A new look at the problem of safety factor in glider design

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Presented at the 10th OSTIV Congress, South Cerney (England), June 1965

Summary

The present conception of a safety factor, which protects the structure both against the possibility of occurence of higher loads than prescribed and against reduction of strength, is not reasonable.

Replacing part of the factor of safety, which safeguards the structure against occurence of higher loads, an ultimate load concept is proposed. The ultimate loads, i.e. the extreme loads which may occur, taking into account the pilot's faults and exceptional meteorological conditions, are to be withstood by the glider structure safety for the crew.

A new value of the factor of safety, which would safeguard the glider structure only against the possibility of reduction of strength is proposed; it seems that this value will be not very far from 1.2

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The problem of the correct selection of the value of the safety factor in the design of aeroplanes is a basic one from the beginning of aviation technology. The factor of safety is a fundamental factor, which affects both the safety and the performances of the aeroplane. The difficulty of this problem is due to the fact that the value of the factor of safety is closely related to the design loads, to the static scheme and the dynamic properties of the structure. to the material properties, to the manufacturing methods and protective coatings used, to the course of service and to the designer's knowledge and experience.

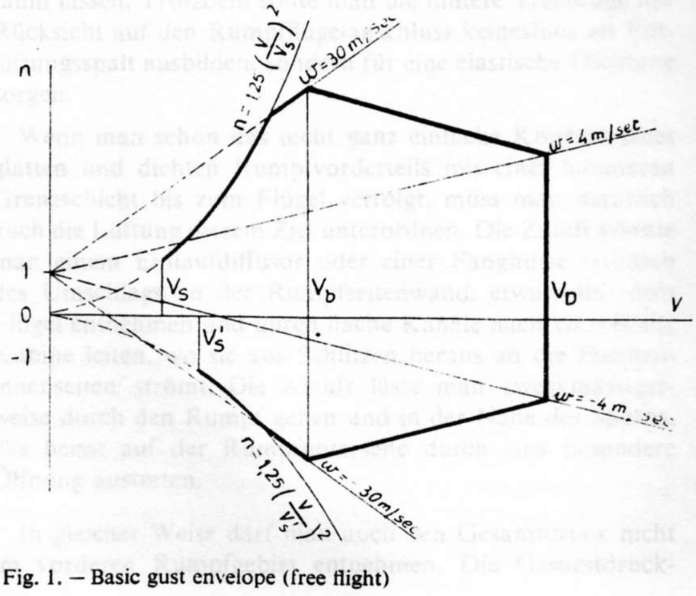

Fig. 1. – Basic gust envelope (free flight)

The above mentioned factors, affecting the factor of safety selection, are taken into account by the designer when he realizes his fundamental task i.e. designing the structure as light as possible-but achieving the required level of safety. The designer must deliver proof that the minimum requirements as concern structural strength, prescribed by the Regulations, are met, in order to obtain a certificate of airworthiness for his aeroplane. These Regulations—design requirements—form a summary of actual experience and knowledge in the field of aviation structural safety. The progress of aviation knowledge is followed by progress in the domain of airworthiness requirements; they take into account the new problems, which appear as a result of performance increase or of growing complexity of aeroplanes and call for critical revision of previously accepted numerical values.

The factor of safety is one of the main elements of airworthiness requirements. Both the International Requirements, worked out by OSTIV for gliders of Standard Class and other known national airworthiness requirements take a factor of safety not less than 1.5. This is also the value of the factor required by the ICAO Aeroplane Requirements.

In recent years we have seen proposals for the revision of the present value of the factor of safety for transport aeroplanes. The factor of safety would be divided into two independent factors -namely one factor to take into account the possibility of the occurrence of higher loads than now prescribed and the other factor to secure the aeroplane against the possibility of ultimate strength reduction in course of manufacture and service of individual aeroplanes. The aim of the present paper is to discuss in a similar way the problem of factor of safety in modern glider structures.

There is no doubt that the use of a single factor of safety in glider design, in order to safeguard the glider against the possibility of occurrence of higher than prescribed loads and of strength reduction, will involve the same considerations as in the case of aeroplane design. We shall discuss both problems.

