A.4.b. Full scale work—
Parts of machines, 15. (T. 1053).

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FULL SCALE EXPERIMENTS WITH ELEVATORS OF DIFFERENT SIZES.—By H. GLAUERT. Presented by the SUPERINTENDENT, Royal Aircraft Factory.

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FULL SCALE EXPERIMENTS WITH ELEVATORS OF DIFFERENT SIZES.

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SUMMARY.—(*a*) *Introductory.* (*Reasons for inquiry.*)—The size of elevators fitted to a tail plane must be chosen from two considerations, the amount of control and the force that must be exerted by the pilot. Model experiments (T. 995) indicated that a reduction in the size of the elevators from the 50 per cent. usually employed would give lighter forces without any loss of control. Experiments were made to test this, and at the same time it was desired to repeat the stability experiments carried out previously on R.E. 8, owing to the unusual values obtained for the tail efficiency and downwash.

(*b*) *Range of the investigation.*—Experiments were therefore carried out by fitting elevators of different sizes to an R.E. 8 machine, chosen so as to be respectively 30, 40, 50 and 60 per cent. of the total tail area, and measuring the force on the control column and the angle at which the elevators were held. A careful series of experiments was also made to obtain a satisfactory determination of the tail efficiency.

(*c*) *Conclusions.*—It was found that the force of the control column required to produce a definite change of tail lift increases with the size of the elevators, and that the movement of the elevators decreases. With gearing arranged to give the same total control the smaller elevators would still require smaller forces from the pilot. The determination of the tail efficiency gave a value of 0·6 and the downwash curve was approximately a straight line passing through the point of no lift. This position of the downwash curve depends on values of the moment coefficient derived from full scale experiments (R. & M. 400).

(*d*) *Applications and further developments.*—The results of these experiments showed that it is advantageous to reduce the size of elevators in general use to approximately half the chord of the fixed tail plane in order to secure lightness of control.

1. An investigation has been carried out recently on the effect of varying the size of elevator surfaces on a standard R.E. 8 machine. A series of four different elevators of the same shape were fitted to the standard fixed tail plane, and the areas were chosen so as to be respectively 30, 40, 50 and 60 per cent. of the total tail area. The form of these elevators is shown in Fig. 1, and details are given in Table 1. The positions of the tail plane and elevators in each experiment were recorded on

(B1675) Wt. 11--101. 6, 375. 6/18. Gp. 32.

two scales at the side of the observers' cockpit. The method of experiment employed was to fly at some definite speed with three different tail settings, and to note the force on the control column and the angle at which the elevators were held. The experiments were carried out at three different speeds both with the engine on full throttle and gliding. Experiments were also made with each set of elevators to determine the trimming speed with free elevators for different tail settings and different positions of the centre of gravity.

2. An exhaustive series of experiments was first carried out with the standard 50 per cent. elevators to determine the tail efficiency, as defined in previous reports on longitudinal stability, and to obtain satisfactory values of the angle of downwash for different attitudes of the machine. By suitable adjustment of the loads carried in the machine it was found possible to move the centre of gravity through a distance of nearly 3 inches, and the corresponding change in tail setting, to trim at the same speed, determines the increase in lift of the tail plane for a definite increase in its angle of incidence. These experiments led to a value of 0·6 for the efficiency of the tail plane, which agrees with the results previously found for other tractor machines. The values of the angle of downwash as obtained from the present series of experiments are shown in Fig. 2, where points derived from different positions of the centre of gravity are shown in a distinctive manner. The curve derived is approximately a straight line passing through the point of no lift, and the mean slope is such that $de/d\theta = 0{\cdot}45$. The moment coefficients used in obtaining these values of e and $de/d\theta$ are derived from full scale experiments in a B.E. 2E (see R. & M. 400). The wing of R.E. 8 is very nearly the same as that of B.E. 2E.

3. The experimental data as to the characteristics of the different elevators has been analysed on the assumption that the lift of a tail plane and the hinge moment on the elevators are both linear functions of the angle of incidence and of the elevator angle. It is therefore permissible to write

$$k'_l = a\theta' + b\eta,$$

and

$$M = c\theta' + d\eta,$$

where

θ' is the angle of incidence of the tail plane.

η is the elevator angle,

k_l' is the lift coefficient of the tail plane,

M is the hinge moment on the elevators at 100 ft. sec.,

a and b are therefore absolute coefficients, while c and d have the dimensions of a moment.

In these expressions, a, b, c, d are the four constants which have to be determined for each set of elevators. The first of these—a—expresses the rate of increase of lift with angle of incidence when the elevators are fixed, and so can be taken to be independent of the size of the elevators, except in so far as changing the chord of the elevators changes the overall section and the aspect ratio of the combination, and the ratio of its value to that derived from model test is given by the tail efficiency of 0·6. In consequence the value of a for each set of elevators is 0·0189. Two more relations between the four constants can be obtained by considering the experiments carried out at the same speed with different tail settings (ψ) and different elevator angles (η). In virtue of the fact that the attitude of the machine is unaltered, the tail lift remains the same, and so there are the following relations between the changes in the tail setting, elevator angle, and hinge moment

$$a\Delta\psi + b\Delta\eta = 0$$
$$c\Delta\psi + d\Delta\eta = \Delta M$$

which give

$$\frac{a}{b} = -\frac{\Delta\eta}{\Delta\psi}$$

$$\frac{bc - ad}{a} = -\frac{\Delta M}{\Delta\eta}$$

These two ratios can both be determined from the experimental data, since the elevator angle and tail setting are recorded by the observer, and the hinge moment (M) is derived directly from the force exerted on the control column. The probable errors of the experimental determination of these ratios were found to be 2 and 3 per cent. respectively. The results are given in Table 2.

4. The complete determination of the constants of the elevators was based on the analysis of the trimming speeds with elevators free. If w is the weight moment of the elevators the conditions when the elevators are hanging freely are

$$k_l' = a\theta' + b\eta,$$

$$-w\frac{2{\cdot}15\,V_o^2}{10^4} = c\theta' + d\eta.$$

and so

$$k_l' = \frac{ad - bc}{d}\theta' - \frac{b}{d}\,\frac{w\,10^4}{2{\cdot}15\,V_o^2},$$

where V_o is the mean indicated airspeed over the elevators in m.p.h. The value of θ'_u (the angle of no lift of the tail at speed V_o, with elevators hanging freely) is

$$\frac{b}{ad - bc}\cdot\frac{w}{2{\cdot}15}\cdot\frac{10^4}{V_o^2}$$

and so can be determined from the values of the ratio of ΔM to $\Delta\psi$, as explained in the previous paragraph. The values of

θ'_u used in the analysis of the trimming speeds were determined in this manner, and the downwash was supposed to be given by the curve derived from the experiments with the 50 per cent. elevators. In this way numerous determinations were made of the quantity $\frac{ad - bc}{d}$, and the mean values given in Table 2 were found to have probable errors of only 2 per cent., but this expresses only the divergence of the experiments amongst themselves, and not the deviation from the truth of the mean values, since the analysis assumes the accuracy of the downwash curve. The values *b*, *c*, and *d* are shown in Fig. 3 corrected to apply to tail planes of the same total area (46 sq. ft.), and are compared with the model tests described in R. & M. 254, which have been reduced to the same basis. These model tests were made on a tail plane of different shape, but it will be seen that the results are in good agreement. The full scale values of *c* and *d* are about 90 per cent., and those of *b* about 60 per cent. of the model values. The latter figure is in accordance with the tail efficiency of 0·6, while the former (90 per cent.) implies that the trailing edge of the tail plane is not affected to the same extent as the leading edge. Slipstream experiments (R. & M. 438) have suggested that about one-half of the tail efficiency factor is due to the difference in the slipstreams of tractor and pusher machines. The remaining portion must be ascribed to interference of the body and to scale effect. Since a smaller proportion of the elevators is under the influence of the slipstream compared with the tail plane as a whole, and since the elevators are not in close contact with the body of the aeroplane, the factor of 0·9 instead of 0·6 appears to be quite reasonable.

5. The results have also been examined on the basis of uniform longitudinal stability. This implies that the tail plane area must be inversely proportional to the value of $\frac{dk_i'}{d\theta'}$ when the elevators are hanging freely.

Correcting the areas in this way, calculations have been made of the force on the control required to hold the aeroplane, first to 75 m.p.h. gliding, and secondly to 65 m.p.h. engine full on, the tail plane being set in each case for a trimming speed of 75 m.p.h. with engine on and elevators free. The results of these calculations are given in Table 4. In each case the force necessary increases with the size of the elevators as might be expected. When the engine is shut off, the necessary movement of the elevators is greatest with the small elevators, but to change to 65 m.p.h. with engine on, the change of elevator angle is practically independent of the size of the elevators.

The reduction in force on the control column, due to reducing the size of the elevators, could also be obtained by changing the gearing. To obtain a fair comparison of the different elevators,

EXPERIMENTAL ELEVATORS.

1/12 SCALE.

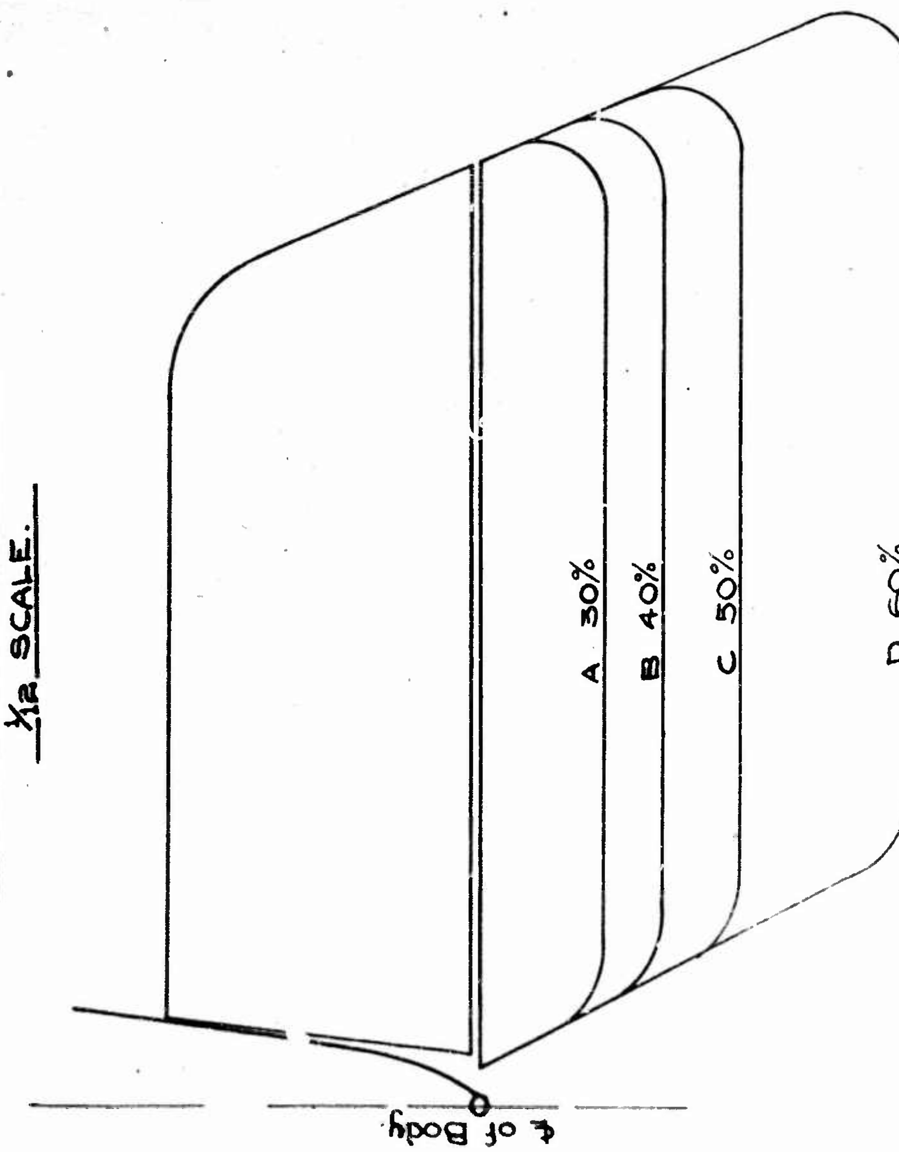

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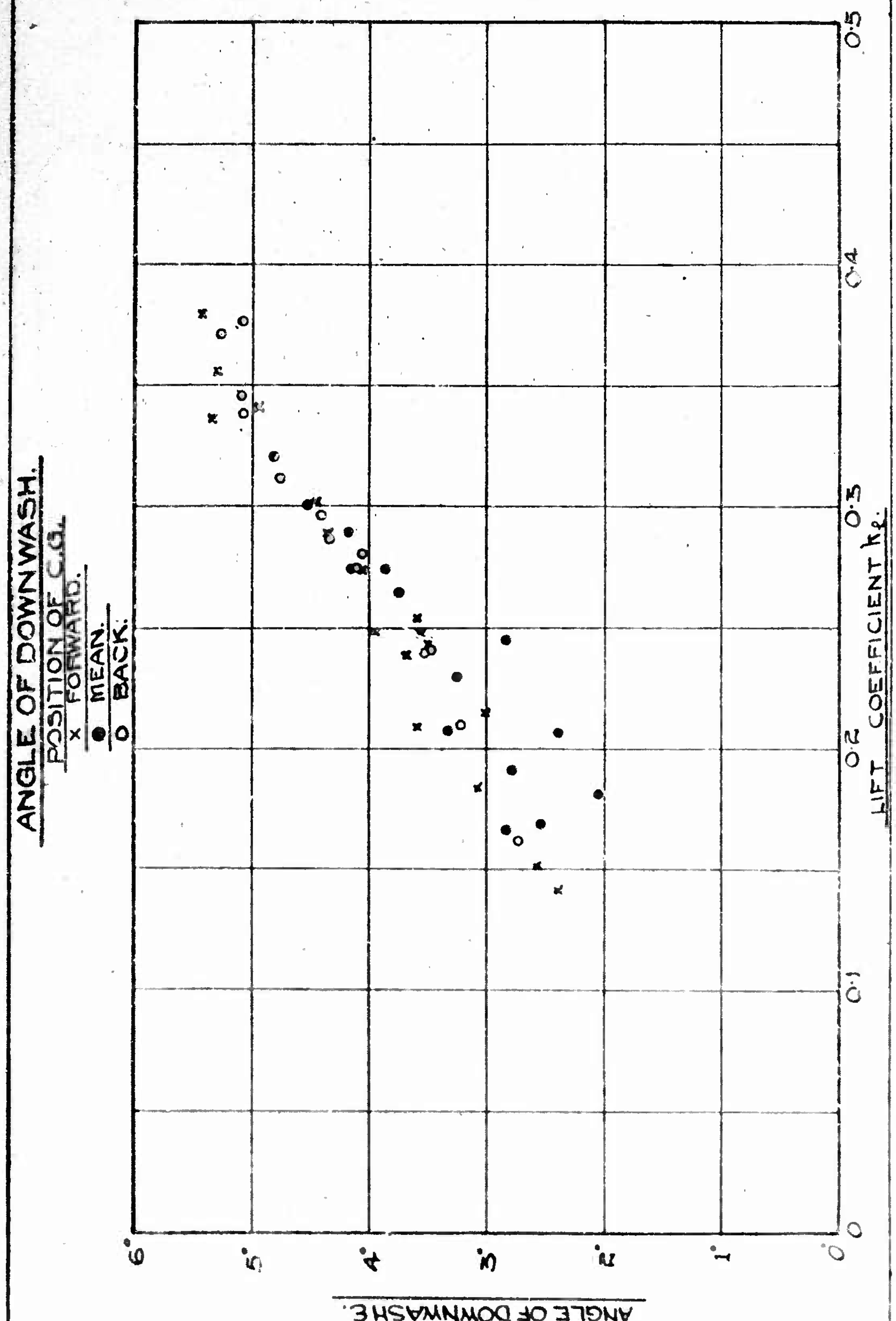
FIG. 2.



