Loadings and Flight Limitations of the Sailplane having the Speed Flap

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1. Introduction

Most of the modern open-class sailplanes use wing flaps which can be deflected both downwards and upwards. Such an arrangement improves the performances at both low and high speeds.

This kind of flap produces variations in aerodynamic characteristics of the basic aerofil. It also complicates loading calculations.

In the last edition of OSTIV Requirements (Sept. 1971) the up-moving–flapped–wing problem is met only by paragraph 3.322, a general statement to the effect that manoeuvre and gust cases must be met at all appropriate flap position.

Each glider has its flight limitations established on the basis of loading and strength analysis as well as on the results of ground and flight tests. The designer's aim is to establish these limitations so as to ensure the safe operation of the aircraft while at the same time utilising as widely as possible the actual strength properties of the structure, to obtain the best competition capabilities of the sailplane.

The loadings of the flapped-wing sailplane are different from those for the unflapped aerofoil wing. The particular loading problems are presented in this paper.

2. Aerodynamic Properties of the Flapped Wing

The wing flap deflected downwards and upwards changes the characteristics C_L versus C_D and C_L versus incidence. Fig. 1 shows these characteristics in the case of the Wortmann profile FX-67-K-170 for the three flap positions: +8°, 0°, −8°. It will be noted that each flap deflection produces a different value of C_{Lmax} and C_{Dmin} and these figures are the deciding ones in the calculations of the basic airspeeds, i. e. stalling speed and design diving speed. In the case shown the C_L versus incidence line has different slopes for the different flap positions. On the real glider the flap is deflected in a continuous or stepped manner giving an envelope of characteristics. From the loading and limitations point of view it is necessary to take into account at least the basic (neutral) and two limit (maximum downwards or positive and maximum upwards or negative) flap positions.

The basic aerodynamic data for loading calculations for some flapped-wing sailplanes designed in Poland are presented in table I.

3. Manoeuvring Loads

The basic airspeeds for the manoeuvring envelope calculations are:

stalling speed:

$$V_s = \sqrt{\frac{2\,W}{\varrho\, A\, C_{Lmax}}}$$

where: W = weight of the sailplane
A = wing area
ϱ = air density
C_{Lmax} = max. lift coefficient

design diving speed:

$$V_D = 18\sqrt[3]{\frac{W}{A\, C_{Dmin}}}$$

where: C_{Dmin} = minimum drag coefficient of the glider

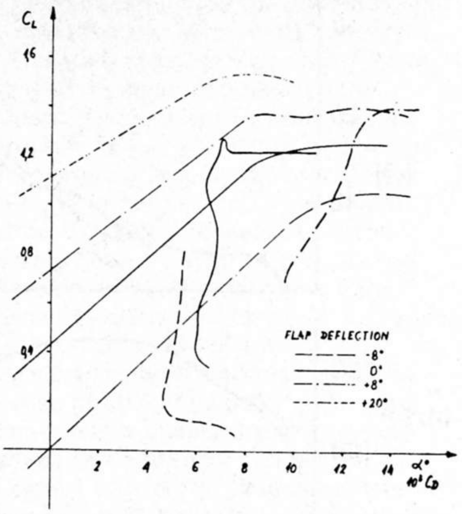

Fig. 1: Characteristics of FX-67-K-170 .

design manoeuvring speed:

$$V_M = V_s\sqrt{n_1}$$

where: n_1 = prescribed load factor appropriate to the sailplane category.

Following the OSTIV Requirements there are three methods of loading calculation philosophy.

3.1. Fixed Load Factor Method

To satisfy paragraph 3.322 of the OSTIV requirements it is necessary to calculate the design manoeuvring speed for each flap position from the formula:

$$V_M = V_s\sqrt{n_1}$$

where the stalling speed V_s depends on the C_{Lmax} for the actual flap de-

Tab I. AEROD. DATA OF SAILPLANES

SAILPLANE	WING SECTION	SPAN [m]	FLAP DEFL [°]	$C_{L\,max}$	$C_{L\,min}$	$C_{D\,min}$	$\frac{dC_L}{di}$
SZD-37x JANTAR	FX-67-K-170 FX-67-K-150	17,5	+8	1,39	-0,66	0,0195	4,72
			0	1,25	-0,8	0,014	5,14
			-8	1,05	-1,0	0,011	5,40
SZD-38 JANTAR-1	–"–	19	+8	1,395	-0,66	0,015	4,71
			0	1,255	-0,8	0,010	5,21
			-8	1,045	-1,0	0,0075	5,44
SZD-40x HALNY	NACA 66(215)416 modified to NN-MM	20	+7	1,49	-0,512	0,0166	6,56
			0	1,20	-0,8	0,014	6,36
			-7	0,92	-1,088	0,0117	6,35

flection. This calculation satisfies the philosophy that the design manoeuvring speed is the speed at which the sailplane stalls at load factor n_1.

