LOAD ALLEVIATING CAPABILITIES OF THE GLIDER STRUCTURE

by

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INTRODUCTION

One of the most important requirements to be met in glider design is to reduce the structural mass as far as possible. The lower the empty glider weight, the wider is the total mass variation range for the assumed all-up weight, especially when water ballast installation is provided.

The dimensions of the elements and, in consequence, the mass of the glider primary structure depend on the loadings calculated for all the critical flight and ground conditions. The value of these loadings results from the prescribed load factors and airspeeds so long as the glider is considered as a rigid body.

The real structure, however, has its special elasticity depending on the geometry and materials used. Under the action of the loadings there appears distortion and displacement of the structure points.

This distortion produces some alleviating effect as a consequence of the energy absorption and the angular displacement of the lift surfaces (changes in incidence). Both these factors affect the aerodynamic forces or the energy and in the critical loading cases may lead to a loading decrement of considerable value.

The calculations, of course, become more complex since it is necessary to define the stiffness characteristics of the main structure units. This problem is considerably smoothed when the loading calculations are carried on for the serial type or even the prototype being the evolution of the existing one. In such cases the stiffness values can be measured during the ground tests and real figures obtained.

The results of the loading calculations for the glider considered as an elastic body are discussed in this paper and compared with those obtained for the stiff body sample. As an illustration of the problem the results for several Polish gliders are shown.

UNDERCARRIAGE

The vertical kinetic energy of the landing glider depends on the sinking speed value "V_s" prescribed by the requirements

$$E_k = m_{red} \frac{V_s^2}{2}$$

where: m_{red} = reduced mass of the glider due to the eccentric impact.

This energy is to be absorbed by the tire and tube and shock absorbing element (if used).

The absorbed energy:

$$E_A = \frac{1}{2} R_w h$$

where:

R_w = ground reaction on the wheel

h = resultant glider c.g. displacement depending on the tire and tube and shock absorbing element characteristics.

Since the kinetic and absorbed energies must be equal, the ground reaction for the stiff structure can be defined:

$$E_k = E_A = m_{red} \frac{V_s^2}{2} = \frac{1}{2} R_w h$$

Thus $R_w = \dfrac{m_{red} V_s^2}{h}$

Such a calculation performed for the sailplane SZD-38 JANTAR 1 gives the result:

$E_k = E_A = 47.5$ kGm and consequently

$R_w = 1470$ kG.

In projecting a new glider design, it is necessary to define the stiffness of at least the fuselage and the wing to obtain the data for the flutter criteria calculation.

These data allow one to find the structure deflection arising under the action of the mass forces in respect to the load factor

$$n = \frac{R_w}{W}$$

where:

n = load factor for landing condition

W = all-up weight of the sailplane

Replacing the continuous mass of the fuselage and wing by the system of concentrated forces, there can be found the deflection lines (Fig. 1). The energy absorbed for the structural distortion is

