

# Effects of Structural Materials on the System of Load Factors to Produce the Optimum Strength

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## I. Introduction

The most important goal of the designer is to produce optimum strength with minimum possible weight of the structure of the sailplane at minimum production cost. The aerodynamic requirements and true load factors influence the efficiency of application of properties of materials used in the structure as well as the configuration of the structure. The choice of the material for the compression structures has to be consistent with the quality of the wing skin surface regarding allowable waviness. The designer choosing reinforced skin either of light alloys or of wood or laminated plastics has to stabilize the surface of the skin. In the development of new shell structures with fiberglass mats and adequate resins the designer has already achieved high buckling strength as well flexural and torsional stiffness even at wide frame or rib spacings.

The aim of this note is to show the "optimal" safety factor of a particular geometry of the structure with a metal skin-stringers combination and its system of load factors.

## II. Optimal factors of safety for the particular structure

For the type of wing structure considered in Reference [1], an aluminium-alloy flat compression panel is used with longitudinal Z-section stringers. With the chosen geometry of the wing section panel and using the design charts from E. Schütte [2] the optimum strength of the panel is achieved. Applying the design parameter

$$\frac{P_1}{L/\sqrt{c}},$$

where  $P_1$  is the compression load per centimeter of the panel width, " $L$ " the panel length between supporting ribs and " $c$ " a coefficient of end fixity at the ribs, we have to find the average stress at failure for the panel  $\bar{\sigma}_f$  against this design parameter. Introducing the results from the NACA design charts for the chosen geometry of the panel of the box-beam, the following factors should be taken in the consideration: structure must have a smooth skin surface carrying the bending moments, shear and torsion at safe load factor  $j = 1,0$  and must satisfy also aeroelastic requirements. For the given wing structure a compromise is made between aerodynamic and structural parameters.

The optimum structural efficiency at given beam strength and the same structural material could be achieved with lower weight—but much higher cost—on an "integral" panel rather than on the riveted structure chosen (Fig. 1).

The average stress at failure  $\bar{\sigma}_f$  against design parameter for the panel considered is

$$\bar{\sigma}_f = f_1 \left( \frac{P_1}{L/\sqrt{c}} \right) = f_2(p, n, j, L)$$

The determination of safety factors " $j$ " (according to the Airworthiness Requirements  $j = 1,5 - 2,0$ ) is achieved

from the condition that at safe or proof load factor " $n$ " the working stress  $\bar{\sigma}_{op}$  of the panel of the structure must not be exceeded. Working stress  $\bar{\sigma}_{op}$  is an average stress without buckling of the beam section at  $j = 1,0$ . For a laminar airfoil wing gust cases must also be satisfied and adequate torsional stiffness achieved for high effectiveness of small ailerons. That is one of the main characteristics of modern sailplane in comparison with e.g. Weihe etc. The assumption made above that the wing surface should be smooth and unbuckled until

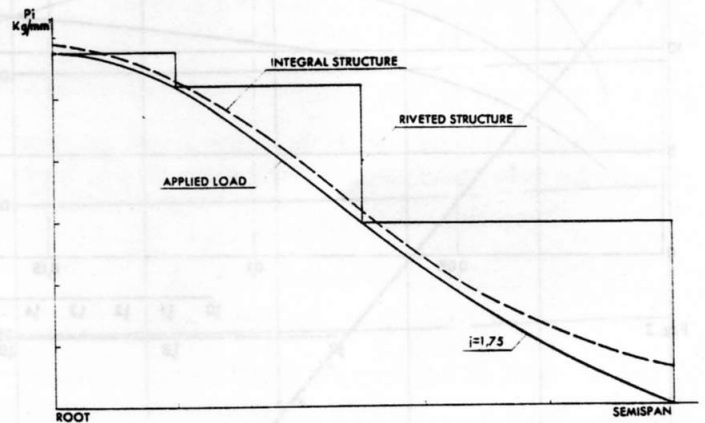


Fig. 1

$j \approx 1,0$  (resp.  $j = 1,0$ ) (ad libitum to designer, as no requirements prescribe this) enables optimal high speed characteristics to be achieved even at rough gust cases. By the adoption of  $t_w/t_s$  we have to look for the necessary value of " $j$ ", which will be the best for given conditions. From  $\sigma f$  we obtain

$$\bar{\sigma}_{op} = \frac{\bar{\sigma}_f}{j}$$

and according to the diagram (Fig. 2) the optimal safety factor for this structure is

$$j = \frac{\left( \frac{P_{failure}}{L/\sqrt{c}} \right)_{NACA}}{\frac{P_{working}}{L/\sqrt{c}}}$$

If the level of working stress  $\bar{\sigma}_{op}$  for the applied structure coincides with the level of Airworthiness Requirements i.e.  $\bar{\sigma}_f_{NACA}/j_{1,5}$  then we get the optimum strength for the structure according to the NACA investigations at the corresponding design parameter.