The design diving speed:

$$V_D = 18 \sqrt[3]{\frac{W}{A\, C_{Dmin}}}$$

depends on the C_{Dmin} for the actual flap deflection and reflects the acceleration capability of the aircraft determined by its aerodynamic properties. Such an interpretation of the manoeuvring envelope (fig. 2) produces considerable difficulty in the selection of the critical loading cases as well as in establishing the flight limitations. Each flap position has its own manoeuvring speed and diving speed. It would be necessary to put the placards in the form of a table where the limitations depend on the flap position. However, such complication cannot be accepted even by the very experienced pilot.

The above method of calculation has been employed for the Polish flapped-wing two-seater SZD-40x 'Halny', the manoeuvring envelope of which is shown on fig. 3. Use of the downward flap deflection has been restricted to landing and circling, and therefore the maximum design airspeed for flaps down is considerably lower than V_M for flaps neutral or up. The design diving speed has been limited for flutter reasons on the basis of flight test results on another sailplane having a similar wing structure.

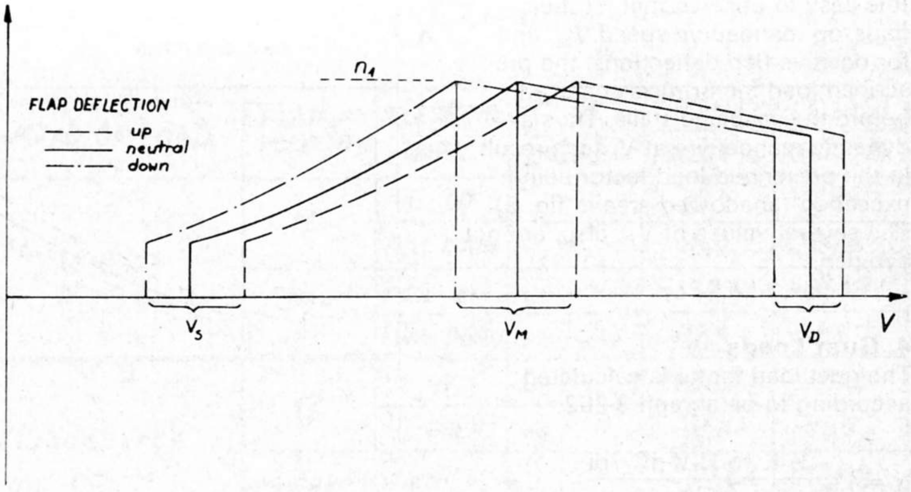

Fig. 2: Fixed load factor method.