1. Loads

The limit (proof) loads, prescribed by the Glider Airworthiness Requirements are the loads which may occur during service life of the glider. The maximum value of limit load is defined by a statistical method to occur once during the whole service life of a single glider. Then it follows that it is probable that during service of a given glider type (i.e. many copies of it) higher loads than limit may occur. Thus the aim of the factor of safety is to safeguard the pilot against the use of the parachute during flight or against injury during landing. There are many loading conditions but the Requirements reduce them to a few cases, so let us look at the possibility of occurrence of maximum limit loads and of even higher loads in some fundamental cases i.e. rough handling in flight, flight in rough air, diving and landing.

a) Rough handling in the air

The attainment or exceeding of maximum limit loads as a result of rough handling of the elevator e.g. when carrying out recovery from the spin or during aerobatics, is related virtually to the pilot's skill and to the control force gradient per "g". When the control force gradient is from 0,5 to 3,0 kG per "g" the attainment of loads in excess of the limit value, is a real possibility, so it must be taken into account by the designer. In the case of rough handling of the ailerons, rudder, flaps or airbrakes eventual exceeding the limit loads depends on the pilot and on the control forces. It should be kept in mind that owing to the use of poorly balanced ailerons in gliders the exceeding of limit loads by rough handling is rather remote as large control forces would be exacted from the pilot.

b) Rough air (gusts)

The possibility of occurrence of higher loads in rough air than those prescribed by the Requirements for normal or strong gusts, depends on gust intensity and flight speed. It follows from the formula

$$\Delta n = a \cdot w \, \eta \, V$$

where Δn = gust load factor increment,
a = glider parameter,
w = gust intensity,
η = gust alleviating factor
and V = flight speed,

that for each value of flight speed V there is a limiting value of gust intensity w; surpassing of w does not increase the load factor as the stall angle of incidence would be exceeded. On the diagram 1 the load factor increment Δn is limited by the curve of 1,25 $C_{L\,max.}$, the factor 1,25 takes into account the possibility of occurrence of the oblique gust and eventual increment of maximum lift factor due to dynamic effect. Accepting any additional factor of safety in that case to take into account the occurrence of stronger gusts is entirely unjustified.

c) Diving

The attainment or surpassing of the design diving speed V_D during aerobatics or during flight without visibility depends entirely on the pilot's skill, so they must be taken into account by the designer. But in that range of the flight speeds the dependence of the loads on the air speed, as a rule, is not of second order (parabolic) due to distortion of the structure. Thus the relation of the factor of safety to the loads, taking place at flight speed V_D, given by the formula

$$P_{ult} = \nu \cdot P_{lim}$$

seems to be unjustified. The relation of the factor of safety to the flight speed directly and calculation of the ultimate load from the formula

$$P_{ult} = f(\nu \cdot V_D)$$

are much more justified. The function "f" may be closely related to the stiffness characteristics of the structure.

Some compromise between these two points of view may be obtained by imposing upon the pilot a maximum permissible flight speed V_{NE}, which is less than V_D; as a result some safety margin, as concerns the flight speed, is obtained in addition to the conventional factor of safety, which concerns mainly "loads".

The above discussion, valid for the influence of the flight speed increase beyond V_D on the considered static loads is also reasonable for dynamic phenomena such as e.g. self-excited vibrations, which is provided for by a factor of safety related only to flight speed V_D and not to load P_{lim}.

d) Landing

The loads during landing are calculated from the landing energy, i.e.

$$P_{lim} = f\left(E_{lim} = \frac{m\, w_{lim}^2}{2}\right)$$

where w is the vertical speed at landing. As the possibility of occurrence of loads equal or even higher than the maximum prescribed values is closely related to the possibility of occurrence of higher vertical speeds, which are related to the pilot's skill, then similarly, as in case of diving—

$$P_{ult} = \nu P_{lim}$$

but

$$P_{ult} = f\left(E_{ult} = \nu \cdot \frac{m\, w_{lim}^2}{2}\right)$$

The function f is entirely nonlinear as the characteristic of the shock absorbing elements for extreme values of landing energy, as a rule, is not linear.

