C.P. No. 112
(14,826)
A.R.C. Technical Report

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Low Speed Wind Tunnel Investigation of Tab Hinge Moment Characteristics

By

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LONDON. HER MAJESTY'S STATIONERY OFFICE

1953

Price 3s. 6d. net

C.P.112

Technical Note No. Aero.2130

November, 1951

ROYAL AIRCRAFT ESTABLISHMENT

Low speed wind tunnel investigation of tab hinge moment characteristics

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SUMMARY

Hinge moments have been measured on tabs of 4.7% local chord on a tailplane with 14° trailing edge angle. The range of investigation covered the effects of 32% nose balance and of the gap between tab and elevator.

For small deflections of the control surfaces c_1 and c_2 are negligible whilst c_3 is -0.36 and -0.28 for the unbalanced and balanced tabs respectively.

With large angles of the elevator, and with moderate angles when the elevator gap is open, c_2 tends to the calculated value for this wing without boundary layer terms. Consequently the curve of tab hinge moment as the tab and elevator both move is not linear.

Values of c_1 and c_3 calculated by thick aerofoil theory, with Bryant's empirical boundary layer terms, are in good agreement with measured values for small deflections.

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1 Introduction

The use of servo tabs on large transport aircraft has made it necessary to obtain data on the hinge moment characteristics of small chord tabs of full span. For this purpose a third scale model of the half tailplane of the Bristol 175 aircraft was mounted in the 24 ft wind tunnel, and tab hinge moments were measured. Previous tests of elevator hinge moments had been made.[1] The mean tab chord, aft of hinge line, is 4½% of the tailplane mean chord, but the tab is of constant chord whilst the tailplane tapers. The main tests were made on one quarter of the tab, and on this the tab chord, aft of hinge line, was 4¾% of the local tailplane chord. The tests included an investigation of elliptic nose balance and of gap size.

2 Description of Model and Tests

The tests were made during April and May 1951. The model is shown in Fig.1, and its dimensions are given in Table I. The mean chord of the model tailplane was 3.58 ft, and since the open jet 24 ft wind tunnel was used, no corrections to hinge moments have been applied. It will be seen in Fig.2 that the model was a half tailplane with endplate rather than a half tailplane completely reflected. The geometric incidences tested were 0° and 10°, but the model lift slope would only correspond to 9° of the completely reflected wing. Since the effects of incidence on hinge moments is small, no correction has been applied.

The tests were made at 160 ft/sec giving a Reynolds number = $3.6\ (10)^6$, based on mean tailplane chord. Transition wires were fitted at 15% chord on both surfaces of the tailplane.

The elevator hinge line was at 65% of the tailplane chord with 30% nose balance. Up to deflections of 20° the elevator nose gap was sealed by sorbo rubber attached to the nose. For deflections greater than 20° the balance nose projected beyond the profile.

This elevator had a full span tab which was divided into four equal parts spanwise, each having two hinges. The hinge moments on section 2 of the tab were measured (see Fig.1).

Two types of tab were tested, one having a 32% elliptic nose balance, the other being an unbalanced tab made by cutting away the balance to leave a semi-circular nose. The tab hinges were made as frictionless as possible in order to measure the true hinge moment coefficient. In full scale aircraft there would probably be a larger frictional force. Each tab was tested with gaps of 0.001 and 0.0025 of the local tailplane chord c'.

The angular position of those parts of the tab which were not connected to the balance could be pre-set. In most of the tests they were fixed at 0° to the elevator, but some tests were made with a tab setting of 25° to enable the results to be corrected to a full-span tab.

The maximum error involved in setting the tab angle β was $\pm\frac{1}{4}\%$, which corresponded to an error of ± 0.002 in the hinge moment coefficient (C_H). The maximum error involved in reading the balance corresponded to an error in C_H of 0.0005, giving a total of ± 0.0025. This error would be increased at large elevator angles due to unsteadiness.

3 Results and Discussion

For small chord tabs the values of c_1, c_2 and c_3 (the partial derivatives of C_H with respect to α, η and tab angle β) are constant for small ranges of α, η and β. These constant values of the derivatives are much smaller than the values calculated without consideration of the boundary layer, and are in fact the values for the tab embedded in a thick boundary layer. For large angles of the surfaces, and when hinge gaps are open (and act as slots), the curves will revert to the values they would have with thinner boundary layer, causing unsystematic looking curves (Figs.3-7).

3.1 Small Angles

Considering first the values at small angles, the values found for the single section of tab are:-

Tail incidence (α°)	Tab balance	Tab gap	c_1	c_2	c_3
0	unbalanced	0.001c	-0.01	-0.02	-0.35
		0.0025c	-0.01	-0.05	-0.38
	balanced	0.001c	-0.01	0	-0.27
		0.0025c	-0.02	-0.01	-0.31
10	unbalanced	0.001c	-	-0.05	-0.38
		0.0025c	-	-0.07	-0.42
	balanced	0.001c	-	-0.02	-0.30
		0.0025c	-	-0.06	-0.35

These would be little altered if the full span tab had been used. This was checked by some tests shown in Fig.8 in which the remainder of the tab was set at 25°, so that the "full span" curve would run from the point representing 0° on all tabs to that representing 25° on all tabs. This would increase the negative value of c_3 by 0.01. c_2 would be unaltered, since the variation of C_H with η is not changed.

The effect of 30% nose balance is to reduce c_3 by 20%.

These values of c_1, c_2 and c_3 for unbalanced tabs have been compared with the following calculations:-

(a) Bent plate theory[2].

(b) Thick wing theory[3]. This is only available for a single flap, giving c_1 and c_3 but not c_2.

(c) Bryants empirical corrections for boundary layer.[3]

The comparison found is:-

	$a_0/2\pi$	c_1	c_2	c_3
Bent plate theory	1.00	-0.14	-0.19	-0.85
Thick aerofoil theory	1.106	-0.09	-	-0.56
Thick aerofoil theory with Bryant empirical corrections	0.865	-0.04	-	-0.36
Measured values	-	-0.01	-0.02	-0.36

This demonstrates the large boundary layer effect. To estimate how much the change from model to full scale Reynolds Number will effect this, the Bryant method has been applied to calculate c_1 and c_3 at $R = 20 \times 10^6$, giving:-

	$R = 3.6 \times 10^6$	$R = 20 \times 10^6$	Without Boundary Layer
c_1	-0 04	-0.05	-0.09
c_3	-0.36	-0.39	-0.56

so that the model results will be substantially applicable to flight conditions.

3.2 Non-linear Parts of Hinge Moment Curve

In Fig.3, hinge moments are plotted against elevator angle: the elevator gap was sealed until the nose began coming out soon after 20°. The hinge is behind the maximum thickness of the elevator, accentuating the bulge outside the wing contour as the elevator rotates. Fig.3 shows that c_2 is only small for quite small values of η and β and shows large changes taking place even with small tab angles between -15° and -25° elevator angle. In Fig.9 some results from section 3 of the tab are given, these were made with elevator gap open, and there was a cut out in the elevator nose. The effect of the gap is to give a higher value of c_2 for $\eta > 8^\circ$, this value being of the order estimated for "without boundary layer".

In Figs.4-7 hinge moments are plotted against tab angle, and the value of c_3 is nearly constant and is small up to 20° or 25° of β as long as the elevator angle is small. In a very crude way this is explained by the thick boundary layer, over the last 5% of the wing, embedding the tab and being carried round with it as it moves.

The effectiveness of the balanced tab is illustrated in Ref.1 (Fig.28). It is seen that 20° of balanced tab will give -25° of elevator whilst 10° of tab give 15° of elevator. Such points are joined in Fig.4(b) by the broken curve. This curve shows the tab hinge moment required to produce the requisite elevator deflection.

4 Conclusions

(1) The values of c_1 and c_3 for small angles are correctly estimated by the method of reference 3, in which however the boundary layer terms are empirical.

(2) The boundary layer terms are large, but a calculation shows relatively small change up to full scale Reynold's number.

(3) The effect of 30% balance from an elliptic nose is to reduce c_3 by 20%.

(4) The hinge moment curves are non-linear with elevator angle; and c_3 for a servo tab with the correct elevator setting may become less stable with increasing angle, becoming unstable within the practical range.

(5) Since the small-angle values depend on being in a thick boundary layer, the only hope of obtaining more linear curves would be in providing slots at the hinges or removing the boundary layer in some other manner. The hinge moments would then be much heavier.

LIST OF SYMBOLS

c	mean tailplane chord
c'	local tailplane chord
α	tailplane incidence
η	elevator angle
β	tab angle of part of tab on which measurements were made.
β'	tab angle of other parts of tab
C_H	tab hinge moment
c_1	slope of C_H v α curve $\left(\frac{\partial C_H}{\partial \alpha}\right)$
c_2	slope of C_H v η curve $\left(\frac{\partial C_H}{\partial \eta}\right)$
c_3	slope of C_H v β curve $\left(\frac{\partial C_H}{\partial \beta}\right)$

LIST OF REFERENCES

No.	Author	Title, etc.
1	Mathews, Hall and Hunt	Type 175. Tests on an elevator operated by a servo tab. Bristol Aircraft Company. W.T.200
2	Perring	The theoretical relationships for an aerofoil with a multiple hinged flap system. R & M No.1171. April 1928.
3	Bryant, Halliday and Batson	Two dimensional control characteristics. R & M 2730. March 1950

TABLE I

Model Details

Tailplane

Area per side	32.70 sq.ft.
Semi-span	9.17 ft
Mean chord	3.57 ft
Root chord	4.78 ft
Aspect ratio	5.143
Section (symmetrical)	R.A.F.28 (modified)
Tailplane thickness	0.125c
Sweepback of leading edge	10°
Sweepforward of trailing edge	5°
Taper ratio	2.00
Trailing edge angle	14°

Elevator

Area aft of hinge	9.07 sq.ft.
Span per side	7.43 ft.
Sweepback of leading edge	2°
Position of hinge line	65% tailplane chord
Nose balance	30%

Tab

Area aft of hinge	0.284 sq.ft.
Span per quarter tab	1.848 ft.
Chord aft of hinge (constant)	0.154 ft
Nose balance	32%
Tailplane chord at centre of tab	3.49 ft
Tailplane chord at centre of section 2 of tab	3.25 ft
Tailplane chord at centre of section 3 of tab	3.74 ft

TABLE II

TAB-HINGE MOMENTS. GAP = 0.001c

Measured on section 2, other sections at 0°.

UNBALANCED TAB

	η° \ β°	-5	0	5	10	15	20	25
$\alpha = 0^\circ$	+ 5.0	0.027	-0.004	-0.038	-0.070	-0.108	-0.145	
	- 0.1	0.026	-0.005	-0.034	-0.066	-0.098	-0.137	-0.173
	- 5.1	0.032	-0.003	-0.031	-0.056	-0.090	-0.125	-0.159
	-10.0	0.036	0.001	-0.027	-0.046	-0.072	-0.101	-0.129
	-15.0	0.045	0.014	-0.013	-0.033	-0.041	-0.054	-0.074
	-20.0		0.067	0.044	0.012	-0.012	-0.021	
	-25.0							
	-30.1		0.110	0.080		-0.027		-0.053
$\alpha = 10^\circ$	+ 5.0	0.019	-0.014	-0.047	-0.081	-0.117	-0.156	
	- 0.1	0.025	-0.007	-0.041	-0.074	-0.108	-0.148	-0.185
	- 5.1	0.027	-0.003	-0.034	-0.057	-0.098	-0.137	-0.174
	-10.0		-0.002	-0.029	-0.057	-0.086	-0.126	
	-15.0	0.035	0.008	-0.020	-0.044	-0.069	-0.100	-0.129
	-20.0		0.015	-0.012	-0.031	-0.049	-0.072	-0.094
	-25.0		0.054	0.036	0.013	-0.011	-0.029	
	-30.1							

BALANCED TAB

	η° \ β°	-5	0	5	10	15	20	25
$\alpha = 0^\circ$	+ 5.0		-0.003	-0.030	-0.055	-0.082	-0.111	
	- 0.1	0.022	-0.002	-0.026	-0.049	-0.071	-0.094	-0.126
	- 5.1	0.021	-0.003	-0.024	-0.043	-0.060	-0.075	
	-10.0	0.026	-0.001	-0.023	-0.038	-0.048	-0.052	-0.074
	-15.0	0.033	0.010	-0.015	-0.028	-0.031	-0.026	
	-20.0		0.049	0.028	-0.008	-0.005	-0.007	-0.001
	-25.0							
	-30.1		0.090	0.056		-0.009		-0.020
$\alpha = 10^\circ$	+ 5.0		-0.013	-0.038	-0.064	-0.095	-0.117	
	- 0.1	0.021	-0.003	-0.031	-0.056	-0.087	-0.109	-0.146
	- 5.1	0.022	-0.002	-0.025	-0.053	-0.075	-0.099	-0.130
	-10.0		0.001	-0.022	-0.044	-0.061	-0.084	
	-15.0	0.024	0.002	-0.018	-0.035	-0.049	-0.058	-0.080
	-20.0		0.009	-0.014	-0.027	-0.034	-0.032	-0.032
	-25.0		0.051	0.031	0.013	0.000	-0.004	
	-30.1							

TABLE III

TAB HINGE MOMENTS.   GAP = 0.0025c

Measured on section 2, other sections at 0°

UNBALANCED TAB

	η° \ β°	-5	0	5	10	15	20	25
$\alpha = 0^{\circ}$	+ 5.0		-0.006	-0.049	-0.078	-0.114	-0.155	
	- 0.1	0.029	-0.005	-0.039	-0.072	-0.104	-0.142	-0.187
	- 5.1	0.033	-0.001	-0.031	-0.059	-0.087	-0.124	-0.165
	-10.0	0.038	0.004	-0.028	-0.046	-0.067	-0.102	-0.140
	-15.0	0.053	0.015	-0.014	-0.034	-0.041	-0.058	
$\alpha = 10^{\circ}$	+ 5.0							
	- 0.1		-0.007	-0.046	-0.081	-0.120	-0.163	
	- 5.1		0.000	-0.034	-0.070	-0.105	-0.143	
	-10.0		0.000	-0.028	-0.059	-0.090	-0.130	
	-15.0		0.003	-0.022	-0.046	-0.071	-0.105	

BALANCED TAB

	η° \ β°	-5	0	5	10	15	20	25
$\alpha = 0^{\circ}$	+ 5.0		-0.006	-0.036	-0.068	-0.099	-0.126	
	- 0.1	0.022	-0.002	-0.031	-0.058	-0.087	-0.111	-0.145
	- 5.1	0.023	-0.004	-0.027	-0.051	-0.072	-0.091	-0.127
	-10.0	0.028	-0.003	-0.024	-0.039	-0.052	-0.068	-0.095
	-15.0	0.042	0.007	-0.018	-0.028	-0.027	-0.030	
$\alpha = 10^{\circ}$	+ 5.0							
	- 0.1		-0.007	-0.039	-0.072	-0.102	-0.129	
	- 5.1		-0.002	-0.030	-0.061	-0.091	-0.118	
	-10.0		-0.001	-0.025	-0.054	-0.076	-0.100	
	-15.0		0	-0.022	-0.041	-0.058	-0.075	

TABLE IV

EFFECT ON TAB HINGE MOMENTS OF SETTING, β',
OF OTHER TABS. GAP = 0.001c, $\alpha = 0^\circ$

UNBALANCED TAB

	β°	-5	0	5	10	15	20	25
$\eta = -0.1^\circ$	$\beta' = 0^\circ$	0.026	-0.005	-0.034	-0.066	-0.098	-0.137	-0.173
	$\beta' = 25^\circ$	0.024	-0.011	-0.042	-0.070	-0.102	-0.142	-0.174
$\eta = -15.0^\circ$	$\beta' = 0^\circ$	0.045	0.014	-0.013	-0.033	-0.041	-0.054	-0.074
	$\beta' = 25^\circ$	0.043	0.011	-0.019	-0.036	-0.044	-0.058	-0.074

BALANCED TAB

	β°	-5	0	5	10	15	20	25
$\eta = -0.1^\circ$	$\beta' = 0^\circ$		-0.001	-0.026	-0.048	-0.071	-0.094	-0.126
	$\beta' = 25^\circ$		-0.009	-0.031	-0.055	-0.078	-0.103	-0.134
$\eta = -15.0^\circ$	$\beta' = 0^\circ$	0.033	0.010	-0.015	-0.028	-0.031	-0.026	
	$\beta' = 25^\circ$	0.028	0.000	-0.020	-0.035	-0.037	-0.029	