## III. Example

In the design stage of the wing structure applying the results of static tests of the panel we have to determine actual stresses with known material properties (Fig. 3).

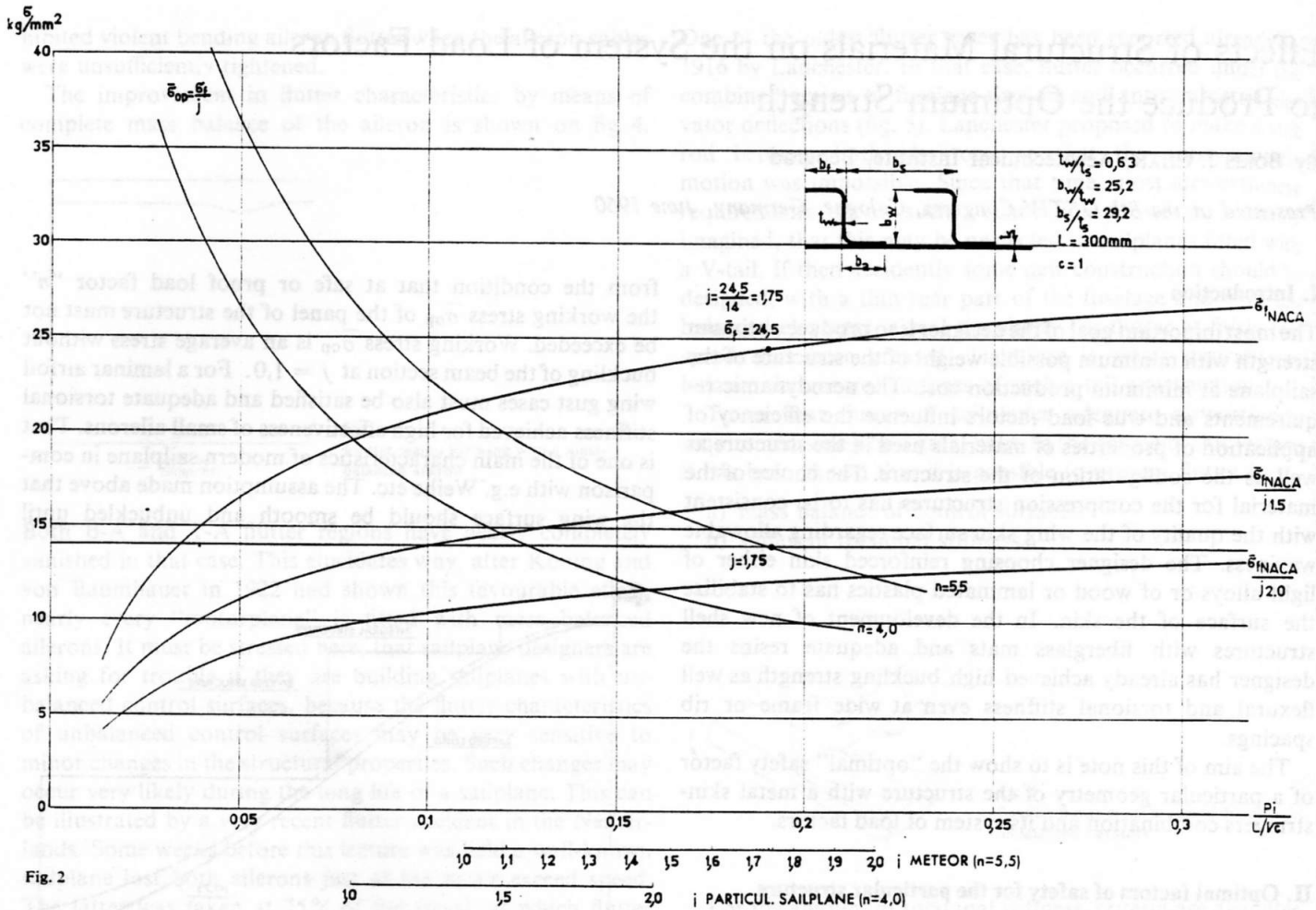


Fig. 2

If the level of the working stress obtained by static tests is for instance  $\bar{\sigma}_{op} = 14,0 \text{ kg/mm}^2$  and the proof load factor  $n = 5,5$ , for the design parameter

$$\frac{P_i}{L/\sqrt{c}} = 0,19$$

the required ultimate factor "j" will be 1,75 (Fig. 2).

