From time to time, *Technical Soaring* will reprint significant papers from the past. These papers are still very relevant, but may have never been seen by some of our newer readers, or worth revisiting by those who enjoyed them when they originally appeared. Some of these classics have become hard to find, so we are glad to have the opportunity to make them available once again. It was originally published in *OSTIV Publication XIV* and in *Technical Soaring*, Vol. IV, No. 2.

Alleviating Capabilities of the Sailplane Structure

Wieslaw Stafiej
SIMP S.Z.D.
Bielsko-Biala, Poland

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Introduction

One of the most important requirements to be met in sailplane design is to reduce the structure mass as far as possible. The lower this is, the greater is the total mass variation range for the assumed all-up weight, especially when water ballast is provided.

The dimensions of the elements, and in the consequence the mass, of the primary structure depend on the loads calculated for all the critical flight and ground conditions. The value of these loads results from the prescribed load factors and airspeeds as far as the sailplane is considered as a rigid body. The real structure, however, is elastic depending on the geometry and materials used. Under the action of the loads there appears the 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 of incidence). Both these factors affect the aerodynamic forces or the energy and in the critical loading cases may lead to the 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 eased when the load calculations relate to development of the type, or even to the evolution of a prototype. 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 sailplane considered as an elastic body are discussed in the paper and compared with these obtained for the corresponding rigid body. As an illustration of the problem the results for several Polish sailplanes are shown.

Main Undercarriage

The vertical kinetic energy of the sailplane when landing depends on the sinking speed value (V_s) prescribed by the Requirements:

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

where: m_{red} is the reduced mass of the glider due to the eccentric impact. This energy is to be absorbed by tyre, tube and (if used) shock absorbing element. The absorbed energy:

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

where R_W is the ground reaction on the wheel and h is the resultant glider c.g. displacement depending on the tyre, tube and shock absorbing element characteristics. Since the kinetic and absorbed energies must be equal, the ground reaction for the rigid structure can be determined:

$$E_K = E_A = m_{red}\frac{V_s^2}{2} = \frac{1}{2}R_W h$$

$$R_W = \frac{m_{red}V_s^2}{h}$$

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 sailplane design it is necessary to define the stiffness of at least the fuselage and the wing to obtain the data for flutter criteria calculation. These data enable the structure deflection, arising under the action of the mass forces in respect to the load factor, to be determined:

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

where n is the load factor for landing condition and W is the all-up weight of the sailplane

By replacing the distributed mass of the fuselage and wing by a system of concentrated masses one can determine the deflection lines (Fig. 1). The energy absorbed for the structural distortion is:

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

where P_i is the concentrated mass force and f_i is the structure displacement at the station at which P_i acts.

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

$$E_K - E_D = E_A$$

For the SZD-38A JANTAR 1 the distortion energy is E_D equals 8,1 kGm and taking this into account results in the ground reaction being reduced to the value R_W equals 1310 kG. Thus elastic structure considerations reduce the ground reaction by ΔR_W equalling 1470 minus 1310 or 160 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 for the motor glider SZD-45 OGAR gives the result: the tail skid load R_{wt} of 211 kG.

The rear fuselage of the SZD-45 OGAR was designed in the form of the slender conical duralumin tube. Such a structure is a good shock absorber. The tail skid ground reaction calculated with respect to the elastic rear fuselage is R_{wt} equals 127 kG. The load reduction is thus ΔR_w equals 211minus 127 or 84 kG. The alleviating capability of the OGAR's fuselage is rather high, but nearly all the modern glass-fibre sailplanes have the slender rear fuselage tubes with extremely small cross section, producing very elastic structure.

