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Appendixes

Calculation Examples

Chapter 9 - Structural loads

9.1 INTRODUCTION

We will refer to the design rules examined in Chapter 8 in this chapter.

We can use the 1942 RAI rules for a simple, quick, preliminary estimate of the loads acting on the structures and a relatively precise evaluation of the structural weight, integrating and implementing these results using BCAR-E rules. The final step will be the use of CS 22 rules for the final check having already safely approached the final structural configuration of the glider and calculated the weight of the parts.

In this chapter we will firstly examine the method to be followed in the calculation of the aerodynamic loads on the wing, passing through the manoeuvre envelope and gust envelope and we will finally calculate the loads on the ailerons and air brakes.

The following step is the calculation of the aerodynamic load on the empennages and the loads transmitted by them to the fuselage tail boom. Landing loads and forces transmitted by the wing to the fuselage-wing fittings will be the last step.

The aim of determining the aerodynamic loads is very broad and is mainly:

- the structural check from the point of view of strength and deformability
- the calculation of the theoretical weights of the glider
- the calculation of the theoretical C.G. position.
- the calculation of the loads acting on wing, fuselage and tailplane

The designer must prepare a complete set of drawings of the glider's structure in order to check if the calculated weight corresponds to a realistic structural scheme.

The drawings should be traced using soft pencils so they can be modified as required after having performed stress analysis and preliminary weight calculations.

Having found the preliminary C.G. position we can proceed to the application of the chosen rule, CS 22, which is valid not only for Europe, and then make a second iteration of the calculations with consequent weight adjustments as by this time the final sizes of the various structural components will be well enough defined.

The calculation methods shown in the next paragraphs are the starting point of the final check that will be performed after the preliminary drafting of the glider structure.

9.2 WING AERODYNAMIC LOAD.

We will start calculating the manoeuvre and gust envelope by using fictitious data, i.e. the weight of the glider's components such as the wing, fuselage and empennages in

order to create a reference structure. The purpose is to find the design limits through the calculation of the above envelopes and, with the help of the preliminary drawings, we must prepare a list of the items making up the structure and calculate the weight of each component. Now we can proceed to determine in a preliminary way the lift and mass distribution, and the wing torsion.
Air loads on ailerons and air brakes will enable us to find the size of their structural components thus completing the preliminary analysis and enabling us to perform a preliminary stress analysis of the wing.

9.3 MANOEUVRE ENVELOPE

Let's consider as already known the following data:

S	wing surface (m^2)
W	max total weight (kg or daN)
W/S	wing loading (kg/m^2 or daN/m^2)
n_1	load factors at the speeds given by CS 22 rules
Cl	lift coefficient at the various angles of attack of the glider

We can now calculate the manoeuvre envelope with this basic data.
Let's refer to fig.1-9 on page 245 with the geometric dimensions indicated.
Stall speed will be calculated with the following formula:

$$V_S = V_{A1} = \sqrt{\frac{n_1 \cdot \frac{W}{S}}{\frac{1}{2} \cdot \rho \cdot Cl_{MAX}}} \tag{9-1}$$

The values used in 9-1 are: $n = 1$, $W/S = 28$ Kg / m^2, $Cl_{MAX} = 1.20$
The stall speed will be in this particular case:

$V_S = 19.321$ m / s = 69.555 km/h

Introducing the other values of " n " (from 2 to 5.3; typical for a glider of the utility type) we will have the rest of the points of the parabolic curve $n = f(V)$.
At the point A, if we follow BCAR-E rules, we will have:

$$V_A = \sqrt{\frac{6 \cdot 28}{0.5 \cdot 0.125 \cdot 1.20}} = 47.328\ m/s = 170.38\ km/h$$

If, for condition B, the load factor and the corresponding speed are given by CS 22 rules or from aerodynamic data, we will find the corresponding Cl that, in our case, is given by the ratio:

$$Cl = \frac{n \cdot \frac{W}{S}}{\frac{1}{2} \cdot \rho \cdot V_D^2} \qquad \text{9-2}$$

The same will be done for condition *C* on the assumption that the load factor and *Cl* value are as per CS 22 rules (*Cl* = - 0.8). We will introduce the values of the load factor " *n* " starting from -1 up to -2.50.
Fig.1-9 on page 245 represents a typical manoeuvre envelope. A more detailed example of these calculations is given with Calculation Example N°16.

