SOME GENERAL CONSIDERATIONS ON SAILPLANE AERODYNAMIC DESIGN

by Dr Ing. Piero MORELLI

Politecnico di Torino - Italia

In the design of a sailplane, the most important process in order to obtain an improvement in aerodynamic performance is obviously the reduction of aerodynamic drag.

The designer has two different possibilities for achieving this aim:

1) the reduction of induced drag;
2) the reduction of parasitic drag, which consists essentially of friction, form and interference drag.

The reduction of induced drag is mainly achievable through an increase of wing aspect ratio.

The reduction of parasatic drag is obtainable through a variety of architectural arrangements and choices. Sailplane design being a problem of compromise, the designer has to

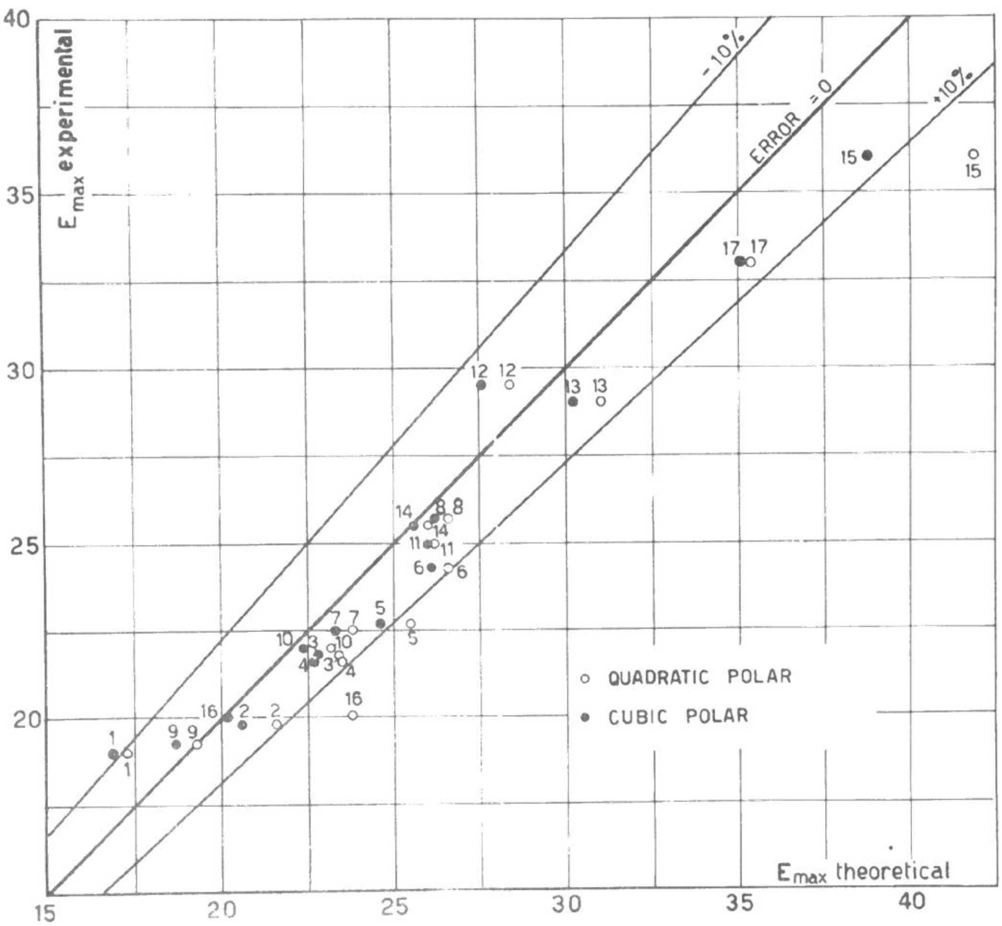

Figure 1

decide for instance if laminar flow sections, or a retractable undercarriage is worth adopting in his particular case, i.e. if the complication, cost and the sacrifice of other qualities which is inherent to them is paid for by the gain achieved in performance.

