# Some Problems of the Dolphin-Mode Flight Technique

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### 1. Preface

Progress in the field of sailplane performance during the last decade influenced considerably the tactics of cross-country flights, being a stimulus to the development of the dolphin-mode flight technique. No wonder that theoretical foundations of this technique, evaluation of weather minima for succesful dolphin-mode flight and principles of selection of the optimum flight speed for a given air mass vertical velocity, have become a topic of numerous papers.

**I will not attempt to sum up present achievements in this field; however. I would like to make a critical examination of the applicability of some results and to point out conclusions important for both active pilots and theorist pilots, interested in further progress in cross-country flight techniques.**

### 2. Classical dolphin-mode cross-country flight

Assuming distribution of vertical air velocities along the flight route and the speed-polar curve of the sailplane, one can calculate (using calculus of variations) the optimal distribution of cruise speeds (without circling) to achieve the lowest flight time and unchanged potential energy of the sailplane at the starting point and final point of the flight route.

The same calculation also gives the solution to the problem as to whether the requirement of maintaining the required height at the final point can be met, i.e. whether the classical dolphin-mode flights is possible.

Although the works of Irving (1), Arho (2), Kauer and Junginger (3) and other authors, yielded solution to the problem of optimal selection of speeds and conditions necessary for maintaining the required height, their usability for the pilot does not reach beyond the formula:

$$\frac{dw}{dV_{opt}} = \frac{w - w_{atm} + w^*}{V_{opt}} \qquad (1)$$

represented graphically in Fig. 1.

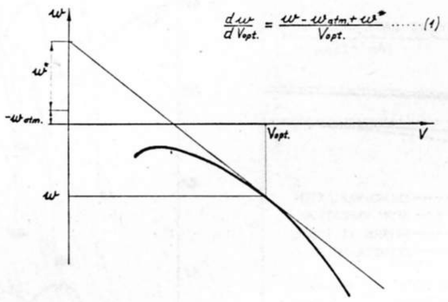



Fig. 1

One can see that the situation here is analogous to that of the flight with circling, the only difference being that the expected lift in the next thermal is replaced by speed w*. If w* were known, the McCready speed ring could be set to it and the best sailplane speed could be evaluated for the whole flight, making the dolphin-mode flight very simple as compared to the flight with circling.

Unfortunately however, calculation of speed w* is generally impossible since it requires knowledge of vertical airspeed distribution along the flight route before the flight – not mentioning the troublesome variation calculus. Some theoreticians suggest division of the flight route into sections and subsequent correction of the w* setting after passing the given section (dependent upon height difference between its beginning and end points), but this method is also of little use because it assumes that the vertical speed distribution along the next section is close to that of the preceding section.

For the pilot, much more usable seems to be simplification made by Tomczyk (4), Jonas (5), Abzug (6) and others, **who analyse optimal speed selection** during flight through the area of constant sink and subsequently through the area of constant lift. For the model speed distribution, presented in Fig. 2, the best speeds $V_1$ and $V_2$ can be calculated without application of the calculus of variations. In the case of flight in the sink area the following relation is obtained:

$$\frac{dw}{dV_{1opt}} = \frac{w - w_1 + w_2^*}{V_{1opt}} \qquad (2)$$

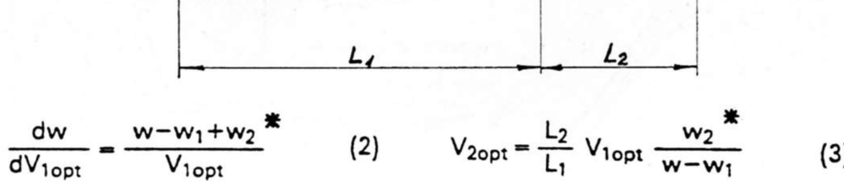
**(where $w_2^*$ is the rate of climb along $L_2$)**
**which is identical with that obtained for the best cruise speed during flight with circling.**

In case of flight in the lift area we obtain:

$$V_{2opt} = \frac{L_2}{L_1} V_{1opt} \frac{w_2^*}{w - w_1} \qquad (3)$$

One can see that the correct selection of speed $V_1$ requires merely the correct estimation of the lift intensity $w_2$ and setting the McCready ring as for the flight with circling. In practice, much more difficult is the selection of the best speed $V_2$, which should meet the requirement of fully regaining the initial height at the end point of the passage through the area of lift. Fig. 3 presents selection of the best speed $V_1$ and achieved cross-country speed; the latter equals, according to formula (4):

$$V_{av} = \frac{V_1 w_2^*}{w - w_1 + w_2^*} \left(1 + \frac{L_2}{L_1}\right) \qquad (4)$$




$$\frac{dw}{dV_{1opt}} = \frac{w - w_1 + w_2^*}{V_{1opt}} \qquad (2) \qquad V_{2opt} = \frac{L_2}{L_1} V_{1opt} \frac{w_2^*}{w - w_1} \qquad (3)$$

