Some Computer Calculations on the Optimum Waterballast of Sailplanes*

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1. Introduction

Most competition sailplanes are able to vary their wing loading by carrying waterballast. It is therefore of primary interest to the pilot to know which wing loading he should use for given meteorological conditions to obtain the highest possible cross-country speed. He further wants to know how much he will probably lose on cross-country speed if he is not able to use any ballast.

To solve this problem by experiment is quite difficult, therefore theoretical methods have to be used. This means that we have to calculate the cross-country speed as a function of the wing loading. For nearly all investigations involving the cross-country speed of sailplanes the calculation model introduced by Späte (1) has been used so far (fig. 1). But most pilots intend to use dolphin flying technique as much as possible and as can be seen from Hans Werner Grosse or from Walter Striedieck (2, 3) this gives extremely high cross-country speed. To take this into account, the model shown in fig. 2 (4) will be used instead. According to this model the pilot flies straight through the thermals, circling in the updrafts from time to time to maintain average height. If the meteorological conditions are good enough he can sustain dolphin flight without having to circle any more. This model differs mainly from the Späte-model by an additional meteorological parameter, the thermal density. The thermal density is defined as the sum of the gliding paths in the updrafts, divided by the whole distance (fig. 3). So dolphin flying conditions will be characterized by the thermal density.

Now, consider two sailplanes that are completely equal except for their

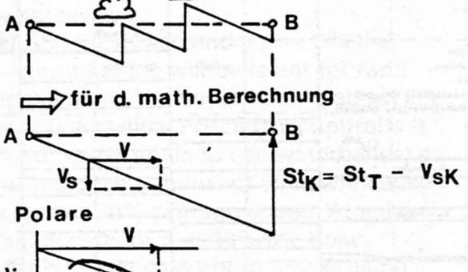


fig. 1:
Model of the cross-country flight according to Späte.

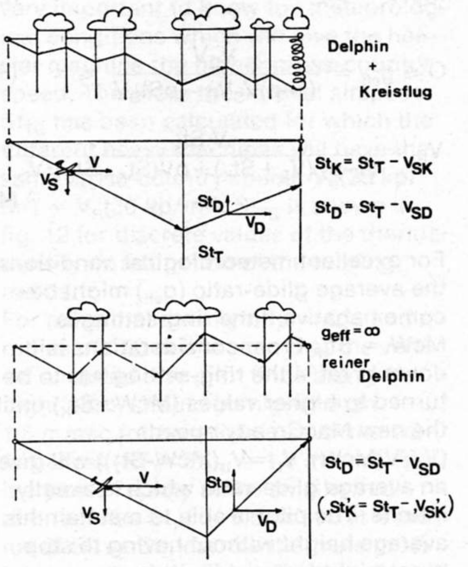


fig. 2:
Model of the cross-country flight according to (4).

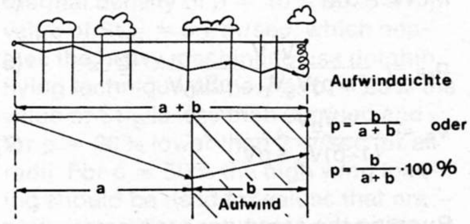


fig. 3:
The model according to (4) differs mainly from the Späte-model by an additional meteorological parameter: the thermal density.

weight. If they were able to achieve the same rate of climb by circling in the updrafts, the heavier machine would achieve a higher cross-country speed according to the better straight flight performance at interthermal speeds. Therefore, it is very important to know the differences in the climb rates of the different heavy machines being compared.

The calculation of the climb rate in turning flight conditions can be performed with the aid of updraft profiles $St_{TK}(R_K)$ (fig. 4). From the rate of sink V_{SK} the actual climbing speed of the sailplane St_K can be calculated:

$$St_K(R_K) = St_{TK}(R_K) - V_{SK}(R_K) \qquad (1)$$

Updraft profiles are to some point problematical (5 to 10). On the right-hand side of fig. 5 are given the updraft profiles for strong, weak and wide thermals assumed by Carmichael (5) and the updraft profile of the British Gliding Association 1975 (9, 10). On the left-

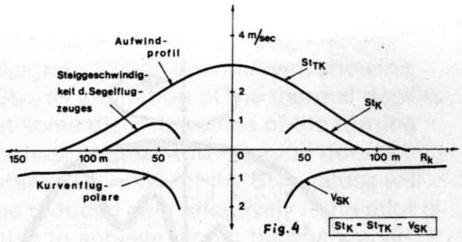


fig. 4:
The calculation of the achieved climb rate (St_K) in an arbitrarily assumed updraft profile.

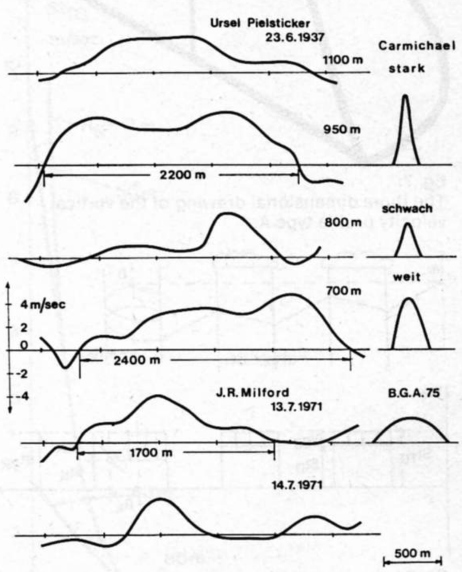


fig. 5:
Measurements of the vertical airspeed in thermals (Pielsticker and Milford) in comparison with Carmichael and BGA profiles.

hand side you see some measurements done by gliders flying straight through the thermals (11, 12). Comparing those measurements with the theoretically assumed profiles, we see that the thermals can be much larger than one thinks they are when one is circling and that the updraft velocity distributions are changing with time. (Therefore, it might be a good method to use mean values of those measured profiles.)

