

# SOME PROBLEMS OF THE DOLPHIN-MODE FLIGHT TECHNIQUE

## CRITICAL REVIEW

by

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### 1. PREFACE

Considerable progress in the area of sailplane performance during the last decade has influenced cross-country flight tactics and has stimulated development of dolphin-mode flight techniques. No wonder that theoretical foundations of this technique, first of all, evaluation of weather minima for successful dolphin-mode flight and principles of selection of the optimum flight speed vs. vertical velocity of air masses, has recently become a topic of numerous papers.

I will not try to attempt to sum up present achievements in this field; however, I would like to critically examine the applicability of some results and point out conclusions important to active pilots (and pilot-theorists) interested in further progress in cross-country flight techniques.

### 2. CLASSICAL DOLPHIN-MODE CROSS-COUNTRY FLIGHT

Assuming a distribution of vertical air velocities along the flight path and the speed-polar curve of the sailplane, one can calculate (using calculus of variations) the optimal distribution of cruise speeds, without circling, to meet the requirement of the lowest flight time and unchanged potential energy of the sailplane at the starting point and final point of the flight path. The same calculation also gives a solution to the problem of whether the requirement of maintaining required height at the final point can be met, i.e., whether classical dolphin-mode flight is possible.

Although the works of Irving [1], Arho [2], Kauer and Junginger [3] and other authors, provided solutions to the problem of optimal selection of speeds and conditions necessary for maintaining required height, their

practical application for the pilot does not extend beyond the formula:

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

represented graphically in Figure 1.

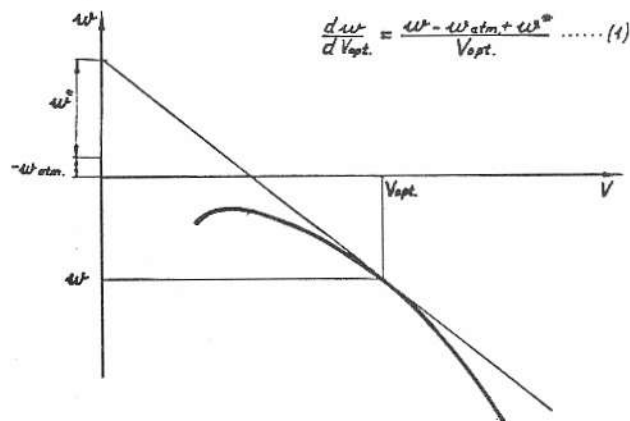


Fig. 1

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

However, calculation of speed  $w^*$  is generally impossible since it requires knowledge of vertical airspeed distribution along

the flight path before the flight, not to mention the troublesome variation calculus involved. Some theoreticians suggest division of the flight path into sections and subsequent correction of the  $w^*$  setting after passing the given section (dependent upon height differences between the beginning and end points). Unfortunately, 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, a more usable simplification was made by Tomczyk [4], Jonas [5], Abzug [6] and others, who analyze optimal speed selection during flight through the area of constant sink and subsequently through an area of constant lift. For the model speed distribution presented in Figure 2, the best speeds  $V_1$  and  $V_2$  can be calculated without application of the calculus of variations.

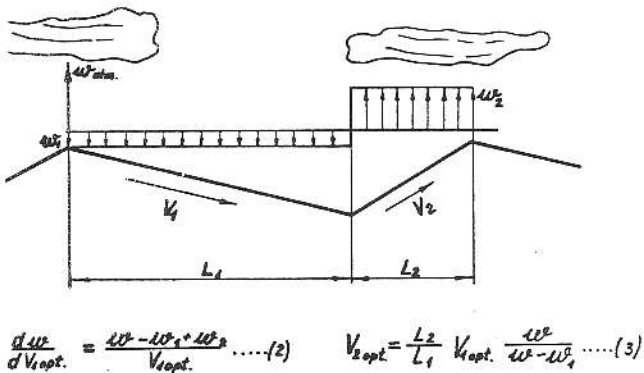


Fig. 2

In case of flight in the sink area, the following relation is obtained:

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

This is identical with that obtained for the best cruise speed during flight with circling.