If A (aspect ratio) and C_{Do} (parasitic drag coefficient) are the variables which affect sailplane design from the aerodynamic point of view, it is certainly convenient to study and to estimate quantitatively their influence on sailplane performance.

This cannot be done in a general way, unless an acceptable analytical expression for the polar curve of a sailplane is established first.

POLAR EQUATIONS

The relationship between lift and drag coefficients is usually given the analytical form

$$C_D = C_{Do} + k \frac{C_L^2}{\pi A} \qquad (1)$$

If C_{Do} is considered a constant, equation (1) gives poor approximation at high C_L, where not negligible C_{Do} increases take place.

The evaluation of k "a priori", moreover, is subject to a rather large amount of uncertainty, k being liable to vary in a rather large interval (between 0,33 and 1,45 in special cases, and from 1,05 to 1,35 in the more common cases), as results from calculations based

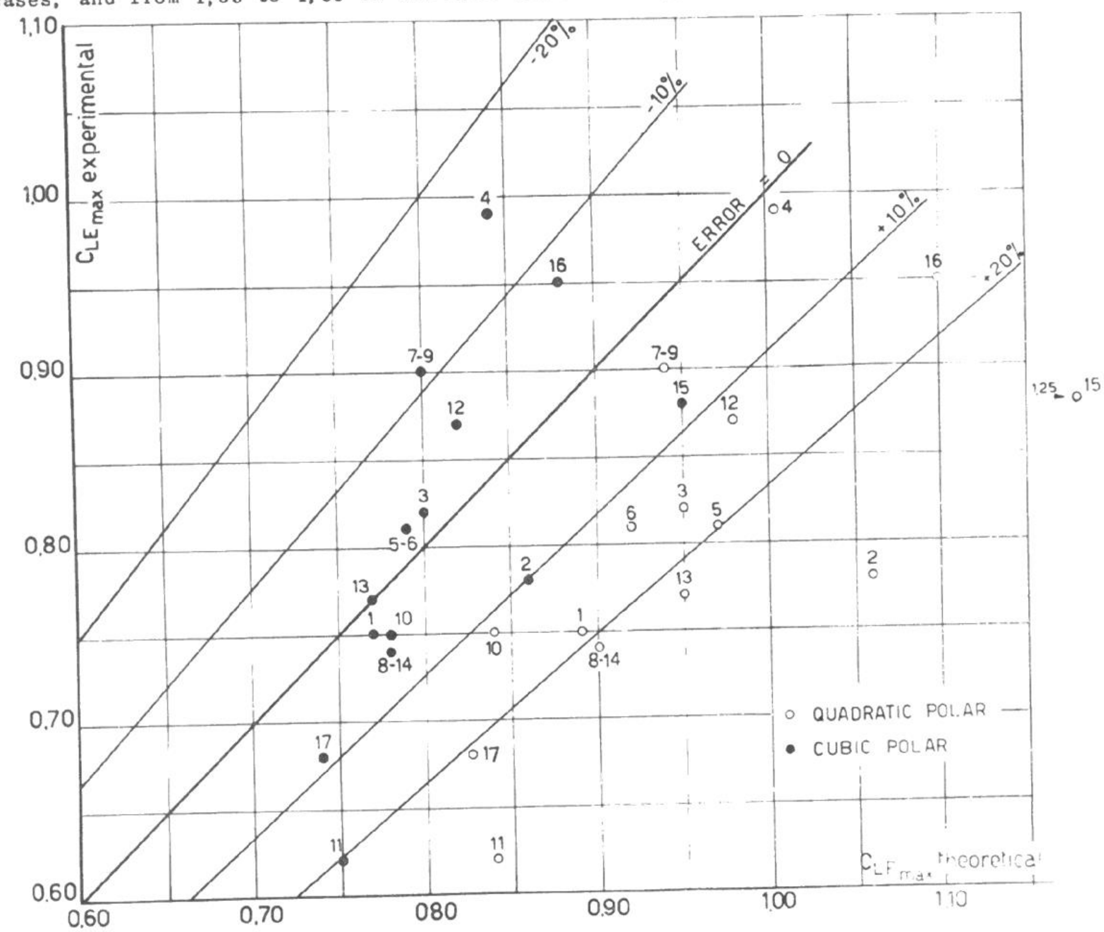

Figure 2

on experimental data (reference 1).

In the case of sailplanes, some of the more interesting flight attitudes, such as that of maximum gliding ratio (E_{max}) or minimum sinking speed (V_{ymin}), occurring at high C_L, it would be desirable to have an analytical expression more suitable to represent the true polar curve in this range of high C_L.

A better approximation is obtainable with the simple cubic equation:

$$C_D = C'_{Do} + \frac{C_L^3}{\pi A} \qquad (2)$$

where C'_{Do} is to be chosen so that the cubic curve is faired to the experimental polar.

If a quadratic polar (k = 1) is established which is based on a certain value of C_{Do}, it is possible to determine C'_{Do} so that the C_D relating to the quadratic and cubic polars at a certain value of C_L (say $C_L^* = 0,6$), coincide:

$$C_D = C_{Do} + \frac{C_L^{*2}}{\pi\ A} = C'_{Do} + \frac{C_L^{*3}}{\pi\ A}$$

$$C'_{Do} = C_{Do} + \frac{C_L^{*2}}{\pi\ A}\ (1 - C_L^*) \qquad (3)$$

$$C_L^* = 0,6$$

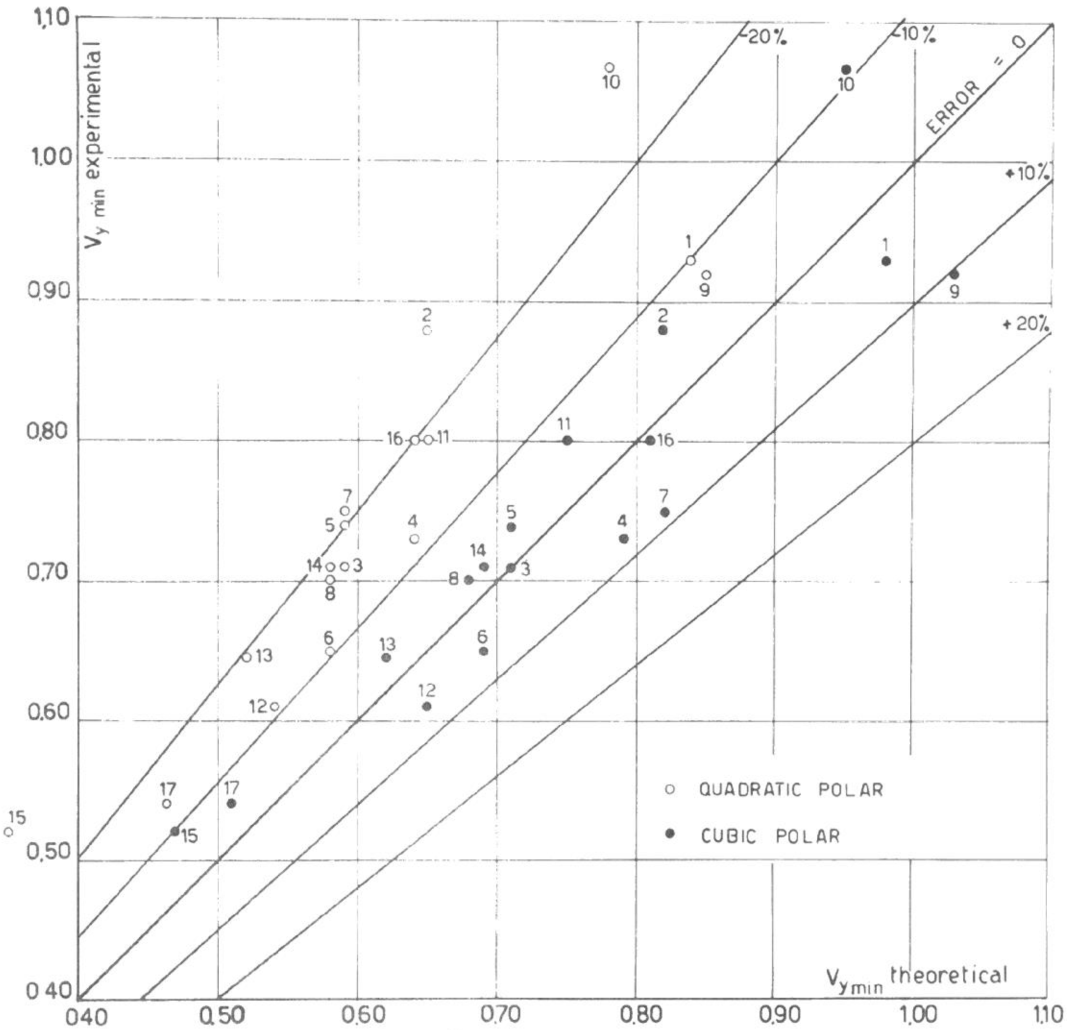

Figure 3

$$C'_{Do} = C_{Do} + 0,046/A \quad \dots\dots (4)$$

The proper value of C_L should be chosen in relation to the C_{Lmax} of the particular sailplane considered. The value of 0,6 is appropriated for $C_{Lmax} = 1,3 - 1,5$.

For most sailplanes, the lift coefficients for maximum gliding ratio and minimum sinking speed, exceed $C_L = 0,6$. It is therefore of interest to calculate the above characteristics from equation (2). The expressions derived from the cubic equation are compared in table I (see page 77) with the corresponding known expressions derived from the quadratic equation (k = 1).

In order to demonstrate the suitability of the cubic equation to approximate the true polar curve at high C_L, reliable experimental values of E_{max}, V_{ymin}, C_{LEmax}, C_{LVymin}, relating to a number of sailplanes with known characteristics (Table II, see page 78) have been compared with the theoretical values (quadratic and cubic) calculated according to the expressions of table I (figures 1, 2, 3 and 4).

C_{Do}, A DIAGRAMS

In figure 5 C_{Do}, A curves, for constant values of E_{max} and C_{LEmax}, are traced, according to the following expressions derived from the quadratic and cubic equations:

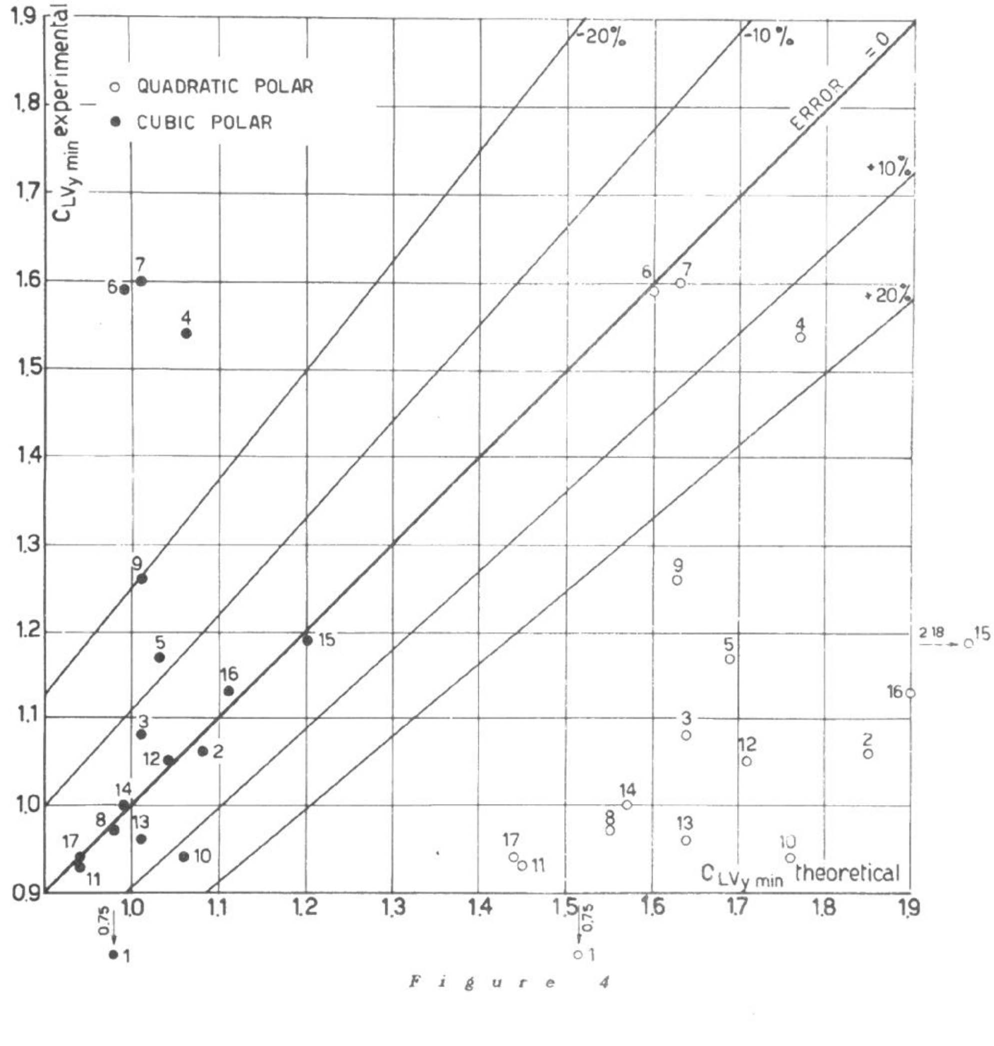

Figure 4

quadratic: $C_{Do} = 0{,}785\ A/E^2_{max}$

$C_{Do} = 0{,}318\ C_{LEmax}/A$

cubic: $C_{Do} = 0{,}685\ \sqrt{A/E^3_{max}} - 0{,}046/A$

$C_{Do} = 0{,}639\ C^3_{LEmax}/A - 0{,}046/A.$

In figure 6 we have C_{Do}, A curves for different values of V_{ymin} (W/S = 20 kg/mq) and C_{LVymin}, according to both quadratic and cubic polar equations:

quadratic: $C_{Do} = 0{,}0322\ 10^{-3} V^4_{ymin} A^3$

$C_{Do} = 0{,}106\ C^2_{LVymin}/A$

cubic: $C_{Do} = 0{,}00245\ V^2_{ymin} A - 0{,}046/A$

$C_{Do} = 0{,}318\ C^3_{LVymin}/A - 0{,}046/A.$

If we assume that the curves based on the cubic polar (full lines in figures 5 and 6)