Aileron

On sailplanes of the normal (utility) category the critical aileron loading appears in the most cases for the full down deflection of the aileron at the speed V_A, or for one third of full down deflection at the speed 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 rigid wing by means of the formula:

$$p_3 = \frac{q}{\tau}\left[\left(11\frac{dC_L}{d\alpha}\alpha + 60C_{m_{ac}}\right)\frac{\tau}{8} + (2\tau - 0.5)\frac{\partial C_Z}{\partial \beta}\beta_A + 6\frac{\partial C_m}{\partial \beta}\beta_A\right]$$

where: q = dynamic pressure

dCL/dα = wing lift curve slope

α = wing incidence

C_{mac} = moment coefficient in respect of the quarter chord station

τ = aileron to wing chord ratio

$dC_Z/d\beta$ = slope of lift coefficient versus aileron deflection

$dC_m/d\beta$ = slope of the moment coefficient versus aileron deflection

β_A = aileron deflection

The elastic wing under the torsional moment is twisted through an angular distortion:

$$\phi_y = \int_0^y \left(\frac{M_t}{GJ_0}\right)_y dy$$

where the torsional moment M_t and the wing torsional stiffness GJ_0 are functions of the span-wise station y. The incidence of the distorted wing is:

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

and in the consequence the aileron pressure formula is:

$$p_3 = \frac{q}{\tau}\left[\left(11\frac{dC_L}{d\alpha}(\alpha - \phi) + 60C_{m_{ac}}\right)\frac{\tau}{8} + (2\tau - 0.5)\frac{\partial C_L}{\partial \beta}\beta_A + 6\frac{\partial C_m}{\partial \beta}\beta_A\right]$$

Since the distortion angle and the lift distribution are varying with the span station y, the pressure value p3 is a function of aileron span. The results obtained for the aileron of the glider SZD-30 PIRAT are the following:

- for the rigid wing the pressure p3 is 145 kG/m2
- for the elastic wing p3 is 128 kG/m2 where both values are for the case of one third of maximum down deflection of the aileron at speed V_D.

Flap

The flap pressure is calculated in the same way 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 only slight. The results obtained for SZD-38 JANTAR 1 are the following: p_3 equals 25 kG/m2 for the rigid wing and p_3 equals 24,4 kG/m2 for the elastic wing. The elastic effect on the flap loading, thus, is of no importance.

Horizontal Tailplane

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

- full elevator deflection at the speed V_A
- one third of full elevator deflection at the speed 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) so that considerations other than elastic phenomena are involved. Therefore the V_D case is not the interesting one.

The tail load force for trim depends on the no-tail moment coefficient:

$$p_H = -C_{m_{TL}}\frac{AqC_s}{L_H}$$

where: Cm_{TL} = no-tail moment coefficient

A = wing area

q = dynamic pressure

C_s = wing mean standard chord

L_H = tail arm with respect to the c.g.

The tail load for trim is obtained, when the necessary elevator deflection for trim is applied as shown in Fig. 3 where:

α = wing incidence

ε = wing downwash

β_{tr} = elevator angle for trim.

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

The tail load for trim for most sailplanes 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 $\beta_{tr}^* = \beta_{tr} + \Delta\beta_{tr}$. Onto the tail load for trim P_H there is superimposed the increment of load ΔP_H resulting the full deflection of the elevator. The force ΔP_H depends on the elevator deflection increment:

$$\Delta\beta_H^* = \beta_{H_{max}} - \beta_{trim}^*$$

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

The fuselage bending elasticity is however not the governing alleviating influence. The elevator deflections are produced by means of the control circuit from the pilot's hand-grip to the control surface. The appropriate elements of the control circuit also suffer strain due to the stresses arising in them. Likewise the brackets and the structure elements to which they are attached become distorted. It is, of course, nearly impossible to calculate these strains, but generalised data are available based on stiffness ground tests.