In case of flight in the lift area:

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

One can see that the correct selection of speed  $V_1$  requires a correct estimation of the lift intensity  $w_2$  and setting of the Mac-

Cready ring as for the flight with circling. In practice, it is much more difficult to select 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. Figure 3 presents selection of the best speed  $V_1$  and achieved cross-country speed.

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

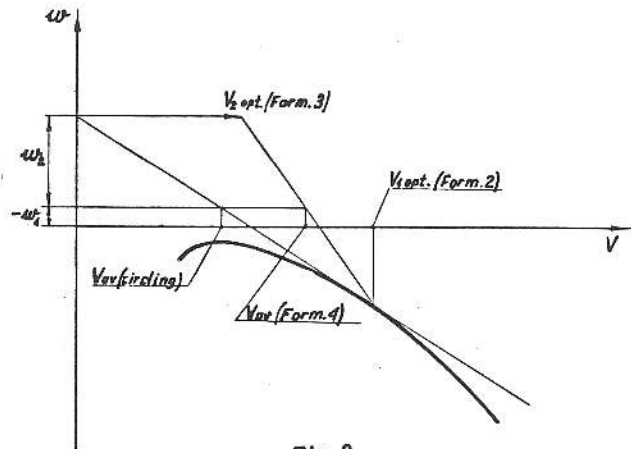


Fig. 3

According to formula (4), the latter equals:

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

when flying over area  $L_2$  with speed  $V_2$  and is  $1 + \frac{L_2}{L_1}$  times higher than 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 cross-country speed  $V_{av}$ , are valid whenever speed  $V_2$ , calculated according to formula (3), is higher than minimum speed. If this condition is not met, further classical dolphin-mode flight requires reduction of the speed  $V_1$  because this simultaneously decreases the height loss to be regained in the area of lift of length  $L_2$ .

It should be pointed out that the main difficulty in the selection of the best speed  $V_2$ , calculated according to formula (3), is estimation of the distance  $L_2$ .

Let us try to avoid this problem by accepting, as presented in Figure 4, a model distribution of air speed which differs from the one previously discussed in the indetermined length  $L_2$  of the area of lift. This

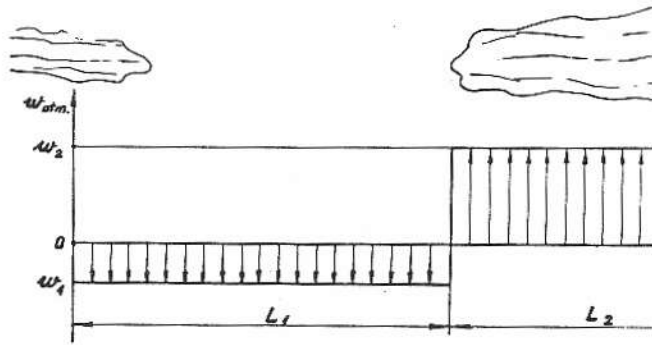


Fig. 4.

model has been introduced in the consideration of 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 a safe speed  $V_2 \sim V_{min}$ .

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

$$\frac{dw}{dV_{lopt}} = \frac{w - w_1 + w_2}{V_{lopt} - V_2} \quad (5)$$

and the cross-country speed

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

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

However, the Abzug suggestion concerning selection of the cruise speed higher than that calculated with the MacCready ring, appears to be incorrect due to two factors: First, the cruise speed resulting from formula (5) is only the best speed 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 initial height is to be regained,  $\Delta H = 0$ , then, according to Figure 5, the best combination of speeds will be the cruise speed according to the MacCready ring and speed  $V_{2opt}$  in the area of lift. Figure 5 also presents the cross-country 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.