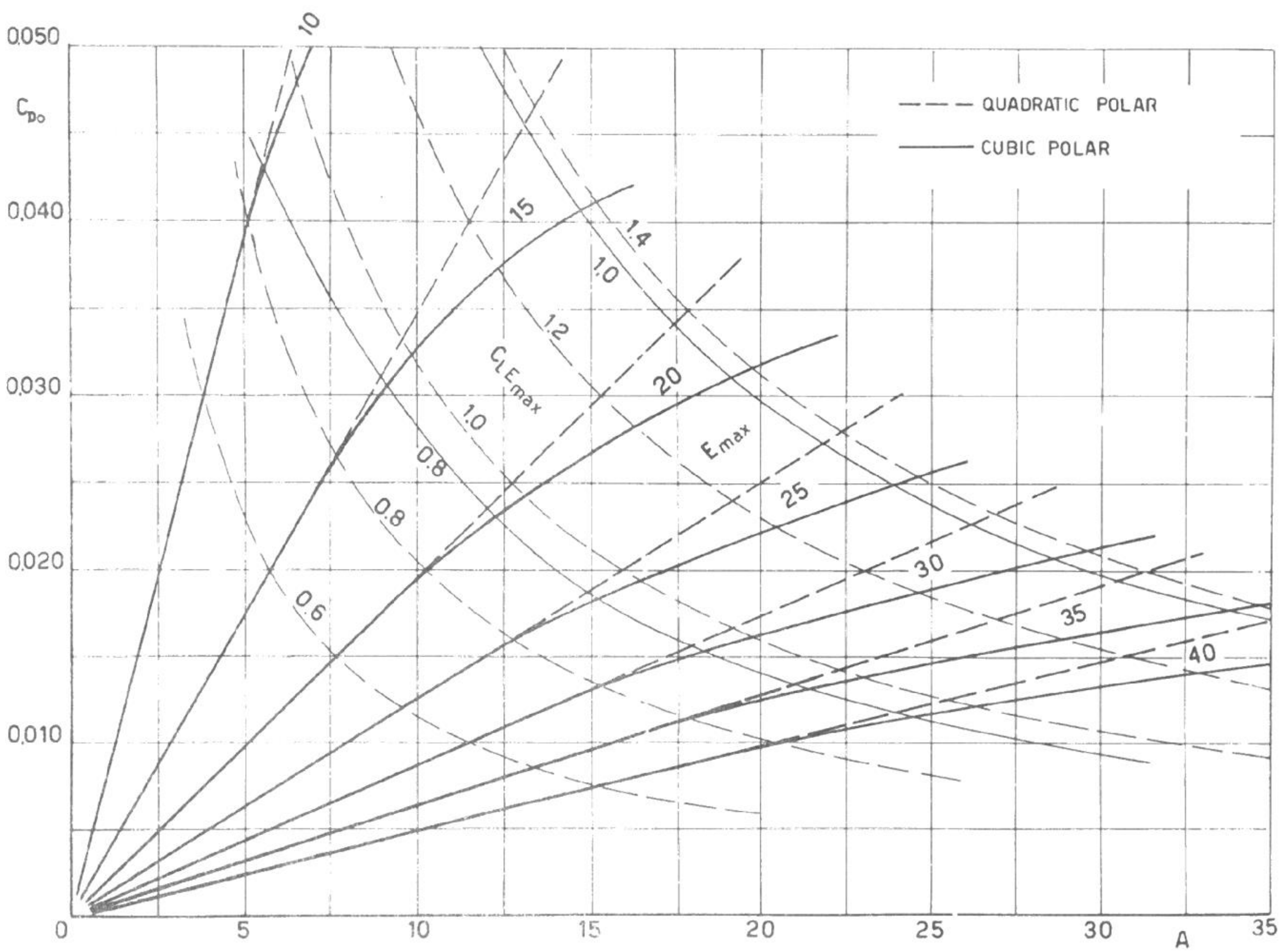

Figure 5

represent the true relationship among the various parameters, some considerations can be made from figures 5 and 6 which may be of interest from the designer's point of view.

From figure 5 it is evident that at a certain value of C_{Do}, there practically exists a value of the wing aspect ratio A, above which only a small gain in E_{max} is attainable.

On the other hand, if the value of E_{max} is fixed, we see from the diagram that this value may be obtained through many combinations of C_{Do} and A. This is quite obvious, but not always the best combinations of C_{Do} and A have been adopted in design.

Sometimes very high wing aspect ratios have been combined with general architectures to which a C_{Do} was pertinent that was far from being the lowest possible. As a result, there was not taken out of the "aerodynamic cleanness" of the sailplane (I mean by this term the goodness of the sailplane in respect of parasitic drag) all the possible advantage, because E_{max} and V_{ymin} occur at lift coefficients at which a C_{Do} increase has already taken place, as may be easily seen from figures 5 and 6.

It might be stated that, for good design, E_{max} and V_{ymin} should occur at lift coefficients of not more than 0,7. In practice V_{ymin} can take place at lift coefficients up to 0,9, without sacrificing much in performance.