Konovalov (13) averaged his straight

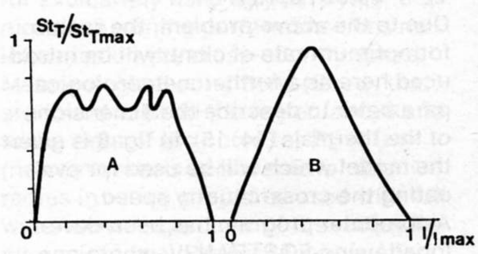


fig. 6:
Konovalov profiles, type A multiple core and type single core.

flight measurements and came to the conclusion that there were two types of thermals (type A and type B in fig. 6). To use those profiles for evaluating the climbing performances in turns one has to assume that both types are of rotational symmetry. A three dimensional drawing of the updraft profile type A (fig. 7) shows that there are two discrete values for the radius where the pilot would find the highest vertical airspeed. This is contrary to experience, so we

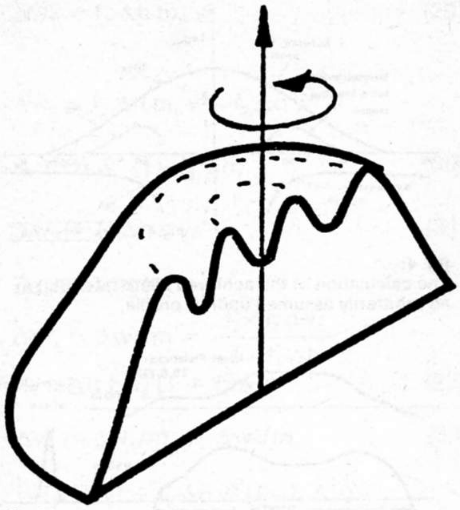


fig. 7:
The three dimensional drawing of the vertical velocity profile type A.

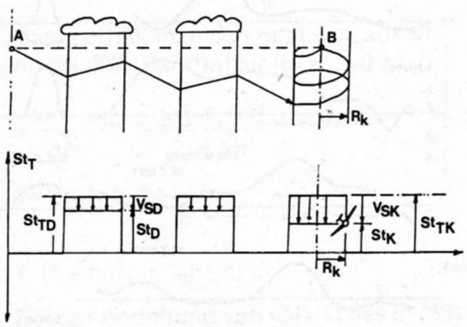


fig. 8:
Model used for the evaluation of the cross-country speed as a function of the radius R_K. It assumes that $St_{TD} = St_{TK} = St_T$.

should not interprete those updrafts in this way – they rather have the meaning of probability distributions. A useful way of obtaining updraft profiles would be perhaps to measure the vertical airspeed not along straight lines but by circling at different radii around the core.

2. Calculation of the cross-country speed as a function of the turning radius:
$V_R = V_R(St_T, p, R_K)$
Due to the above problem, the radius for optimum rate of climb will be introduced here as a further meteorological parameter to describe the dimensions of the thermals (14, 15). In fig. 8 is given the model which will be used for evaluating the cross-country speed.
A computer program has been developed using FORTRAN IV, where one can enter the vertical airspeed St_T, the thermal density p, the radius for optimum climb R_K and, as a fourth parameter, the wing loading F. With an additional program the optimum wing loading can be found by iterative methods, thus reducing the free parameters to the meteorological ones (St_T, p, R_K) alone.
The performance of the sailplane under investigation will be characterized by the straight flight polar. Points of this polar are used to find a polynomial of higher order (for example four) thus making it easier to calculate the polars, the turning performance etc. at any other wing loading. From the rate of sink in the turns (V_{SK}) the rate of climb of the glider (St_K) will be calculated first. This gives the optimum ring-setting (McW) for the MacCready-speeds (V, V_D). If the average glide-ratio (g_{eff}) is below infinity (see ref. 4) the cross-country speed may be expressed in the following manner:

$$McW = St_K \tag{2}$$

$$O \leq g_{eff} = \frac{V_D V}{(1-p)V_S V_D - pSt_D V} \leq \infty \tag{3}$$

$$V_R = \frac{V.St_K}{(1-p)\,(V_S + St_K) + pV(St_K - St_D)/V_D} \tag{4}$$

For excellent meteorological conditions the average glide-ratio (g_{eff}) might become negative if the ring-setting is McW = St_K. From considerations laid down in ref. 4 the ring-setting has to be turned to higher values (McW>St_K) until the new MacCready-speeds (V=V(McW), V_D=V_D(McW-St_T)) will give an average glide-ratio which is exactly infinite. The pilot is able to maintain his average height without having to stop his straight forward flight for turning in the updrafts:

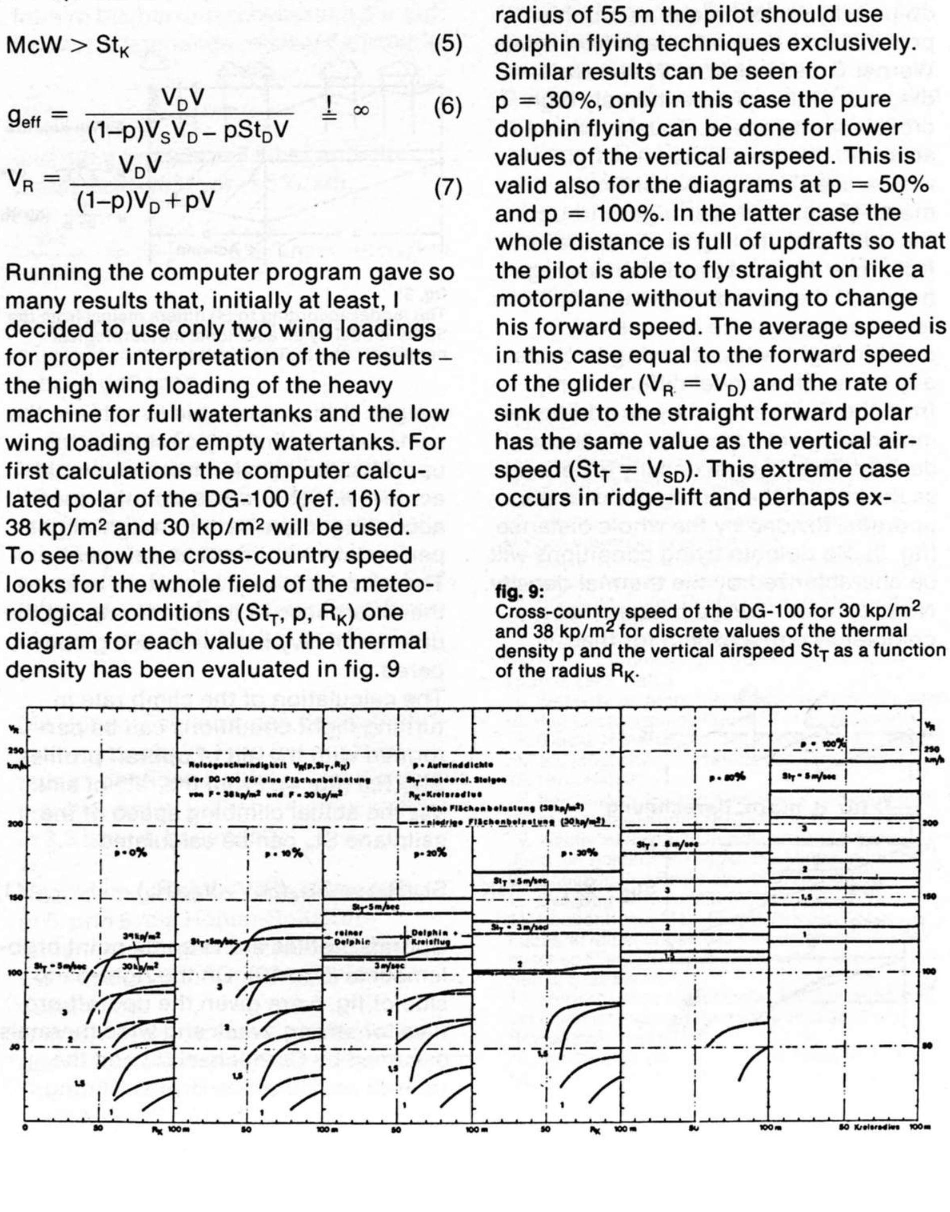
$$McW > St_K \tag{5}$$

$$g_{eff} = \frac{V_D V}{(1-p)V_S V_D - pSt_D V} \stackrel{!}{=} \infty \tag{6}$$

$$V_R = \frac{V_D V}{(1-p)V_D + pV} \tag{7}$$

Running the computer program gave so many results that, initially at least, I decided to use only two wing loadings for proper interpretation of the results – the high wing loading of the heavy machine for full watertanks and the low wing loading for empty watertanks. For first calculations the computer calculated polar of the DG-100 (ref. 16) for 38 kp/m² and 30 kp/m² will be used.
To see how the cross-country speed looks for the whole field of the meteorological conditions (St_T, p, R_K) one diagram for each value of the thermal density has been evaluated in fig. 9 showing the cross-country speed at different values of the vertical airspeed as a function of the radius. To be able to distinguish between the two wing loadings the average speed of the DG-100 for 30 kp/m² has been drawn with interrupted lines.
In the case of p = 0% of pilot has to circle in every updraft, thus being unable to do any dolphin flying. At low vertical airspeeds (St_T = 1 m/sec or 1,5 m/sec) the DG-100 with empty watertanks achieves a higher cross-country speed than with full watertanks. At higher values of the vertical airspeed (for example St_T = 3 m/sec) the low wing loading will be better only at small radii in narrow thermals.
The diagram for p = 10% shows nearly the same result, it differs only in that the curves indicate a somewhat higher cross-country speed due to dolphin flying.
At p = 20% and a vertical airspeed of St_T = 5 m/sec the pilots do not have to circle in the updrafts at all. The average speed is therefore independent on the radius. The same can be said of the light machine at a vertical airspeed of St_T = 3 m/sec, but not of the heavy one which will still circle in wide thermals (besides the dolphin flying) to obtain optimum cross-country speed. Below a radius of 55 m the pilot should use dolphin flying techniques exclusively.
Similar results can be seen for p = 30%, only in this case the pure dolphin flying can be done for lower values of the vertical airspeed. This is valid also for the diagrams at p = 50% and p = 100%. In the latter case the whole distance is full of updrafts so that the pilot is able to fly straight on like a motorplane without having to change his forward speed. The average speed is in this case equal to the forward speed of the glider (V_R = V_D) and the rate of sink due to the straight forward polar has the same value as the vertical airspeed (St_T = V_{SD}). This extreme case occurs in ridge-lift and perhaps ex-

fig. 9:
Cross-country speed of the DG-100 for 30 kp/m² and 38 kp/m² for discrete values of the thermal density p and the vertical airspeed St_T as a function of the radius R_K.