From the diagram in fig. 2 we can see, that with the chosen structure with an increase of working stress  $\bar{\sigma}_{op}$  to approximately  $15,8 \text{ kg/mm}^2$  the airworthiness level for  $j = 1,5$  could be achieved but at another design parameter of 0,165. From the diagram we can see that by changing the design parameter from 0,19 to 0,165 the whole geometry of the panel must be altered. But for  $\bar{\sigma}_{op} = 14 \text{ kg/mm}^2$  the ultimate factor must be taken as  $j = 1,75$ . Below the scale for the chosen structure for j (Meteor) is put another scale for j (particular sailplane) which corresponds to the chosen load factor of  $n = 4$ . It is evident that for this case of another loading, the structure is not rational, as the working stress for the same design parameter as for "Meteor" is far below the available stress ( $10,3 \text{ kg/mm}^2$ ) instead of  $14 \text{ kg/mm}^2$ . For each geometry of the structure and applied load factors one obtains another optimal safety factor.

#### IV. The application of safety factors

Dynamic tests on different types of structure show that the fatigue or endurance strength of the structural components are below yield and even proportional limit stresses, and the

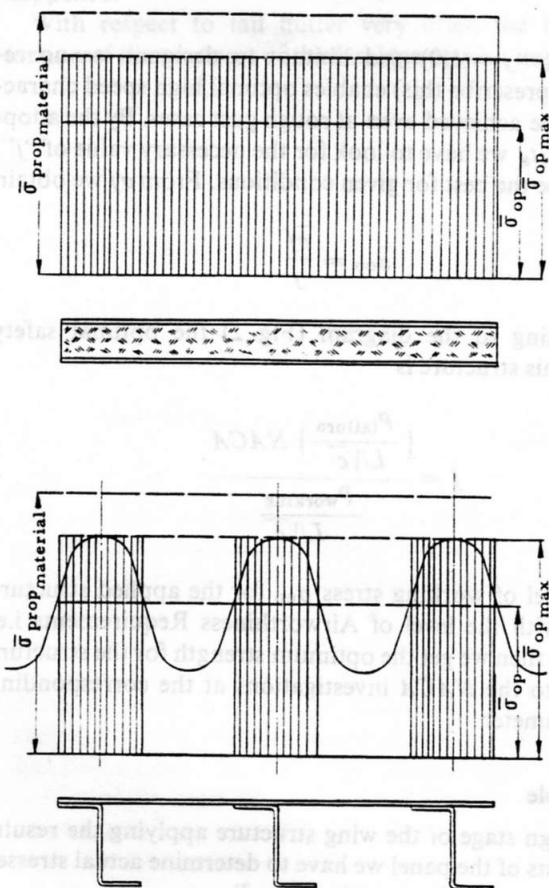


Fig. 3

effective life of the sailplane should be covered by factors of safety-inter alia. In sailplane construction wood has been commonly used as the material for the structural members, where local stress concentrations under fluctuating loads may be circumvented by applying well designed types of member better than on metal. The fatigue strength could be covered by using e.g.  $j = 2$  (BVS). On several tests was found that no reduction was needed between fatigue strength of wooden flanges in the spars compared with fatigue strength of the wood. O. Kraemer [3] has found the dependence of the endurance strength from the strength in compression of wood according to fig. 4.

For instance at  $\sigma_c = 450 \text{ kg/cm}^2$  the endurance strength is  $\sigma_w = 265 \text{ kg/cm}^2$ , otherwise expressed, the ratio between endurance strength  $\sigma_w$  and ultimate compressive stress  $\sigma_c$  is between 0,45 — 0,59. If the designer deals with ultimate loads applying safety factor  $j = 2$  and proof load factor for instance  $n = 4$ , we can see that the spar under elastic deformations has also covered the endurance strength.

#### Example:

The proportional limit stress for wood in compression  $\sigma_p$  is within the limits of 0,75 of ultimate compressive stress  $\sigma_c$ .

According to fig. 4 for  $\sigma_c = 450 \text{ kg/cm}^2$  we obtain  $\sigma_w = 265 \text{ kg/cm}^2$  and  $\bar{\sigma}_{prop} = 450 \times 0,75 = 337 \text{ kg/cm}^2$  so that endurance strength is below proportional limit stress. Thus

$$n \times j \times 0,59 \geq n_{Airw. Req.}$$

$$4 \times 2 \times 0,59 = 4,7 \text{ which is } > 4,0_{Airw. Req.}$$

For  $n_{Airw. Req.} = 4,0$  the needed  $j = 1,725$ .

