Structural Parameters for a Metal Wing in Design Stage

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I. Introduction

In the development and progress of gliding, the trend towards improved performance and effectiveness is clear.

The aerodynamic and structural features influenced by conditions in competitive flying on one side and conditions in high altitude soaring on the wave system on the other side, demand different "operational" speed range at which the sinking speed of the sailplane has to be a minimum. The use to which the sailplane is put determines such features as aspect ratio, wing loading and low drag, the optimum values of variables in aerodynamic design depending on the type of atmospheric energy being used. Good performance characteristics must be combined with good flying-qualities in thermals. For given loads specified in design requirements a structure must be designed to achieve minimum weight, any weight excess will cause deterioration in performance, particularly in turns.

In the following, the structural design of a high aspect ratio all metal wing of multistringer design will be considered, the analysis being based on the experience with prototype all-metall sailplane «Orao III—Meteor».

In the design stage of a sailplane we are concerned with predicting the structural weight required to achieve adequate strength and stiffness. Stiffness requirements cause greater weight than that needed for the strength alone.

II. Structure strength and weight for manoeuvre cases

For the estimation of sailplane structure weight there are few satisfactory methods, ref. [1] and [2] being examples.

For the determination of elastic behaviour of the wing the distribution of normal stresses across the sections along the wing span must be known. It is assumed that approximately uniform distribution of stresses across a section of stressed skin is achieved (fig. 1).

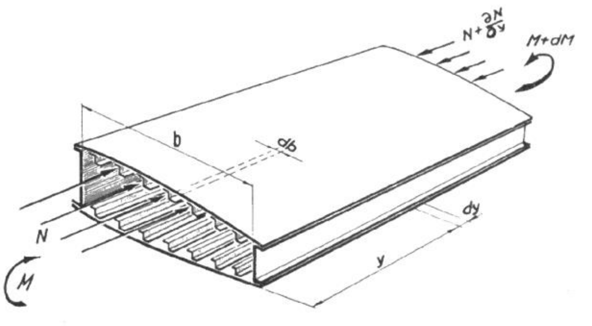

Fig. 1

From the uniform chordwise stress level, at a given spanwise position, the section of bending material must be proportional to b. From $\frac{\delta N}{\delta b}$, selected local b and prescribed allowable stress we get the necessary area A of the bending material in every section (fig. 2 and 3).

From bending moments we have to compute the force in unit width of the shell (fig. 4).

$$\frac{\delta N}{\delta b} = \frac{M}{F} \tag{1}$$

Along the wing span we have to check critical stations for bending material area. The amount of the bending material required at the root section A_{os}, can be derived from expression

$$A_{os} = \frac{M_o \cdot n}{h_o \cdot \sigma_o} \tag{2}$$

The buckling deformations have to be avoided in all normal flight cases.

From above consideration we obtain the structural shape of the wing root. According to the distribution of the bending material along the span the volume of this material can be determined.

III. Selection of A_o from stand point of gust cases

The wing deflection under static load as well as the weight of the wing and natural frequency of the wing are dependent on the value A_o. The cross-sectional area of the bending material due to manoeuvre cases only, is A_{os} and is determined by the expression (2).

By calculation of bending and torsional frequency with chosen $A_o = k \cdot A_{os}$, we obtain the ratio of the two frequencies, which is an important factor affecting flutter speed.

To obtain the actual cross-sectional area of the wing bending material the strength required to meet gust cases has also to be considered; this may override the requirements of the manoeuvre cases.