9.4 DETERMINATION OF GUST ENVELOPE

As we have seen, CS 22 rules give the values of the gusts to be considered at the speeds V_A and V_B.The max value to be considered, given by BCAR-E, at the speed V_A is:

U = 66 ft / s = 20.11 m/sec

At condition *A*, which is when the load factor is: *n* = 6, we have calculated the corresponding speed V_A and we know the value of the wing loading *W/S*.
We find the corresponding gust speed from the following:

$$n = 1 + \frac{1}{2} \cdot \rho \cdot \frac{V^2}{W/S} \cdot \frac{dCl}{d\alpha} \cdot arctg \frac{FU}{V} \qquad \text{9-3}$$

where the factor *F* is given by:

$$F = 0.30 \cdot W^{0.25} \qquad \text{9-4}$$

In the case of the BCAR-E rule the value of weight *W* and the wing loading *W/S* are given in imperial units, i.e. lbs and lbs/ft^2.
The value of the slope of the lifting curve must be calculated for the real wing as we have seen in Chapter 4 at §4.18. We will have from 9-3 and 9-4 that:

$$FU = V \cdot tg \frac{(n-1) \cdot \frac{W}{S}}{\frac{1}{2} \cdot \rho \cdot V^2 \cdot \frac{dCl}{d\alpha}} \qquad \text{9-5}$$

As the value of the lift curve slope is given in radians, the calculated value must be divided by 57.3 to convert it from radians to degrees. Having calculated the value of " *F* " from 9-4 we can now get the value of the gust speed *U* from the ratio:

$$FU / F = U \ \ ft/s \qquad \text{9-6}$$

The calculated gust speed can be higher, equal to or lower than that indicated in the rules.

In the first two cases we assume that the gust speed is the same as indicated in the rules while in the third case the “straight” gust will cut the manoeuvre envelope.
The resulting flight envelope is shown in fig.2-9 on page 245. See also Calculation Example 17.

9.5 TOWING SPEED

This speed is indicated in CS 22 rules and must be higher than the calculated one.
On the basis of the designer’s chosen speed some cases of load must be foreseen as shown in fig 3-9 on page 246 and a structural check of the glider’s nose structure made accordingly. This part of the glider, generally, is not a critical one when towing loads are applied. Nevertheless this structure must be carefully designed also in view of the fact that the cockpit crashworthiness depends on the nose structural type.

9.6 LIFT DISTRIBUTION ALONG THE WING SPAN

Two methods are available to calculate the lift distribution along the wing span: the Weissinger and the Schrenk method.
If the reader wants to know more about this matter, there are classic references at the end of this chapter (bibliography). Since the purpose of this book is to introduce the reader to the practical aspects of the calculations involved in a glider’s design rather than explain theories, we will show the procedure to be followed in theory and prepare a table giving the required data.
The practical example of what follows is given in Calculation Example N°18, in which we have used the Shrenck method, having in mind a schematic wing as shown in fig.4-9 on page 246. Dimensions and data are shown below:

b	wingspan
S	wing surface
C	wing chord in the rectangular zone
C_1	wing chord in the intermediate trapezoidal zone
C_2	wing chord in the trapezoidal tip zone
$a_o = \dfrac{dCl}{d\alpha}$	slope of the lifting curve
ε_o	aerodynamic twist between $y = 0$ and $y = 7.50$ m
α_{GEOM}	geometric twist
Λ	sweep at 25 % of the chord between $y = 0$ and $y = 7.50$ m

The wing section, to simplify what follows, is constant, starting from the root sections up to the tip. The geometric twist is 0.00° and the sweep at 25 % of the chord is also 0.00° with the same purpose.
A wing with an elliptic planform having the same surface and aspect ratio of our wing

has chords given by the following formula:

$$\frac{C_{ELL.}}{2}=\frac{2S}{\pi\cdot b}\cdot\sqrt{1-\left(\frac{2\cdot y}{b}\right)^2} \qquad 9\text{-}7$$

The product between the local chord, which is the average chord between the equivalent elliptic chord and the effective chord, and the average lift coefficient of the wing, assumed as a unit, is:

$$C\cdot Cl_{GLIDER}=\frac{C+C_{ELL}}{2} \qquad 9\text{-}8$$

given that

$$Cl_{GLIDER}=1$$

The product between the local chord and local lift coefficient is given by:

$$C\cdot Cl=C\cdot Cl_{GLIDER}+C\cdot Cl_b \qquad 9\text{-}9$$

and the first addendum in the above sum has already been calculated.
Let’s calculate the second addendum $C \cdot Cl_b$ .This is the product between the local chord, measured at different sections of the wing, and the local lift coefficient due to the wing twist Cl_b .is the basic lift coefficient at various wing sections due to the wing twist. This coefficient is calculated from :

$$Cl_b=\frac{\varepsilon_1\cdot\alpha_O}{2} \qquad 9\text{-}10$$

In 9-10, ε_1 ,the angle of attack of each wing section, in degrees, refers to the angle of attack of zero lift:

$$\varepsilon_1=\varepsilon_O-\alpha_{ZL} \qquad 9\text{-}11$$

$$\alpha_{ZL}=\frac{2}{S}\cdot\int_0^{\frac{b}{2}}\varepsilon_O\cdot C\,dy \qquad 9\text{-}12$$

given that :

ε_O the twist, in degrees, of the wing sections relating to the glider’s datum line wing section; only aerodynamic twist
α_{ZL} is the zero angle of attack given by 9-12

In our calculation example, as $\varepsilon_O = 0$ it is also $Cl_b = 0$, but if this is not the case, it will be necessary to calculate the values of the second addendum and then we can determine all the values of the products $C \cdot Cl$ for all the load conditions to be examined.

The lift distribution along the wingspan for each load condition is given by: