THE OPTIMUM C.G. POSITION FOR A FLAPPED SAILPLANE

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Introduction. At the XVIIth Congress of OSTIV, held at Paderborn, I submitted a paper entitled "The Optimum Centre of Gravity Position for Minimum Overall Energy Loss" (Ref 1), which was mainly concerned with fixed-geometry sailplanes. In this paper, and based largely on Ref 2 and Ref 3, the following expressions were derived:

Loss of Total Energy per hour:

$$\delta h_e = (1800\, V_o^2 / E_m W^2)\,[(b_1/b_2)^2 - 1][(L_{2C}^2/V_c)P_c + (L_{2g}^2/V_g)(1 - P_c)] \quad (1)$$

Proportion of flight time spent in circling flight:

$$P_c = [(V_g/V_o)^4 + 1]/[3(V_g/V_o)^4 - 1 \quad (2)$$

Tail lift in circling flight:

$$L_{2C} = [\, C_{moc}\, 1/2 P_o V_c^2 S\, c + (h - h_o)\, c\, n\, W] \,/\, I_t' \quad (3)$$

Tail lift in straight flight:

$$L_{2g} = [C_{mog}\, 1/2 P_o V_g^2 S\, c + (h - h_o]\, cW]\, 1_t' \quad (4)$$

In the present paper, I will not repeat the proofs of these equations. It is worth noting, however, that Equn. 2 depends on the classical theory of thermal flying and the main assumption in deriving Equn. 1 is that the wing and tail and the vortex sheets of these surfaces lie close to the same plane. Also, it is now necessary to introduce two symbols for the pitching moment, one for straight flight, the other for circling flight, since the flap settings will generally be different for the two conditions. See Appendix I for a list of symbols.

Application to Flapped Sailplanes. When contemplating Standard Class machines, as in Ref. 1, the number of variables is relatively small, and it is possible ta come to some conclusions of quite general applicability. With flapped machines of spans around 25 m. and masses of the order of 750 kg. there are many more variables and the only solution is to perform calculations such as these for each particular case. Fortunately, the geometry of most sailplanes is such that we can continue to assume that everything lies in the same plane as indicated in Ref 4. The procedure is as follows:

1. Choose a dimensionless centre of Favity position, *h*.
2. Estimate a likely speed, V_c, the load factor, *n*, and the flap deflection in circling flight.
3. Hence find the pitching moment coefficient in circling flight C_{moc} and hence L_{2C} the tail load in circling flight, from (3).
4. Choose a gliding speed, V_g, and at the same time, the corresponding flap angle.
5. Hence find C_{mog}, the pitching moment coefficient in straight flight. Please note that when finding the pitching moment coefficient both in straight and circling flight, spanwise variations in flap angle must be taken into account.
6. Hence find L_{2g}, the tail load in straight flight, from (4).
7. Also find P_c from (2).
8. Substitute these values of L_{2C}, V_c, L_{2g}, V_g and P_c in (l) to find δh_e per hour.
9. Repeat the procedure for different values of *h*, keeping the same value of V_g.
10. Plot δh_e per hour against *h*.
11. Repeat the whole procedure for a new value of V_g.

In applying this theory, consider the sailplane described in Appendix II. This is a machine of conventional proportions, having a span of 25 m. and a maximum mass of 750 kg. It is assumed that under circling conditions, the flap deflection is +10°, for gliding speeds of 60 and 70 knots the flap is neutral, and for speeds of 80, 90 and 100 knots the flap deflection is -10°. The flap span is 63% of the total span and if the flap deflection is ,β, then the aileron deflection is 0.5 β. If we assume that C_{mo} corresponding to $\beta = 0$ is -0.1 and $\Delta C_{mo} / \Delta \beta = -0.0087$ for a two-dimensional flap, then at $\beta = 10°$, $C_{moc} = -0.1707$ and at $\beta = -10°$, $C_{mog} = -0.0293$, taking into account the diminished deflection of the ailerons.

It is assumed that, when circling in thermals, the speed is 47 knots (87 km/hr) and the angle of bank 35°, giving a load factor of 1.22.

