Loading Consequences of the Wing Upper Surface Air Brake

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1. Introduction
The continuous trend to improve sailplane performance leads to new design conceptions aimed at reducing drag as far as possible. It is well known that competing pilots seal all the slots and grooves on the external surfaces of the ship to avoid any leakage in the air flow and to preserve the "healthful" stream over the surfaces of the sailplane and especially on the wing. The slots or grooves produce discontinuities of the aerofoil contour, so contributing extra drag as a result of "turbulization" of the flow.
The air brake housing slots appear to be one distinct source of the wing flow turbulization. They destroy the stream continuity along the chord on the length of air brake span.
Where the conventional air brake has been used the upper and lower plates, in the extended position, produce flow disturbance over both upper and lower wing surfaces giving the desired drag effect. On the other hand when the air brake is retracted the slots on the wing surface cannot be avoided and the glider performance is spoiled.
To reduce this disadvantage the idea of utilising the upper-surface-only air brake has been realized (Fig. 1). This concept offers the following improvements:
- wing surface is spoiled on the upper side only,
- braking efficiency does not suffer appreciably when compared with the conventional upper and lower surface air brake,
- production of the wing is simplified (only one air brake plate, and simple single plate housing box).

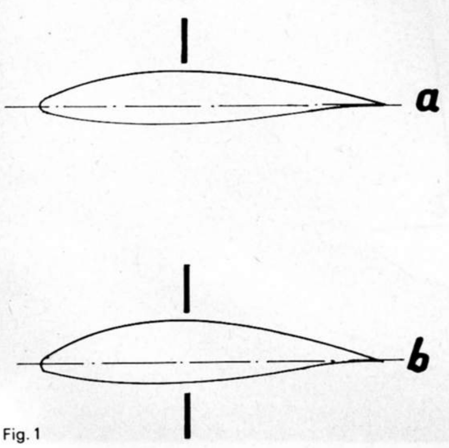


Fig. 1

2. Aerodynamics
Wind tunnel characteristics of the aerofoil FX 67 K-170 for the various positions of the air brake with respect to the chord have been measured at Stuttgart University. Fig. 2 shows the

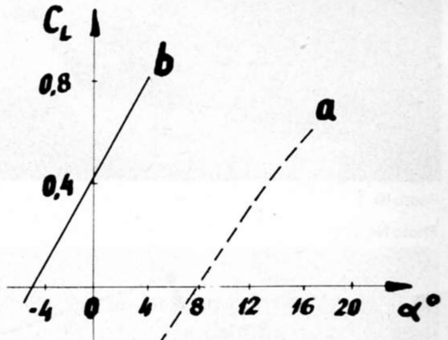


Fig. 2

lift versus incidence characteristics for the smooth and air braked aerofoil, with the air brake on the upper surface only. Line "a" is for the air brake extended configuration, line "b" the smooth aerofoil. The measured air brake had the following characteristics:
- air brake position: 60 per cent of chord
- air brake plate height: 11.4 per cent of chord
- slot between the wing surface and air brake lower edge: 3.6 per cent of chord

The most important changes introduced into the aerofoil lift characteristics as a consquence of the air brake extended on upper surface only are:
- small change in the slope of the lift-line: dC_L/di
- large change in the "zero lift" angle.

Obviously the braking efficiency of the upper surface air brake must be lower than that of a conventional upper and lower plate arrangement having plates of the same size. To define this efficiency a series of flight measurements on SZD-42 "JANTAR 2" sailplane was performed. The lower air brake plates were removed, the slots sealed and smoothed. The results of the measurements for the airspeed range of 90–110 km/h are plotted on the speed polar diagram (Fig. 3). Line "a" concerns the smooth wing (brakes closed) configuration, line "b" the upper surface air brake extended and line "c" the conventional upper and lower surface air brake extended.