In general, for taking from a high aspect ratio all the possible advantage, it is necessary first to have attained the maximum possible reduction in parasitic drag.

The graphics of figures 5 and 6 can be used, in my opinion, for quantitative evaluation of the influence of the various parameters in sailplane performance.

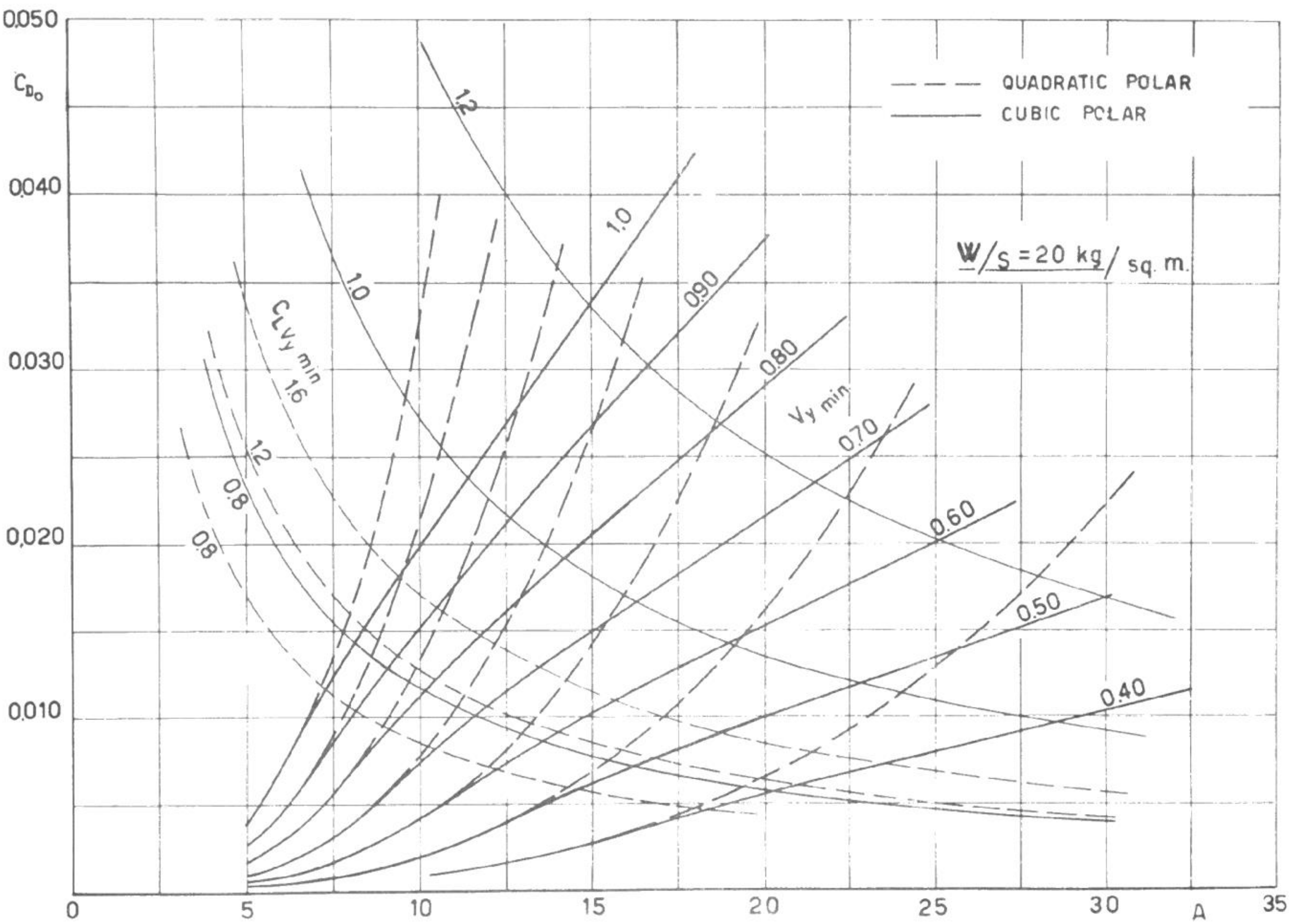

Figure 6

REFERENCES TO LITERATURE

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(8) INTERAVIA, Feb. 1949 "L'amelioration des performances en vol à voile par la construction en aile volante", W.M. HORTEN;

(9) AIRCRAFT ENGINEERING, April 1946 "The DFS Reiher sailplane", B.S. SHENSTONE.