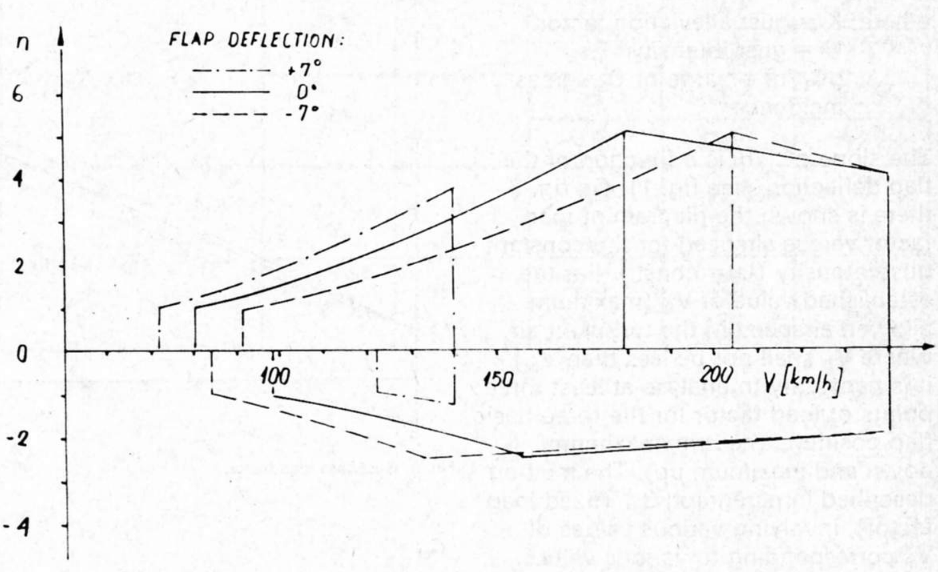

Fig. 3: Fixed load factor method applied to 'Halny'.

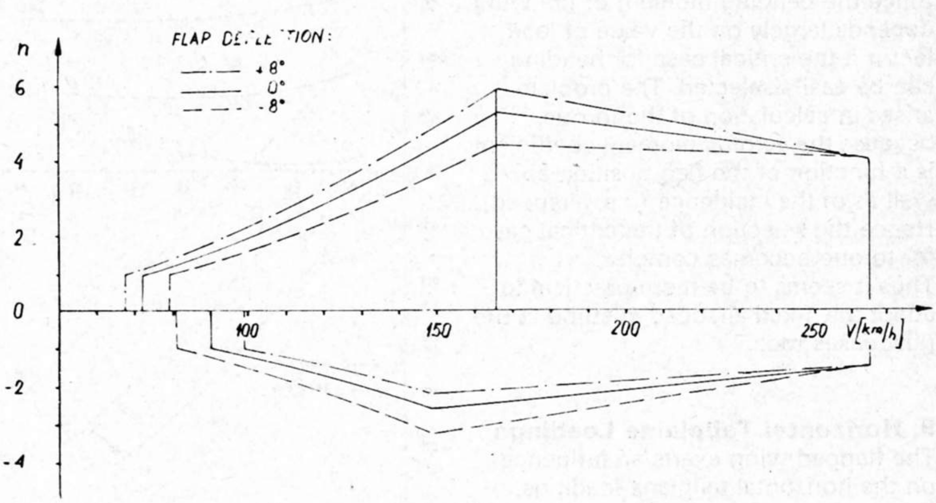

Fig. 4: Fixed airspeed method applied to 'Jantar 1'

3.2. Fixed Airspeed Method

It seems to be more practical to follow paragraphs 3.241 and 3.246 of OSTIV requirements, which prescribe design manoeuvring and during speeds, taking into account the values of C_{Lmax} and C_{Dmin} for the neutral flap. Then there is obtained only one fixed value of manoeuvring speed and one fixed value of the diving speed. This, however, would not enable paragraph 3.322 to be satisfied. Following the fact that at the design manoeuvring speed the sailplane stalls at load factor $n = n_1$ with flap neutral, it must stall at factor $n > n_1$ for flap down and $n < n_1$ for flap up. The design diving speed is calculated for the C_{Dmin} value of the sailplane with the neutral flap. In this case it is necessary to reconsider the V_D-value philosophy, but in most cases the certification limitation on V_{NE} results from handling properties, stability, flutter or other flight reasons. This method of calculation gives a great benefit in structural analysis as well as in establishing flight limitations. There is only one speed V_M and one speed V_D which can be easily remembered by the pilot. This simplification is paid for by the slightly greater value of maximum load factor and the consequent increase in strength and weight of the structure.

The envelope for the SZD-38 'Jantar 1' sailplane, determined in this manner, is shown in fig. 4.

3.3. Mixed Method

Simultaneous satisfying of paragraphs 3.241, 3.246 and 3.322 of OSTIV requirements leads to the envelope shape shown on fig. 5.

It is easy to observe that, at the flaps-up manoeuvre speed V_M, and for positive flap deflections, the prescribed load factor n_1 is achieved before the sailplane stalls. Thus a dynamic manoeuvre at V_M can result in the prescribed load factor being exceeded (shadowed area in fig. 5). The several values of V_D, also, are not avoided.