If we apply to the same example for instance the OSTIV Airworthiness Requirements and suppose the same life time of the structure as in the previous example, then the ultimate factor should be not less than  $j = 1,5$  and for  $n_A = 5,3$  (or 5,333) we obtain the same product  $n \cdot j = 8$ , but the "safe" load factor is 4,7 which is less than 5,333. From the above mentioned reasons for endurance resp. life time of the structure we have to increase with the same structural material the safety factor for a margin of safety = 1,1277. Thus the effective safety factor should be regarded as  $j = 1,5 \cdot 1,1277 = 1,6915$  and  $n \cdot j = 8,965$  which is  $> 8,0$ . From this point of view we cannot treat the product " $n \cdot j$ " as a constant value ( $n \cdot j \neq \text{const}$ ) and from the previous example the system of load factors

$$\underbrace{(4 \times 2)}_{\text{System I}} \neq \underbrace{(5,333 \times 1,5)}_{\text{System II}}$$

All these considerations lead to the problem that the safety factor must not be regarded literally and must be based on the particular type of structure and material applied and the required ultimate factors from Airworthiness Requirements have to be applied as the minimum factors. The "optimal" safety factor should not be only a function of characteristics of the type of structure but has also to include the life time of the sailplane and fatigue effects, construction quality etc. In the progress of sailplane structures we have to associate safe loads to the required loads according to the Airworthiness Requirements and to deal with "optimal" safety factors which can be higher than the minimum required. Dr. Gassner [4] mentioned that the application of a uniform safety factor to all materials is untenable.

## V. Concluding remarks

The level of the Airworthiness Requirements should correspond to the progress of sailplane design, to the materials used for the construction, and to the service life of the sailplane. With increase in the speed of sailplanes, using low drag airfoils, the heretofore commonly used single spar wooden wing structure will be less and less used. It can be said that progress in the structure of new sailplanes has overridden the old Airworthiness Requirements. The safety factor resp. the system of load factors must be accommodated to the material and chosen type of structure. The " $n \cdot j$ " has not to be regarded only as a "product" but as a system of capabilities of the structure regarding the working (operational) loads and the stress conditions of the structure i.e. optimal structure.

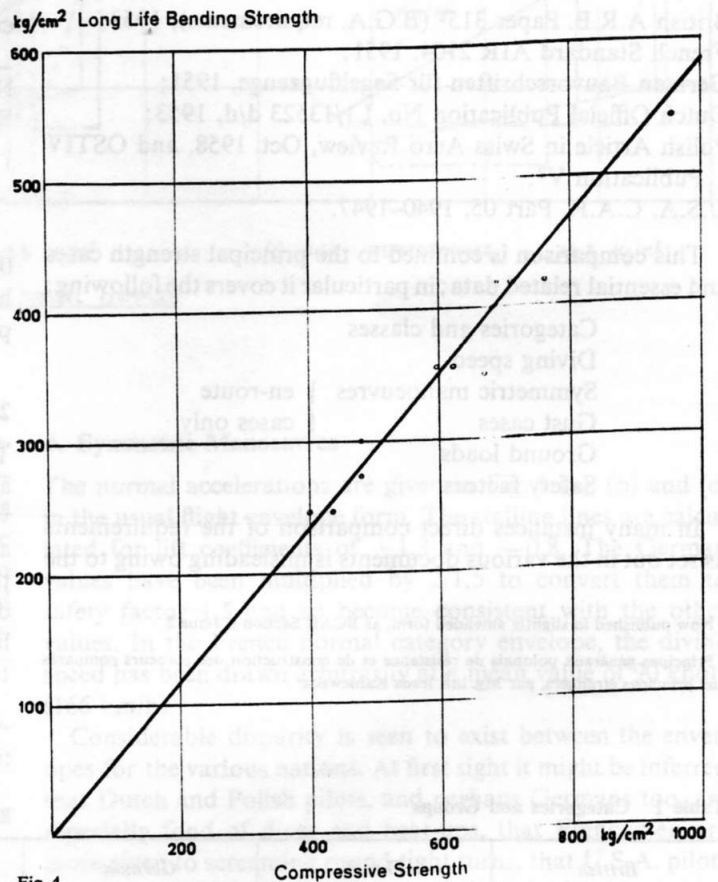


Fig. 4

The writer does not claim to have attained a complete picture of knowledge of the behaviour of the particular type of sailplane structure under compressive load, but he wishes to awaken the interest of designers regarding the operational loads and system of the load factors.

## VI. References

- [1] Cijan, B.: "Structural parameters for a metal wing in design stage." OSTIV Publication IV.
- [2] Schütte, Evan H.: "Charts for the minimum-weight design of 24 S-T aluminium-alloy flat compression panels with longitudinal Z-section stiffeners." NACA TR No. 827
- [3] Kraemer, O.: LUFO Bd. 8
- [4] Gassner, E.: "The problem of fatigue Strength in Aircraft structure". Aircraft Engineering, July 1956.