RATIONAL REQUIREMENTS FOR TAIL BOOM DESIGN

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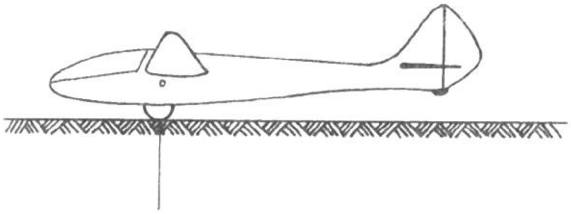
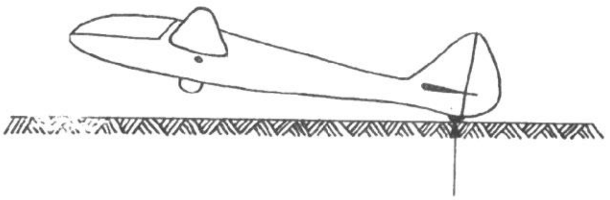
I. SUMMARY.

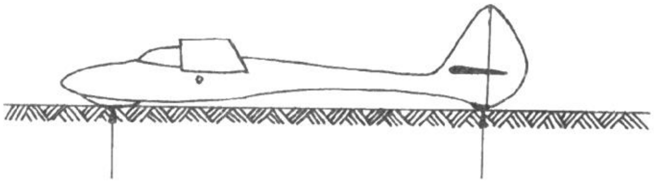
The present investigation represents a special case in which the structural design of a tail boom has been based upon aeroelastic considerations. Due attention has, therefore, to be paid to the fact that a properly designed tail boom should be able to transfer both tailplane loads up to the design diving speed which should, of course, be smaller than the critical flutter speed, and to endure landing loads on the tail skid. When considering the structural problems of tail boom design the required useful life of the glider has to be taken into account.

II. VERTICAL LOADS ON TAIL BOOM.

The landing load factor at the C.G. of sailplane, for various positions of fuselage during the landing, is three to four times the weight of the sailplane (fig. 1).







Calculations should indicate which of these two cases (fig. 1 b and c) is more critical.

The procedure which leads to a satisfactory level of safety and high strength - weight ratio of tail boom is based upon the following *Requirement*:

The ground force should be about one third of the maximum force which acts during the most critical combinations of manoeuvres in flight.

From fatigue investigations of various wooden materials, ref [2], and metals, ref. [3], we have information on the ratio of fatigue limit against stress. For tail booms this ratio is about 0,5, for an appropriate number of 10^5 load reversals. These data are available for wooden and metal elements which form a tail boom structure.

The above considerations should be combined with:

a. fuselage flexibility in the vertical plane of symmetry according to the aeroelastic requirements, and

b. ratio of work done by tail skid (A_d) and by fuselage (A_t).

The equations for the work done by tail skid and fuselage, have the form

$$\left.\begin{aligned} A_d &= \eta' \cdot b \cdot P_d^2 \\ A_t &= 0,5 \cdot a \cdot P_d^2 \end{aligned}\right\} \qquad (1)$$

$$A_{system} = A_d + A_t = P_d^2 \, (0,5 \; a + \eta \; b), \qquad (2)$$

where

η efficiency of shock absorber

a [m per kg] vertical flexibility of the fuselage

b [m per kg] vertical flexibility of the shock absorber

P_d [kg] the tail skid load

The fuselage stiffness in the vertical plane, according to the flexural criterion, ref [1], applicable to vertical loads can be expressed

as $i \geq 2,46^2 \cdot V_D^2 \cdot \tau_H \cdot S_H \cdot \delta_o$ [kgm per radian of kgm per $\frac{a}{\tau_H}$]

$$\text{or } a \leq \frac{\tau_H}{2,46^2 \cdot V_D^2 \cdot S_H \cdot \delta_o}, \; [\text{m per kg}]$$

where

V_D Design Diving Speed, E.A.S. (meters per second)