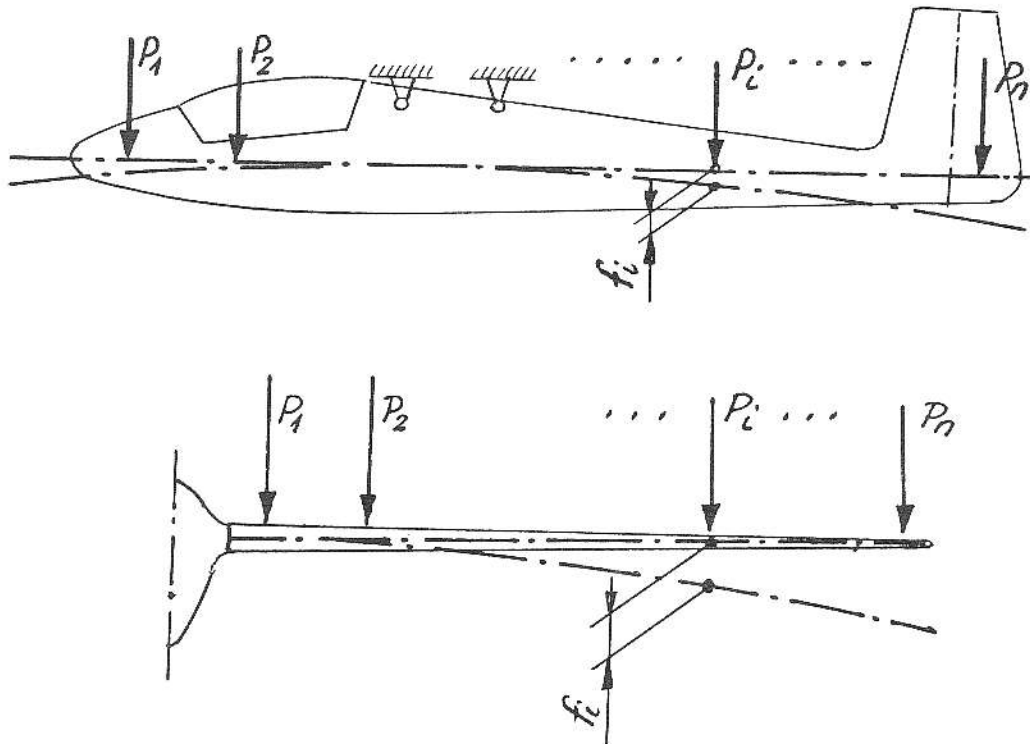$$E_D = \frac{1}{2} \sum_{i=1}^{n} P_i f_i$$

FIGURE 1. Representation of fuselage and wing by a system of concentrated mass forces.

where:

P_i = concentrated mass force

f_i = structure displacement in the station of the force P_i.

The distortion energy is absorbed mainly by the fuselage and wing. Since the kinetic energy of the landing glider is partly absorbed for the structure distortion, the ground reaction is defined now from the equation:

$$E_k - E_D = E_A$$

For the glider SZD-38A JANTAR 1 the distortion energy is E_D = 8.1 kGm and results in the ground reaction being reduced to the value of R_w = 1310 kG. The elastic structure considerations allowed for the ground reaction decrement:

$$\Delta R_w = 1470 - 1310 = 160 \text{ kG.}$$

TAIL SKID (OR WHEEL)

The tail skid or wheel normally has no shock absorbing element. The skid impact force is calculated on the basis of the requirements formula comprising the terms depending on the glider geometry and mass. Such a calculation in the case of the motor glider SZD-45 OGAR resulted in the tail skid loading:

$$R_{wt} = 211 \text{ kG.}$$

The fuselage rear section of the motor glider SZD-45 OGAR has been designed in the form of a slender conic duraluminium tube. Such a structure is a good shock absorber. The tail skid ground reaction calculated in respect to the elastic fuselage rear section is:

$$R_{wt} = 127 \text{ kG.}$$

The load decrement is then

$$\Delta R_{wt} = 211 - 127 = 84 \text{ kG.}$$

The alleviating capability of the OGAR's fuselage is rather high, but nearly all modern fiberglass sailplanes have slender rear fuselage tubes with extremely small cross section, producing a very elastic structure.

AILERON

On gliders of the normal category the critical aileron loading appears in the most cases for the full down-deflection of the aileron at the airspeed V_A, or for 1/3 of the full down deflection at the airspeed V_D.

