sinks below the reference line he has to stop his interthermal cruise to climb back to the reference line, where he meets the motorplane again, and he will stay back if he continues to climb up in the updraft higher than the reference line. The idea now is to develop an instrument which is able to perform and display the cross-country speed of the comparing motorplane to the glider pilot. We see from this example that the so-defined cross-country speed of the glider is not zero if the glider is in the thermaling mode, and not equal to the indicated air speed in the gliding or interthermal cruising mode, except for the case where the glider flies along the reference line.

For the evaluation of the average cross-country speed we could use the model of Späte, Nickel and MacCready, where the reference line might have a slope ($k = tg\alpha$) due to Reichmann (Ref. 2). The cross-country speed then is (Fig. 3):

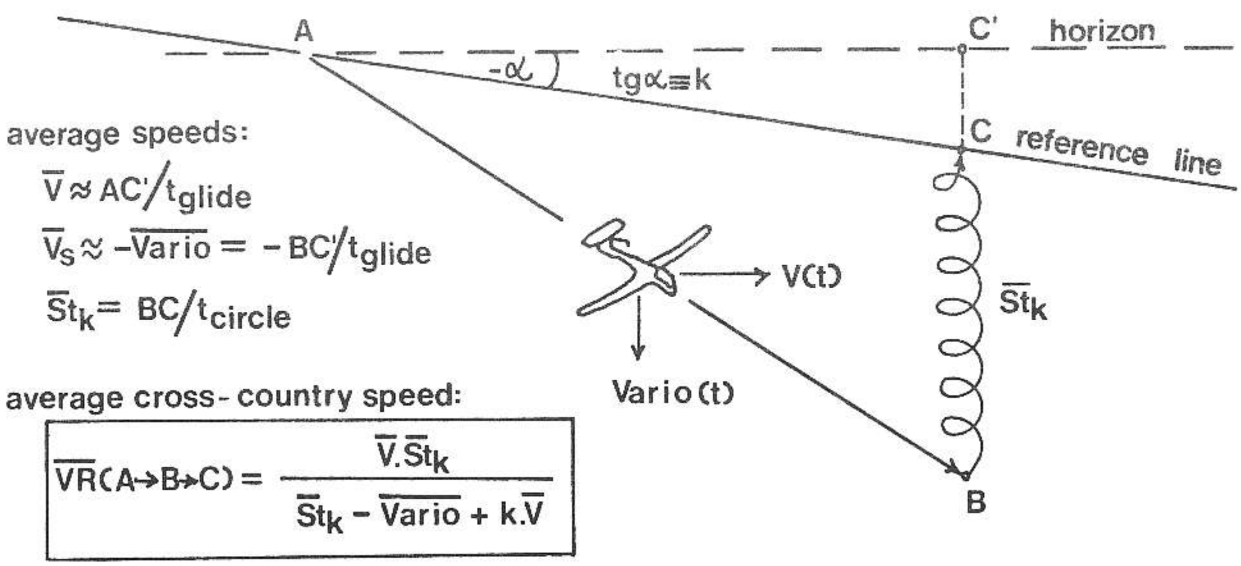


FIG.3

$$\overline{VR}_{ABC} = \frac{s_{AC}}{t_{AB} + t_{BC}} = \frac{\overline{St}_k \cdot \overline{V}}{\overline{Vs} + \overline{St}_k + k \cdot \overline{V}} \quad (10)$$

for the average speeds:

$$\overline{V} = \frac{s_{AC}}{t_{AB}}; \quad \overline{St}_k = \frac{s_{BC}}{t_{BC}}; \quad \overline{Vs} = \frac{s_{BC}}{t_{AB}} \quad (11)$$

The average speeds V, Vs can only be determined after the pilot has finished his interthermal glide and St_k after the pilot has reached the reference line again. According to this calculation method the cross-country speed could only be evaluated after the pilot has gone through the complete period starting from A to B and then ending up in C. This means that we would get the average cross-country speed only after passing certain discrete points of the flight path. But what we really want is to measure the average cross-country speed continously.

We could do this by using for instance (see Fig. 4):

$$\overline{VR}(t) = \frac{S(t) - S(to)}{(t-to) + \frac{h(t)ref - h(t)}{MC}} \quad (12)$$

where MC is the MacCready-setting, estimating the rate of climb with which the pilot would be able to climb back again to the reference line where h(t)ref is the height of the reference line at the position S(t), h(t) is the height of the glider and S(to) represents the position at the time t_o at the beginning of the considered flown distance S(t) - S(to). This expression is only useful for long term integration, since $d\overline{VR}(t)/dV(t) = 0$ is not necessarily fulfilled for MacCready flying speeds (Ref. 3).

A continuous display of the cross-country speed could be achieved if we change our method of averaging in the MacCready model of Fig. 3 by using, for instance, running integrators (low pass filters, Ref. 1):

$$\overline{f}(t) = \frac{1}{T}\int_{to}^{t}(f(t)-\overline{f}(t))dt + \overline{f}(to) \quad (13)$$

f(t) being an arbitrary function and T

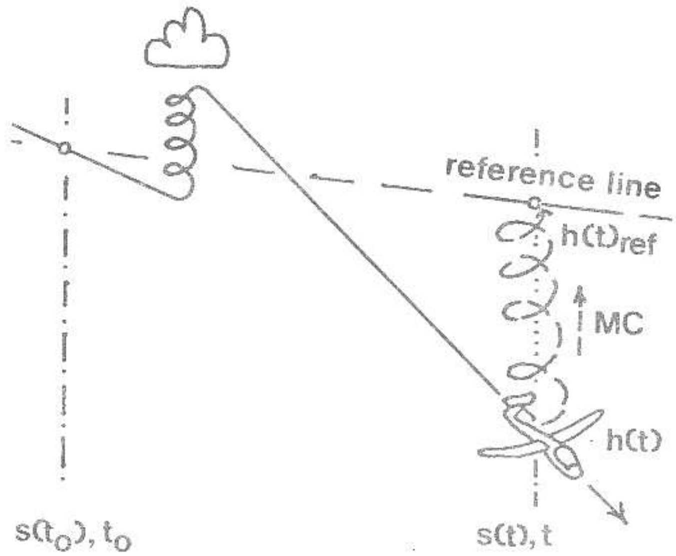


FIG. 4

the time constant.