For a gliding speed of 80 knots (148 km/hr), the losses of energy height are then as follows:

CG position	δh_e / hr, feet (metres)		
h	Circling	Gliding	Total
0.25	9.44 (2.87	0.77 (0.23)	10.21 (3.10)
0.30	0.84 (0.26)	0.50 (0.15)	1.34 (0.41)
0.35	1.53 (0.47)	5.24 (1.60)	6.77 (2.07)
0.40	11.47 (3.50)	15.03 (4.58)	26.50 (8.08)
0.45	30.70 (9.36)	29.77 (9.07)	60.47 (18.43)
0.50	59.18 (18.04)	49.56 (15.10)	108.74 (33.14)

From this table, it will be seen that the loss of energy height/hr in circling flight is not too different from that of the Standard Class machine of Ref.l, but that in straight flight (remembering that we will now have -10° of flap) is markedly different.

Figures for the total loss of energy height per hour are plotted for various gliding speeds in Figs. 1 and 2. Each curve has a minimum and, as with the glider of Ref. 1, the higher the speed during gliding flight, the further aft is the minimum. But the losses of energy height are very small for a reasonable range of C.G. positions, and in this case, a position between about 0.3 and 0.35 of the mean aerodynamic chord leads to losses less than 5 ft. per hour for a wide range of gliding speeds. However, the losses increase quite rapidly for more extreme values of the C.G. position. In the case of this particular aircraft, the stick-free neutral point would be at about 0.5 of the mean aerodynamic chord.

DOLPHIN FLYING.

The main effect of large amounts of dolphin flying would be to cause the factor n in Equn.3 to be 1.0 or thereabouts. For a given gliding speed, it is likely that the proportion of time spent in the thermals would not be greatly different from that given by Equn. 1, and so we can investigate the effect by simply putting the load factor equal to 1.0. In the case of gliding at 80 knots, the effect would be to diminish somewhat the figures in the second column. But the figures are so small that the effect on the total loss, near the minimum, would be negligible.

DISCUSSION.

The main effect of this example is to indicate that, as for Standard Class machines, the C.G. should be reasonably, but not extremely, far aft. A position of between 0.3 and 0.35 of the mean aerodynamic chord should be suitable. Again, it is extremely unlikely that any arrangement for varying the C.G. position in flight would be worthwhile. Once again, it ought to be remembered that these results only apply to one particular machine and ought to be worked out in detail for each type.

REFERENCES.

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Appendix I: symbols.

V_O Speed for max. L/D.

E_m Max. L/D.

W Total mass of the laden sailplane.

b_1 Wingspan.

b_2 Tailplane span.

L_{2C} Tail lift in circling flight.

L_{2g} Tail lift in straight flight.

V_g Speed in straight flight.

P_c Proportion of time spent in circling flight.

C_{moc} Pitching moment coefficient of the glider (without tail) about its aerodynamic centre in circling flight.

C_{mog} As above but in gliding flight.

P_o Standard sea-level air density.

S Wing area.

c Mean aerodynamic chord.

h Dimensionless C.G. position. (Actual position = hc aft of datum).

h_o Dimensionless position of the aerodynamic centre of the glider (without tail).

n Load factor, L/W.

L Total lift.

l_t' Distance between the aerodynamic centre of the glider (without tail) and the a.c. of the tail.

β Flap angle, positive downwards.

h_e Energy height.

APPENDIX II: a typical Open-Class Sailplane.

E_m	60.
W	750 kg, 1654 Ib.
b_1/b_2	8.
C_{moc}	-0. 1707.
C_{mo}	-0. 1.
C_{mog}	-0.0293
P_o	0.00238 slugs/cu.ft.
V_c	47 knots.
S	175 sq.ft.
c	2.1 ft.
h_o	2.14 ft.
n	1.22.
V_o	52.6 knots.
l_t'	17.06 ft.

Energy height loss vs. C.G. position (fig. 1) for gliding speeds of 60 and 70 knots and (Fig. 2) for speeds of 80, 90 and 100 knots. In the former case, the flap deflection is zero and in the latter case it is -10°