TABLE I

QUADRATIC POLAR	CUBIC POLAR
	$C'_{Do} = C_{Do} + 0,046/A$
$E_{max} = \sqrt{\frac{\pi A}{4 C_{Do}}} = 0,886\sqrt{\frac{A}{C_{Do}}}$	$E_{max} = \sqrt[3]{\frac{8\pi}{54}}\sqrt[3]{\frac{A}{C'^{2}_{Do}}} = 0,777\sqrt[3]{\frac{A}{C'^{2}_{Do}}}$
$C_{LEmax} = \sqrt{\pi A C_{Do}} = 1.77\sqrt{A C_{Do}}$	$C_{LEmax} = \sqrt[3]{\frac{\pi A C'_{Do}}{2}} = 1,16\sqrt[3]{A C'_{Do}}$
$V_{ymin} = 13.3\sqrt[4]{\frac{C_{Do}}{A^2}}\sqrt{\frac{W/S}{20}}$ (m/sec)	$V_{ymin} = 20,2\sqrt{\frac{C'_{Do}}{A}}\sqrt{\frac{W/S}{20}}$ (m/sec)
$C_{LVymin} = \sqrt{3\pi A C_{Do}} = 3,07\sqrt{A C_{Do}}$	$C_{LVymin} = \sqrt{\pi A C'_{Do}} = 1,462\sqrt{A C'_{Do}}$

TABLE II

*)	FALKE R.Va.	RHONBUSSARD	PRaSIDENT	RHONSPERBER	SPERBER Senior	SPERBER Junior	KRANICH	MINIMOA	GoVIER	TG.4	WLM-1	WEIHE	SKY	MEISE	D.30	ASIAGO	REIHER
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
source of data (ref.)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(4)	(4)	(6)	(1,7)	(7)	(5)	(5)	(5)	(9)
aspect ratio (A)	9,8	14,6	14,1	15,3	15,8	15,6	14,3	15,2	11,5	15	14	17,8	18,7	15	33,4	14,8	18,6
wing loading, W/Ś (kg/mq)	15,1	17,1	14,8	19	18	18,1	20,5	17,5	20,8	26,8	20	18,9	20	17	22,1	16,5	17
E_{max}	19	19,8	21,8	21,6	22,7	24,3	22,5	25,7	19,2	22	25	29,5	29	25,5	36	20	33
V_{Emax} (km/h)	64,5	67,3	61,2	63	67	68	68,5	69,9	69,3	36	82	67	75,5	69	72	60	72
V_{ymin} (m/sec)	0,93	0,88	0,71	0,73	0,74	0,65	0,75	0,70	0,92	1,07	0,80	0,61	0,64	0,71	0,52	0,80	0,54
V_{Vymin} (km/h)	64,5	57,7	53,3	50,5	56,5	48,5	51,5	60,9	53,5	77	66	61	65,5	59,4	62	55	61
V_{y100} (sink. speed at 100 km/h)	2,58	2,08	2,03	1,74	1,63	1,50	1,56	1,52				1,43	1,22				1,2
100 C_{Do} **)	2,58	2,48	2,03	2,13	1,91	1,74	1,93	1,69	2,44	2,20	1,60	1,74	1,53	1,74	1,5	2,60	1,17

*) *Numbers refer to points indicated in figures 1, 2, 3 and 4.*

**) C_{Do} *are calculated at* $V = 100$ *km/h; where* V_{y100} *is not known,* C_{Do} *is calculated at* V_{Emax}.