Special measurements have been carried out on the motor sailplane SZD-45 OGAR. The force P necessary for the elevator deflection $\beta_{H\varphi}$, when the stick in the cockpit was held against the stops, was measured (Fig. 5). The force P was applied at a distance of $1/3\ \tau \cdot l$ aft of the hinge, reproducing a hinge moment of:

$$M_H = \frac{1}{3} P \tau l$$

necessary to balance the strain effect of the system. The hysteresis on the diagram results from system friction. The resultant elevator deflection increment is:

$$\Delta\beta_H = \beta_{H_{max}} - \beta_{trim}^* - \beta_{H\phi}$$

The calculation requires the step by step method because the angles $\Delta\beta_H$ and $\beta_{H\varphi}$ depend on one another. The resultant tail load increment is then:

$$\Delta P_H = \frac{\partial C_{L_H}}{\partial \alpha_H} \cdot \frac{\partial \alpha_H}{\partial \beta_H} \cdot \Delta\beta_H q A_H$$

where:

$$\frac{\partial C_{L_H}}{\partial \alpha_H}$$

equals the slope of the tailplane lift curve and

$$\frac{\partial \alpha_H}{\partial \beta_H}$$

equals the effective change of the tailplane incidence with elevator deflection while

$$A_H$$

represents the tailplane area. The resultant tail load is given by

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

where P_{mass} is the inertia force depending on the tailplane mass and the acceleration produced by the tail load increment ΔP_H. The results for the motor sailplane SZD-45 OGAR are listed in Table 1. It is seen that for upward deflection the control circuit and fuselage elasticities are equally important, whereas for downward deflection the circuit elasticity is the one which matters, since that of the fuselage has very little effect.

Fin and Rudder

For the fin and rudder loadings the same considerations apply as for the horizontal tailplane, except that the load for trim for the vertical tailplane is zero. The elastic rudder control circuit etc. distortion under rudder side load has been measured for SZD-45 OGAR motor sailplane in the same manner as on the elevator. The results are shown on Fig. 6 where the distortion angle is $\beta_{V\varphi}$. The fin and rudder loads for the SZD-45 OGAR for the rigid and elastic control circuit and fuselage rear part are listed Table 2. It is seen that the control circuit elasticity is important, but the fuselage elasticity is not.

Conclusions

When the elasticity of the sailplane under investigation is taken into account there is some alleviation of the loads at critical conditions. The distortion of the structure changing the incidence of the control surfaces or absorbing a portion of the energy results in a decrement of the load values. In particular the maneuvering loads on the control surfaces are considerably alleviated as a result of the elasticity of the control circuit elements. Such an investigation, thus, permits some reduction in the mass of the sailplane.

