

# The Influence of Sailplane Performance and Thermal Strength on Optimal Dolphin-Flight Transition Piloting Techniques

Dr. J. Gedeon, Technical University Budapest (Hungary)

Presented at the XV OSTIV Congress, Räyskälä, Finland (1976)

In order to complement previous dynamic dolphin-flight transition optimisation work done by the author, traverses through Konovalov "a" type quadruple thermal models of  $c_o = 2$  m/sec and  $c_o = 5$  m/sec strength and of  $R = 100$  m and  $R = 200$  m cell radii respectively have been computed for a Nimbus 2 type sailplane. Results show the optimum point for transition initiation, the best pull up/push over load factors and the correct climb angle to vary only moderately with sailplane performance and thermal parameters. Ideal dolphin-flight performance charts can be corrected for transition losses by factoring V values with  $\eta_v = 0.85$  to 0.87. This lowered performance curve may be taken as valid for speeds up to about the ideal cross-country speed for greatest range.  $(S/L)_{max}$  may amount to  $\eta_s = 0.76$  to 0.80 times its ideal value.

## Introduction

Nowadays there is a steadily growing interest in the problems of dolphin-style cross-country flying. So Arho [1], Pirker [2], Reichmann [3], Meyer [4] have added to our knowledge in this field, while Westerboer [5] worked on problems of instrumentation, to name only a few of recent publications. In practical dolphin flying the problem of optimal transition is a very real one, because the length of the slowing-down and that of re-accelerating may be in the order of a third to a half of the thermal length. The usual quasi-stationary calculation methods being unsuitable for solving the transition problem, the author tried to work out a finite time-element computer method for it [6]. In its developed form the programme gave optimum or near-optimum transition piloting parameters for an ASW 15 type standard class sailplane riding a street of  $c_o = 2$  m/sec lift,  $R = 100$  m nominal radius, four-cell thermals [7].

For completing this work, both

- the sensitivity of optimum transition parameter values to changes in sailplane performance and in meteorological conditions, and
- the possibility of correcting quasi-stationary, ideal dolphin-flight performance charts for transition losses,

had to be investigated. For that purpose, dolphin thermal traverses were calculated for a Nimbus 2 type sailplane, having substantially higher cross-country performance than standard class gliders, in 100 m cell-radius, 2 m/sec and 5 m/sec, furthermore in 200 m cell-radius 5 m/sec thermals respectively.

## Notation

c	thermal lift	m/sec
$c_o$	maximum thermal lift	m/sec
g	gravity acceleration	m/sec <sup>2</sup>
n	normal load factor	
x	distance from centre of thermal	m
$x_A$	point of pull-up initiation	m
L	updraft section length	m
R	(nominal) thermal radius	m
$R_{\infty}$	theoretical minimum radius of turn	m
S	spacing of thermals	m
$\Delta(S/L)$	range deficit	
V	sailplane speed (in wind coordinates)	km/h
$V_{AT}$	cross-country speed for zero wind	km/h
$\Delta V_{AT}$	speed deficit	km/h
$\beta$	pull-up lead coefficient	
$\bar{\epsilon}$	glide ratio for maximum lift coefficient	
$\eta_s$	glide coefficient	
$\eta_v$	speed coefficient	
$\Theta_H$	climb angle for middle part of slow-down section (in wind coordinates)	degrees

## Subscripts

e	climb
s	glide
G	push-over
L	pull-up

## Superscript

quasi-static idealized conditions, "square" thermal

## 1. Thermal Models and Flight Efficiency Coefficients

Realistic dolphin-flight calculations are to be based on thermal models having an appropriate downdraft zone surrounding the lift core. The first dynamic calculations reported on in Ref. [6] used the so-called profile type 1, given by

$$c = c_o \cdot e^{-\left(\frac{x}{R}\right)^2} \left[ 1 - \left(\frac{x}{R}\right)^2 \right] \quad (1)$$