Fig. 2

$$V_{av} = \frac{V_1 w_2^*}{w - w_1 + w_2^*}\left(1 + \frac{L_2}{L_1}\right) \qquad (4)$$

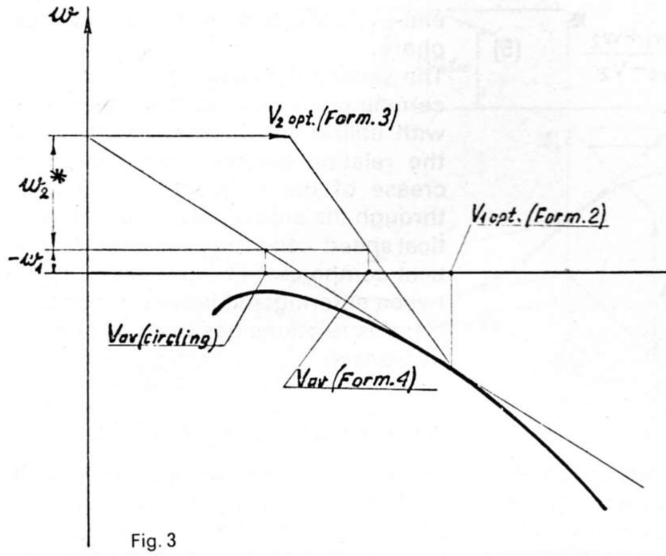


Fig. 3

when flying over area $L_2$ with speed $V_2$, and is $\left(1 + \frac{L_2}{L_1}\right)$ times as high as the cross-country speed in flight with circling in a thermal of $w_2$ intensity.

The above formulae for the best speeds $V_1$ and $V_2$ and the cross-country speed $V_{av}$ are valid whenever speed $V_2$ calculated from formula (3) is higher than the minimum speed. If this condition is not met, further classical dolphin-mode flight requires reduction of the speed $V_1$, because at the same time the height loss to be regained in the area of lift of length $L_2$ also decreases. It should be pointed out, that the main difficulty in the selection of the best speed $V_2$ from formula (3), is estimation of the $L_2$ distance.

Let us try to avoid this problem, accepting the model-distribution of air speed, presented in Fig. 4, which differs from the one previously discussed in the undetermined length $L_2$ of the area of lift. This model has been introduced into the considerations concerning dolphin-mode flight theory by Abzug, who also assumed that the pilot, after approaching the cloud street i.e. after covering distance $L_1$, began regaining the lost height with safe speed $V_2 \sim V_{min}$.

Now, let us consider the equations obtained by Abzug resulting from the above assumptions. The best cruise speed is

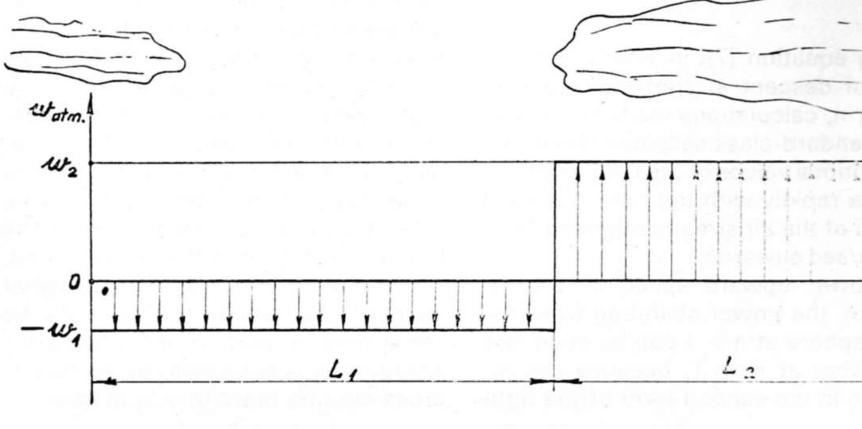
$$\frac{dw}{dV_{1opt}} = \frac{w - w_1 + w_2^*}{V_{1opt} - V_2} \qquad (5)$$

and the cross-country speed is

$$V_{av} = \frac{V_1 w_2^* + V_2 (w - w_1)}{w - w_1 + w_2^*} \qquad (6)$$

Comparing equations (2) and (5), it becomes evident that for the assumption $V_2 = V_{min}$ the best cruise speed is higher than that calculated with the McCready ring.

Fig. 4




Abzug prepared a special ring scale corresponding to the formula (5) which can be used together with the McCready ring.