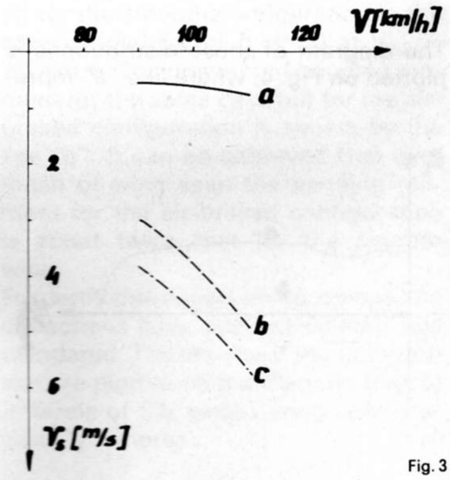


Fig. 3

While the line "b" shows smaller effectiveness of the air braking than line "c", this effectiveness appeared quite sufficient to ensure the safe approach and landing of "JANTAR 2".
During these flight tests it has been observed that wing tip deflections were moderate at an airspeed of 150 km/h but abnormally great at V_{NE} = 250 km/h. The tests were performed with the assistance of the towing aeroplane, which after releasing the towing rope flew side by side with the sailplane; a portable television camera was used to record the picture. The magnetovision recording tape was played-back on the ground using a simple television monitor screen. The screen pictures were then photographed. The photos, while not sharp,

illustrate clearly the different deflections. The wing bending deflection at the airspeed of 150 km/h is shown on photo Nr 1 and at V_{NE} = 250 km/h on photo Nr 2 and 3.
Such a great wing deflection at V_{NE} = 250 km/h should be subjected to closer analysis to gain an opinion on the wing structure safety properties.

3. Load Distribution along the Span
The lift coefficient distribution along the wing span consists of two components:

- normal lift coefficient distribution being the function of the incidence;
- "zero lift" coefficient distribution arising from the aerodynamic twist introduced, in effect, by the extended air brake, being independent of the incidence.

The diagram of those distributions is plotted on Fig. 4, where line "a" repre-

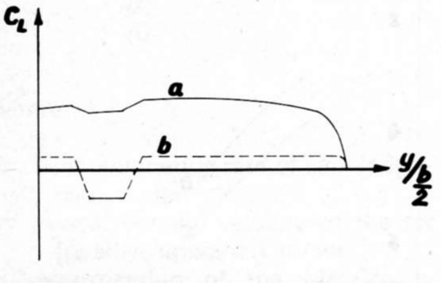


Fig. 4

sents the normal and line "b" the "zero lift" distribution versus semispan station "y/b/2". Both the lines are hollowed in the air brake span region.
The influence of the "zero lift" distribution increases when the incidence decreases i.e. the airspeed increases. This fact is illustrated by Fig. 5, by which shows lift coefficient distributions for the "JANTAR 2" sailplane (flight without water ballast) for total lift coefficient C_L = 0,105 and load factor n = 1,0 (straight glide) at V_{NE} = 250 km/h. Line "a" represents the normal and line "b" the "zero lift" distributions.
For analysis purposes the most interesting is the comparison of the resultant lift distributions (normal + zero) for the smooth and air brake extended configurations (Fig. 6). This diagram yields the following observations:

- for the smooth wing configuration (line "a") the lift distribution is nearly constant along the wing semispan,

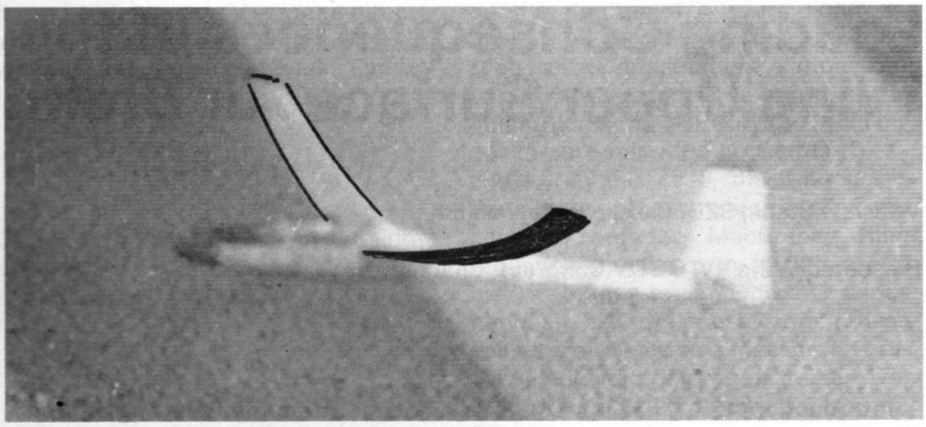


Photo Nr. 1

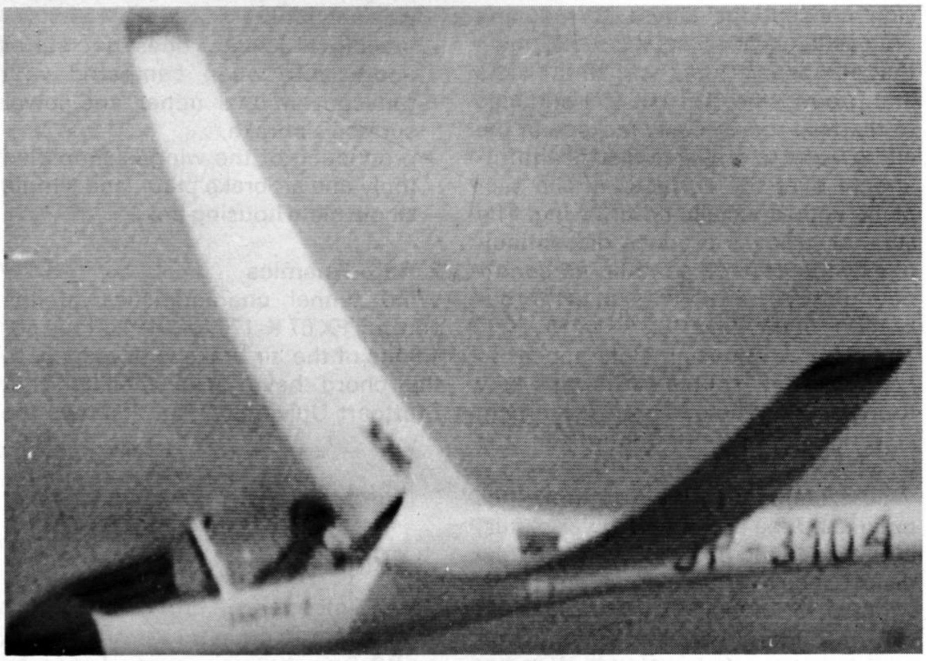
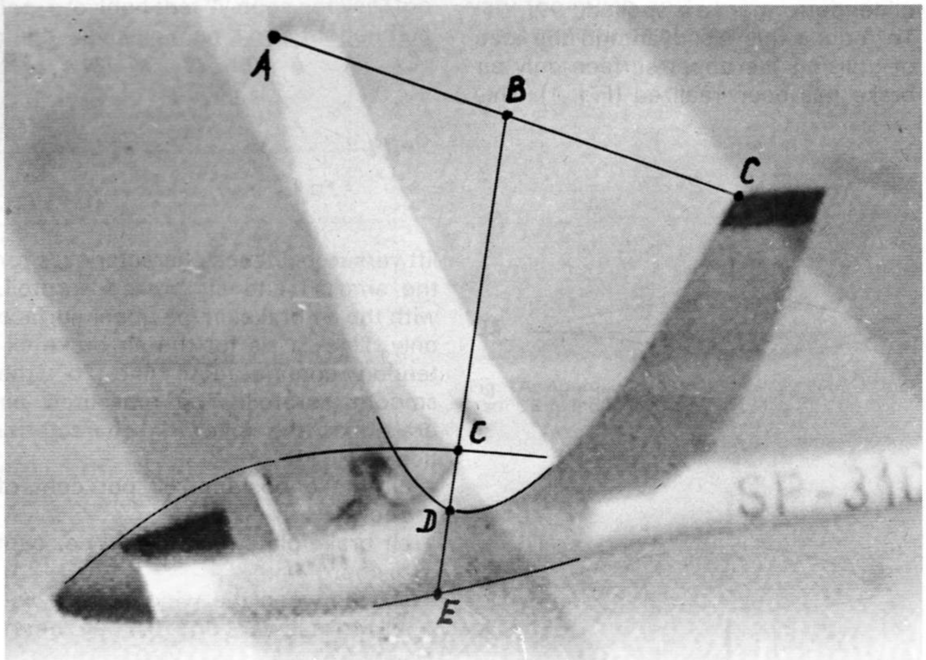


Photo Nr. 2

Photo Nr. 3



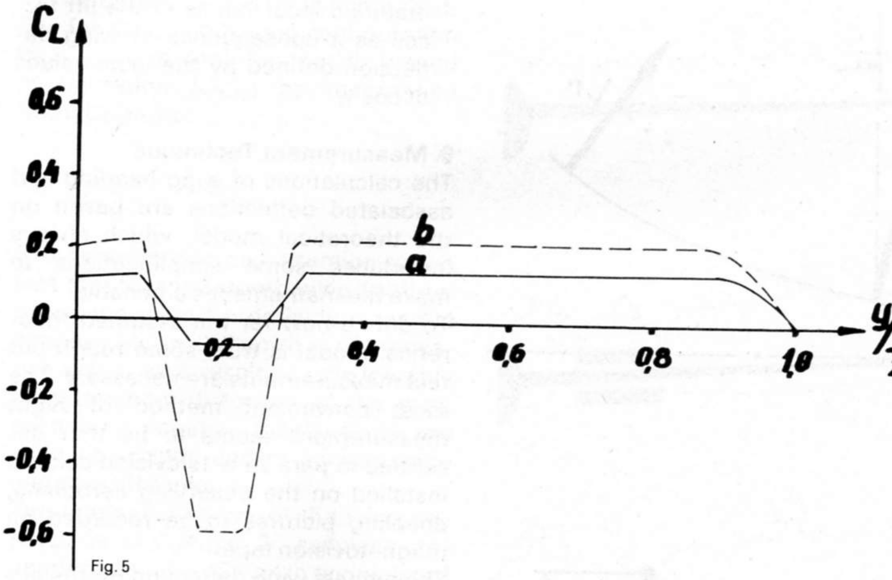


Fig. 5

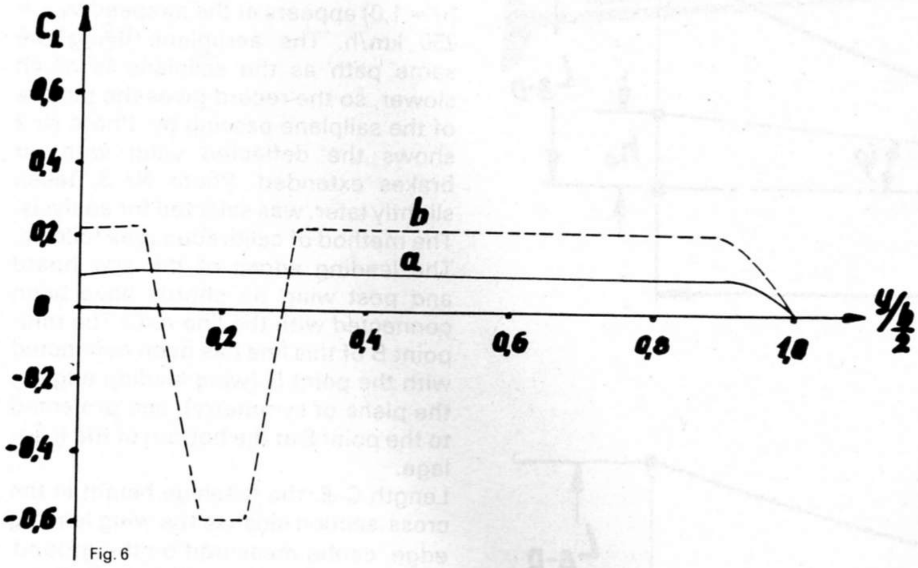


Fig. 6

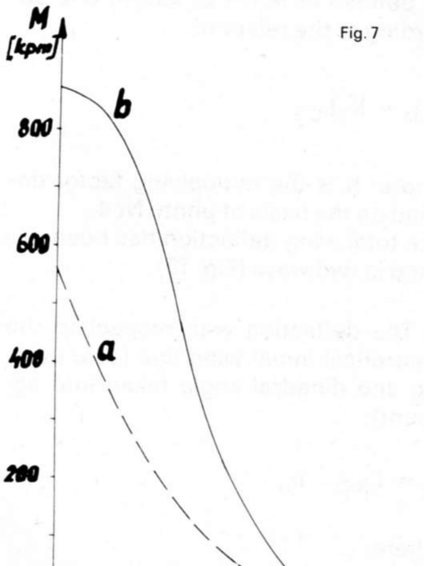


Fig. 7

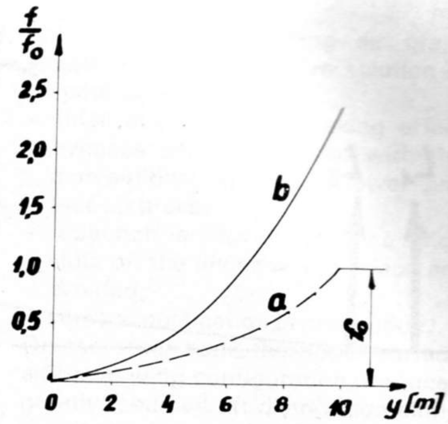


Fig. 8

- for the air braked configuration (line "b") the lift distribution is considerably hollowed at the air brake region and reaches a negative value,
- on the outer wing part the lift coefficient for the air-braked configuration is higher than for the smooth one,
- the total lift of the smooth and air-braked wing must be the same,
- the hollowed lift coeficient distribution due to the air brake extended modifies the distribution of bending moment and shearing force of the wing.

4. Wing Loading

The above-described lift coefficient distributions along the wing semispan involve considerable increases in the wing loads calculated for the smooth and air-braked configurations. The diagram "a" (Fig. 7) shows the bending moment of "JANTAR 2" wing calculated for the smooth configuration in the case of load factor n = 1,0 at V_{NE} = 250 km/h. The diagram of bending moment for the same case but for the air-braked configuration is shown by the line "b". It can be observed that over much of wing span the bending moment for the air-braked configuration is about twice that for the smooth wing.

For both the wing configurations the deflections have been calculated and compared. The results of the comparison are plotted on the diagram (Fig. 8) in terms of f/f_0 versus wing span stations "y" where:

f – wing deflection for the air braked configuration

f_0 – wing tip deflection for the smooth configuration.

5. Strength Consequences

Following the Airworthiness Requirements it is prescribed to calculate the wing loadings for the case of load factor n = 0 to 3,5 at V_{NE} airspeed for the air brake extended configuration. Referring to Fig. 7 the case of loading at n = 0 to 3,5 may be the critical one when the upper surface air brake has been incorporated.

We are familiar with the fact that the critical wing strength station appears usually in the vicinity of the spar root, whereas the wing tip part is rather overdimensioned as to the strength, since stiffness considerations define here the necessary spar cross section. On wings having only upper surface air brakes the wing tip must be analyzed in respect of strength as well as the medium span stations.

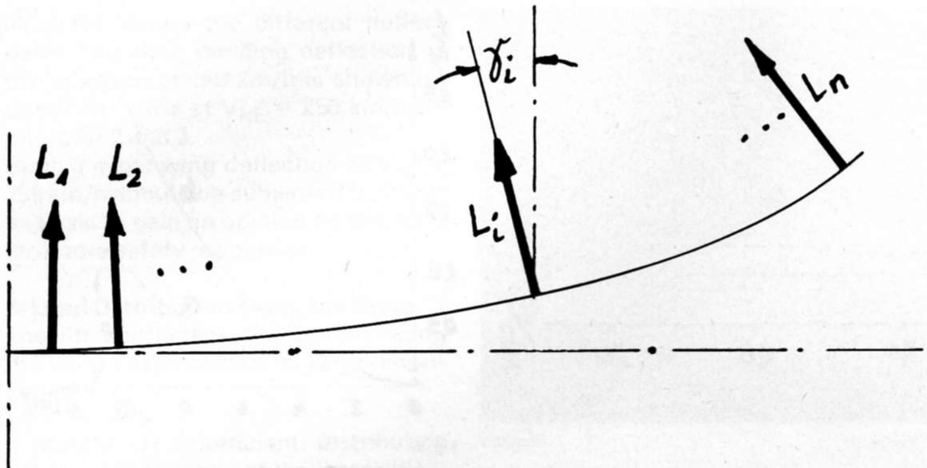
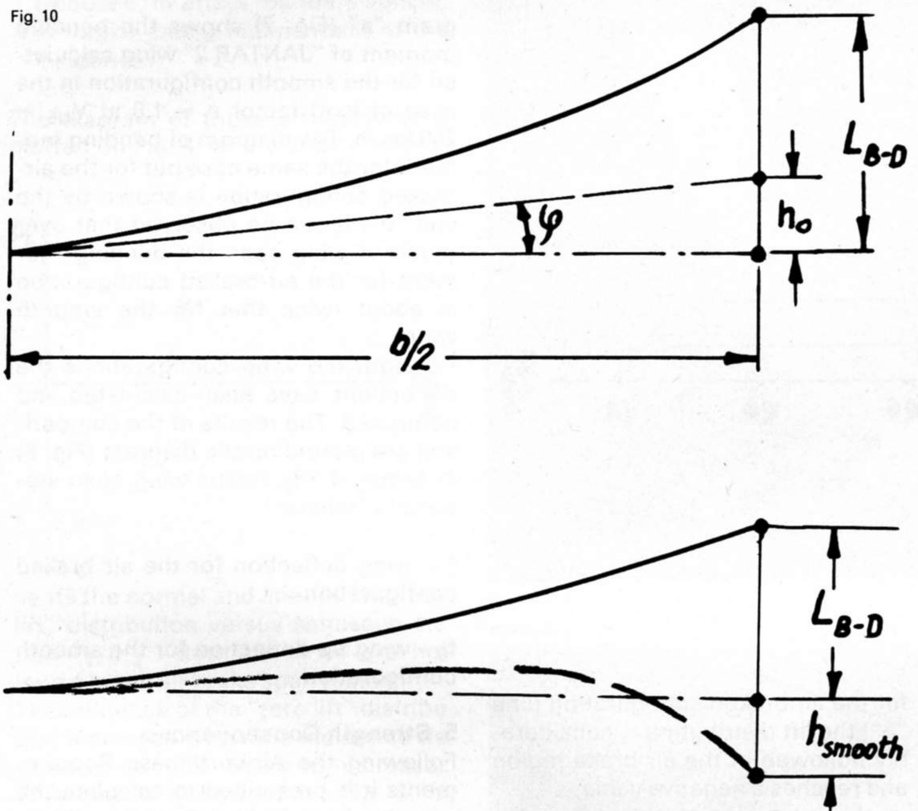


Fig. 9

Fig. 10



Moreover the high wing deflections lower the total lift (Fig. 9). For the stiff wing (no deflection exists) the total lift is:

$$L_{tot} = \sum_{i=1}^{n} L_i$$

In the case the wing suffers the deflection the total lift is:

$$L_{tot} = \sum_{i=1}^{n} L_i \cdot \cos\gamma_i$$

To satisfy the equilibrium equations of lift force and sailplane weight "W", being:

$$L_{tot} = W$$

the value of the L_i force for the deflected wing must be higher than for the stiff one, depending on the local value of "$\cos \gamma_i$".

When performing the structural analysis of the wing with upper surface air brake it is necessary to consider:

- modified lift distribution along the wing span
- modified local values of the lift forces as a consequence of wing deflection defined by the local values of $\cos \gamma_i$.