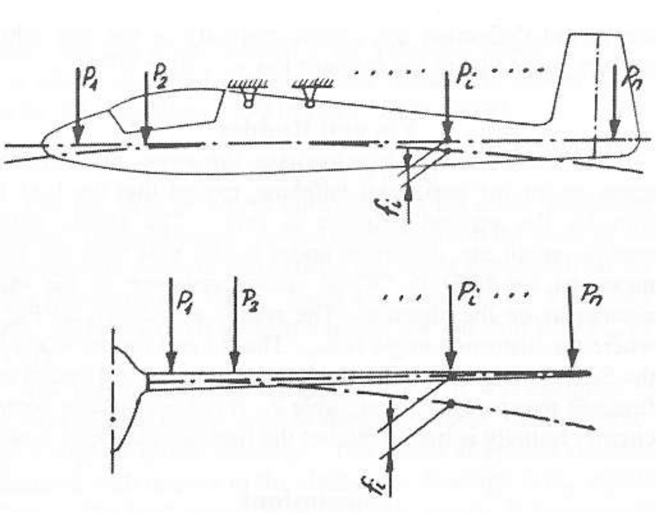

Figure 1

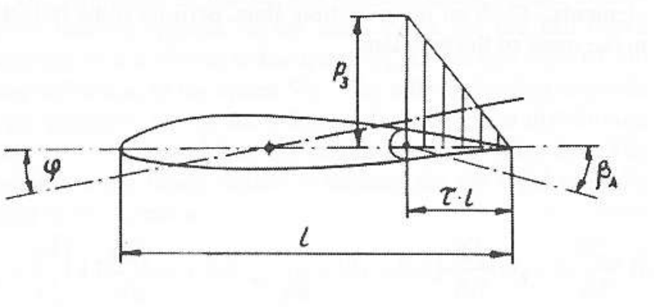

Figure 2

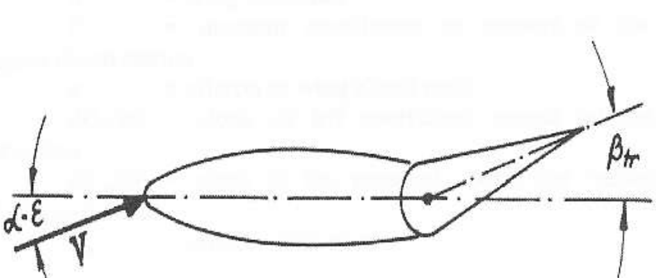

Figure 3

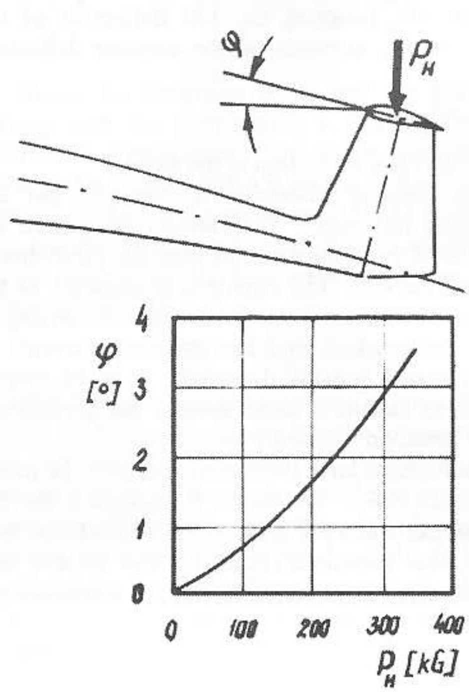

Figure 4

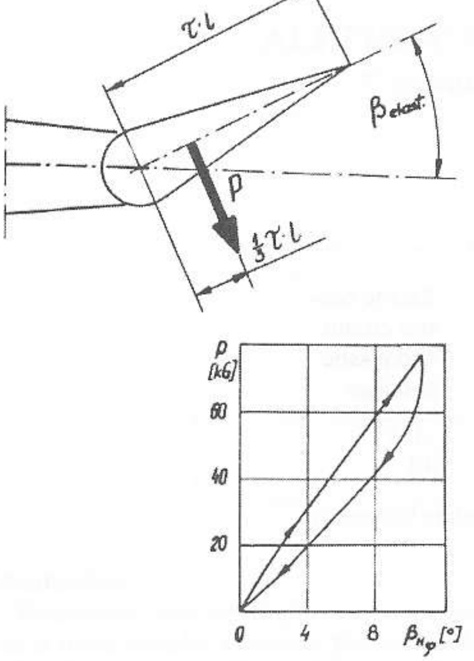

Figure 5

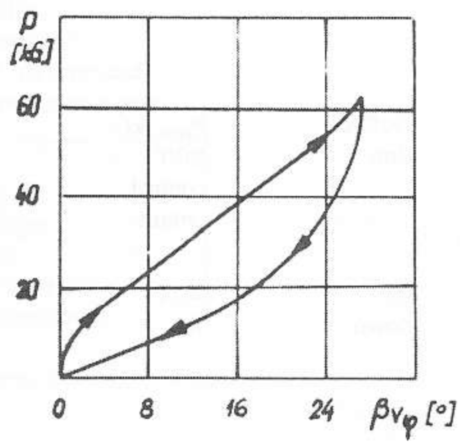

Figure 6

Table 1

Deflection	P_{Hres} /kG/		
	Stiff control circuit	Elastic control circuit	Elastic control circuit and elastic fuselage
up down	-424 76	-372 45	-325 40

Table 2

	P_{Vres} /kG/		
Full rudder deflection at V_A	Stiff control circuit	Elastic control circuit	Elastic control circuit and elastic fuselage
	±238	±160	±152