REPORT No. 409. FIG.3.

CONSTANTS OF ELEVATORS OF DIFFERENT SIZE.

⊙ DEDUCED FROM T. 825.

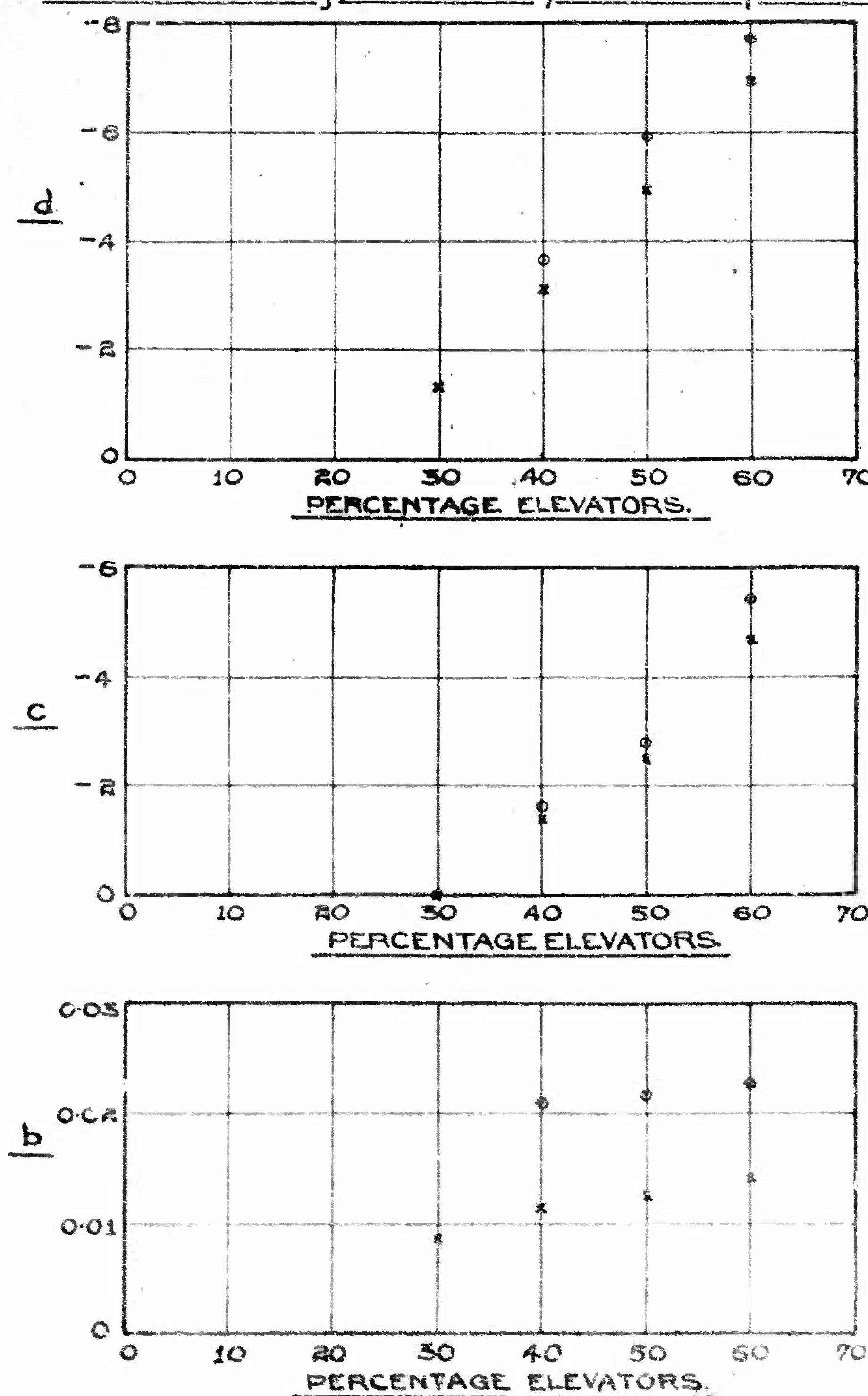
x EXPERIMENTAL DETERMINATION.