So we get, if the averaging is done during the interthermal cruise (see Fig. 5):

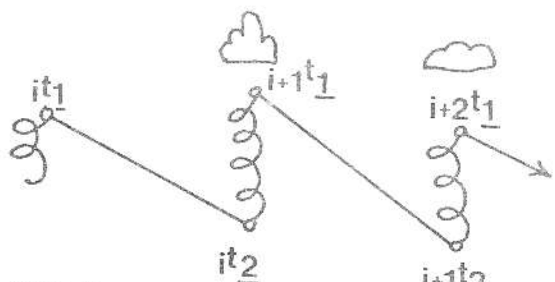


FIG. 5

$_it_1$ t $_it_2$; (i = number of section; 1 = pilot stops thermaling and starts interthermal cruise; 2 = pilot stops interthermal cruise and starts thermaling in the updraft)

$$\overline{V}(t) = \frac{1}{T_V}\int_{_it_1}^{_it_2}(V(t)-\overline{V}(t))dt + \overline{V}(_it_1)$$

$$\overline{Vs}(t) = \frac{1}{T_{Vs}}\int_{_it_1}^{_it_2}(Vs(t)-\overline{Vs}(t))dt + \overline{Vs}(_it_1) \quad (14)$$

$$= -\overline{Vario}(t)glide$$

$$\overline{St}_k(t) = \overline{St}_k(_it_1) = \overline{St}_k$$

the last named being constant during interthermal cruise and for the averaging during thermaling:

$${}_it_2 \leq t \leq {}_{i+1}t_1$$

$$\left.\begin{aligned} \overline{V}(t) &= \overline{V}({}_it_2) = \overline{V} \\ \overline{Vs}(t) &= \overline{Vs}({}_it_2) = \overline{Vs} \end{aligned}\right\} \text{constant during thermaling} \tag{15}$$

$$\overline{St}_k(t) = \frac{1}{T_{St}} \int_{{}_it_2}^{{}_{i+1}t_1} (St_k(t) - \overline{St}_k(t))dt + \overline{St}_k({}_it_2) = \overline{\text{Vario}(t)\text{circle}}$$

We see from this that there are two different flying modes:

a) the interthermal cruising mode where we have to average $V(t)$ and $Vs(t)$ to obtain $\overline{V}(t)$ and $\overline{Vs}(t)$, while the (in previous sections measured) average rate of climb $\overline{St}_k$ is held constant, and

b) the circling (thermaling) mode where the averaging of the rate of climb $St_k(t)$ takes place to obtain $\overline{St}_k(t)$, while the values for $\overline{V}$, $\overline{Vs}$ are now kept constant.

So, we get the following expressions for the average cross-country speed $\overline{VR}(t)$:

$$\overline{VR}(t)\text{glide} = \frac{\overline{V}(t).\overline{St}_k}{\overline{Vs}(t) + \overline{St}_k + k.\overline{V}(t)} \tag{16}$$

$$\overline{VR}(t)\text{circle} = \frac{\overline{V}.\overline{St}_k(t)}{\overline{Vs} + \overline{St}_k(t) + k.\overline{V}} \tag{17}$$

$\overline{VR}(t)$glide is the cross-country speed for the interthermal cruise and $\overline{VR}(t)$circle for the thermaling mode.

With this method the average cross-country speed is not measured for certain discrete sections or periods of the distance, but for time constants of integration: T_V, T_{Vs}, T_{St}. To find the time-constants that are practicable in flight they should be easily adjustable in an electronic variometer system.

If we choose very small time constants (short integration time, for instance T = 1 sec) then it is not common to talk of average speeds anymore, but of instant speeds ($\overline{V}(t) \to V(t)$ for $T_V \to 0$, $\overline{Vs}(t) \to Vs(t)$ for $T_{Vs} \to 0$, $\overline{St}_k(t) \to St_k(t)$ for $T_{St} \to 0$). According to this, we are able to define now the instant cross-country speed $VR(t)$:

$$VR(t)\text{glide} = \frac{V(t).\overline{St}_k}{Vs(t) + \overline{St}_k + k.V(t)} \tag{18}$$

$$VR(t)\text{circle} = \frac{\overline{V}.St_K(t)}{\overline{Vs} + St_k(t) + k.\overline{V}} \tag{19}$$

Here we should stop for a moment and consider the philosophy concerning the present, past and future:

The expressions (16 and 17) measure the average cross-country speed from the past up to the present, where the influence of the past situations gradually fade away depending on the time constant used. This is very useful if we want to analyse our flight for time periods that have just passed. But if we consider the expressions (18 and 19) for the instant cross-country speed, the combination of the present situation, characterized by $V(t)$, $Vs(t)$, $St_k(t)$ and the past situation ($\overline{St}_k$, $\overline{V}$, $\overline{Vs}$) seems now not to be very useful.

If we want to find the best tactic (according to the flight route, the optimum ring-setting, the decision whether we should thermal or continue our dolphin flying etc.), then we have to consider only the present situation and the estimated conditions of the future. Unless we expect similar conditions in the future, we should take care not to get influenced by things that have just happened and lie now behind us. Actually, we should forget the past as quickly as possible.

If we fly now according to a chosen tactic with optimum speeds, we expect that the displayed instant cross-country speed also shows an optimum. This is only possible if the instant cross-country speed is a combination of the present and the estimated future. Therefore, instead of the measured average rate of climb $\overline{St}_k$, we have to use the rate of climb which we expect in the next thermal MC, and, instead of the averaged values of $\overline{V}$, $\overline{Vs}$, the average speeds $\overline{V}_{future}$, $\overline{Vs}_{future}$ we expect on our next interthermal glide. The latter is easy if the weather conditions are not expected to change since in that case $\overline{V}_{future}$, $\overline{Vs}_{future} = \overline{V}_{past}$, $\overline{Vs}_{past}$.

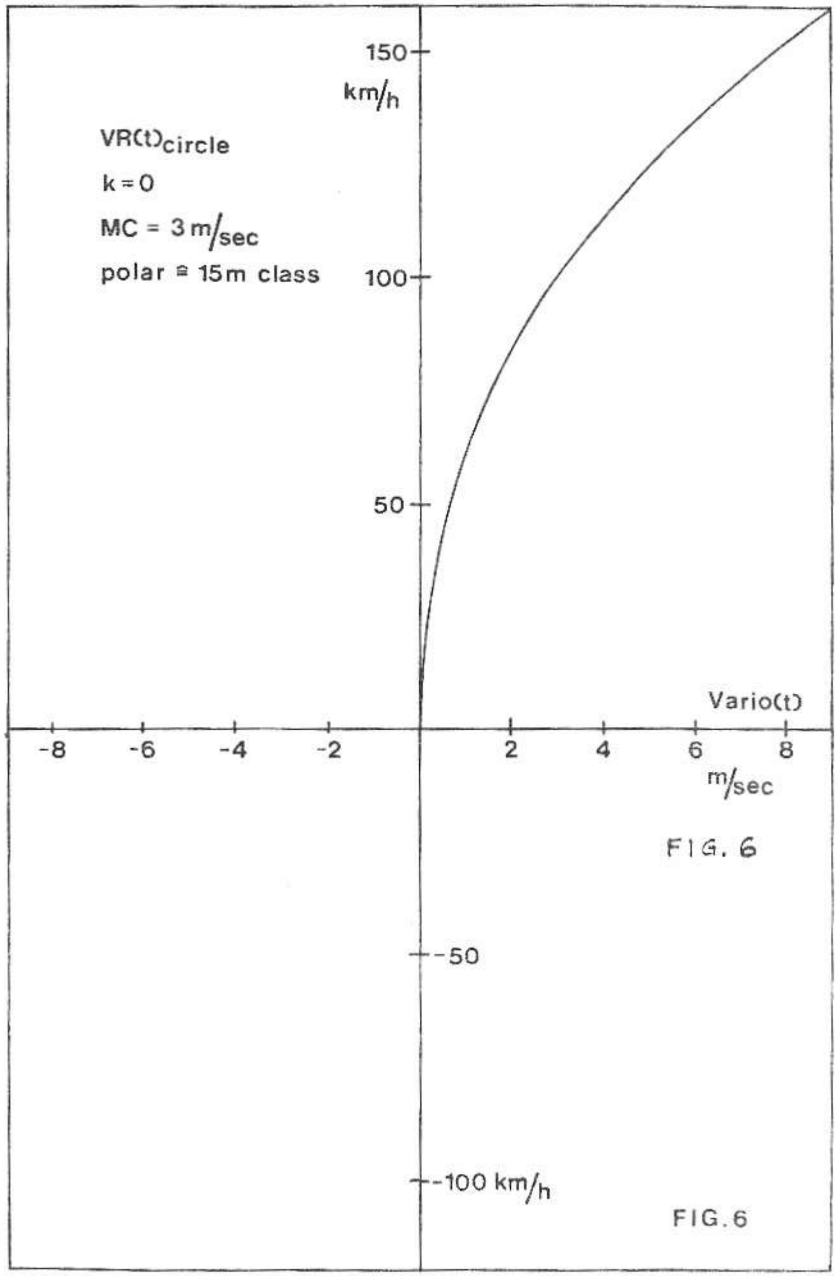

VR(t)circle
k = 0
MC = 3 m/sec
polar ≅ 15m class
150
km/h
100
50
-50
-100 km/h
Vario(t)
-8
-6
-4
-2
2
4
6
8
m/sec
FIG. 6

FIG.6

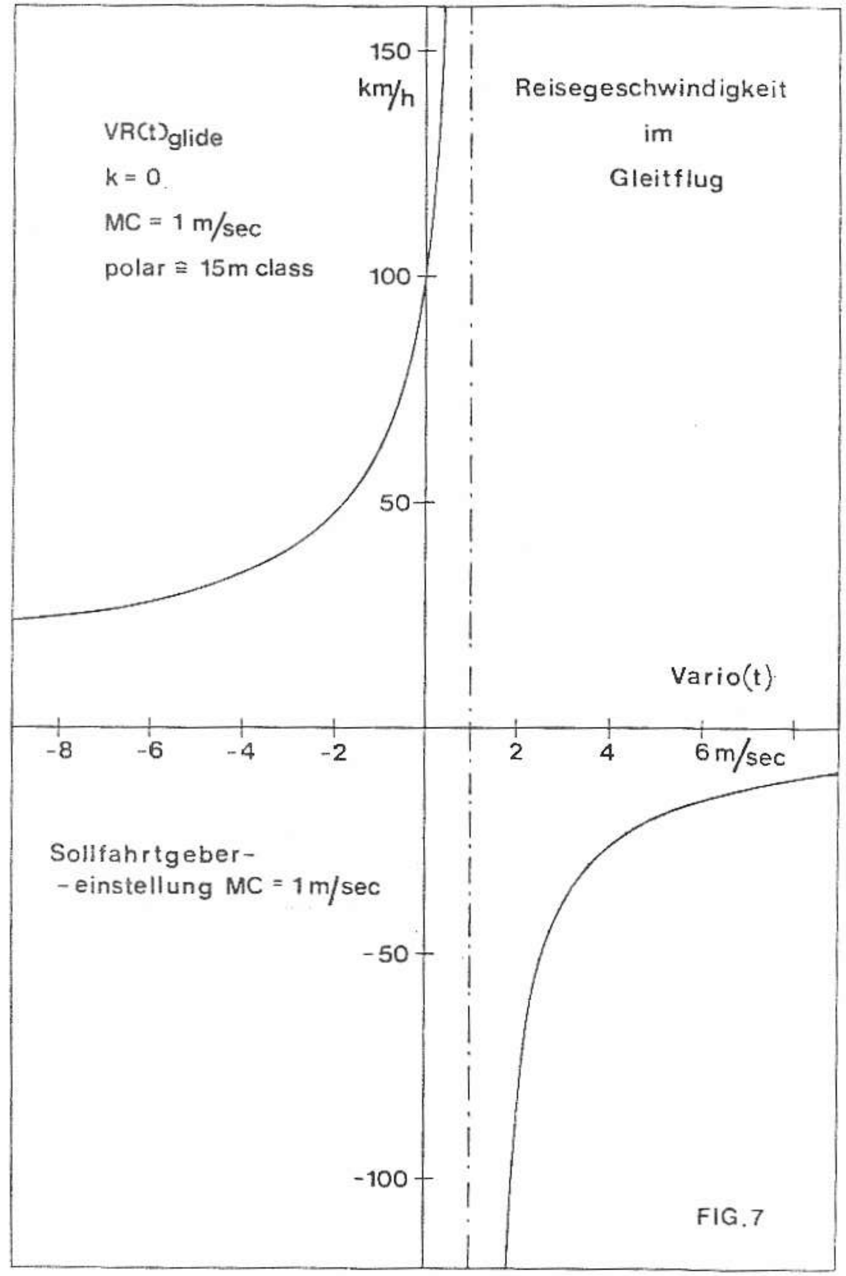

VR(t)glide
k = 0
MC = 1 m/sec
polar ≅ 15m class
Reisegeschwindigkeit
im
Gleitflug
150
km/h
100
50
-50
-100
Vario(t)
-8
-6
-4
-2
2
4
6 m/sec
Sollfahrtgeber-
-einstellung MC = 1 m/sec