6. Measurement Technique

The calculations of wing bending and associated deflections are based on the theoretical model, which always introduces some simplifications to make the mathematics amenable.

To define how far the assumed theoretical model is true, some rough but real measurements are necessary. The most convenient method of flight measurement seems to be that described in para 2 i.e. television camera installed on the observing aeroplane, enabling pictures to be recorded on magnetovision tape.

The highest wing deflection for the airbraked configuration and steady flight ($n = 1{,}0$) appears at the airspeed V_{NE} = 250 km/h. The aeroplane flying the same path as the sailplane is much slower, so the record gives the picture of the sailplane passing by. Photo Nr 2 shows the deflected wing with air brakes extended. Photo Nr 3, taken slightly later, was selected for analysis.

The method of calibration is as follows. The leading edges of the star board and post wing tip chords have been connected with the line A–C. The midpoint B of this line has been connected with the point D (wing leading edge in the plane of symmetry), and projected to the point E at the bottom of the fuselage.

Length C–E, the fuselage height in the cross-section close to the wing leading edge, canbe measured on the ground. The full-scale wing deflection B–D can be defined in terms of length C–E according to the relation:

$$L_{B-D} = K \cdot L_{C-E}$$

where: K is the multiplying factor defined on the basis of photo Nr 4.

The total wing deflection has been defined in two ways (Fig. 10):

1) The deflection with respect to the theoretical initial wing line (zero loading and dihedral angle taken into account):

$$h_1 = L_{B-D} - h_o$$

where:

$h_o = b/2 \cdot \mathrm{tg}\varphi$

φ – dihedral angle

2) The difference between the deflection for the smooth wing configuration (h_{smooth}) and that for the air-braked configuration (L_{B-D}) as determined from the photo:

$$h_2 = L_{B-D} - h_{smooth}$$

It is necessary to pay attention to the fact that for the smooth wing configuration the wing tip deflection for the airspeed V_{NE} = 250 km/h is of a negative value, as a result of considerably high torsional distortion of the wing producing negative incidence in the wing tip vicinity and in consequence negative lift force.
The numerical values of the wing deflections of "Jantar 2" sailplane appearing at V_{NE} = 250 km/h and defined using both the above methods were:

h_1 = 1,9 m
h_2 = 2,2 m.

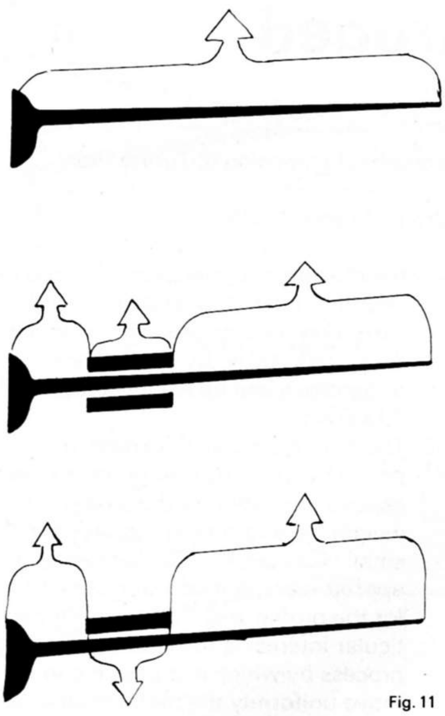


Fig. 11

7. Conclusions

The upper surface wing air brake seems to be an attractive solution in respect to its advantages:

- small decrement of braking effectiveness when compared with the conventional, upper and lower surface air brake,
- reduction in flow disturbance since slots on the lower wing surface are avoided,
- some simplification in production.

On the other hand the upper surface air brake wing configuration produces greatly modified lift distribution along the span when compared with that of the smooth wing configuration. This modification leads to very serious increment of wing loadings (Fig. 11).
Before the application of the upper surface air brake is decided, close calculation of loadings and structural analysis should be performed to be sure that the required safety level of the wing structure is maintained.