The aileron loading depends on the pressure which, according to the linearized distribution along the wing chord, has the triangular form (Fig. 2). The pressure on the hinge station is defined for the stiff wing by means of the formula:
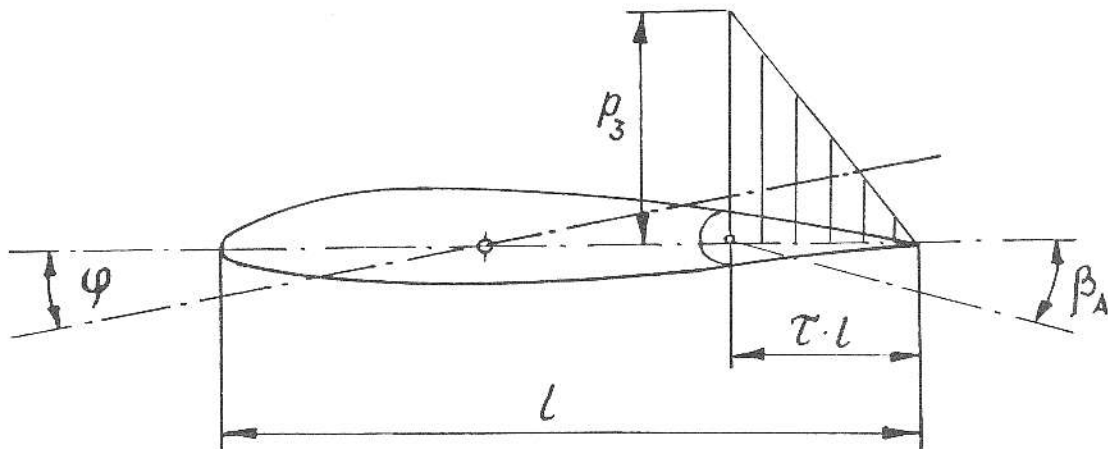

FIGURE 2. Linearized distribution of pressure along aileron.

$$P_3 = q \left[\left(11 \frac{dC_l}{d\alpha} \alpha + 60C_{mac} \right) \frac{\tau}{8} + \left(2\tau - 0.5 \right) \frac{\partial C_z}{\partial \beta} \beta_A + 6 \frac{\partial C_m}{\partial \beta} \beta_A \right]$$

where:

q = dynamic pressure
$dC_l/d\alpha$ = wing lift curve slope
α = wing incidence
C_{mac} = moment coefficient in respect to the 25% chord station
τ = aileron to wing chord ratio
$\partial C_z/\partial \beta$ = slope of lift coefficient versus aileron deflection
$\partial C_m/\partial \beta$ = slope of moment coefficient versus aileron deflection
β_A = aileron deflection

The elastic wing under the torque moment gets the angular distortion:

$$\Phi_y = \int_0^y \left(\frac{M_t}{GJ_o} \right)_y dy$$

where the torque moment M_t and the wing torsional stiffness GJ_o are the functions of the span station y.

The incidence of the distorted wing is:

$$\alpha_{dist} = \alpha - \Phi$$

and in the consequence the aileron pressure formula is:

$$P_3 = q \left[\left(11 \frac{dC_l}{d\alpha} (\alpha - \Phi) + 60C_{mac} \frac{\tau}{8} \right) + (2\tau - 0.5) \frac{\partial C_l}{\partial \beta} \beta_A + 6 \frac{\partial C_m}{\partial \beta} \beta_A \right]$$

Since the distortion angle and the lift distribution are varying with the span station y, the pressure value p_3 is a function of aileron span.

The results obtained for the pressure p_3 for the aileron of the glider SZD-30 PIRAT are the following:

p_3 = 145 kG/m^2 for the stiff wing
p_3 = 128 kG/m^2 for the elastic wing

where both values concern the case of 1/3 of the maximum down deflection of the aileron at the airspeed V_D.

FLAP

The flap pressure is calculated on the basis of the same formula as for the aileron. It is easy to observe that the torsional distortion of the wing on the inner portion of the span (flap region) is considerably lower than on the aileron region, therefore, the alleviating effect of the distortion is rather poor. The results obtained for SZD-38 JANTAR 1 are the following:

p_3 = 25 kG/m^2 for the stiff wing and
p_3 = 24.4 kG/m^2 for the elastic wing.