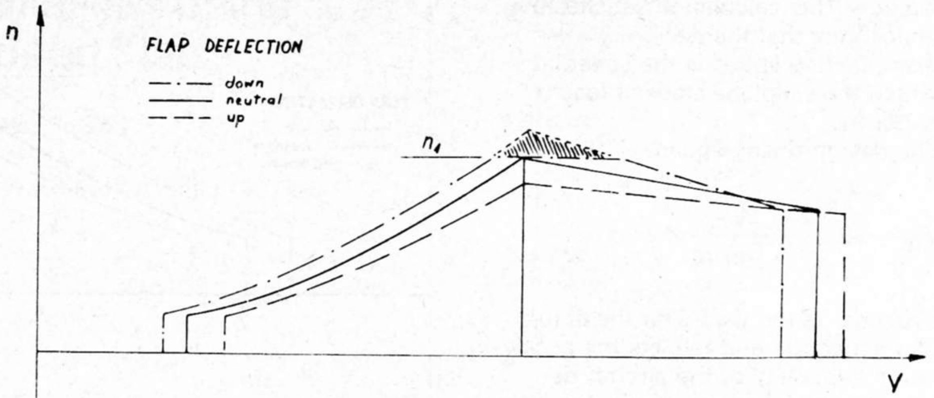

Fig. 5: Mixed method

4. Gust Loads

The gust load factor is calculated according to paragraph 3.262:

$$n = 1 \pm \frac{\frac{1}{2} K \varrho o\, U\, V\, dC_L/di}{\frac{W}{A}}$$

where: K = gust alleviation factor
U = gust intensity
dC_L/di = slope of C_L versus incidence

The slope dC_L/di is a function of the flap deflection (see fig. 1). On fig. 6 there is shown the diagram of load factor versus airspeed for the constant gust intensity (U = const.). For the established value of V_B (maximum allowed airspeed in the turbulent air, where V_B shall not be less than V_M) it is necessary to analyse at least three points of load factor for the three basic flap positions (neutral, maximum down and maximum up). The method described in paragraph 3.1 (fixed load factor), involving various values of V_B corresponding to various values of V_M, will give an untidy range of loading points.
Since the bending moment of the wing depends largely on the value of load factor n the critical case for bending can be easily selected. The problem arises in calculation of the torque, because the aerofoil moment coefficient is a function of the flap position as well as of the incidence (i. e. airspeed). Hence the selection of the critical case for torque becomes complex.
Thus it seems to be more practical to adapt the 'fixed airspeed' method in the gust cases too.

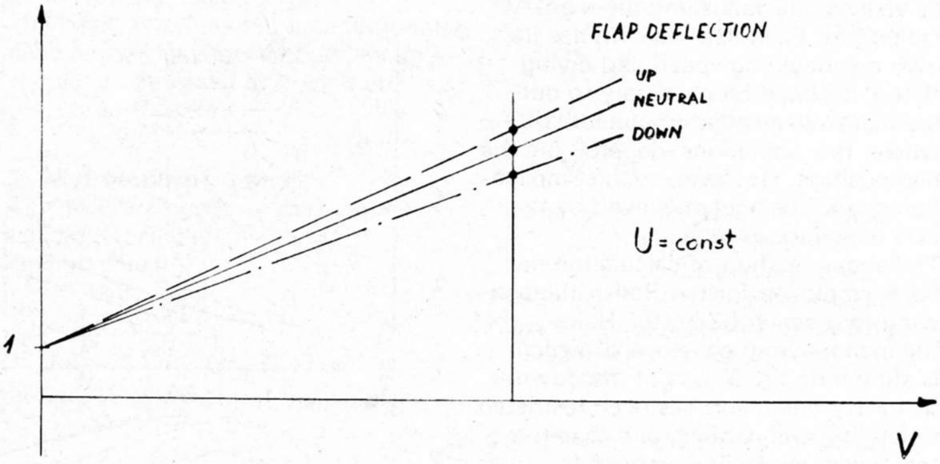

Fig. 6: Gust case load factor.

5. Horizontal Tailplaine Loadings

The flapped wing exerts an influence on the horizontal tailplane loadings. The no-tail moment coefficient, as well as the elevator deflection for trim, depend considerably on the flap configuration. To illustrate this influence are shown the no-tail moment coefficient (fig. 7) and elevator deflection for trim (fig. 8) for the sailplane SZD-38 'Jantar 1'. The solid lines concern the front and dashed lines the rear C. G. position. The curves for neutral and limiting flap deflections are shown.