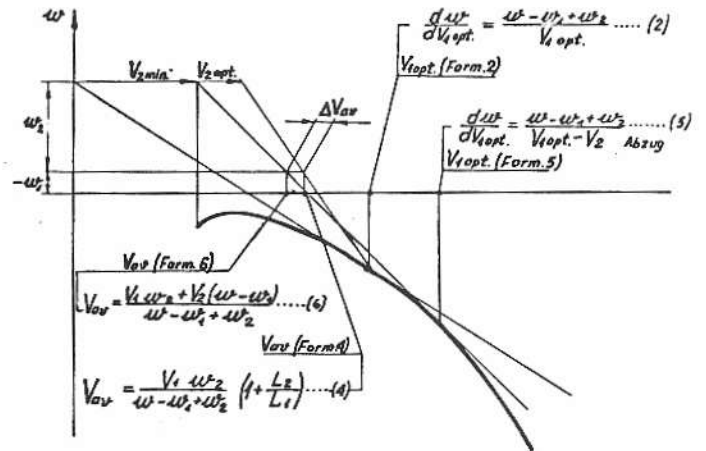


Fig. 5

We should pay attention to the fact that choice of the best combination of speeds can be made, with fairly good approximation, in flight along cloud streets. To find the best cruise speed it is only necessary to have a good assessment of the expected mean rate of climb and, after approaching the cloud street, choose the  $V_2$  speed for the observed length of the street so that at the end of the area of lift the initial height is regained.

The other reason one should choose the cruise speed according to the MacCready 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 assumed meteorological conditions enabling the pilot to apply classical dolphin-mode flight techniques, i.e., the speed  $V_2$  calculated after formula (3) is not less than the minimum speed. When, however, the meteorological conditions are too weak, i.e., when  $V_{2opt} < V_{min}$ , the possibility of continuing the flight still exists. This would be done along the elongated track  $L_3 > L_2$  by "essing" or by circling between straight sections so that the flight time would meet the requirement:

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

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

Another possibility of continuing the dolphin-mode flight utilizes a reduced setting of the MacCready ring which means decreased cruise speed in order to reduce height loss. The limit setting is:

$$w^* = 0$$

and cruise at the speed corresponding to the maximum range. However, if - even in this case - speed  $V_2$  is less than minimum speed, a rectilinear flight through the area of lift will not result in regaining the initial height.

Assuming that meteorological conditions are too weak for the classical dolphin-mode flight, but encourage one to fly according to the MacCready ring setting

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

one should choose - from the two above techniques - the first one. A combination of speed according to the MacCready ring and speed  $V_{2opt}$  (for the elongated track  $L_3$  at  $V \sim V_{min}$ ) will result in better cross-country speed than any other combination of speeds, including the cruise speed less than the MacCready ring reading and  $V_2 = V_{min}$ .

Based on the above considerations, under any meteorological conditions suitable for dolphin-mode flight (classical or combined), one should - for the cruise - obey the MacCready ring readings (set on the expected rate of climb). After approaching the cloud street one should choose speed and flight track so that the initial height is regained at the end of the track.

#### 4. CROSS-COUNTRY FLIGHT WITH UTILIZATION OF DYNAMIC EFFECTS

Previous considerations and equations have been based on the polar curve of a sailplane which determines its performance under conditions of quasi-steady flight when lift is balanced by weight. In fact, the pilot changes speed dynamically, i.e., the speed changes are accompanied by changes in normal acceleration factor  $n$ .

The effect of the sailplane's normal acceleration, on its efficiency 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, in his paper presented at the XVth OSTIV Congress, introduced basic equations relating power absorbed by the sailplane from the atmospheric stream  $E'$  to the amount of normal acceleration  $n$ , intensity of the velocity component normal to the flight path  $w_{atm} \cos \psi$ , and to the sailplane characteristics:

$$\frac{E'}{mg} = n w_{atm} \cos \psi - w \quad (7)$$

From equation (7), where  $w$  is the rate of descent at speed  $V$  and load factor  $n$ , and from calculations made for a typical Standard Class sailplane, it follows that the optimal values of the load factor increase rapidly with the rise in upward speed of the air stream, beginning from 1-2 m/sec onwards.

For lower upward speed of the air stream, power absorbed from the atmosphere at  $n > 1$  can be even less than that at  $n = 1$  because increase in the second term of the right side of equation (7) during pullup, i.e., increase of energy dissipated due to increased drag, can exceed total energy absorbed from the atmosphere.