FIG.7

Normally, however, it is too difficult to estimate those two parameters V_{future}, Vs_{future}. But by similarity with the problem of estimating the glide ratio for the final glide, we might characterize the weather conditions ahead by using only one parameter - the MacCready setting. Here, V_{future} = V(MC)opt; Vs_{future} = Vs(MC)opt are the MacCready speeds calculated from the polar of the glider ($Vs = a.V^2 + b.V + c$). Additionally, we have to assume that the vertical air movement on our next interthermal flight path is negligible. In this case the tactic we choose will be characterized by the MacCready setting MC alone, and in the expressions (18 and 19) the following parameters should be exchanged:

$$\begin{aligned} &\overline{St}_k \rightarrow MC \\ &\overline{V} \rightarrow Vopt(MC) \qquad (20) \\ &\overline{Vs} \rightarrow Vs(MC)opt \end{aligned}$$

For the instant cross-country speed we get therefore:

$$VR(t)glide = \frac{V(t).MC}{Vs(t) + MC + k.V(t)} \qquad (21)$$

and in that case, where the conditions up to the next thermal are exactly the same as in the past, we could use the expression in (19) for VR(t)circle.

To be able to study the functions for the cross-country speed (22), VR(t)circle will be calculated for an assumed polar in dependance of the vario signal ($St_k(t)$ = Vario(t)circle) with a chosen MacCready setting of MC = 3m/sec and a horizontal reference line (k = 0). The result is shown in Fig. 6. We see that the function behaves normally and that the cross-country speed is higher for higher values of the achieved rate of climb.

We study now the function (21) for the instant cross-country speed during interthermal cruise in dependance of the variometer signal(Vs(t)=-Vario(t)glide) also for K = 0 and a MacCready setting of MC = 1m/sec. See Fig. 7. As long as the variometer signal is negative, the indicated cross-country speed seems to be correct, but for Vario(t) greater than zero the function rapidly becomes infinite (VR(t)glide = ∞ for Vario(t) = MC) and for even higher values of the variometer signal changes its sign. The indicated cross-country speed becomes negative although the pilot is flying in best conditions! This is clearly nonsense. The explanation for this may be given by Fig. 8: for Vario(t) greater than k.V(t) the glider climbs above the reference line. The model used according

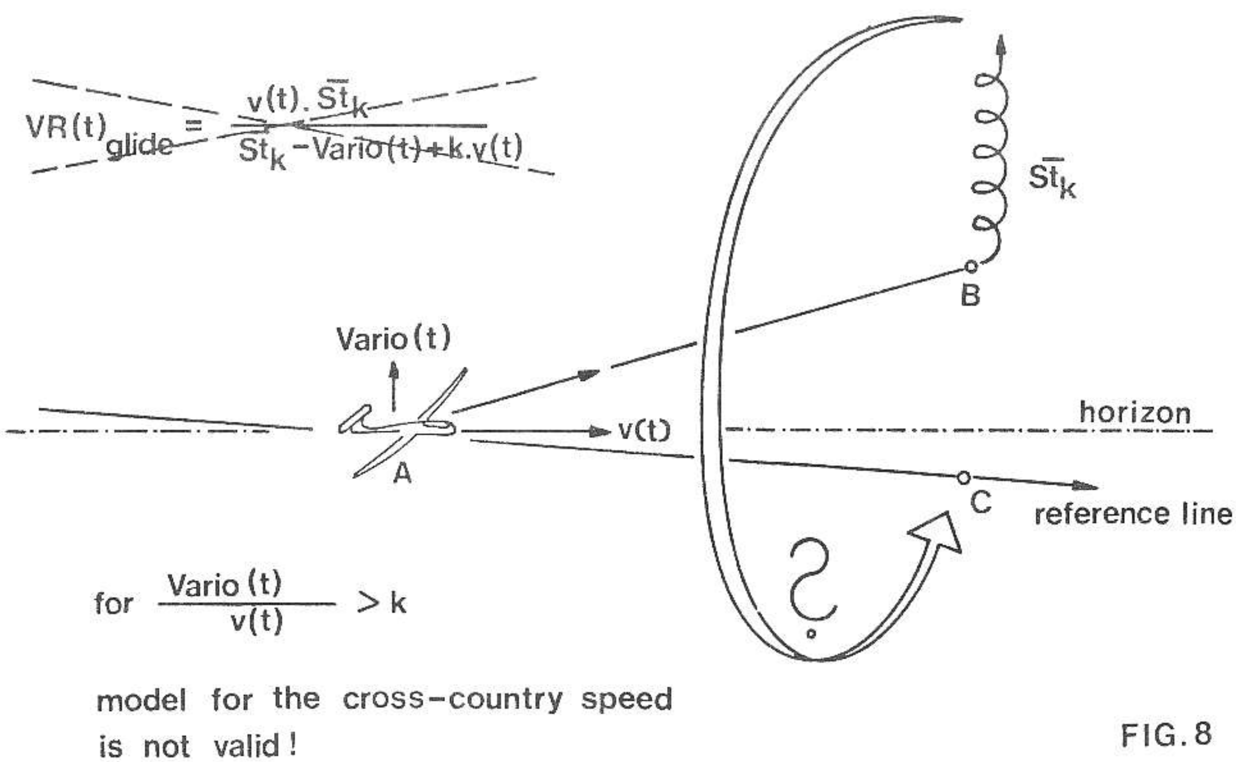


FIG. 8

to Fig. 3 assumes that the pilot at the end of his interthermal cruise in B changes to thermaling to climb back to the reference line. In this case this is absolutely impossible by climbing up in the updraft. Therefore, the model in this case is not valid; in other words, for Vario(t) greater than k.V(t), it is impossible to define something like a cross-country speed. This is now quite a serious problem since we want to determine somehow the influence of our present situation on our cross-country performance or on our average cross-country speed as far as this average cross-country speed is also defined (the slope of the corresponding average glide path has to be less than the slope of the reference line).

A Solution to this Problem

To find a solution to this problem we could at first change our calculation model and use a model according to Fig. 9 (Ref. 4 and 5). In this new model we assume that the present situation ($V(t)$, $Vs(t) = -Vario(t)$) holds only for p% of the considered section S. For the rest ((1-p)% of the distance S) we assume that the pilot flies with the average speed $\overline{VR}(t)$ which might be measured according to (16 and 17).

If we calculate now the cross-country speed $VR^+(t)$ for the whole section S, we see that this new cross-country speed is a combination of $\overline{VR}(t)$ and the instant cross-country speed VR(t) according to (21) and (22):

$$VR(t)circle = \frac{St_k(t).Vopt(MC)}{Vs(MC)opt + St_k(t) + k.Vopt(MC)} \quad (22)$$

$$VR^+(t) = \frac{1}{\frac{p}{VR(t)} + \frac{(1-p)}{\overline{VR}(t)}} \quad (23)$$

The value of $VR^+(t)$ is valid as long as p is small enough so that the average glide path ends up below the reference line at the end of the distance S. See Fig. 10 where $VR^+(t)$ has been calculated for a 15m machine with MC = 3m/sec in dependance of Vario(t) for several values of p.