The elastic effect on the flap loading is of no importance.

HORIZONTAL TAILPLANE

The critical cases for the horizontal tailplane loading are generally the conditions:

- full elevator deflection at the airspeed V_A
- 1/3 of full elevator deflection at the airspeed V_D

The second condition nearly always leads to the wing incidence exceeding the load factor limits imposed by the load envelope (n - V diagram) and the alleviation of the loading depends on another philosophy than the elastic phenomena. Therefore, the V_D case is not an interesting one.

The tailplane force for trim depends on the tailless moment coefficient:

$$P_H = - C_{mTL} \cdot \frac{A \, q \, C_s}{L_H}$$

where:

C_{mTL} = tailless moment coefficient
A = wing area
q = dynamic pressure
C_s = wing mean standard chord
L_H = tailforce arm in respect to the glider's c.g.

The tailforce for trim is obtained, when the necessary elevator deflection for trim is applied (Fig. 3) where:

α = wing incidence
ε = wing downwash
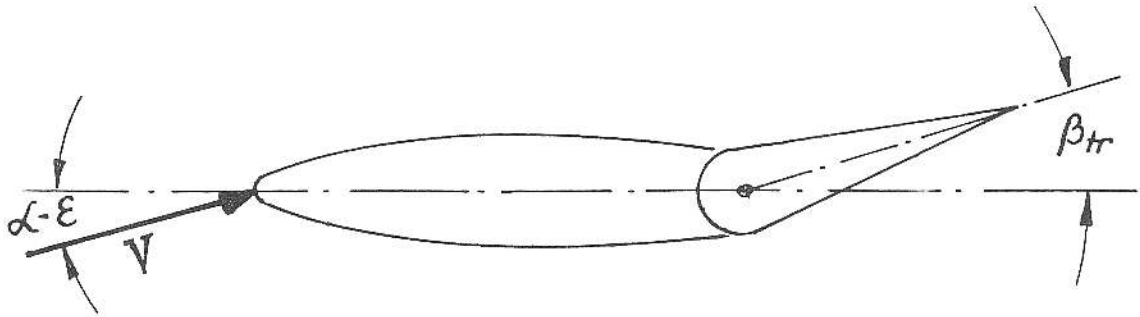β_{tr} = elevator angle for trim

FIGURE 3. Horizontal tailplane trim angle.

The fuselage bending elasticity disturbs the relation between the stabilizer incidence, α-ε, and the elevator deflection for trim, β_{tr}.

The tailforce for trim for most of the gliders is directed downward and produces the positive tailplane incidence increment ϕ (Fig. 4).

To restore the trimmed flight condition it is necessary to deflect the elevator to the angle

$$\beta_{tr}^* = \beta_{tr} + \Delta\beta_{tr}$$

On the tailforce for trim, P_H, there is superimposed the tailforce ΔP_H involved by the full deflection of the elevator.
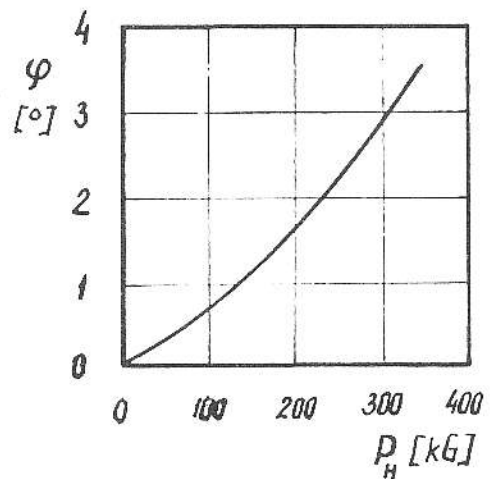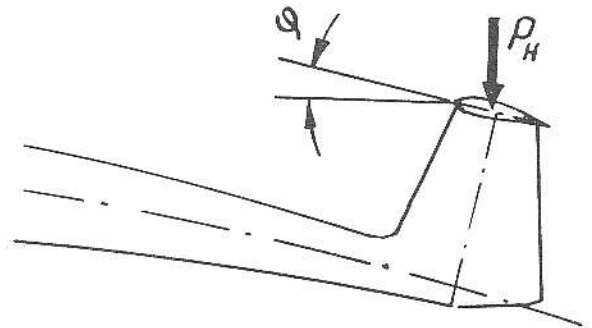
The force ΔP_H depends on the elevator deflection increment:

$$\Delta\beta_H^* = \beta_{Hmax} - \beta_{tr}^*$$

where β_{Hmax} is the maximum elevator deflection to the stops.

The fuselage bending elasticity, however, is not the deciding alleviating influence. The elevator deflections are realized by means of the control circuit from the pilot's hand to the control surface. The particular elements of the control circuit suffer the strains due to the stresses arising in them. There appears also the displacement of the brackets and the structural elements to which the brackets are fitted. It is, of course, nearly impossible to calculate these strains, but there are available the data based on statistics, especially when the stiffness ground tests are carried on before the first flight is realized.

Special measurements have been carried out on the motor glider SZD-45 OGAR. There has been registered the value of the force P necessary for the elevator deflection, $\beta_{H\phi}$ when the stick in the cockpit was fixed to the stops (Fig. 5). The force P has been applied in the distance of $1/3\ \tau\ \ell$ in respect to the hinge, reproducing the hinge moment:

FIGURE 4. Horizontal tailplane incidence increment ϕ.

$$M_H = [1/3] P \tau \ell$$

necessary to balance the strain effect of the system. The hysteresis on the diagram depends on the system friction.

The resultant elevator deflection increment is:

$$\Delta\beta_H = \beta_{Hmax} - \beta_{tr}^* - \beta_{H\Phi}$$

The calculation requires a step by step method because the angles $\Delta\beta_H$ and $\beta_{H\Phi}$ depend one on the other.

The resultant tailforce increment is then:

$$\Delta P_H = \frac{\partial C_H}{\partial \alpha_H} \cdot \frac{\partial \alpha_H}{\partial \beta_H} \Delta\beta_H \cdot q \, A_H$$

where:

$\frac{\partial C_H}{\partial \alpha_H}$ = slope of the tailplane lift curve

$\frac{\partial \alpha_H}{\partial \beta_H}$ = change of the tailplane incidence with the elevator deflection

A_H = tailplane area

The resultant tailplane force:

$$P_{H\,res} = P_H + \Delta P_H - P_{mass}$$

where:

P_{mass} = the inertia force depending on the tailplane mass and the acceleration produced by the tail-force increment ΔP_H.

The results obtained for the motor glider SZD-45 OGAR are listed in the table below:

Deflection	$P_{H\,res}$ (kG)		
	Stiff control circuit	Elastic control circuit	Elastic Control circuit and elastic fuselage
up	-424	-372	-325
down	76	45	39.8