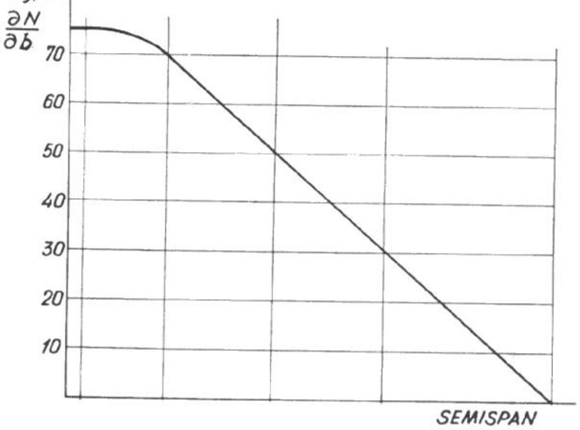

Fig. 2

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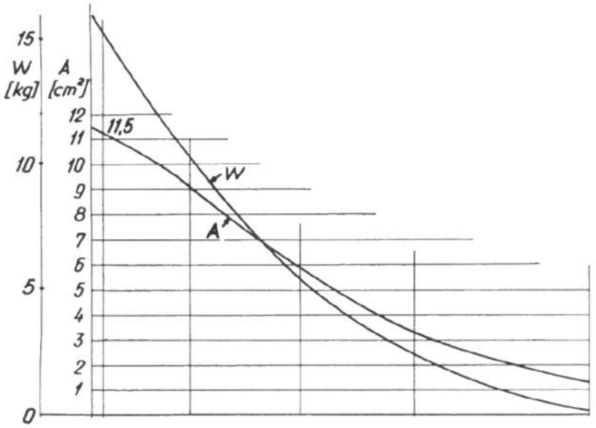

Fig. 3

The design of the wing of "Meteor" is such that the ratio of torsion to bending frequency is about 12 and the factor k is about 1,6. The gust case calls for 1,6 times the bending material needed to meet the manoeuvre cases.

By designing only for the bending case we get for gust conditions the following relationships between bending frequency and design flight speed. According to the theory of *M. Mazovec* [4] for the wing of "Meteor" we obtain, for the wing loading of 31,5 kg/m²

$$f \geqq 0{,}041\, V_g$$

in metric units:

$$f \geqq 0{,}685\, V_g \qquad V_g \text{ in km/h}$$

$$V_g \leq f/0{,}685 \qquad f \text{ in c. p. m.}$$

The ratio of cross sectional area of the wing bending material due to the gust requirements to the bending material due to the manoeuvre requirements, expressed by $k = A_0/A_{0s}$ as a function of f and V_g is shown in the table and fig. 5

$k = A_0/A_{0s}$	f (c. p. m.)	V_g (km/h)
1,0	93	135
1,2	102	149
1,4	110	161
1,6	117,5	172
1,8	124,5	182
2,0	131	191

IV. Comparison of high speed design

In the design of high speed high performance sailplanes we have to consider the required speed range. The results of the analysis quoted in part III are typical for problems of this kind. Increasing of the flight speed in gust conditions i. e. from 135 km/h to 191 km/h causes to increase the material in the structure by 100%; thus the "stiffness-factor" $k = A_0/A_{0s} = 2{,}0$. In the fig. 6 are shown the results of variation of W, f and z plotted against stiffness factor k. If we compare the characteristics of wing flexibility of the well known sailplane "D-30" with "Meteor" which have approximately the same frequency ratio [3] we see, that the main difference between the wings of both sailplanes is the considerable difference in design speed range.

