Choice of Design Parameters for Standard Class Sailplanes*

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Presented at the 8th OSTIV Congress, Cologne, Germany, June 1960

1. Summary

The study consists of relating variations in the main design parameters such as aspect ratio, fuselage length and wing section to the aerodynamic characteristics of the sailplane. In addition, the relation between wing weight and aspect ratio is studied on the assumption that metal construction is used. The effect of aspect ratio on climbing conditions in certain thermal currents is studied on the assumption that laminar wing sections are used.

It is shown that the use of large aspect ratios of the order of 25 to 30 with laminar wings gives the best gliding angles but not the best sinking speeds. The real optimum depends on the meteorological conditions, so that it might be worth consideration to supply Standard Class sailplanes with several sets of wings with aspect ratios from 15 to 30.

2. Approximate Calculations on Lift-Drag Polar

The section deals with the relations between the aerodynamics and the wing area, aspect ratio, loading, wing section, frontal and wetted areas.

For the given span of 15 m we have (metric system):

$$S = \frac{225}{A} \tag{1}$$

It can be shown that the wing Reynolds' Number at 1000 m altitude may be approximated by:

$$R = 4{,}44 \times 10^6 \frac{\sqrt{\dfrac{W}{S}}}{A} \tag{2}$$

The sailplane drag is the sum of the component drags of wing, fuselage empennage and undercarriage.

a) *Wing Drag Coefficient*

Fig. 1 shows the variation of profile drag with Reynolds' Number for two laminar sections. If such data from low turbulence tunnels or free flight measurements are not available the following approximation may be used:

$$C_{Dpmin} = 0{,}925 \times 2\, C_{Df}\, \eta \tag{3}$$

* A shortened English version of the lecture delivered in German.

Fig. 1

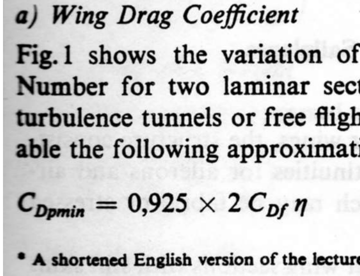


Fig. 2

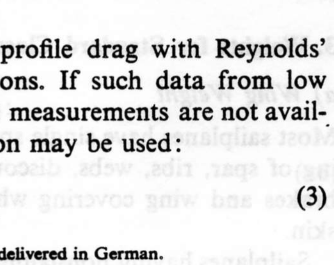


Fig. 2 is due to E. M. Minskiy, based on many wind tunnel tests on wing sections. The vertical scale is the difference between the point of transition and the point of minimum pressure in the chord direction. This diagram can give a rough approximation for the transition point at any Reynolds' Number for sections suitable of Standard Class sailplanes.

The overall lift coefficient is not as high as that of the section alone, so we have

$$C_{Lmax} = K_\eta\, C_{Lpmax} \tag{4}$$

and we can find values of K_η in Fig. 3 and typical values of C_{Lpmax} in Fig. 4 as function of the Reynolds' Number.

Values of $\Delta\, C_{Dp}$ for NACA 63(420)517 are shown in Fig. 5 for several Reynolds' Numbers and similar curves can be drawn for other sections. For most sections we can take as a first approximation, assuming $C_L < 0.8$, that $\Delta\, C_{Dp}$ is a function of the cube of the lift coefficient.

It can be shown that making reasonable assumptions for the various calculable factors, the wing drag coefficient may be taken as:

$$C_{Dw} = 0{,}0075 - 0{,}00169 \frac{\sqrt{\dfrac{W}{S}}}{A} + 0{,}345 \frac{C_L^2}{A} + 0{,}01\,(C_L - 0{,}5)^3 \tag{5}$$

This assumes the use of NACA 63(420)−517.