Abzug's suggestion concerning the selection of the cruise speed higher than that calculated with the McCready ring seems to be wrong, however, because of two factors. First – the cruise speed resulting from formula (5) is the best speed only relative to the speed $V_2 = V_{min}$ in the area of lift. If, from those two speeds and air speeds $w_1$ and $w_2$, one calculates the distance $L_2$ along which the initial height is to be regained, $\triangle H = 0$, then according to Fig. 5, the best combination of speeds will be the cruise speed according to the McCready ring and the speed $V_{2opt}$ in the area of lift. Fig. 5 also presents cross-country speed gain which can be obtained when flying slower than' suggested by Abzug on the cruise and faster than $V_{min}$ in the area of lift.

We should pay attention to the fact that choice of the best combination of speeds can be made, to a fairly good approximation, in flight along cloud streets. To find the best cruise speed it is necessary only to have a good assessment of the expected mean rate of climb; then, after approaching the cloud street, the pilot should choose a $V_2$ speed for the observed length of the cloud street, and at the end of the area of lift the initial height will be regained. The other reason why one should choose the cruise speed according to the McCready ring, is "reliability" of the cross-country flight; lower cruise speed results in lower height loss and the whole flight is not only faster but is also carried out at a "higher level".

### 3. Dolphin-mode, cross-country flight under weak weather conditions

The above remarks apply in meteorological conditions enabling the pilot to apply classical dolphin-mode flight technique, i.e. the speed $V_2$ calculated from formula (3) is not less than the minimum speed. When however, the meteo-conditions are too weak, i.e. when $V_{2opt} < V_{min}$, the possibility of continuing the flight still exists, namely along the elongated track $L_3 > L_2$, S – shaped ("essing") or including circling between straight sections so that the flight time would meet requirement:

$$t = \frac{L_2}{V_{2opt}} = \frac{L_3}{V_{min}} \qquad L_3 = L_2 \frac{V_{min}}{V_{2opt}}$$

In this case all the previously obtained equations, i.e. (2), (3) and (4) remain valid.

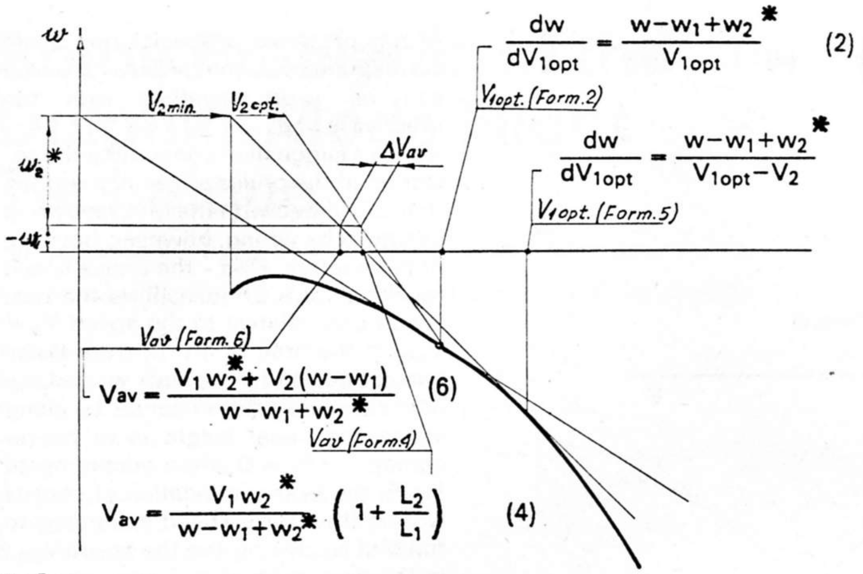


Fig. 5

Another possibility of continuing the dolphin-mode flight gives the reduced setting of the McCready ring, that means decreased cruise speed in order to reduce height loss. The limit setting is:

$$w^* = 0$$

and cruise at the speed corresponding to maximum range. If however, even in this case speed $V_2$ is less than minimum speed, straight flight through the area of lift will not result in regaining the initial height.
Assuming that meteo-conditions are to weak for the classical dolphin-mode flight but encourage flying according to the McCready ring setting

$$w^* < w_{climb}$$

one should choose – from the two above techniques – the first one, since combination of speed according to McCready ring and speed $V_{2opt}$ (for the elongated track $L_3$ at $V \sim V_{min}$) results in better cross-country speed than any other combination of speeds, including the cruise speed less than the McCready ring reading and $V_2 = V_{min}$.
It is evident from the above considerations, that under any meteo-conditions suitable for dolphin-mode flight (classical or combined) one should – for the cruise – obey the McCready ring readings (set on the expected rate of climb) and after approaching the cloud street choose a speed and flight track so that the initial height is regained at the end of the track.

*the word "dynamic" seems to fit better than "unsteady".