plains why Striedieck could make his 1000 miles flight. It is seen that the heavy machine will be better than the light one for almost all values of the vertical airspeed (i.e. except for weak lift).

In fig. 10 and 11 the gain on cross-country speed due to waterballast, given by:

$$\Delta V_R = \frac{V_R(38\ kp/m^2) - V_R(30\ kp/m^2)}{V_R(30\ kp/m^2)} \cdot 100\% \qquad (8)$$

is shown as a function of the radius for discrete values of the vertical airspeed and the thermal density.

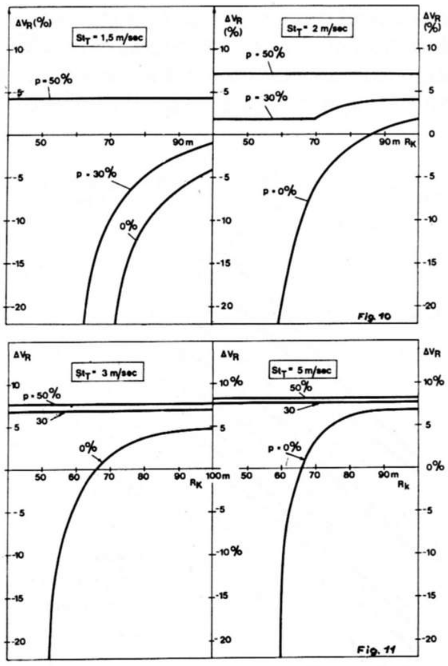


fig. 10 and 11:
Gain (or loss) on cross-country speed of the heavy glider (DG-100, 38 kp/m²) due to waterballast in comparison to the light one (DG-100, 30 kp/m²) as a function of the radius R_K.

At a vertical airspeed of St_T = 1,5 m/sec and a thermal density of p = 0% the heavy machine will lose on cross-country speed in comparison to the light one for all radii up to 100 m and more. The loss on cross-country speed increases rapidly, in the case of narrow thermals. Dolphin flying at a thermal density of p = 30% reduces the loss on average speed and at p = 50%, where the heavy machine is able to do dolphin flying without any circling, a gain of about 4% is achievable.

At St_T = 2 m/sec and a p = 0% the heavy machine will be faster for radii above 85 m, the benefit being about 2% at 100 m radius. For narrow updrafts it is not worth while to use waterballast as for instance a radius of 65 m will cause a loss of 20% average speed. At a thermal density of p = 30% the heavy machine will gain about 2% by using dolphin flying technique alone beneath a radius of 70 m and reaching about 4% for mixed dolphin flying and turning techniques at a radius of 100 m. A p of 50% assures that dolphin flying can be done without any circling, giving a gain on cross-country speed of about 7%. Similar results can be seen for stronger updrafts (St_T = 3 m/sec and St_T = 5 m/sec) only in these cases the achievable gain on cross-country speed is somewhat higher. One interesting thing is that the loss on average speed might be very high if one has to use radii below R_K = 65 m.

For the proper use of waterballast it is very important to know the meteorological conditions which will give the heavier machine the higher cross-country speed. Therefore the vertical airspeed St_{TG} has been calculated for which the different heavy machines will have the same cross-country speed: V_R(38 kp/m²) = V_R(30 kp/m²). St_{TG} is shown in fig. 12 for discrete values of the thermal density as a function of the turning radius.

For a thermal density of p = 0% and a radius of 150 m it is seen that the vertical airspeed, the pilot finds along his flight path, should be higher than 1,5 m/sec for beneficial use of the waterballast ($ST_T \geq St_{TG}$ = 1,5 m/sec). St_{TG} increases rapidly at the smaller radii and reaches St_{TG} = 9,5 m/sec at a radius of 50 m. So, narrow thermals must be very strong for use of waterballast to give optimum results.

A similar result can be seen for the thermal density of p = 10% up to a value of St_{TG} = 5,7 m/sec, which enables the heavy machine to use dolphin flying technique alone. For p = 20% the value of St_{TG} is less than 3 m/sec and for p = 30% lower than 2 m/sec for all radii. For p = 50% the high wing loading should be used for values that are higher than St_{TG} = 1,2 m/sec and for p = 100%, where the whole distance is full of updrafts, the limit St_{TG} has the value of 0,7 m/sec.

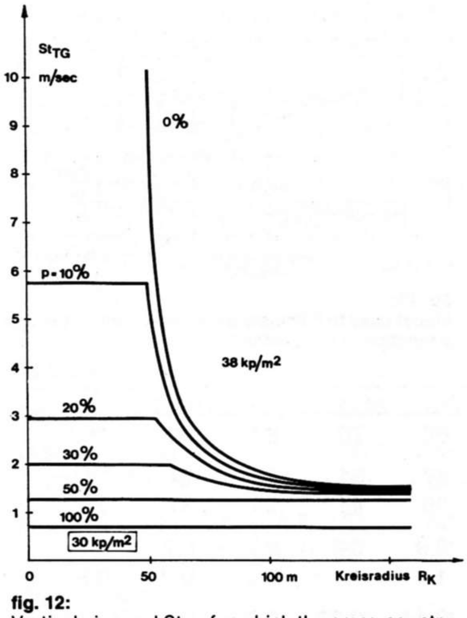


fig. 12:
Vertical airspeed St_{TG} for which the cross-country speeds of the two gliders are equal (V_R(38 kp/m²) = V_R(30 kp/m²)) as a function of the radius R_K

To demonstrate the influence of the thermal density on the St_{TG} – values diagram 13 has been drawn, showing St_{TG} as a function of the thermal density at some discrete values of the turning radius. At small turning radii (for instance R_K = 50 m) the St_{TG}-values will be reduced very effectively if the pilot is able to achieve higher thermal densities.

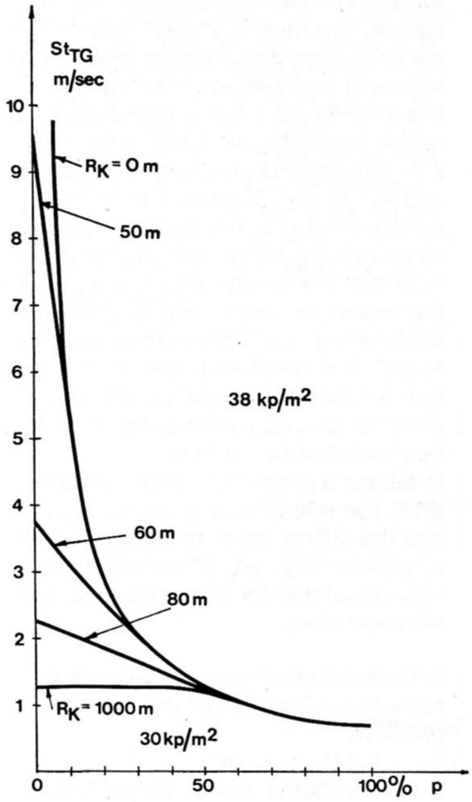


fig. 13:
ST_{TG} (vertical airspeed for which V_R(38 kp/m²) = V_R(30 kp/m²)) as a function of the thermal density. R_K = 0 m means that due to the infinite sink rate for this radius of turn cross-country flight can only be performed by dolphin flying technique.

At high values of the thermal density the St_{TG}-curves for the different radii come together due to the fact that for exclusively used dolphin flying technique the turning performance has no influence on the cross-country speed. Meteorological conditions (St_T, p) that are found to be in the region above and to the right of the curve for R_K = 0 m (no climb rate is achievable for this radius in turns) should be used with full watertanks, regardless of the radius the pilot might use. Beneath the curve for $R_K = \infty$ (here R_K = 1000 m) the pilot will do better to drop his waterballast. The pilot is not able to measure the vertical airspeed by direct methods, therefore the St_{TG}-values of fig. 12 have been transformed to the rate of climb the heavy machine gains in the updrafts by turning (St_K(38 kp/m²)). The pilot is able to consult diagram 14 if he starts his task with full watertanks by measuring the rate of climb in the turns by his variometer and the radius by his watch and speed indicator. If the measured weather conditions (St_K(38 kp/m², R_K)) are better than those indicated by the

curve at p = 0%, he should keep his waterballast for optimum cross-country speed. But if the measured points (St_K, R_K) are found to be beneath the curve for p = 0% the proper decision of keeping or dropping the waterballast depends on the amount of dolphin flying the pilot is able perform along his flight path.
One interesting thing is that the curves for p ≠ 0% have a maximum. For instance, at a thermal density of p = 10% the pilot should use waterballast for all values of climbing speeds that are higher than 2,9 m/sec, regardless of the radius he might use in his turns. For p = 20% the maximum is at St_K(38 kp/m²) = 1 m/sec. The maxima of the curves are due to the fact that the pilot stops turning in the updrafts for those radii that are smaller than the radius for the maximum, because dolphin flying alone will give a higher cross-country speed. It is therefore not recommended that the meteorological conditions (thermal strength) in this region should be measured by circling.
In table 1 the optimum angle of bank (Phi), the rate of sink in the turns (V_{SK}) and the difference in the rate of climb (St_K(30 kp/m²) – St_K(38 kp/m²)) have been tabulated for some values of the turning radius.