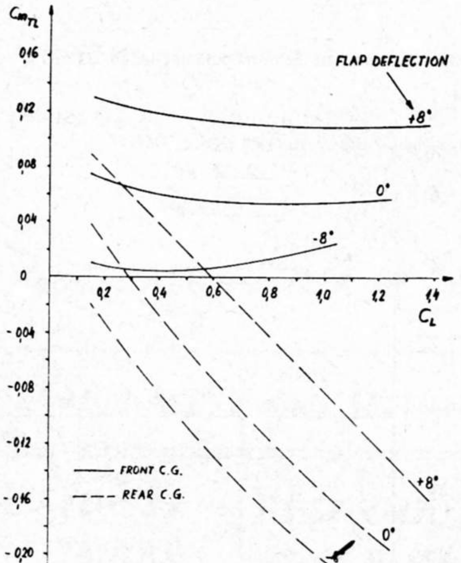

Fig. 7: No-tail pitching moment, 'Jantar 1'.

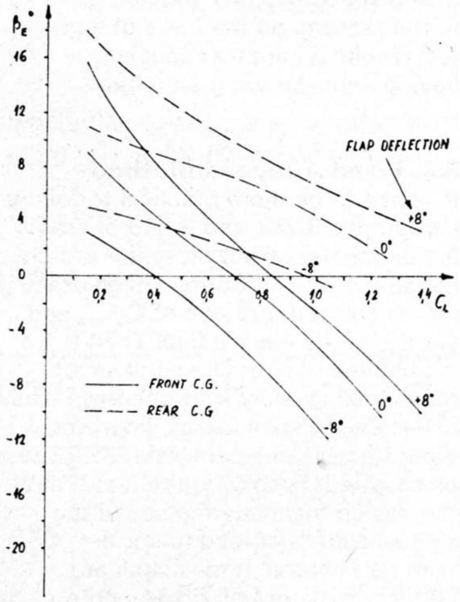

Fig. 8: Elevator angle to trim, 'Jantar 1'.

The calculation of the tail loads should be carried out for at least three flap deflections. The results of manoeuvre and gust tail load calculations made for the sailplane SZD-40x 'Halny' are shown in table II. In this case only neutral and upward flap positions are included because the downward flap deflection was limited to landing and circling.
The values of tail load in comparison with the strength of the tail-unit, can also be a factor in determining the flight limitations.
Ensuring adequate tail strength may result in a heavy tail unit and produce

stability troubles due to the consequent rearward C. G. movement.

6. Conclusions

The flapped wing produces some complications in the calculation of loadings. It seems to be most convenient to calculate the basic airspeeds (V_M and V_D) for the neutral flap position. In consequence it is necessary to determine the load factors n_1 and n_4 for other flap deflections resulting from the aerodynamic properties of the wing. This way leads to simplification of the calculations as well as in establishing flight limitations for the manoeuvring and gust conditions.

It is proposed to develop paragraph 3.322 of OSTIV Requirements using the following wording:

'If high speed flaps are installed the design manoeuvring speed and design diving speed shall be calculated for the neutral flap position. The manoeuvring load factors n_1 and n_4 result from the intersection of the stalling line for the appropriate flap position with the vertical Line of V_M. The manoeuvring load factors n_2 and n_3 shall be established acc. to paragraph 3.251. For the gust loadings the condition of paragraph 3.26 shall be met.

Tab. II SZD-40x TAILPLANE LOADINGS

KIND OF LOAD	FLAP POSITION	ELEVATOR DEFL.	GUST [m/s]	TAILFORCE [kG]	
				FRONT C.G.	REAR C.G
Manoeuvres on V_M	0°	FULL UP	-	-293	-288
		FULL DOWN	-	58,4	54,6
	-7°	FULL UP	-	-336,3	-333,7
		FULL DOWN	-	112,1	116
Manoeuvres on V_D	0°	1/3 UP	-	-290,7	-285,1
		1/3 DOWN	-	-18,3	-9,5
	-7°	1/3 UP	-	-249,8	-232,4
		1/3 DOWN	-	23,9	37,9
Gust on V_B	0°	-	15	54,3	70,4
			-15	-152,5	-129,4
	-7°	-	15	70,3	86,9
			-15	-136,1	-112,8
Gust on V_D	0°	-	7,5	-17,4	17
			-7,5	-172,9	-152,4
	-7°	-	7,5	20	37,4
			-7,5	-135	-112,6