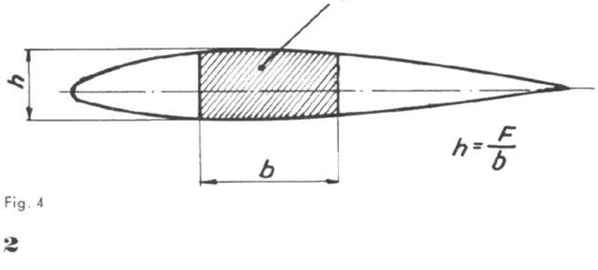

Fig. 4

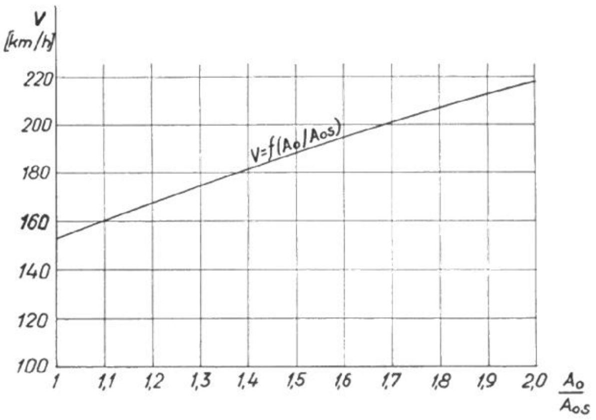

Fig. 5

"D-30"-W/S = 24 kg/m², $k = 1$, speed range $70 < V_D$
< 150 km/h

"Meteor"-W/S = 31,5 kg/m², $k = 1{,}6$, speed range $70 < V_D$
< 250 km/h

This is an important consideration for wave system soaring, where the difference between V_g and V_D is small.

V. Wing structure

From aerodynamic design point of view desired speed range in which the mean value of sinking speed is a minimum is influenced by optimum loading [5].

Therefore from the design point of view optimum structural weight is increasingly important.

A multistringer wing structure is probably the best from this point of view because it uses all the skin for bending as well torsional loads. The high torsional stiffness of such a structure enables maximum rolling power and excellent roll performance.

The "Meteor" has a width of the box $b = 360$ mm and the average thickness of the flange (skin and stringers) at the wing root is $A_0/b = 3{,}0$ mm.

The ratio of weight of spar material to wing weight in comparison with two known sailplanes (with flaps and same load factor) is:

i) "Košava"	(19 m span)	35 : 106 = 0,33
ii) "Orao"	(19 m span)	37,5 : 110 = 0,34
iii) "Meteor"	(20 m span)	38 : 110 = 0,345

It is evident that the box structure has many advantages compared with the classical structure of sailplane wings.

VI. Summary

This note considers factors which have to be taken in consideration in the design stage of a sailplane wing. The great influence of maximum flight speed on structural

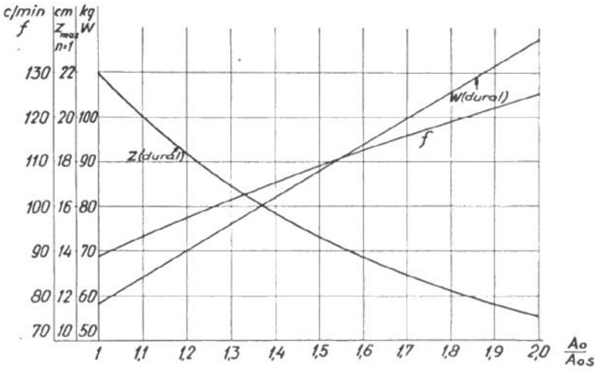

Fig. 6

weight is shown. Requirements for bending strength resulting from gust and manoeuvres loads have to be considered; requirements for torsional stiffness may be overriding at high speed.

VII. Acknowledgment

The author is indebted to Mr. M. Mazovec for his continued support in the preparation of this note.

VIII. Notation

A_o	Cross-sectional area of the bending material root section	cm²
A_{os}	Cross-sectional area of the bending material due to strength requirements (manoeuvre cases)	cm²
F	Area of box section (in fig. 4 shaded area)	cm²
k	ratio of increasing of bending material due to the elastic requirements (stiffness factor)	
n	load factor	
σ_o	normal stress at wing root section	kg/cm²
δ_N/δ_b	axial load in the panel	kg/cm
M	bending moment	kg/cm
h	average depth of box section	cm
b	width of box section	cm
f	bending frequency	c. p. m.
V_g	speed of the sailplane during the gust	m/sec
V_D	max. permissible speed of the sailplane	m/sec

IX. References

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