The thermal street was supposed to consist of thermals identical in maximum updraft  $c_o$  and in nominal radius R, having equal spacings S. Calculations performed with this model showed only limited possibilities for sustained dolphin-flying in isolated thermals due to the relatively high thermal lift and/or density values required for it. As everyday experience and thermal profile measurements published by Konovalov [8] and by Milford [9] indicate, in higher thermal density atmospheric conditions there is a tendency for forming thermal groups. In order to account for this, the four-cell type 2 thermal model patterned, after the Konovalov type "a" profile was introduced [7]. Its equation reads as follows:

$$c = c_o \cdot \left\{ \frac{1}{4} e^{-\left(\frac{x+2R}{R}\right)^2} \left[ 1 - \left(\frac{x+2R}{R}\right)^2 \right] + \frac{1}{4} e^{-\left(\frac{x+R}{R}\right)^2} \left[ 1 - \left(\frac{x+R}{R}\right)^2 \right] + \frac{1}{4} e^{-\left(\frac{x}{R}\right)^2} \left[ 1 - \left(\frac{x}{R}\right)^2 \right] + \frac{1}{4} e^{-\left(\frac{x-2R}{R}\right)^2} \left[ 1 - \left(\frac{x-2R}{R}\right)^2 \right] \right\} \quad (2)$$

Dynamic calculations reported on in the present paper have been performed all using this model. The profile is shown in nondimensional form on Fig. 1.

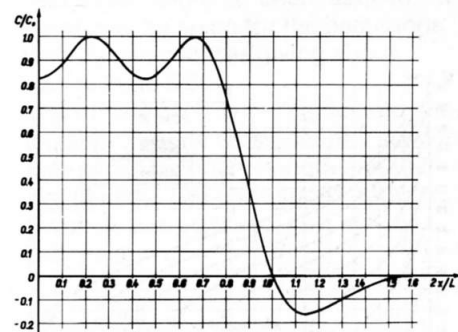


Fig. 1: Four-Cell Thermal Model

Direct optimum search can be made only for the all-out longest glide distance, otherwise, e. g. for highest speed in a given thermal density L/S, trial-and-error sounding for it would use up too much computer time. For the indirect optimisation at first a "square" idealized thermal model with uniform downdraft zone extending to the next thermal core was used. Results looked fine at first, but later, for the  $c_o = 5$  m/sec,  $R = 200$  m case, full dynamic traverse calculations were giving a better maximum range with than without losses. This being the very thing an honest second order approximation should not do, the problem was investigated and the fault traced to the unnatural extent of the sink zone. As a logical correction, a balanced downdraft zone idealized square thermal was introduced. Formulae describing the single-cell variant of it read as follows:

$$|x| \leq L : \quad c = c_o \quad (3a)$$

$$L \leq |x| \leq 2.76887 L : \quad c = -0.15 c_o \quad (3b)$$

$$|x| \geq 2.76887 L : \quad c = 0 \quad (3c)$$

The lift profile is to be seen on the left side of Fig. 2. It has a four-cell variant, too:

$$|x| \leq L: \quad c=c_0 \quad (4a)$$

$$L \leq |x| \leq 1.58962 L: \quad c=-0.15c_0 \quad (4b)$$

$$|x| \geq 1.58962 L: \quad c=0 \quad (4c)$$

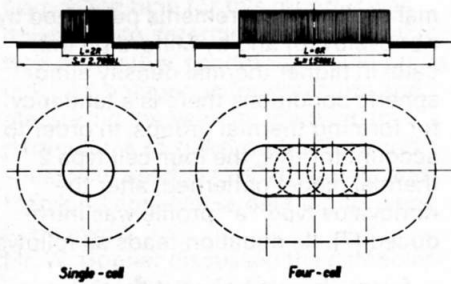


Fig. 2: Single-Cell and Four-Cell Square Thermal Models

as shown on the right side of Fig. 2. This type 4 thermal being the idealized counterpart of Equ. [2], it was selected for serving as an optimisation scale. Ideal dolphin-flight performance charts for the types ASW 15 and Nimbus 2 are