The constants correspond to the equations:—

$$k_{\ell}' = a\theta' + b\eta.$$

$$m = c\theta' + d\eta.$$

where M is the hinge moment at 100'/sec. for a tailplane of 46□'.



the gearing must be adjusted so that the maximum possible movement of the control column—which is limited by the size and shape of the pilot's compartment—shall give some definite change in the attitude of the machine. For the elevators used in these experiments the gearing was unaltered, and so it follows that the forces should be increased in the ratio of the elevator movement necessary for the particular manœuvre in question. The basis of comparison becomes, therefore, the product of the force, and the change of elevator angle. Using this criterion, it is found that the elevators improve steadily with decreasing size over the range tested in these experiments.

TABLE 1.

DETAILS OF ELEVATORS.

	Tail plus Elevator.	Elevator.			
	Area. Sq. ft.	Area. Sq. ft.	Chord. Ft.	Weight. Lbs.	Weight Moment about Hinge. Lbs.ft.
A	34	10·3	0·94	11½	3·2
B	39½	15·8	1·38	12½	5·7
C	46	22·3	1·88	14½	7·9
D	60	36·3	3·08	19½	17·5

TABLE 2.

CHARACTERISTICS OF ELEVATORS.

	$\frac{a}{b}$	$\frac{bc-ad}{a}$	$\frac{bc-ad}{d}$	b.	c.	d.
A	2·25	0·81	−0·0188	0·0084	0	− 0·81
B	1·69	1·79	−0·0138	0·0112	−1·12	− 2·45
C	1·52	3·28	−0·0126	0·0124	−2·50	4·92
D	1·36	5·20	−0·0095	0·0139	−7·00	−10·35

a and b are absolute coefficients, and c and d are constants having the dimensions of the moment. They are defined by the equations

$$k'_l = a\theta' + b\eta,$$
$$M = c\theta' + d\eta,$$

where

θ' is the angle of incidence of the tail plane.
η is the elevator angle.
k'_l is the lift coefficient of the tail plane.
M is the hinge moment on the elevators at 100 ft./sec.

Table 3.

TAIL PLANES OF EQUAL AREA (46 Sq. Ft.).

% Elevators.	*b.*	*c.*	*d.*
30	0·0084	0	– 1·28
40	0·0112	– 1·41	– 3·09
50	0·0124	– 2·50	– 4·92
60	0·0139	– 4·70	– 6·95

Table 4.

TAIL PLANES OF EQUAL STABILITY.

The machine is supposed to be trimmed at 75 m.p.h.

% Elevator.	To Trim at 65 m.p.h.		To Trim at 75 m.p.h. Gliding.		
	Elevator Movement. degrees	Force. Lbs.	Elevator Movement. degrees	Force. Lbs.	Product.
30	– 0·6	0·7	– 3·8	2·5	9·5
40	– 0·7	1·5	– 2·4	5·3	12·7
50	– 0·7	2·2	– 2·0	7·4	14·8
60	– 0·8	3·7	– 1·5	11·5	17·3