Now we can use $VR^+(t)$ as an indication for the instant cross-country performance instead of VR(t) as it will behave normally. Unfortunately, for small values of p, $VR^+(t)$ is rather insensitive to changes in the momentary situation, which is still characterized in (23) by VR(t). That means that $VR^+(t)$ will show rather small deviations from $\overline{VR}(t)$ for small values of p:

$$\lim_{p \to 0} (VR^+(t) - \overline{VR}(t)) = 0 \quad (24)$$

We are interested in functions that are able to show the effect of the present situation on the cross-country speed. $VR^+(t)-\overline{VR}(t)$ would be such a function, but it depends strongly on the chosen factor p. To avoid this, we divide this function by p, which is working here as a scale factor. This new function

$$\frac{VR^+(t) - \overline{VR}(t)}{p} \quad (25)$$

is not very sensitive to changes in p, as can be seen in Fig. 11 for an assumed example with MC = 3m/sec. If we now consider very small values of p, we get the following expression:

$$\lim_{p \to 0} \frac{VR^+(t)-\overline{VR}(t)}{p} = \frac{VR(t)-\overline{VR}(t)}{VR(t)} \cdot \overline{VR}(t) \quad (26)$$

An interpretation of this result shows that we have found a function which fulfills all requirements and which we might call the Relative Cross-country Performance function:

$$P(t)rel = \frac{VR(t) - \overline{VR}(t)}{VR(t)} \quad (27)$$

$$P^+(t)rel = P(t)rel \cdot 100\% \quad (28)$$

The function (28) shows the relative gain of the cross-country speed as a percentage of the instant cross-country speed.

Some Advantages and Characteristics of P(t)rel:

1. Due to the fact that (27) may be written also by

$$P(t)rel = 1 - \frac{\overline{VR}(t)}{VR(t)} \qquad (29)$$

we see that VR(t) may be negative or infinite, but the Relative Performance function still remains finite.

2. The relative Performance function shows an optimum if the pilot flies with optimum speeds according to MacCready, but is is not necessary here to know the polar of the glider as it is for the normally used Speed-to-Fly instrument.

3. If k=0 (reference line is horizontal) then for $Vs(t) = -Vario(t)glide = MC$: $P(t)rel \cong 1$ or $P^{+}(t)rel = 100\%$. If $VR(t) = \overline{VR}(t)$ then $P(t)rel = 0$.

4. Since

$$VR(t)-\overline{VR}(t) \approx \frac{VR(t)-\overline{VR}(t)}{VR(t)} . \overline{VR}(t) = P(t)rel.\overline{VR}(t)$$

we find another method of calculating the cross-country speed where we only have to use one integration time constant T_{VR}:

$$VR(t) \approx \frac{1}{T_{VR}} \int_{to}^{t} P(t)rel.\overline{VR}(t)\, dt + \overline{VR}(to) \qquad (30)$$

Another Solution to the Problem:

If we study the cross-country model according to Fig. 9, we see that the instant cross-country speed VR(t) of (21) and (22) still plays a dominant role. $VR^{+}(t)$ of (23) and P(t)rel of (27) are always finite for finite values of Vario(t) because the reverse function of VR(t) is used. This suggests that the cross-country performance should be displayed by the reverse function of the cross-country speed which we define:

$$P(t) = -1 / VR(t) \qquad (31)$$

Consider what this could mean to the pilot. For simplicity let us assume that the reference line is horizontal (k=0). Then, according to Fig. 3:

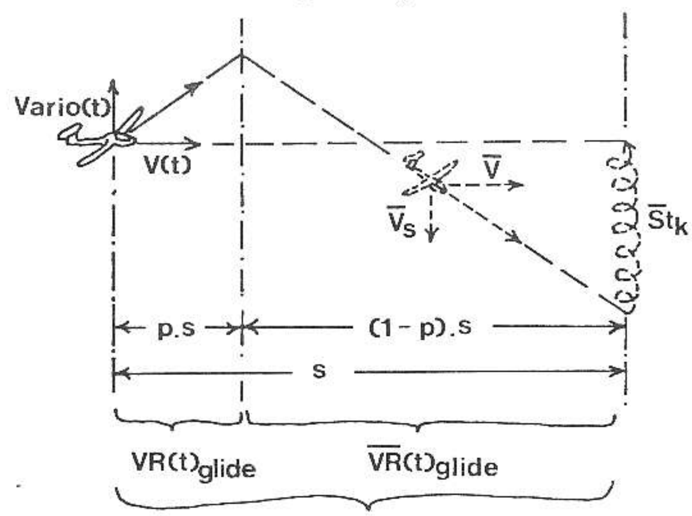
$$\frac{1}{\overline{VR}(ABC)} = \frac{t_{AB} + t_{BC}}{S} = \frac{t_{AB}}{S} + \frac{t_{BC}}{S} = \qquad (32)$$

$$= \frac{1}{\overline{V}} + \frac{\overline{Vs}}{\overline{V}.\overline{St}_k} = T(1) + T(2)$$

is the Time-loss of the glider per flown section S. The first Term T(1) indicates the loss of time over distance S due to the fact that the glider flies from A to B. The second Term T(2) shows the time-loss due to the fact that the pilot has to thermal in the updraft to climb back to the reference line. If the glider is sinking below the reference line on his interthermal cruise, then T(2) is positive and greater than zero. If the glider manages now to do some dolphin flying so that he loses no height according to the reference line, the second Term T(2) is Zero (T(2)=0). In this case no time will be lost per flown section S for thermaling in the updraft. The cross-country speed is equal to the air speed of the glider ($\overline{VR} = \overline{V}$).

What happens now if the glider gains height on his interthermal cruise? Then the Term T(2) becomes negative. This means that the glider has gained a time bonus according to the gain of height on the interthermal flight. This gain of time can be spared if the glider has to thermal again in the next updraft. If $\overline{Vs} = -\overline{St}_k$, that means if the glider is able on the interthermal cruise to climb with the same vertical speed as it would climb by circling in the updraft at the end of the section S, then T(2) = -T(1)

for instance: straight flight



$$VR^{+}(t)_{glide} = \frac{1}{\dfrac{p}{VR(t)_{glide}} + \dfrac{(1-p)}{\overline{VR}(t)_{glide}}}$$

FIG.9

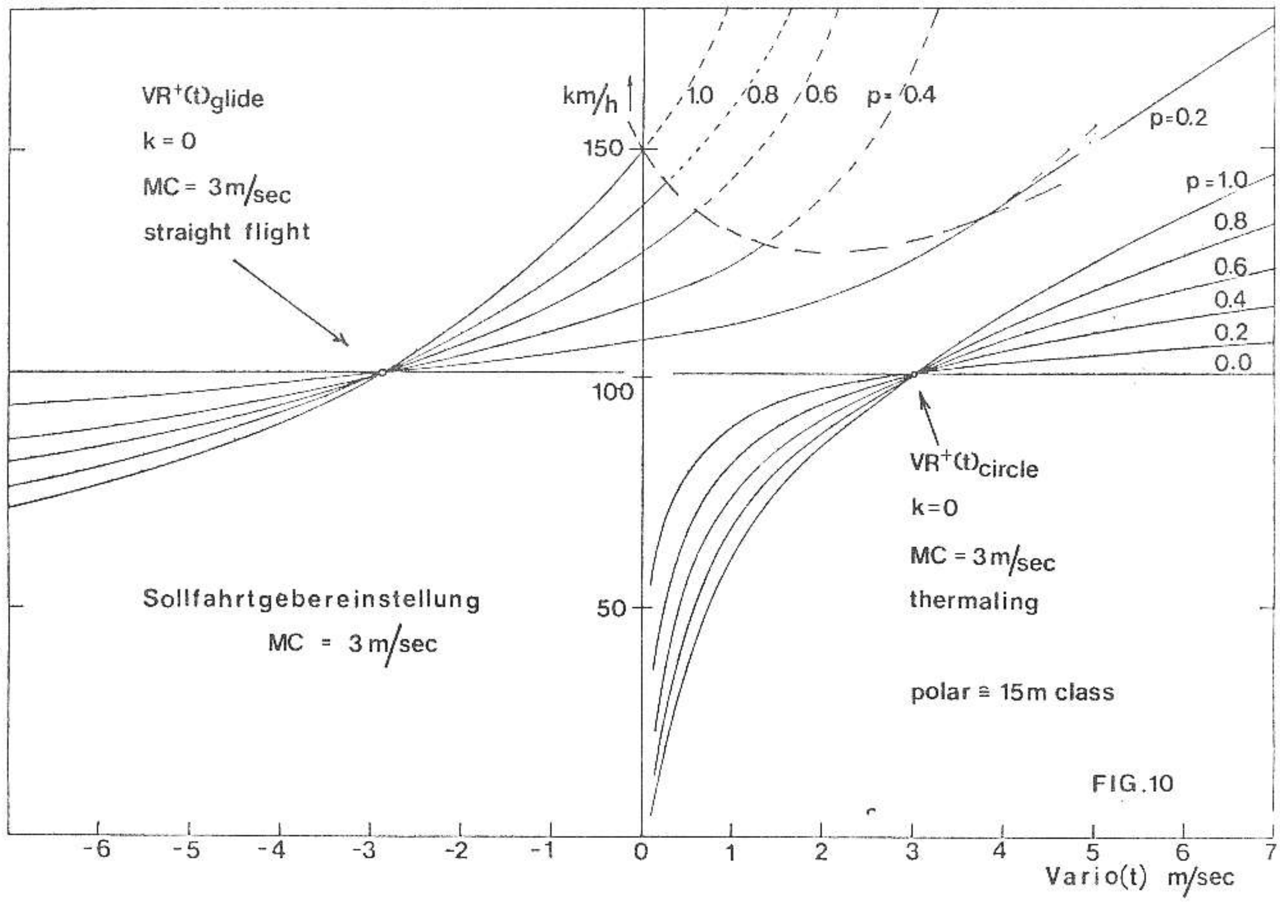

VR⁺(t)glide
k = 0
MC = 3 m/sec
straight flight
km/h
150
100
50
1.0 0.8 0.6 p = 0.4
p=0.2
p = 1.0
0.8
0.6
0.4
0.2
0.0
VR⁺(t)circle
k=0
MC = 3 m/sec
thermaling
Sollfahrtgebereinstellung
MC = 3 m/sec
polar ≙ 15m class
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Vario(t) m/sec