3. Calculation of the cross-country speed as a function of the updraft gradient:

$V_R = V_R(St_T, p, grad)$
In the foregoing model we had assumed that the different heavy sailplanes circle at the same radius for optimum rate of climb. As a matter of fact, this assumption is only valid for those updrafts for which the vertical airspeed falls off rapidly (i.e. discontinously) beyond the turning radius. For many updrafts the mean value which the pilot achieves on his circling flight path decreases continously. Therefore it is quite useful to describe the circling conditions by the updraft gradient, taken at the turning radius (17a). The gradient will be defined here as the negative derivative of the updraft profile: grad = $-dSt_{TK}/dR_K$.
For example, if the radius is raised to 100 m and if the vertical airspeed along the turning flight path will be reduced by 1,5 m/sec the gradient is: grad $\approx \Delta St_{TK}/\Delta R_K$ = 1,5(m/sec)/100(m) = 0.015 sec⁻¹.
If the radii of the different heavy machines are not differing too much, the

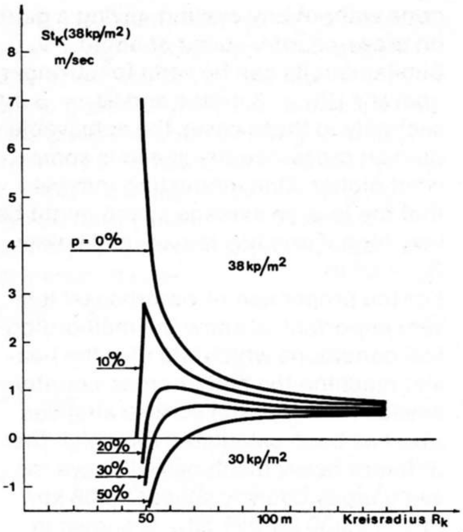


fig. 14:
Climb rate St_K(38 kp/m²) that the heavy machine (DG-100, 38 kp/m²) must achieve in the turns to obtain a higher cross-country speed than the light one (DG-100, 30 kp/m²).

same gradient for both machines can be used, the error being negligible to the first order. The actual updraft profile can be replaced by a triangular one, which has a constant gradient. The rate of climb can be evaluated by:

$$St_K(F) = St_{T\Delta}(Om) - R_K(F)grad - V_{SK}(F, R_K) \quad (9)$$

and the difference in the climb rate:

$$\Delta St_K = \Delta R_K grad + \Delta V_{SK} \quad (10)$$

In fig. 15 you see the model which will be used for the evaluation of the cross-country speed. For dolphin flying rectangular updraft profiles have been assumed, St_{TD} being interpreted as a mean value achieved by flying straight through the thermals. The pilot to some extent is able to choose the updrafts he wants to use by dolphin flying technique or by turning. Therefore, we have to distinguish between the updrafts the pilot uses by dolphin flying and the

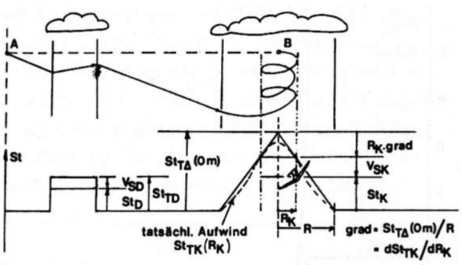


fig. 15:
Model used to calculate the cross-country speed as a function of the gradient.

updrafts that will be used by turning. To reduce the calculation effort and the number of free parameters (St_{TK}, St_{TD}, p, grad) from four to three, a connection between those two updrafts according to the thermal strength has to be assumed. The following relations could be taken arbitrarily:

$$St_K(30\ kp/m^2) = St_{TD} - 1.5\ m/sec \quad (11)$$

$$St_{TD} = St_{T\Delta}(Om)/2 \quad (12)$$

The second relation describes meteorological conditions where all updrafts have a triangular profile with the same gradient and the same thermal strength. The computer program of the foregoing model had to be slightly modified for the calculation of the climb rate as a function of the updraft gradient. It will be assumed that the pilot always flies with optimum forward speed and opti-

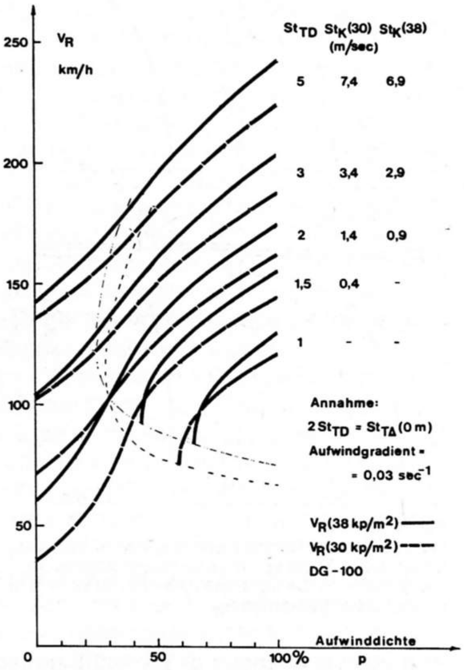


fig. 16:
Cross-country speed of the DG-100 at 30 kp/m² and 38 kp/m² as a function of the thermal density p for some discrete values of the vertical airspeed (St_{TD} = 1; 1.5; 2; 3; 5 m/sec). And updraft of triangular profile and gradient of 0,03 sec⁻¹ causing the light glider to fly at R_K = 52 m and Phi = 45° and the heavy one at R_K = 64 m and Phi = 46°.

mum angle of bank in the rather calm updrafts of rotational symmetry.
In fig. 16 is seen the cross-country speed of the sailplanes as a function of the thermal density. It is assumed that the relation (12) is valid and that the updrafts have a gradient of 0,03 sec⁻¹. The heavy sailplane with full watertanks will lose about 0,5 m/sec in circling conditions compared to the light one. For St_{TD} = 1 m/sec only pure dolphin flying can be done without losing average height, because both machines, the heavy and the light one, cannot gain height by turning in the updrafts. For St_{TD} = 1,5 m/sec the light machine achieves an admirable cross-country speed for all values of the thermal density. Contrary to this the heavy machine

Table 1

radius (m)		40	50	60	70	80	90	100
angle of bank: (°)	Phi (30)	65	47	37	31	27	24	21
	Phi (38)	–	67	50	41	35	31	27
sinkrate: (m/sec)	V_{SK} (30)	2.3	1.1	0.9	0.8	0.7	0.7	0.7
	V_{SK} (38)	–	2.9	1.4	1.1	0.9	0.9	0.8
St_K (30) – St_K (38) (m/sec)		–	1.78	0.48	0.27	0.20	0.16	0.14

will lose height at low values of the thermal density due to the high sink rate in turns and therefore will have to land. At high values of the thermal density the heavier machine will be faster if dolphin flight technique is used exclusively.
For $St_{TD} = 2$ m/sec the heavy machine is slower than the light one at low values of the thermal density. For $St_{TD} = 3$ m/sec the heavy machine will be better for all values of the thermal density.
Fig. 17 shows the cross-country speed as a function of the thermal strength (St_{TD}, St_K(30 kp/m²)). The diagram de-

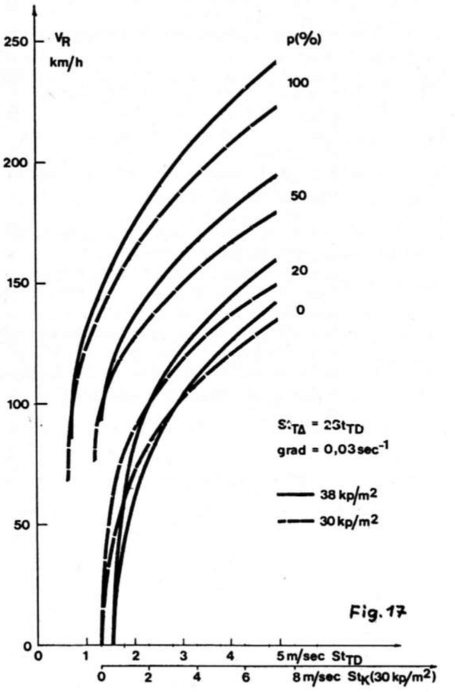


fig. 17:
Cross-country speed as a function of St_{TD} (or St_K(30 kp/m²)) for different values of the thermal density. The same assumptions have been made as in fig. 16.

monstrates clearly the difference of this model from the Späte-model, which is only valid for p = 0%. The curves for p = 100% are identical to the polars of the sailplanes in straight flight, because the whole distance will be flown in updrafts. The forward speed is in this case identical with the cross-country speed. According to this diagram the cross-country flight can be performed by dolphin flying technique (p = 50%, 100%) at smaller values of the vertical airspeed than is the case for mixed dolphin and turning flight (p = 0%, 30%).
Fig. 18 and 19 show the gain (or loss) on cross-country speed of the heavy glider (DG-100, 38 kp/m²) relative to that of the light one (DG-100, 30 kp/m²) as a function of the climb rate the heavy glider achieves by circling in the updrafts:

$$\Delta V_R = [(V_R(38\ kp/m^2) - V_R(30\ kp/m^2))/V_R(30\ kp/m^2)] \cdot 100\%$$

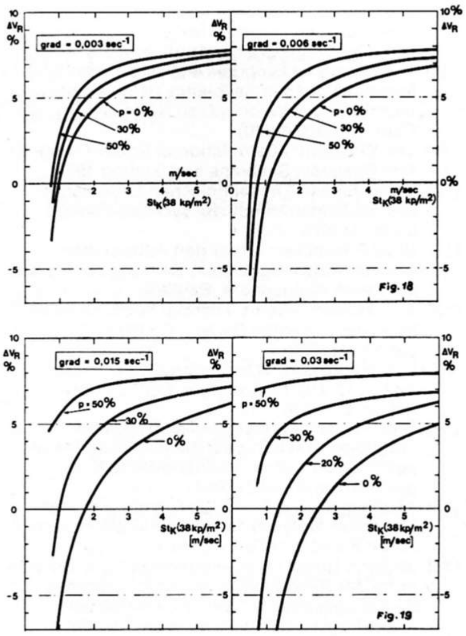


fig. 18 and 19:
Gain (or loss) on cross-country speed of the heavy glider (DG-100, 38 kp/m²) due to waterballast in comparison to the light one without water (DG-100, 30 kp/m²) as a function of the climb rate the heavy machine is able to achieve by turning (St_K(38 kp/m²)).

For each value of the gradient (grad = 0,003; 0,006; 0,015; 0,03 sec⁻¹ a diagram has been evaluated. It can be seen that for climb rates up to St_K(38 kp/m²) = 6 m/sec the gain on cross-country speed due to waterballast never exceeds 5 to 8% contrary to the loss in weak thermals, which easily reaches 20% and more. Dolphin flying (p = 30%) raises the benefits of waterballast, especially for narrow thermals with high gradients. The points where the curves are crossing the ΔSt_K-axes indicate the minimum rate of climb the heavy machine should achieve for optimally used waterballast. For a gradient of 0,003 sec⁻¹ (Phi(38 kp/m²) = 27°) this value is for instance 1 m/sec and for grad = 0,015 sec⁻¹ (Phi(38 kp/m²) = 40°) 1,8 m/sec. The thermal density of p = 30% will reduce these values to 0,8 m/sec for 0,003 sec⁻¹ and to 1 m/sec for 0,015 sec⁻¹.
Fig. 20 shows the St_K(38 kp/m²)-values for which the cross-country speeds for the different heavy machines are equal: V_R(38 kp/m²) = V_R(30 kp/m²) as a function of the gradient. The curves for p = 0% have a maximum which is 3 m/sec for p = 10% and 1,1 m/sec for p = 30%.

The diagrams 18, 19 and 20 can be an aid to the pilot only if he is able to measure the gradient. In table 2 the turn radius and the angle of bank for maximum rate of climb have been evaluated for some values of the gradient. It can be seen there that the optimum angle of bank is nearly independent on the weight of the sailplane and therefore could be used for measuring the updraft gradient. This could be done for instance by using the «attitude indicator», the «Bohli-compass» or the «Phi-psi-theta»-disc of the Idaflieg (18, 19). The pilot could start his task with full watertanks, and by measuring the rate of climb in the turns and the gradient via the angle of bank he is able to consult the diagrams 18, 19 and 20 to make up his decisions according to the optimal use of waterballast.

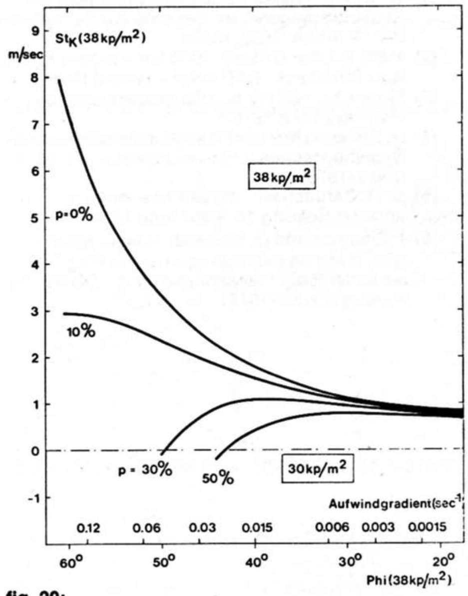


fig. 20:
Rate of climb the heavy glider (DG-100, 38 kp/m²) must achieve in the turns to fly faster than the light one without waterballast (DG-100, 30 kp/m²) as a function of the gradient or the angle of bank (Phi(38 kp/m²)).

4. Summary

Two calculation models have been developed to investigate the effect of waterballast on the optimum cross-country speed of sailplanes. Results for the computed polar of the DG-100 at a wing loading of 38 kp/m² and 30 kp/m² for full and empty watertanks show that waterballast should be used for thermals with high vertical airspeeds or large diameters and for the case that the pilot is able to do much dolphin flying. The gain (or loss) on cross-coun-

Table 2

updraft-gradient (sec⁻¹)	0.12	0.06	0.03	0.015	0.006	0.003	0.0015
radius: (38 kp/m²)	55	59	64	72	87	103	124
(m) (30 kp/m²)	44	47	52	58	71	84	102
angle of bank: (38 kp/m²)	58	52	46	40	32	27	22
(°) (30 kp/m²)	57	51	45	39	31	26	21
St_K (30 kp/m²) – St_K (38 kp/m²) (m/sec)	1.6	0.9	0.53	0.33	0.20	0.15	0.11

try speed due to waterballast has been calculated for a variety of meteorological conditions. For practical purposes some diagrams (especially 14 and 20) have been evaluated for the optimal use of waterballast.

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Symbols:

F	=	wing loading (kp/m^2)
g	=	glide ratio
g_{eff}	=	average glide ratio
grad	=	updraft-gradient $= -dSt_{TK}/dR_K$ (sec^{-1})
p	=	thermal density = sum of the slide paths flown in the updrafts in percentage of the whole distance AB (%)
Phi	=	angle of bank (°)
R_K	=	radius of turn (m)
St_T	=	vertical airspeed, thermal lift (m/sec)
St_{TD}	=	vertical airspeed of the updrafts which will be used by dolphin flying technique (m/sec)
St_{TG}	=	vertical airspeed of the updrafts for which $V_R(38\ kp/m^2) = V_R(30\ kp/m^2)$
$St_{T\Delta}$ (Om)	=	vertical airspeed at the center of the triangular updraft profile (m/sec)
St_{TK}	=	vertical airspeed at the radius of turn (R_K), updraft-profile
St_K	=	climb rate of the sailplane achieved by turning (m/sec)
St_D	=	climb rate of the sailplane achieved by dolphin flying technique, here by flying straight through the thermals at the speed V_D (m/sec)
V	=	interthermal speed of the sailplane (km/h)
V_S	=	rate of sink at the velocity V according to the straight forward polar of the glider (m/sec)
V_{SK}	=	rate of sink in the turns at the radius R_K (m/sec)
V_D	=	straight forward speed of the glider in the updraft (km/h)
V_{SD}	=	rate of sink at V_D (m/sec)
V_R	=	cross-country speed = distance (AB) divided by the time (t): AB/t. It is assumed that the start-point A has the same height as the endpoint B. (km/h)
$_\Delta V_R$	=	gain on cross-country speed of the DG-100 with full watertanks (38 kp/m^2) in comparison to the light one (30 kp/m^2) without waterballast in percentage of the cross-country speed at 30 kp/m^2. (%)