b) *Fuselage Drag Coefficient*

We may write

$$C_{Df} = C_f\, \eta \frac{S_f}{S} \tag{6}$$

C_f depends on interferences, the state of flow, the surface finish and Reynolds' Number, but can be approximated by:

$$C_f = \frac{0{,}455\, n}{\left(5{,}471 + lg\, L_f + 0{,}5\, lg \dfrac{W}{S}\right)^{2{,}58}} \tag{7}$$

n can vary between 0.8 and 1.0

Fig. 3

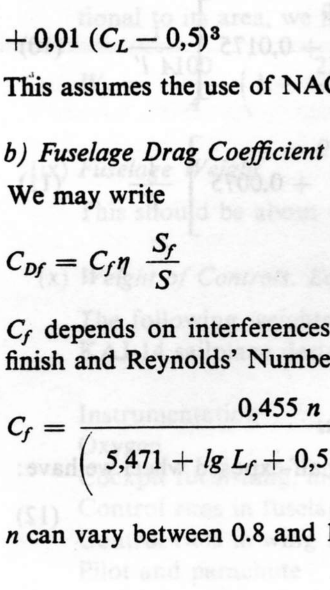
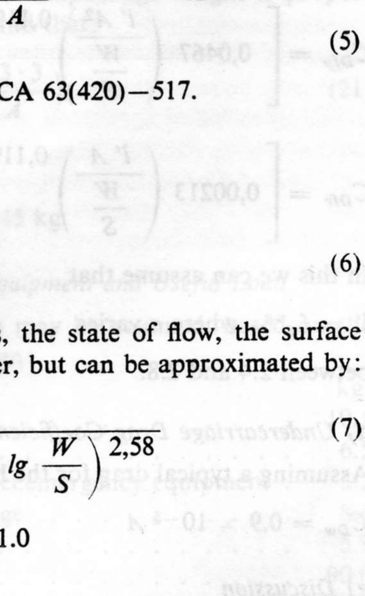


Fig. 4



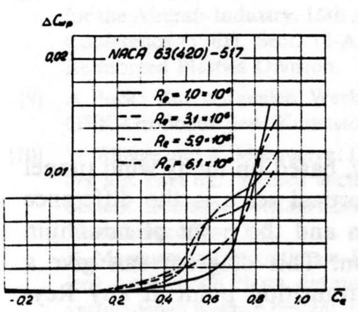


Fig. 5

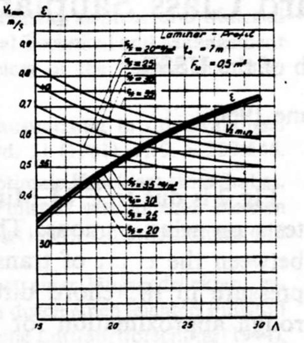


Fig. 6

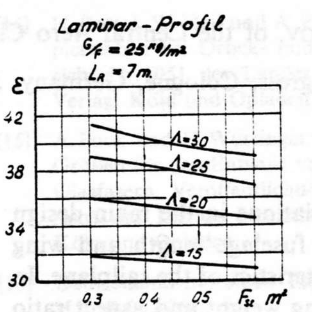


Fig. 7

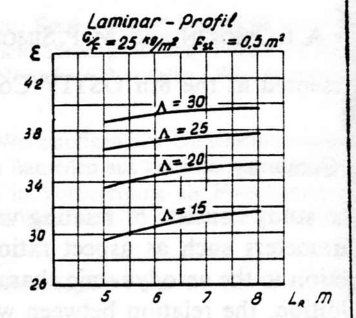


Fig. 8

n depends on the slenderness of the fuselage, and for practical purposes may be expressed as:

$$n = \frac{1+8{,}92\,S'}{L^2_f} \tag{8}$$

We now have for the fuselage drag coefficient after making realistic assumptions regarding cross-section area, length, etc.:

$$C_{Df} = \frac{0{,}0203\,A}{\left(6{,}316 + 0{,}5\,lg\,\dfrac{W}{S}\right)^{2{,}58}} \tag{9}$$

c) Empennage Drag Coefficient

If reasonable assumptions are made regarding Reynolds' Number, flow regimes, likely sizes and proportions, we obtain:

$$C_{Dfp} = \left[\,0{,}0467\left(\frac{l'\,A^2}{\frac{W}{S}}\right)^{0{,}119} + 0{,}0175\right]\frac{1}{A\,l'} \tag{10}$$

$$C_{Dfr} = \left[\,0{,}00213\left(\frac{l'\,A}{\frac{W}{S}}\right)^{0{,}119} + 0{,}0075\right]\frac{1}{l'} \tag{11}$$

In this we can assume that

$l' = L_f^{-a}$ where a varies

between 2.4 and 2.8.

d) Undercarriage Drag Coefficient

Assuming a typical drag for the half-exposed wheel we have:

$$C_{Dw} = 0{,}9 \times 10^{-5}\,A \tag{12}$$

e) Discussion

With the aid of the above analysis of the lift-drag polar it is possible to see how the main characteristics of the sailplane are affected by geometrical and wing loading variations. This is shown in Figures 6, 7, 8 and 9.

A study of these figures shows that the gliding angle improves as the wing aspect ratio is increased. As an example, increasing the aspect ratio from 20 to 25 improves the gliding angle by 2.7 units. However, a further increase in aspect ratio may well be undesirable because the wing loading increases considerably with a consequent increase in sinking speed.

In recent years several designers have made an effort to reduce the fuselage cross-section with the result that the pilot's view was considerably worsened. But as can be seen from Fig. 7, such efforts are very effective in improving gliding angle.

As we know by experience from the KAJ-14 sailplane, it is possible for the pilot to be comfortably seated with a fuselage cross-section area of 0.3 m². Reducing the fuselage cross-section area from 0.5 m² to 0.3 m² results in an improvement of the gliding angle of 1.5 units, assuming a wing aspect ratio of 25. By increasing the aspect ratio, the improvement in gliding angle is accelerated if the fuselage cross-section is reduced at the same time.

For comparison we see in Fig. 9 how the main characteristics of sailplanes with classical wing sections vary with aspect ratio and wing loading.

In Figures 6 and 9 it will be seen that the use of laminar wing sections not only improves the gliding angle but makes larger aspect ratios more worth while.

3. Weights for Standard Class Sailplanes

a) Wing Weight

Most sailplanes have single spar wings, the structure consisting of spar, ribs, webs, discontinuities for ailerons and airbrakes and wing covering which may be fabric or stressed skin.

Sailplanes having non-laminar wing sections with stiff skins (plywood or metal) normally used them only from the leading edge to spar, but with laminar flow wing sections it is necessary to use stiff covering over about 60% of the chord. The sensitivity of laminar flow wing sections requires a thick skin with a very fine finish.

When using plywood covering, it is advisable to use stiffened panels so that the effectively thick skin can resist bending.

When using metal covering stiffened by spanwise stringers, the resulting panels are not effective in bending resistance at low wing loadings. For one thing, the bending resistance of the longitudinals is too low, and if a very large number are used, they tend to distort the wing section shape. The single

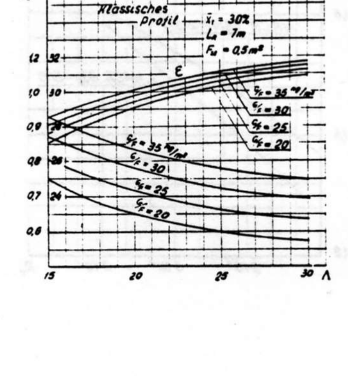
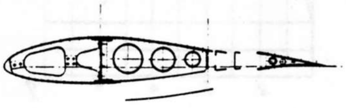


Fig. 9

Fig. 10



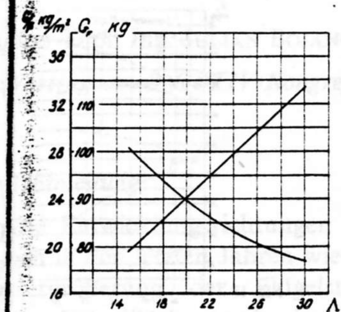


Fig. 11

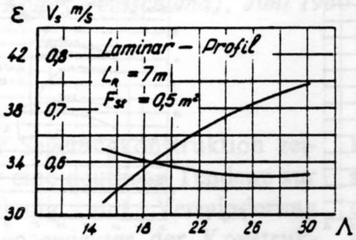


Fig. 12

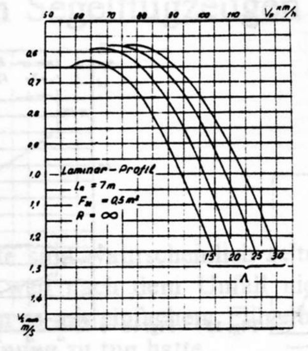


Fig. 13

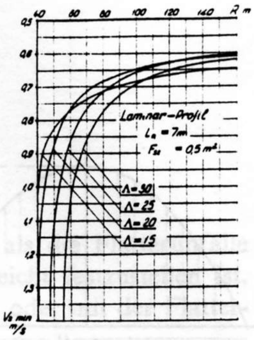


Fig. 14

spar is therefore desirable for metal wings, particularly when the aerodynamic requirements demand a fairly thick wing skin (Fig. 10).

To calculate wing weight we may make the following assumptions:

1. The aerodynamics require a dural covering 0.88 mm (0.03 in) thick.
2. The planform is linearly tapered.
3. The spanwise airload distribution and structure and other weight distribution is proportional to the wing chord.

(i) *Spar Flange Weight*

For Standard Class sailplanes, reasonable assumptions indicate that the spar flange weight would be:

$$W_f = C_l\, n_A\, (W - W_w)\, \frac{A}{t/c} \tag{13}$$

where C_l is a constant.

(ii) *Spar Web Weight*

This may be expressed as:

$$W_{web} = C_2\, n_A\, (W - W_w) \tag{14}$$

(iii) *Weight of Wing Ribs*

This may be expressed as:

$$W_r = C_3\, n_A \left(\frac{W}{A}\right) \tag{15}$$

(iv) *Wing Skin Weight*

This may be expressed as:

$$W_s = C_4 \left(\frac{1}{A}\right) \tag{16}$$

(v) *Aileron Weight*

Approximated, this is:

$$W_a = C_5 \left(\frac{W}{A}\right) \tag{17}$$

(vi) *Airbrake Weight*

$$W_{ab} = C_6 \left(\frac{1}{A}\right) \tag{18}$$

(vii) *Miscellaneous Weights*

$$W_m = C_7 \left(\frac{1}{A}\right) \tag{19}$$

Experience and statistics indicate that the constants used above should have the following values:

$C_1 = 0.11 \times 10^{-3}$ $\quad C_5 = 0.1$
$C_2 = 0.0039$ $\quad C_6 = 60$
$C_3 = 0.048$ $\quad C_7 = 75$
$C_4 = 855$

On this basis the wing weight for Standard Class sailplanes of metal construction should be:

$$W_w = W - \frac{W - \frac{1}{A}\,(0{,}148\, n_A\, W + 1090)}{1 + n_A \left(C_1\, \frac{A}{t/c} + C_2\right)} \tag{20}$$

(viii) *Empennage Weight*

If one assumes that the empennage weight is proportional to its area, we find that:

$$W_t = \frac{100}{A}\left(1 + \frac{23 \cdot 3}{A}\right) \tag{21}$$

(ix) *Fuselage Weight*

This should be about 45 kg.

(x) *Weight of Controls, Equipment and Useful Load*

The following weights may be assumed, based on the KAJ-14 sailplane design:

	kg
Instrumentation	10.5
Oxygen	6.5
Cockpit furnishing, incl. emergency equipment	3.5
Control runs in fuselage	8.4
Control runs in wing	5.9
Pilot and parachute	90.0
Total	125.0

In Fig. 11, we see wing loading and wing weight plotted against aspect ratio, the basis for which are the formulae discussed and listed above. One can see from Fig. 11, that as the aspect ratio increases, the wing loading increases rapidly.

Using data from Fig. 6 and 11, the best gliding angle and minimum sink are plotted against aspect ratio.

But Fig. 12 does not enable one to choose the optimum aspect ratio because the data shown are valid only for level flight. It is not concerned with the effect of thermal upcurrents.

For a complete solution of the problem it is necessary to investigate the variation in mean cruising speed with aspect ratio under the best possible weather conditions.

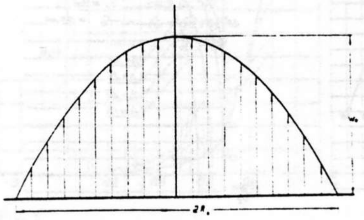


Fig. 15

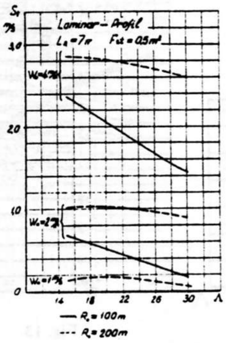


Fig. 16

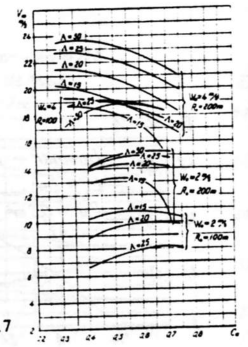


Fig. 17

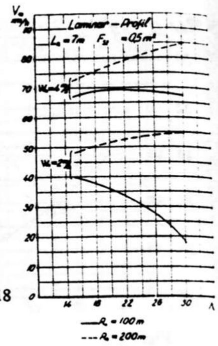


Fig. 18

In Fig. 13, several speed polars are shown assuming different aspect ratios. Using such speed polars one can calculate a series of such polars for circling flight, and then work out minimum sinking speeds for various radii of turns (Fig. 14).

In such considerations, one must be sure that the lift coefficients involved are in the safe flying regime. In general the top limit would be about $C_L = 1.2$.

4. Calculation of Rate of Climb

The assumption is that in calculating the rate of climb, the sailplane is rising spirally in a thermal, and the distribution across the thermal is parabolic as indicated in Fig. 15.

The rate of climb is, of course, the difference between the updraft and the sinking speed.

If it is assumed that the sailplane is centred on the thermal, the maximum climbing speed can be estimated for any assumed updraft (Fig. 16).

As may be seen from Fig. 16, the rate of climb of a Standard Class sailplane is reduced as the aspect ratio is increased, particularly in steeper spirals. To improve the rate of climb, one must use wing sections having the best lift: drag ratio.

5. Estimating Average Cruising Speed

The following assumptions are made:
1. No downdrafts occur.
2. A sufficient number of updrafts are available, so that optimum conditions occur during the flight.
3. The pilot makes no mistakes.
4. The pilot flies in the centre of the updraft so that the maximum rate of climb is used.

In Fig. 17 and 18, the mean cruising speed is plotted against gliding angle, flight conditions and aspect ratio.

From these figures, it is obvious that high aspect ratios fit strong large diameter updrafts, whereas low aspect ratios fit the weaker and smaller diameter updrafts. Hence, knowing the likely weather conditions, it is possible to choose the best aspect ratio for such conditions.

It would probably be of value to provide the sailplane with two alternative wings having different aspect ratios and thereby suitable for different weather conditions.

Summary

1. By taking into account the interaction between aspect ratio and laminar flow wings, it is possible to improve the best gliding angle to a considerable extent.
2. Increasing the aspect ratio reduces the climbing performance of the sailplane particularly in restricted thermals (radius of the order of 100 m).
3. The best aspect ratio depends on the weather conditions on a particular flight.

If the updraft is 2 m/sec with a radius of 100 m, with aspect ratio of 15 the cruising speed would be 38.9 km/h and only 18.4 km/h if the aspect ratio is 30. If, however, the updraft is 4 m/sec with a radius of 200 m, the speed for an aspect ratio of 15 would be 73 km/h and 85 km/h for an aspect ratio of 30.

The provision of several different wings of different aspect ratios would permit the best use of the weather conditions occurring.

Symbols

S	=	Wing area
A	=	Aspect ratio
R	=	Reynolds' Number
W	=	Flying weight
C_{Dpmin}	=	Minimum profile drag coefficient
C_p	=	Flat plate drag coefficient
η	=	Coefficient to take account of the ratio of flat plate drag to profile drag
C_{Lmax}	=	Maximum lift coefficient
C_{Lpmax}	=	Maximum profile lift coefficient
ΔC_{Dp}	=	Change in drag coefficient due to lift
C_L	=	Overall lift coefficient
C_{Dw}	=	Wing drag coefficient
C_{Df}	=	Fuselage drag coefficient
S_f	=	Fuselage wetted area
n	=	Factor of fuselage slenderness
S'	=	Fuselage cross section area
L_f	=	Fuselage length
C_{Dtp}	=	Tailplane and elevator drag coefficient
C_{Dfr}	=	Fin and rudder drag coefficient
l'	=	Tail arm
C_{Du}	=	Undercarriage drag coefficient
W_f	=	Spar flange weight
n_A	=	Load factor at point A of v–n diagram
W_w	=	Wing weight
t/c	=	Thickness/Chord ratio of wing
W_{web}	=	Web weight
W_r	=	Rib weight
W_s	=	Wing skin weight
W_a	=	Aileron weight
W_{ab}	=	Airbrake weight
W_m	=	Miscellaneous weights
W_t	=	Empennage weight