FIG.10

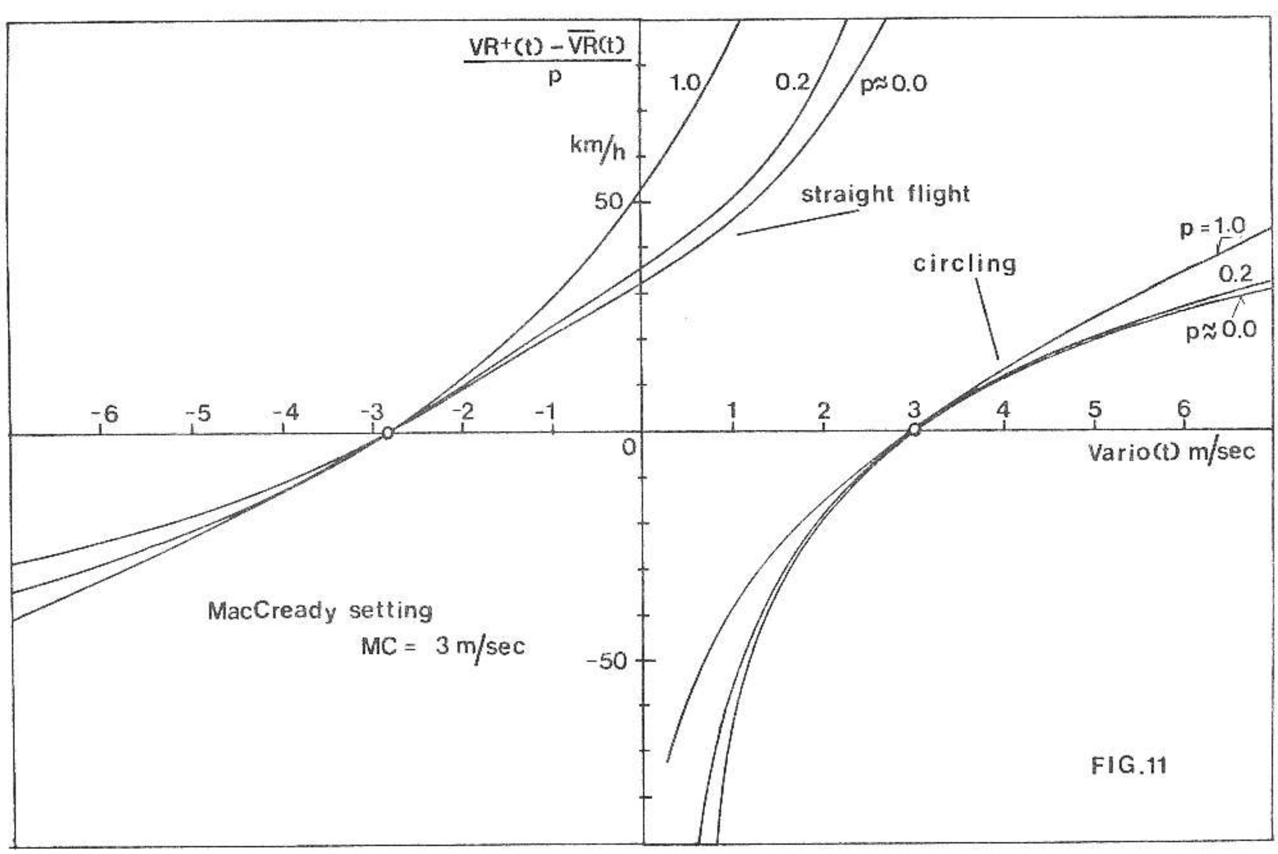

VR⁺(t) − V̄R(t) / p
km/h
50
-50
1.0 0.2 p≈0.0
straight flight
circling
p = 1.0
0.2
p≈0.0
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Vario(t) m/sec
MacCready setting
MC = 3 m/sec

FIG.11

and $1/\overline{VR} = 0$. The gain of time (-T(2)) due to gaining height equals the loss of time (=T(1)) due to gliding forward. And if the pilot climbs even better in the gliding configuration, then the gain of time (-T(2)) is higher than the loss of time due to T(1); that is, the sum of T(1) and T(2) becomes negative ($1/\overline{VR}$ is negative). The cross-country speed VR is then negative, but not because the pilot is flying in the negative direction, but because the time appears to be flowing backwards. This is quite remarkable!

For small integration time constants we have defined the instant cross-country speed VR(t) in (21 and 22). As a result of the definition (31) the cross-country performance function P(t) is now the gain of time per flown distance, which might be measured in units of min/km, sec/m etc., whatever is practicable for the pilot.

The problems discussed above (Fig. 8) show that it is not possible to define a cross-country speed in all situations. It is therefore preferable to talk in soaring not about the cross-country speed but about the gain or loss of time achieved per flown distance. Our intention on a cross-country flight should be to optimize the performance function P(t) during interthermal cruise and thermalling.

$$P(t)_{glide} = \frac{Vario(t)_{glide} - MC - k.V(t)}{V(t).MC} \qquad (33)$$

$$P(t)_{circle} = \frac{Vs(MC)_{opt} + Vario(t)_{circle} + k.V_{opt}(MC)}{-V_{opt}(MC).Vario(t)_{circle}} \qquad (34)$$

For the average values we might use a running integrator according to

$$\overline{P}(t) = \frac{1}{T_P}\int_{to}^{t}(P(t)-\overline{P}(t))dt + \overline{P}(to) \qquad (35)$$

or more accurately by using:

$$\overline{P}(t) = -1 / \overline{VR}(t) \qquad (36)$$

with $\overline{VR}(t)$ according to the definitions of (16) and (17).

Now, if we replace in (27) for the relative performance function P(t)rel and the instant cross-country speed $\overline{VR}(t)$ by $\overline{P}(t)$ of (33 and 34), and VR(t) by P(t) of (36) we get:

$$P(t)rel = \frac{VR(t)-\overline{VR}(t)}{VR(t)} = \frac{P(t)-\overline{P}(t)}{-\overline{P}(t)} \qquad (37)$$

We see now that the relative performance function of (27) is the relative gain of time per flown distance as a percentage of the mean loss of time per flown distance.

In Fig. 12 the working principle of an instrument performing the cross-country performance function is shown.

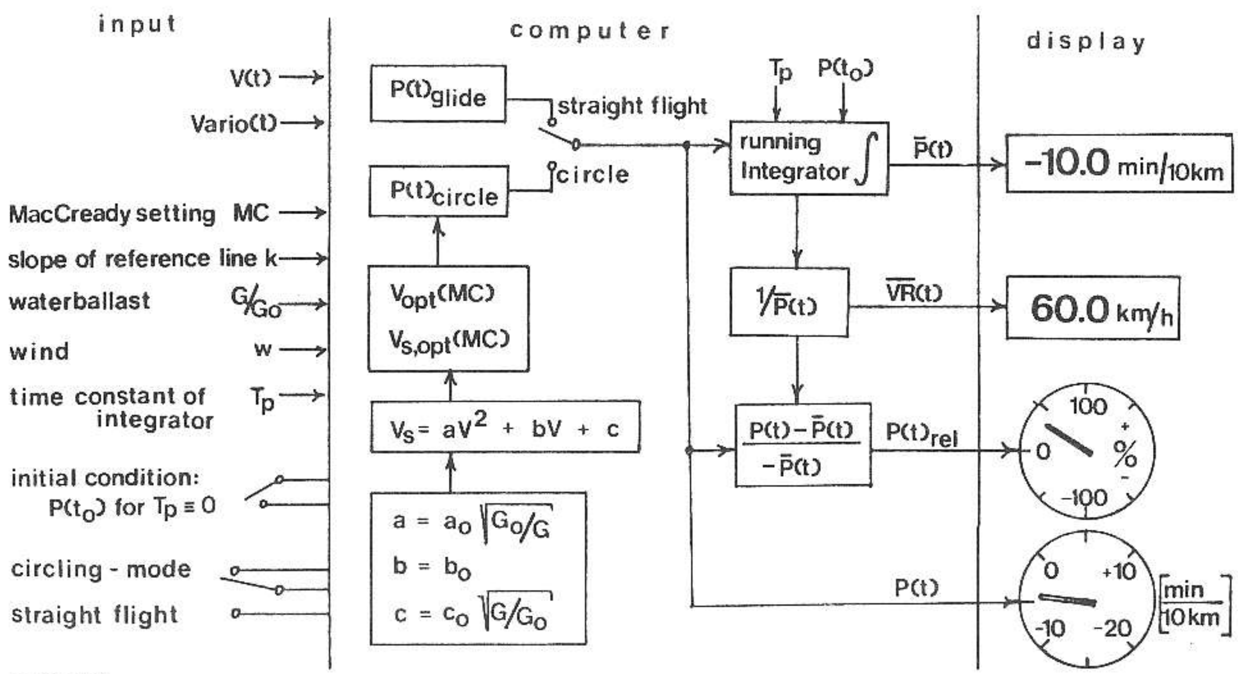


FIG.12

Some Advantages of Measuring the Cross-country Performance:

In the following we will summarize why it could be useful to measure and display to the pilot the functions P(t), $\overline{P}$(t) and P(t)rel during flight.

A variometer is an excellent instrument as long as the pilot tries to optimize his rate of climb in the thermal. In this case this instrument delivers feedback information to the pilot so that he is able to find out by trial and error optimum flying techniques for highest rates of climb. On interthermal cruise, the variometer loses its importance as the pilot is not interested in minimizing his rate of descent. The fundamental idea of cross-country performance measuring equipment is that the pilot gets feedback information which he can try to optimize, not only in ther thermaling mode, but also on interthermal cruise. According to this:

1. The instrument should be able to teach and train the cross-country soaring beginners much more quickly in obtaining higher and correct cross-country speeds.
2. The pilot could study the effect of various dolphin flying techniques on the cross-country speed and so could determine the best technique for those updrafts he actually finds on his cross-country flight. Up to now, for theoretical work and computer analysis, assumed updraft distributions have been used of which nobody knows whether they are of any practical value or not.
3. The technique of circling in a thermal for climbing and of leaving the updraft after having gained height could be studied.
4. The pilot gets quantitative information on how much time he is losing because of a mistake so that the pilot is able to minimize the amount and effect of his mistakes on the cross-country performance.
5. The time gain or loss due to the amount of waterballast can be determined
6. The instrument should help the pilot in his decisions - whether he should thermal or continue his interthermal cruise (dolphin flying).
7. To calculate departure angle from a cloudstreet off course you have to know, according to Ahrens (Ref. 6), the average cross-country speed which the instrument is able to measure.
8. The influence of tail and headwinds on the cross-country speed or performance could be studied very easily.
9. Due to an adjustable K-factor (slope of the average glide path) the pilot is able to measure his performance on the final glide.
10. The pilot should be able to find the "Speed-to-Fly" without having to know the polar of the glider, which is a necessary requirement for the MacCready-ring and the other known Speed-to-Fly instruments.

The Test Instruments:

A test instrument (Fig. 13) has been developed which is able to perform the proposed functions P(t), P(t)rel, $\overline{P}$(t), $\overline{VR}$(t), glp(t), etc. Six knobs allow adjustment of the time constants of the various integrators. In a later version, after practicable values for the time constants have been found in test flights, they might be omitted. The remaining four knobs allow adjustment of the MC-value (determining the tactic of the pilot), the K-factor (slope of the reference line), the weight of the glider (wing loading due to waterballast) and the value of the wind. Cross-country flying in the coming season with the instrument will show whether the suggested functions are of any help to the pilot or not.

Summary:

The concept of an electronic variometer system has been developed that should be able to measure, in addition to the already known functions of a variometer system, the slope of the glide path (glide ratio) and the cross-country performance during flight. Due to the fact that it is not possible to define a cross-country speed for all flying situations, the cross-country performance will be characterized by the time bonus (or time loss) the pilot gains (or has to spend) per flown

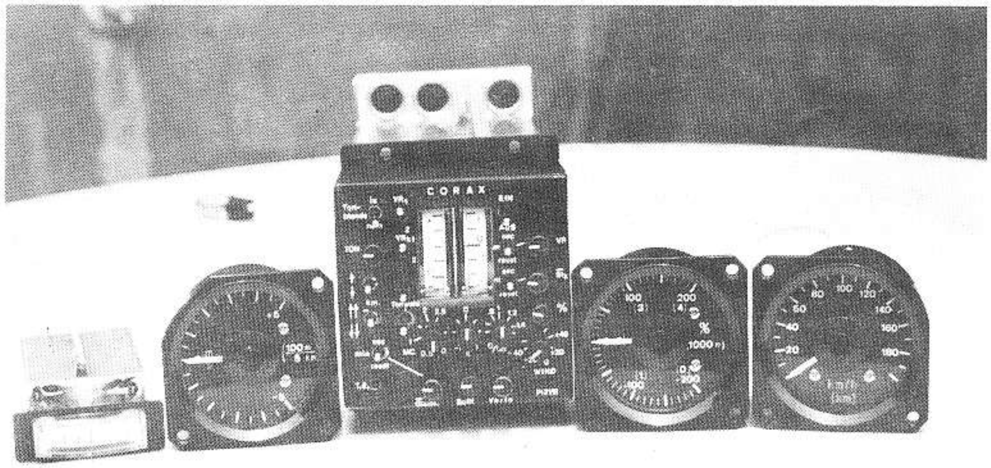
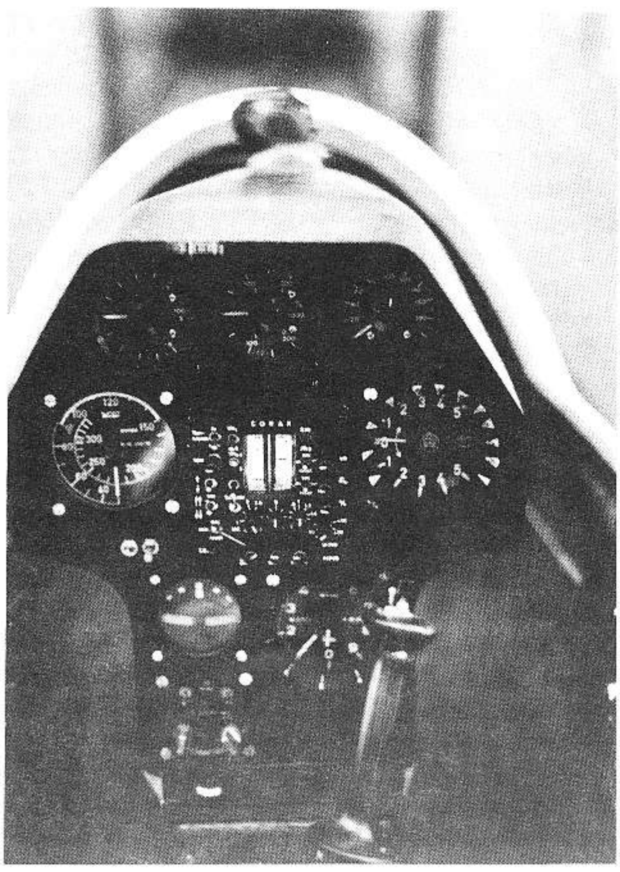


FIG.13



distance. By using this quantity for the cross-country performance the pilot is able to find out by trial and error (feedback) optimum flying techniques regardless of the immediate situation (dolphin flying, thermaling, etc.).

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