From the discussed four basic load cases the use of the factor of safety in order to take into account the possibility of occurrence of higher loads than limit in form—

$$P_{ult} = \nu \, P_{lim}$$

is justified only in the case of rough handling in flight (subject to correction when large control forces are the limiting factor) and to a limited extent for loads in a gusty atmosphere. It is evident that, reserving the problem of safeguarding against reduction of structural strength, the use of a single factor of safety to take into account for all cases, contained in the Airworthiness Requirements, the possibility of occurrence of loads ν-times higher than maximum limit loads is unjustified and false.

In such a situation it seems to be reasonable to throw away the present factor of safety and to accept in the strength analysis of the glider a new factor—an ultimate load. This ultimate load will be defined as maximum admissible load, which is to be safely withstood by the structure only once. The safety is related to the crew only. It follows from this definition that the glider may be subjected to some degree of damage, but that damage must not endanger the crew—directly or indirectly (e.g. render impossible a safe landing). The ultimate loads for 4 basic cases of loading conditions should be set as a result of an analysis of extreme but technically real flight and landing cases, which will take into account the pilot's faults and exceptional meteorological conditions. In the case of rough flight handling the result of this analysis will be the definition of ultimate loads, rough flight handling ultimate speed and ultimate control forces; in case of gusty atmosphere—ultimate gust intensity and ultimate flight speed in gusty air; in case of diving—ultimate flight speed; in case of landing—ultimate sinking speed during landing. The aim of the present paper is to show the main problem and not to define any details. It is worth mentioning that in the case of loads in gusty air the simultaneous consideration of ultimate gust and ultimate flight speed is not justified and in case of diving it is reasonable to relate the ultimate flight speed to the maximum permissible flight speed, as concerns the flutter prevention, equal to 1.35 V_D.

2. Strength

The glider airworthiness requirements take into account the possibility of occurrence of factors, which reduce the strength of some elements of primary structure of a glider in course of manufacture or service. That is achieved by means of a universal factor of safety equal to 1,5. It is evident that if that factor of safety also safeguards the structure against reduction of strength, then the value of 1,5 is very exaggerated.

Van Osnabrugge (1) considers this problem for transport aeroplanes and suggests a factor equal to 1.2 based on probability data. Not taking the problem for granted it seems that such a value may be accepted for gliders which are manufactured industrially (by renowned establishments) and used in aeroclubs under expert supervision of licenced inspection staff. The above considerations concern of course only the ultimate strength, which is to be proved by calculations and static test. As concerns the fatigue strength then, contrary to transport aeroplanes, the relatively short service life of gliders, not exceeding 2,000 hours (in Poland the average service life is equal to ca. 1,000 hours) allows that problem to be disregarded.

3. Conclusions

a) Present conception of factor of safety, which ensures the structure both against the possibility of occurrence of higher loads than prescribed and against reduction of strength, is not reasonable.

b) Replacing part of the factor of safety, which safeguards the structure against occurrence of higher loads, an ultimate load concept should be accepted, i.e. for each load case an extreme load is to be taken, which may occur taking into account the pilot's faults and exceptional meteorological conditions.

c) The ultimate loads are to be withstood by the glider structure safely for the crew i.e. the eventual damage or distortion of the glider structure should not prevent the carrying out of a safe landing.

d) The present requirement that the structure shall withstand the maximum limit loads without permanent deformations is to be left unchanged.

e) A new value of the factor of safety, which would safeguard the glider structure against the possibility of reduction of strength, should be fixed. This factor is influenced by manufacture and service conditions: it seems that the value of it will be not very far from 1.2.

f) The glider strength calculations and the static test shall prove that—

- there are no permanent structural deformations in the full range of the limit loads,
- there are no effects in the range of the ultimate loads, which may endanger the crew or make impossible a safe landing,
- the glider ultimate strength is not less than the ultimate load multiplied by the new factor of safety.

Reference

(1) *Van Osnabrugge:* Draft PAMC on gust criteria, ICAO Airworthiness Committee, Third Meeting Report. Stockholm 1959.

(Swiss Aero-Revue 10/1965)