FIN AND RUDDER

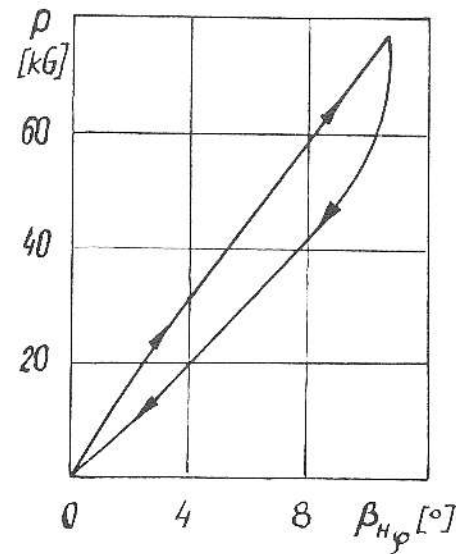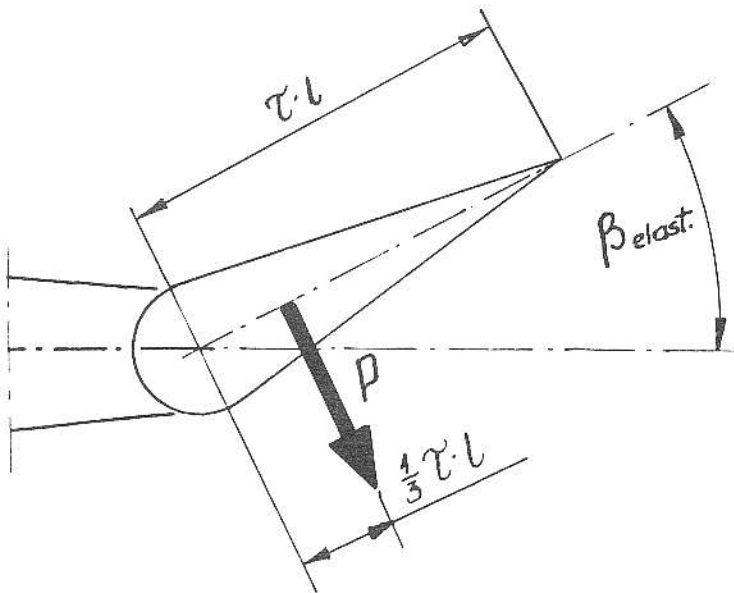For the fin and rudder loadings the same considerations can be applied as for the hori-

FIGURE 5. Force P necessary for elevator deflection $\beta_{H\Phi}$.

zontal tailplane except in the force for trim which for the vertical tailplane is equal to zero.

The elastic rudder distortion under the hinge moment loading has been measured for the SZD-45 OGAR motor glider in the same manner as on the elevator. The results are shown on the diagram (Fig. 6) where the distortion angle is $\beta_{V\phi}$.

The fin and rudder loadings calculated for the motor glider SZD-45 OGAR for the stiff and elastic control circuit and fuselage rear section are listed in the table below:

	$P_{V\ res}$ (kG)		
Full rudder deflection at V_A	Stiff control circuit	Elastic control circuit	Elastic control circuit and elastic fuselage
	± 238	± 160	± 152.4

CONCLUSIONS

When the glider under calculation is assumed to be an elastic body there are some possibilities of alleviating the loadings at some critical conditions. The distortion of the structure changing the incidence of the
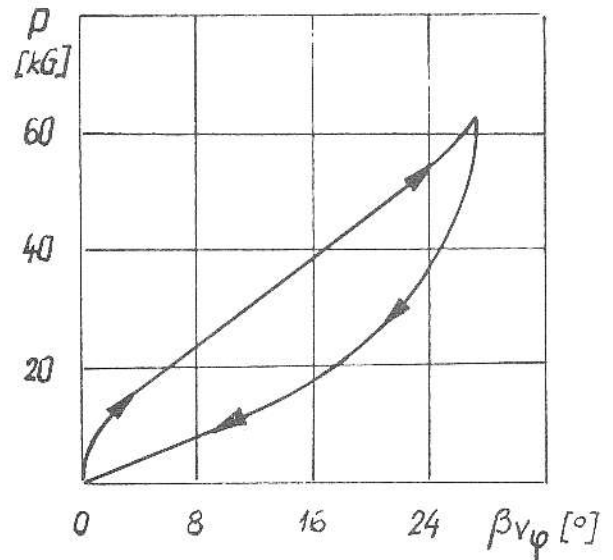

FIGURE 6.   Elastic rudder distortion under hinge moment loading.

control surfaces or absorbing a portion of the energy allows for decrement of the loading values.

The maneuvering loadings, especially on the control surfaces, are considerably alleviated due to the elasticity of the control circuit elements. Such a calculation allows for the design reduction of the glider mass as far as possible.