Elevator-Induced Manoeuvring Loads from the Standpoint of Airworthiness Requirements for Sailplanes

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Reference is made to the following previous papers published by the author on the same subject:
1 «On the Dynamic Response of Sailplanes to Longitudinal Manoeuvres» – OSTIV Publication IX;
2 «Tail Loads due to Abrupt Longitudinal Manoeuvres» – OSTIV Publication X.
In the first of these works the following expression was derived for the incremental aerodynamic load on the horizontal tail, produced by an instantaneous elevator deflection:

$$\Delta P = \Delta n\, W \left[\frac{x_{CG}}{l_t} - \frac{S_t}{S}\, \frac{a_t}{a} \left(1 - \frac{d\epsilon}{d\alpha}\right) - \frac{0.613\, S_t\, a_t\, l_t}{W} \right] \qquad (1)$$

(for symbols: see later).
This expression was derived as a particular solution of the classical dynamic equations relating to the abrupt longitudinal manoeuvre of an aircraft, on the basic consideration that the dynamic response of a sailplane is aperiodic or quasi-aperiodic.
The formula shows that $\triangle P$ is independent of the airspeed and simply related to the incremental load factor $\triangle n$, pertinent to the post-manoeuvre steady flight condition, corresponding to the new elevator angle.
The incremental tail loads thus calculated, as those necessary to accelerate the sailplane from an initial flight condition at $n = 1$ to a post-manoeuvre flight condition at n_{lim} (where the n_{lim} values are to be taken from the prefixed design manoeuvre n-V envelope) were proposed to replace the manoeuvring incremental loads specified by the OSTIV Airworthiness Requirements (and other national Reqs.). These requirements, in fact, simply specify an instantaneous elevator deflection:
1. up to elevator stops, at V_A; 2. up to one-third of the available range of elevator deflection, at V_D. They do not correlate the incremental tail load to the corresponding incremental load factor, and appear, therefore, not to be rationally based.
The second of the above mentioned papers, apart from the necessity of a precise definition of the incremental elevator angles in the actual OSTIV Reqs., showed additionally that:
1. formula (1) yields incremental tail loads which cover also cases of checked manoeuvres. Several types of checked manoeuvres were investigated, times for reaching full elevator angle being assumed as low as 0.15 sec.
2. OSTIV loads compared with loads calculated by formula (1) appear to be, in general, conservative (but often unduly large, it is believed) as far as incremental down-loads are concerned, and unconservative for the uploads.
Discussion of the subject within several meetings of the OSTIV Sailplane Development Panel, indicated the opportunity of taking into consideration other manoeuvring conditions, in addition to those starting from a «$n=1$» initial condition and leading to a «n_{lim}» loading condition. The argument for this necessity was the following.
The dynamic response (in terms of $\triangle P$ as a function of time) of an aircraft to an abrupt longitudinal manoeuvre is such that a «first maximum» of the tail incremental load is generally followed by a so-called «second maximum», of opposite sign. The absolute value of the latter may be greater than the former, and generally it is if «aerodynamic» incremental loads are considered. If «aerodynamic + inertia» incremental loads are considered, several sample calculations seem to show that the «second maximum» is always less severe than the first, as far as absolute values of incremental loads are concerned.
The necessity, however, to cover all possible maxima, either positive or negative, suggests the consideration of additional manoeuvring conditions. It seems, therefore, rational to take into consideration also «return» manoeuvres, i.e. those necessary to bring the sailplane form a «$n = n_{lim}$» accelerated state flight condition to a «$n = 1$» steady flight condition.
Obviously, the incremental load for such a «$n_{lim} \rightarrow 1$» manoeuvre is equal but of opposite sign of that relating to the «$1 \rightarrow n_{lim}$» manoeuvre. It is not so, however, for the total tail load (aerodynamic incremental load $\triangle P +$ inertia load $P_i +$ tail weight $W_t +$ tail balance load P_b), owing to P_b being different at the different points of the n-V envelope and also to W_t adding to or subtracting from P_i.
Another suggestion, for airworthiness purposes, may be that of specifying «$1 \rightarrow n_{lim}$» and «$n_{lim} \rightarrow 1$» manoeuvres for «Utility» (U) sailplanes (fig. 1 a), and more severe manoeuvres for «Acrobatic» sailplanes: for instance, manoeuvres tending to accelerate the sailplane from a positive to a negative n_{lim}, and vice versa, at constant (or quasi-constant)* airspeed (fig. 1b).
A modification of OSTIV Reqs. according to the above outlined criteria, might be proposed as follows (reference is made to the amendment draft considered at Paris international meetings**).

* Points A and D of the n-V manoeuvre envelope correspond to slightly different airspeeds.

** In 1969 and 1970 international meetings promoted by the French National Authorities, have taken place in Paris. Their aim is to achieve agreement on Airworthiness Requirements for Sailplanes, a first step towards the definition of internationally accepted airworthiness regulations on the subject. The meetings were attended by representatives of most National Authorities and experts. The basic document for the discussion was, by general agreement, the «OSTIV Airworthiness Requirements for Sailplanes», Dec. 1966 issue. At the present time, under invitation of the above mentioned international meeting, OSTIV is preparing a 1971 edition of the Reqs. taking into account the conclusions achieved hereto in the Paris meetings. An Appendix to the Reqs. will collect the controversial views, on the points on which the different National Authorities have not reached an agreement.