A second valuable piece of information concerning cross-country flight technique with utilization of dynamic effects, is the relation between energy increase of the sailplane passing through an area of lift of constant vertical speed and change in the vertical component of flight speed  $z'$  between entering and leaving the area of lift. This relation has been introduced by Gorisch.

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

Gorisch interprets this relation as follows: The first term on the right side he calls the "unsteady increase", while the second term is "steady increase". The name for the second term explains itself since it represents the known relation between sailplane energy rise and 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  $m w_{atm} \Delta z'$  is independent of time and its magnitude is proportional to the difference between vertical components of the sailplane speed (relative to ground) on entering and leaving the area of lift (Figure 6).

It should be emphasized that this dynamic\* term can have a positive or

\* The word "dynamic" seems to fit better than "unsteady".

$$\Delta E = m \cdot w_{atm} \cdot \Delta z' + m \cdot g (w_{atm} - w_{mean}) \Delta t \dots (8)$$

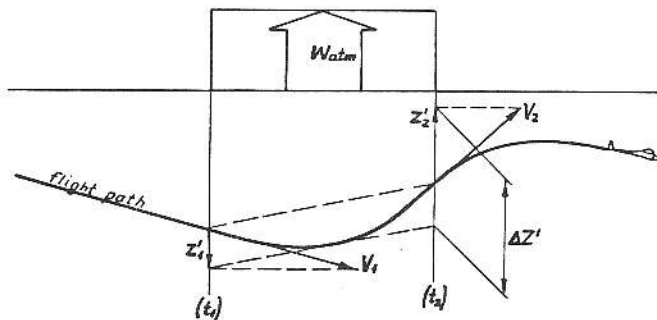


Fig. 6

negative value, which means gain or loss of the sailplane's energy respectively.

The "+" sign appears when both  $\Delta z'$  and  $w_{atm}$  are positive or negative. For the pilot, it means that in the upward moving air stream the flight path should be curved so that the center of curvature is above the sailplane ( $\Delta n$  positive); in the descending air stream the flight path curvature should correspond to the speed gain ( $\Delta n$  negative). It should also be taken into account that, when observing the above rule, the dynamic energy gain is the larger the higher the cruise speed is since, in that circumstance, higher value of  $\Delta z'$  can be achieved. At the same time, utilization of the dynamic energy gain is equivalent to the steady cross-country flight ( $n = 1$ ) in favorable weather conditions, i.e., at higher values of  $w_{climb}$ . One can conclude from 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, therefore, that the pilot using the described technique can, and should, set the MacCready ring at a higher rate of climb than that expected. For selection of cruise speed and speed in the area of lift, employ the same rules as in the case of steady cross-country flight.

## REFERENCES

- 1 F.G. IRVING, "Cloud-Street Flying", *Technical Soaring*, Vol. III, #1.
- 2 R. ARHO, "Optimal Dolphin Soaring as a Variation", *Technical Soaring*, Vol. III, #1.
- 3 E. KAUER, H.G. JUNGINGER, "Segelflug im Delphin-Stil", *Aerokurier* 9, 10/73.
- 4 A. TOMCZYK, "Cross-Country Flight Without Circling", *Skrzydłata Polska*, 8/72 (in Polish).
- 5 K. JONAS, "Leistungsmöglichkeiten und Leistungsgrenzen von Segelflugzeugen verschiedener Klassen", *Aerokurier*, 8/'74.
- 6 M.J. ABZUG, "A Speed Ring for Cloud Street Flying", *Technical Soaring*, Vol. IV, #1.
- 7 W. GORISCH, "Energy Exchange between a Sailplane and Moving Air Masses...", *Aero Revue* 11, 12/'76.
- 8 J. Gedeon, "Dynamic Analysis of Dolphin-Style Thermal Cross-Country Flight", *Technical Soaring*, Vol. III, #1 & 3.
- 9 J. SANDAUER, "Theory of the Dolphin-Mode Cross-Country Flight and Principles of the Dynamic Flight", *Techn. Lotnicza i Astronautyczna*, 12/'77 & 1/'78 (in Polish).