V_s Sinking Speed (meters per second)

S_H Gross Area of the tailplane and elevator (square meters)

l_H distance between wing root quarter-chord point and elevator hinge line (meters)

Density of air at sea-level (kg sec^2/m^4)

For the total energy which is absorbed by the tail skid at the moment of impact, the following expression is assumed

$$A_s = 0,5 \; \frac{W}{g} \; \frac{V_s^2}{1 + (\frac{\tau_H}{i_y})^2}, \qquad (4)$$

where i_y is sailplane radius of gyration about y axis. Equating (2) and (4)

$$P_d^2 (0,5 \; a + \eta \; b) = 0,5 \; \frac{W}{g} \; \frac{V_s^2}{1 + (\frac{\tau_H}{i_y})^2},$$

and by approximating

$\eta \approx 0,5$

follows

$$P_d^2 \; (a + b) = \frac{W}{g} \; \frac{V_s^2}{1 + (\frac{\tau_H}{i_y})^2}$$

and

$P_d = f \; (V_s)$.

In practice it has been found that the sinking speed of gliders is much higher during the approach to landing with airbrakes extended than at the moment of impact. It is, therefore, assumed that sinking speed at landing is $\approx 0,75 \; V_s$ (airbrakes extended) for high performance sailplanes, and $\approx 0,85 \; V_s$ (airbrakes extended) for training gliders.

The equation (5) gives the relation $P_d = f(b)$ for the case of landing on tail skid. The magnitude of P_d in that case is limited to one half of the largest force to which a tailplane is submitted during manoeuvres in flight.

III. ILLUSTRATIVE EXAMPLE

For a high-performance sailplane with the following data
$W = 446{,}0$ [kg]
$S_H = 2.04$ [square meters]
$l_H = 4.6$ [meters]
$i_y = 1{,}36$ [meters]
$V_D = 60$ [meters per second]
P_{max} [tail] $= 150$ [kg]
find:
a. what will be the ratio of the energy absorption of the shock absorber and of the tail boom respectively,
b. what will be the vertical travel of the shock absorber.
ad a.
From equation (3) follows

$$a < \frac{4.6}{6.025 \cdot 3600 \cdot 2.04 \cdot 0.125} = 0.000332 \text{ [meters per second]}$$

Sinking speed at the impact with airbrakes extended is assumed
$V_s = 1.8$ [meters per second]

$$\text{Hence } \frac{W}{g} \cdot \frac{V_s^2}{1 + (\frac{\tau_H}{i_y})^2} = \frac{446}{9.81} \cdot \frac{1{,}3^2}{12.45} = 11.85$$

From equation (5)

$$P_d^2\,(0{,}000332 + b) = 11.85.$$

and according to the *Requirements*, taking into account one half of the maximum tail load
$75^2\,(0.000332 + b) = 11.85$
the value for b is
$b = 0.001275$ [meters per kg]

The tail skid shock absorber should have the flexibility:
1.275 [milimeters per kg]

The minimum ratio according to the *Requirements* should be

$$\frac{b}{a} = \frac{1.275}{0.332} = 1{,}53$$

This ratio indicates that the energy absorption of shock absorber for this special case should be much larger than that of the tail boom itself.
ad b.
The vertical travel of the tail skid shock absorber is calculated as follows

$$\frac{\eta}{0.5} \cdot b \cdot P_d = 1{,}275 \cdot 75 = 95 \text{ milimeters}$$

IV. REFERENCES

[1] Technische voorschriften voor zweefvliegtuigen, Ministerie van Verkeer en Waterstaat. Holland. June 1953.

[2] F. Kollman, Technologie des Holzes und der Holzwerkstoffe, Erster Band, Springer Verlag, Berlin. Berlin 1951.

[3] Fatigue and Fracture of metals. A symposium held at the Massachusetts Institute of Technology June 19-22, 1950. Edited by W. M. Murray, New York 1952.