**4. Cross-country flight with utilization of dynamic effects**

Previous considerations and equations have been based on the polar curve of the sailplane, which states its performance under conditions of quasi-steady flight when lift is balanced by weight. In fact, the pilot changes speed dynamically rather, i.e. the speed changes are accompanied by changes in normal acceleration coefficient, n.
The effect of normal acceleration on the efficiency of the sailplane in utilization of vertical air streams has been analyzed by Gorisch (7), while Gedeon (8) tried to take this phenomenon into account in his calculations of the cruise speed.
Gorisch introduced basic equations relating power absorbed by the sailplane from the atmospheric stream E′ to the amount of normal acceleration n, intensity of the stream component normal to the flight path $w_{atm} \cos \varphi$ and to the sailplane characteristics:

$$\frac{E'}{mg} = n\, w_{atm} \cos \varphi - w \qquad (7)$$

Using equation (7), in which w is the rate of descent at speed V and load factor n, calculations made for a typical standard-class sailplane show that the optimal values of the load factor increase rapidly with the rise in upward speed of the air stream, begining from 1–2 m/sec onwards.
For lower upward speed of the air stream, the power absorbed from the atmosphere at $n > 1$ can be even less than that at $n = 1$, because the increase in the second term of the right hand side of eq. (7) during the pull-up, i.e. the increase of energy dissipated in increased drag, can exceed the total energy absorbed from the atmosphere.
The second valuable information concerning cross-country flight technique with utilization of dynamic effects, is the relation between the energy increase of the sailplane as it passes through the area of lift of constant vertical speed – and the change in the vertical component of flight speed ź, between entering and leaving the area of lift; this relations has been introduced by Gorisch

$$\Delta E = m\, w_{atm} \Delta z' + mg\,(w_{atm} - w_{mean}) \Delta t \qquad (8)$$

Gorisch interprets this relation as follows: the first term of the right hand side he calls the "unsteady increase" while the second term is the "steady increase". The name for the second term explains itself easily since it represents the known relation between the sailplane energy rise and the time of passing through the vertical air stream and the mean value of the sailplane rate of descent (which can be obtained from the speed-polar curve for the given speed V and loading factor n). On the other hand, the term: m $w_{atm} \triangle z'$ is independent of time and its magnitude is proportional to the difference between the vertical components of the sailplane speed (relative to ground) at entering and leaving the area of lift (Fig. 6).
It should be emphasized that this dynamic* term can have a positive or negative value, which means gain or loss of the sailplane energy respectively.

The "+" sign appears when both $\triangle z'$ and $w_{atm}$ are positive or negative; for the pilot, it means that in the upward air stream the flight path should be curved so that the centre of curvature is above the sailplane ($\triangle$ n positive) while in the descending air stream the flight path curvature should correspond with the speed gain ($\triangle$ n negative). It should also be taken into account that, when observing the above rule, the dynamic energy gain is the larger; the higher is the cruise speed, since in such circumstances a higher value of $\triangle z'$ can be achieved. At the same time, utilization of the dynamic energy gain is equivalent to the steady cross-country flight (n = 1) in favoura-

$$\Delta E = m \cdot w_{atm.} \cdot \Delta Z' + m \cdot g \left( w_{atm.} - w_{mean} \right) \Delta t \ldots\ldots (8)$$

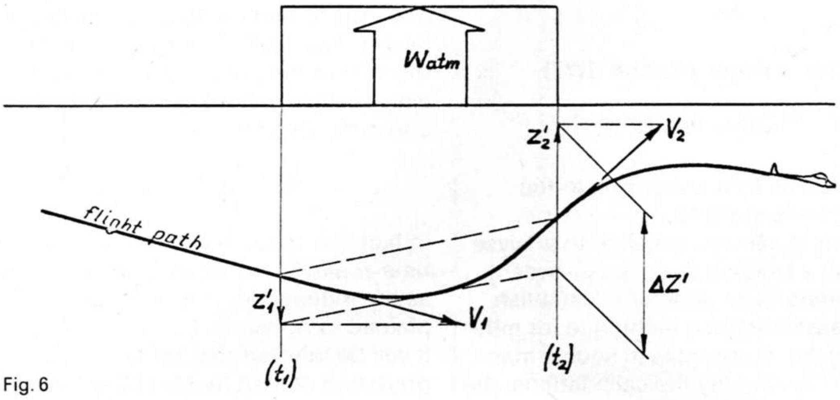



Fig. 6

bleweatherconditions, i.e. at higher values of $w_{climb}$. One can conclude from both the above remarks that the best cruise speed in dolphin-mode cross-country flight, with utilization of the possibilities offered by correct controlling of the load factor, is higher than the best cruise speed calculated in the preceding section under the assumption of slow changes in speed. It follows then, that the pilot using described technique can – and should – set the McCready ring at a higher rate of climb than that expected. For the selection of cruise speed and speed in the area of lift, employ the same rules as in the case of steady cross-country flight.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