Loads on Horizontal Tail Surface

Balancing Loads

A horizontal tail balancing load is a load necessary to mantain equilibrium in any specified flight condition with no pitching acceleration. Horizontal tail surfaces must be designed for the balancing loads occurring at any point on the manoeuvring envelope and in the flap conditions specified in paragraph 3.28.

Manoeuvring loads

Manoeuvring loads due to control surface deflection must be calculated as those necessary to accelerate the sailplane from a given equilibrium condition (corresponding to a point on the n-V manoeuvring envelope) to another equilibrium condition (corresponding to another point on the n-V manoeuvring envelope). The control surface deflection shall be assumed to take place instantaneously and then to be mantained, the sailplane, therefore, not changing its attitude and airspeed before full control surface deflection is attained.

Category U: The manoeuvres shall be assumed as those necessary to accelerate the sailplane from the loading condition corresponding to point A_1 of the n-V manoeuvring envelope to A, from B_1 to B, from A_1 to D, from B_1 to C, and inversely, from A to A_1, from B to B_1, from D to A_1 and from C to B_1.
The corresponding load factor increments are, therefore:

at speed V_A: $\Delta n = n_1 - 1 \quad 1 - n_1$
$\qquad\qquad\qquad n_4 - 1 \quad 1 - n_4$
at speed V_D: $\Delta n = n_2 - 1 \quad 1 - n_2$
$\qquad\qquad\qquad n_3 - 1 \quad 1 - n_3$

Category A: The manoeuvres shall be assumed as those necessary to accelerate the sailplane from the loading condition corresponding to point A of the n-V manoeuvring envelope to D, from B to C, and, inversely, from D to A, from C to B.
The corresponding load factor increments are, therefore:

at speed V_A: $\Delta n = n_4 - n_1 \quad n_1 - n_4$
at speed V_D: $\Delta n = n_3 - n_2 \quad n_2 - n_3$

The tail load increment due to control surface deflection in the above stated conditions can be calculated from the following expression:

$$\Delta P = \Delta n\, W \left[\frac{x_{CG}}{l_t} - \frac{S_t}{S}\frac{a_t}{a}\left(1 - \frac{d\epsilon}{d\alpha}\right) - \frac{0.613\, S_t\, a_t\, l_t}{W} \right]$$

where:

Δn	– load factor increment
W	– sailplane total weight (kg)
x_{CG}	– longitudinal distance of sailplane CG from wing aerodynamic center (positive if CG is aft of wing a.c.) (m)
l_t	– tail arm ≅ distance of elevator hinge line from sailplane CG (m)
S_t	– horizontal tail surface (m²)
S	– wing surface (m²)
a_t	– horizontal tail lift curve slope (rad⁻¹)
a	– wing lift curve slope (rad⁻¹)
$1 - \frac{d\epsilon}{d\alpha}$	– downwash factor at the tail

ΔP is positive when directed upwards. Both W_{max} and W_{min}, and the corresponding CG locations, shall be investigated.
The total load on the horizontal tail surface is the algebraic sum of the balancing load P_b, the manoeuvring load ΔP, and the mass load P_i (horiz. tail weight plus inertia load) acting on the horizontal tail, i.e.:

$$P_t = P_b + \Delta P + P_i$$

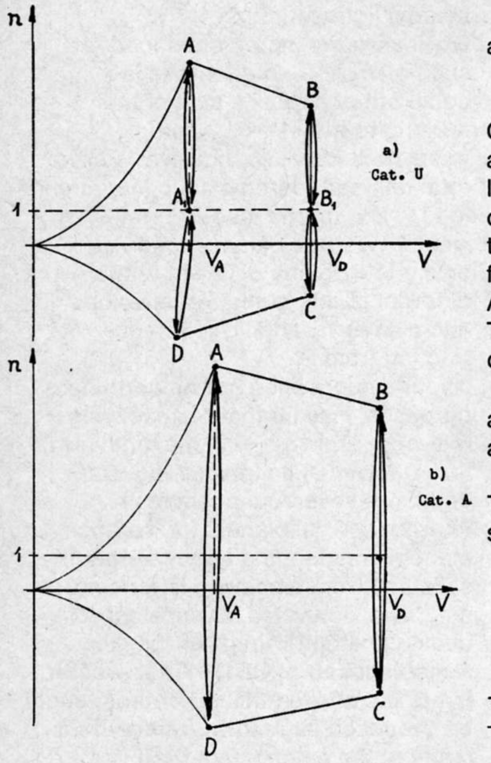

Fig. 1

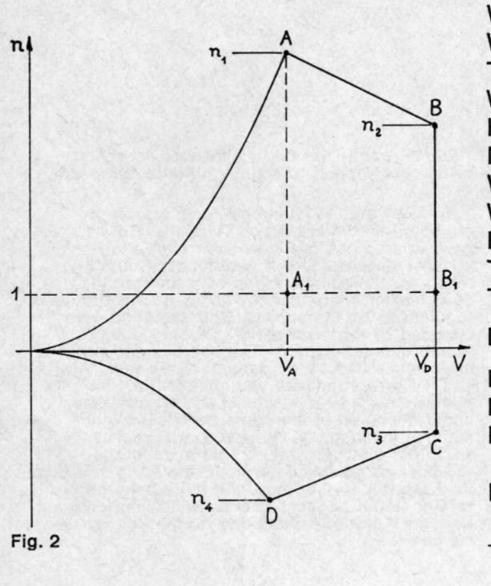

Fig. 2

Table I

			Sailplane A	Sailplane B
Wing span	b	m	15	18.15
Wing surface	S	m²	13.1	17.4
Wing aspect ratio	A		17.1	19
Total weight	W	kg	315	570
Wing loading	W/S	kg/m²	24	32.8
Horizontal tail weight	W_t	kg	7	13
Moment of inertia about y	J_y	kgm.sec²	42	76
Wing reference chord = m.a.c.	c	m	0.94	1.06
Wing lift curve slope	a	rad⁻¹	5.39	5.42
Horizontal tail surface	S_t	m²	1.6	2.48
Tail arm	l_t	m	3.7	4
Tail lift curve slope	a_t	rad⁻¹	4.3	4.1
Downwash factor at tail	$1 - \frac{d\varepsilon}{d\alpha}$		0.75	0.75
Design manoeuvring speed	V_A	m/sec	37.1	45
Design diving speed	V_D	m/sec	70	71.7
Limit load factor at V_A	n_1		5.3	5.3
	n_4		−2.65	−2.65
Limit load factor at V_D	n_2		4	4
	n_3		−1.5	−1.5

The mass load P_i is given by:

$$P_i = -W_t \left(n + \frac{\triangle P}{W} + \frac{\triangle P\, l_t^2}{g\, J_y}\right)$$

where:

W_t – horizontal tail weight

J_y – sailplane moment of inertia about the pitching axis.

n – pre-manoeuvre load factor

Sample calculations

Sample calculations have been carried out for two typical sailplanes: a single seater (sailplane A) and a two-seater (sailplane B), the data of which are reported in table I.

Two CG locations have been considered:

Sailplane A:
CG at 15 % and 40 % c
(x_{CG} = –0.094 and +0.141 m)

Sailplane B:
CG at 20 % and 30 % c
(x_{CG} = –0.053 and +0.106 m)

The same sailplane total weight (W_{max}) has been considered at both CG locations. This assumption is, in general, conservative, the total tail loads resulting higher due to lower values of the alleviating P_i, corresponding to higher J_y.

It is interesting to note that the maximum positive and negative total loads correspond to different CG locations and to different $\triangle$n. Moreover, maximum total loads P_t do not at all correspond to maximum aerodynamic incremental loads.

Table II

SAILPLANE A :

loads in kgs.

		$1 \to n_1$	$1 \to n_4$	$1 \to n_2$	$1 \to n_3$	$n_1 \to 1$	$n_4 \to 1$	$n_2 \to 1$	$n_3 \to 1$
	Δ n	4,3	-3,7	3	-2,5	-4,3	3,7	-3	2,5
C.G. at 15% c W = 315 kgs.	Δ P	-202	+172	-140	+116	+202	-172	+140	-116
	P_i	+44	-51	+29	-37	-88	+63	-64	+40
	P_b	-37	-37	-112	-112	-72	-6	-137	-92
	P_T	-195	+84	-233	-33	+42	-115	-61	-168
C.G. at 40% c W = 315 kgs.	Δ P	-115	+98	-80	+66	+115	-98	+80	-66
	P_i	+22	-32	+13	-24	-66	+44	-48	+27
	P_b	-19	-19	-92	-92	+14	-48	+68	-111
	P_T	-112	+47	-159	-50	+63	-102	+100	-150

SAILPLANE B :

loads in kgs.

		$1 \to n_1$	$1 \to n_4$	$1 \to n_2$	$1 \to n_3$	$n_1 \to 1$	$n_4 \to 1$	$n_2 \to 1$	$n_3 \to 1$
	n	4,3	-3,7	3	-2,5	-4,3	3,7	-3	2,5
C.G. at 20% c W = 570 kgs.	ΔP	-341	+294	-238	+198	+341	-294	+238	-198
	P_i	+90	-102	+59	-73	-116	+76	-85	+47
	P_b	-66	-66	-156	-156	-99	-38	-179	-137
	P_T	-317	+126	-335	-31	+126	-256	-26	-288
C.G. at 30% c W = 570 kgs.	ΔP	-271	+233	-189	+158	+271	-233	+189	-158
	P_i	+69	-83	+44	-61	-95	+57	-70	+35
	P_b	-50	-50	-138	-138	-18	-77	-115	-156
	P_T	-252	+100	-283	-41	+158	-253	+4	-279