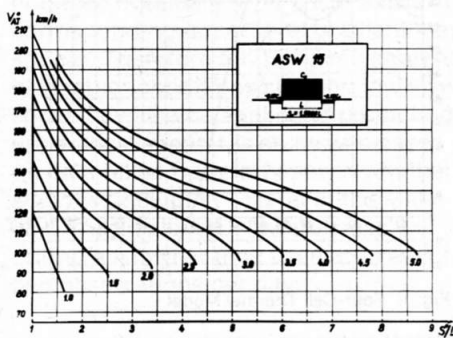


Fig. 3: ASW 15 Ideal Dolphin-Flight Performance Chart

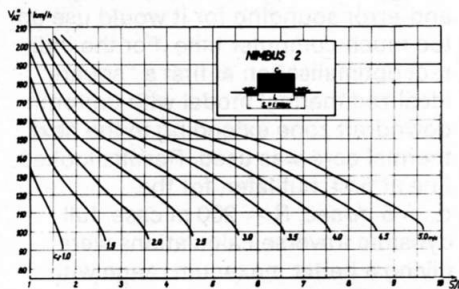


Fig. 4: Nimbus 2 Ideal Dolphin-Flight Performance Chart

shown on Fig. 3 and 4 respectively. Both of them were calculated for a height of 1500 metres. Optimisation by way of the ideal performance curve is made as follows: Supposed a dynamic traverse calculation has given the glide distance  $S/L$  and the cross-country speed  $V_{AT}$  (see point P on Fig. 5). We can now deter-

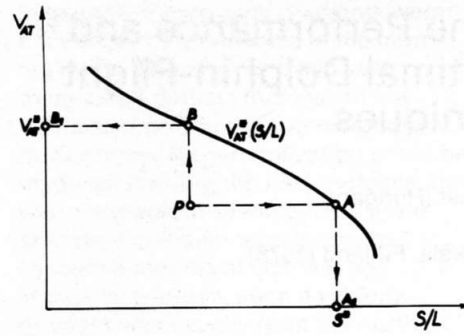


Fig. 5: Determination of  $V^*$  and  $S^*$

mine from the graph the ideal glide distance  $S^*/L$  for the speed  $V_{AT}$  (points A and  $A_1$ ) and the ideal cross-country speed for  $S/L$   $V^*$  (points B and  $B_1$ ). Using these the following indicators may be formed:

The range deficit:

$$\Delta(S/L) = S^*/L - S/L \quad (5)$$

The glide coefficient:

$$\gamma_S = S/S^* \quad (6)$$

The speed deficit:

$$\Delta V_{AT} = V_{AT}^* - V_{AT} \quad (7)$$

The speed coefficient:

$$\gamma_V = V_{AT}/V_{AT}^* \quad (8)$$

## 2. Results of the Dynamic Calculations

Using the type 2 four-cell thermal model, the following dynamic traverse calculations have been made:

ASW 15 glider,  $c_0 = 2$  m/s,  $R = 100$  m thermal: 54 runs/Ref. [7]

Nimbus 2 glider,  $c_0 = 2$  m/s,  $R = 100$  m thermal: 62 runs,

Nimbus 2 glider,  $c_0 = 5$  m/s,  $R = 100$  m thermal: 48 runs,

Nimbus 2 glider,  $c_0 = 5$  m/s,  $R = 200$  m thermal: 78 runs,

in all: 242 runs.

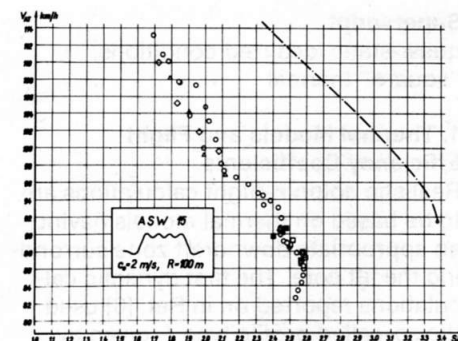


Fig. 7: General View of Calculation Results for ASW 15 Flights through  $c_0 = 2$  m/sec,  $R = 100$  m Thermal

$n_L$	$n_S$	$\theta_H$						
		$0^\circ$	$15^\circ$	$18^\circ$	$19^\circ$	$21^\circ$	$23^\circ$	$25^\circ$
1.00	1.000	+						
1.30	0.769					⊙		
1.40	0.714					⊙		
1.45	0.690					⊙		
1.50	0.700			⊕				
1.50	0.667					⊙		
1.60	0.625					⊙		△
1.70	0.590			⊕		⊙		
1.80	0.700		◇	⊕				
1.80	0.556		◇	□	×	○	▽	△
1.90	0.526					●		
2.00	0.650			■				
2.00	0.500					●		▲

Fig. 6: Symbols Used on the Dynamic Performance Graphs

Furthermore, we shall need the formula for the theoretical minimum radius of turn:

$$R_{-} = \frac{V_{min}}{g} \sqrt{1 + \epsilon^2} \quad (9)$$

used in the expression for the pull-up lead coefficient:

$$\beta = (0.5L - x_A)/R_{-} \quad (10)$$

All of them, except run 31 for the ASW 15, have given glide distances values over 10R, suitable for further evaluation. The load factor/climb angle

combinations investigated are shown on Fig. 6. The results are summarised in Figs. 7-10.

Points for the best dynamic traverse results are lying nearly parallel to the ideal performance curve shown in dots and dashes. First of all, let us give account of how much dolphin-flying is improving cross-country performance over steady-speed gliding conditions. With that object, runs for the Nimbus 2 in 2 m/sec,  $R = 100$  m thermal were computed as constant speed but dynamic traverses (see crosses in Fig. 8).

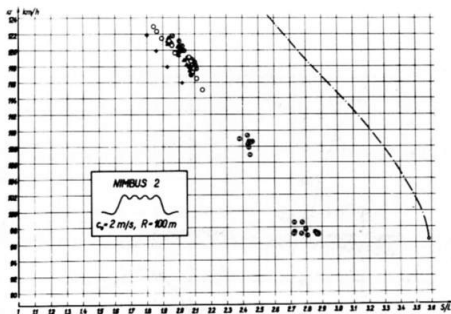


Fig. 8: General View of Calculation Results for Nimbus 2  
Flights through  $c_0 = 2$  m/sec,  $R = 100$  m Thermal

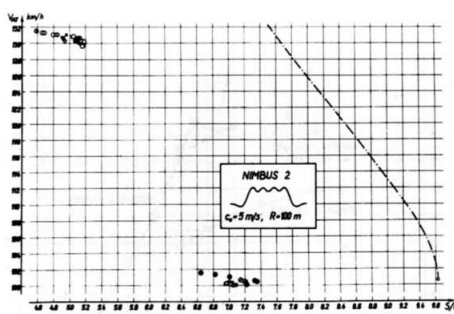


Fig. 9: General View of Calculation Results for Nimbus 2  
Flights through  $c_0 = 5$  m/sec,  $R = 100$  m Thermal

As it seems, correct speed management may earn 5 to 6 km/h in mean speed or about 10% in range between thermals over constant-speed tactics – not the spectacular break through many of us have dreamed of, but significant nevertheless in contest conditions.

For the same sailplane-thermal combination we have also experimented with varying the speed in climb  $V_e$ . For glide speeds of  $V_s = 140$  km/h and  $V_s = 135$  km/h, respectively, best cross-country speeds could be obtained with the speed in climb corresponding to that for lowest sink,  $V_e = 86$  km/h. Later, for  $c_0 = 5$  m/sec and  $R = 200$  m, a similar search, this time for the best all-out range, yielded some improvements by going down to  $V_e = 76.5$  km/h.

The choice of climb angle is simple and clear, best performances being associated always with  $\Theta_H = 21^\circ$ . Concerning the other parameters, the following can be said.

a) *Greatest All-Out Range*

Best parameter combinations found so far are listed in Table 1, variation of all-out range with pull-up lead coefficient being shown separately on Fig. 9.

The results are mostly self-explanatory. Best S/L values for the first three plane/thermal combinations could still slightly be improved upon by lowering  $V_e$  and – for the ASW 15 – by lowering the pull-up and increasing the push-down load coefficients.

b) *Highest Cross-Country Speed*

Optimal transition tactics for best speed are summed-up in Table 2. Speed deficit curves against pull-up lead coefficient are pictured on Fig. 10.

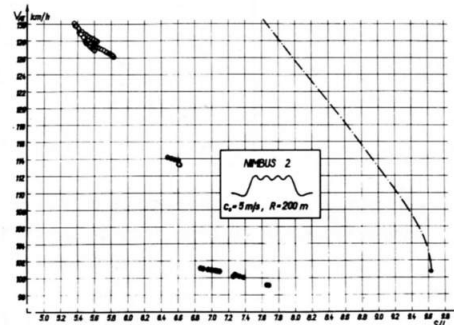


Fig. 10: General View of Calculation Results for Nimbus 2  
Flights through  $c_0 = 5$  m/sec,  $R = 200$  m Thermal

The general picture is again in fair agreement with the statements made on the basis of the ASW 15 calculations. For greatest range as well as for highest speed, variations in optimum parameter values are well within the probable estimation error band in practical piloting. Even the conclusion may be ventured that it would not be necessary to continue making more full dynamic calculations in case a reliable conversion procedure for ideal dolphin-flight performance data can be found.

3. *Conversion of Quasi-Static Performance Charts*

In view of the position of the best dynamic performance points relative to the idealized range-speed curve on the figures and according to the performance coefficients achieved, a first proposal for a conversion procedure may look like the following.

Transition losses can be accounted for by factoring ideal cross-country speed values  $V^*$  by say  $\eta_V = 0.85$  to  $0.87$ , point to point. The transformation may be valid until a speed  $V_{AT}$  about equal to the ideal cross-country speed for all-out maximum range has been reached. This point may be taken for the best range with dynamic losses giving about  $\eta_S = 0.76$  to  $0.80$ .

The transformed S/L –  $V_{AT}$  curve is showing approximate cross-country speeds for a given thermal strength and thermal density. The glide speed between thermals can be taken, as it may be easily shown:

$$V_s = \frac{S/L - 1}{S/L - V_{AT}/V_e} \quad (11)$$

This first order theoretical approximation errs some 1 to 2 km/h to the high side as indicated by the following example. In the series Nimbus 2,  $c_0 = 5$  m/s,  $R = 200$  m, run No. 16 was for  $V_s = 140$  km/h,  $V_e = 86.08$  km/h giving  $S/L = 5.730$  and  $V_{AT} = 126.748$  km/h. From Equ. (11):

$$V_s = 126.748 \frac{5.730 - 1}{5.730 - 126.748/86.08} = 140.81 \text{ km/h}$$

**Summary**

Continuing dynamic dolphin-flight traverse calculations through type 2, four-cell thermal models have given following results:

a) Optimal transition piloting techniques are not significantly different from those found for the type ASW 15. A medium level of load factors and climb/dive angles should be chosen. For optimum glide distance, the pull-up should be started before entering the updraft. For best cross-country speed, the correct pull-up point is a little way in the core.

Table 1: **Transition Parameters for Optimum Range**

Type:	Thermal		At		$n_L/n_G$	$\Theta_H^\circ$	$\beta$	S/L	$\eta_S$
	$c_0$ m/s	R m	$V_s$ km/h	$V_e$ km/h					
ASW 15	2.0	100	103.3	72.092	1.80/0.556	21	2.8	2.583	0.76377
Nimbus 2	2.0	100	103.3	86.08	1.45/0.69	21	1.9	2.877	0.80392
Nimbus 2	5.0	100	103.3	86.08	1.45/0.69	21	1.7	7.353	0.76338
Nimbus 2	5.0	200	103.3	86.08	1.45/0.69	21	0.6	7.100	0.73715
Nimbus 2	5.0	200	103.3	76.5	1.45/0.69	21	1.4	7.681	0.79743

Table 2: **Transition Parameters for Optimum Speed**

Type:	Thermal		At		$n_L/n_G$	$\Theta_H^\circ$	$\beta$	$V_{AT}$ km/h	$\eta_V$	$\eta_S$
	$c_0$ m/s	R m	$V_s$ km/h	$V_e$ km/h						
ASW 15	2.0	100	129.12	72.09	1.80/0.556	21	-1.50	15.885	0.87108	0.71138
ASW 15	2.0	100	139.88	72.09	1.80/0.556	21	-1.35	17.038	0.86919	0.70082
Nimbus 2	2.0	100	140.00	86.08	1.60/0.625	21	-0.60	17.905	0.87125	0.74334
Nimbus 2	5.0	100	140.00	86.08	1.70/0.590	21	-0.20	24.274	0.84337	0.66951
Nimbus 2	5.0	200	140.00	86.08	1.80/0.556	21	-1.40	23.814	0.84427	0.69952

b) Conversion of ideal dolphin-flight performance charts is possible by factoring ideal cross-country speeds with a suitable value for the speed coefficient.

#### Acknowledgement

The author wishes to thank Prof. Dr. Paul Michelberger for making possible the research and our Faculty Computing Center led by dr. Attila Ágoston for their patient work. The neat drawing of the figures has been made by Mr. Charles Bedöcs.

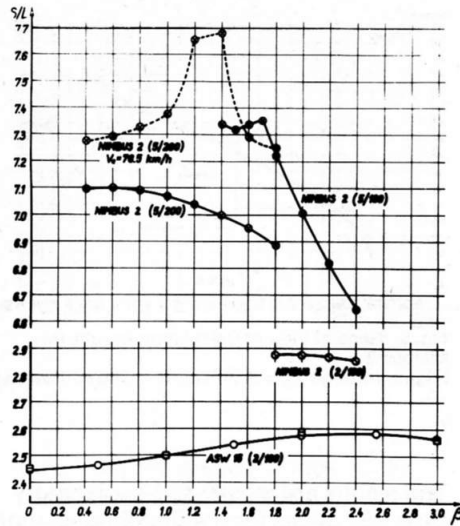


Fig. 11: Influence of Pull-Up Point on Glide Distance ( $V_s = 103.3 \text{ km/h}$ )

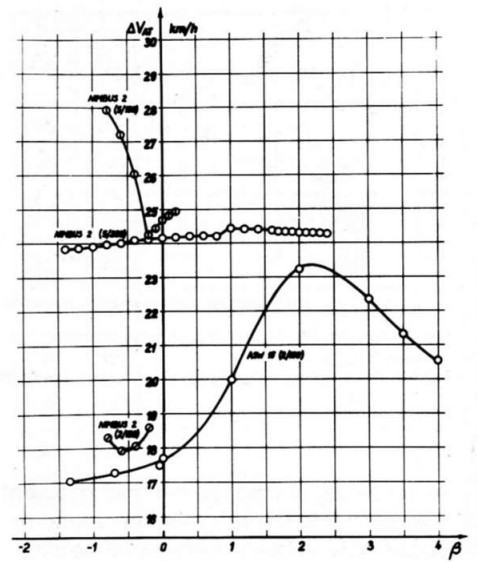


Fig. 12: Influence of Pull-Up Point on Cross-Country Speed ( $V_s = 140 \text{ km/h}$ )

#### References:

- [1] Arho, R.: Optimal Dolphin Soaring as a Variation Problem. Technical Soaring, Vol. III. No. 1. (1973.) pp. 20-26.
- [2] Pirker, H.: Über die Reisegeschwindigkeit von Segelflugzeugen. 2. Teil: der Delphinflug. Flugsportzeitung, 1975. Nr. 1. 15. Februar, pp. 17-25.
- [3] Reichmann, H.: Streckensegelflug. (Motorbuch-Verlag, Stuttgart, 1975.)
- [4] Meyer, R.: Segelflug im Delphinstil. Aero-Revue, 1975. No. 12, pp. 671-678.
- [5] Westerboer, I.: Die Sollfahrt im Segelflug. Berichte der Fachhochschule Regensburg, 1976. Heft 2.
- [6] Gedeon, J.: Dynamic Analysis of Dolphin-Style Thermal Cross-Country Flight. Part I. Technical Soaring, Vol. III., No. 1., OSTIV Publication XII.
- [7] Gedeon, J.: Dynamic Analysis of Dolphin-Style Thermal Cross-Country Flight. Part II. Technical Soaring, Vol. III., No. 3.
- [8] Konovalov, D. A.: On the Structure of Thermals. OSTIV Publication XI.
- [9] Milford, J.: Some Thermal Sections Shown by an Instrumented Glider. OSTIV Publication XII.