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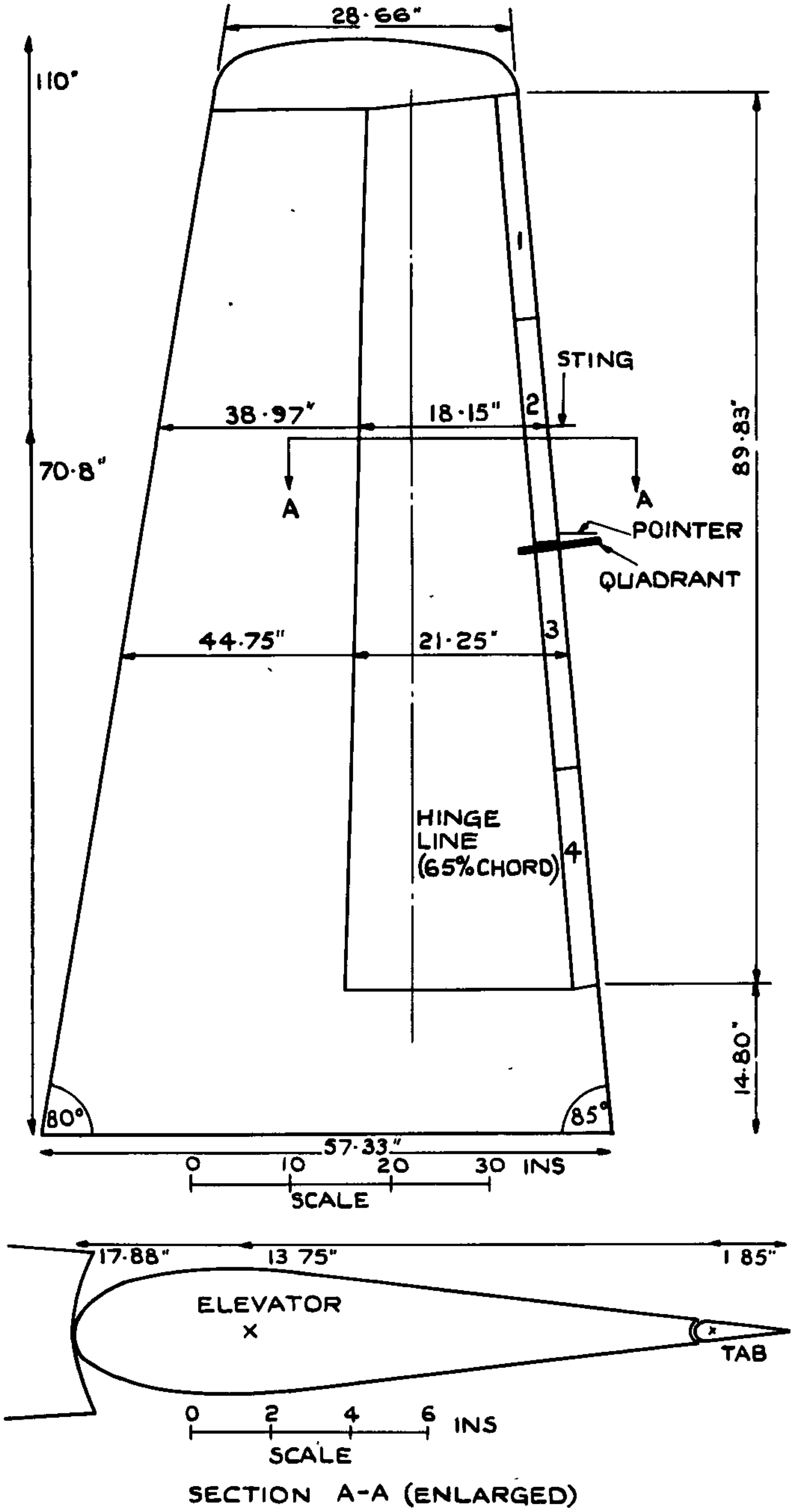


FIG. 1. G.A. OF MODEL TAILPLANE

FIG. 2

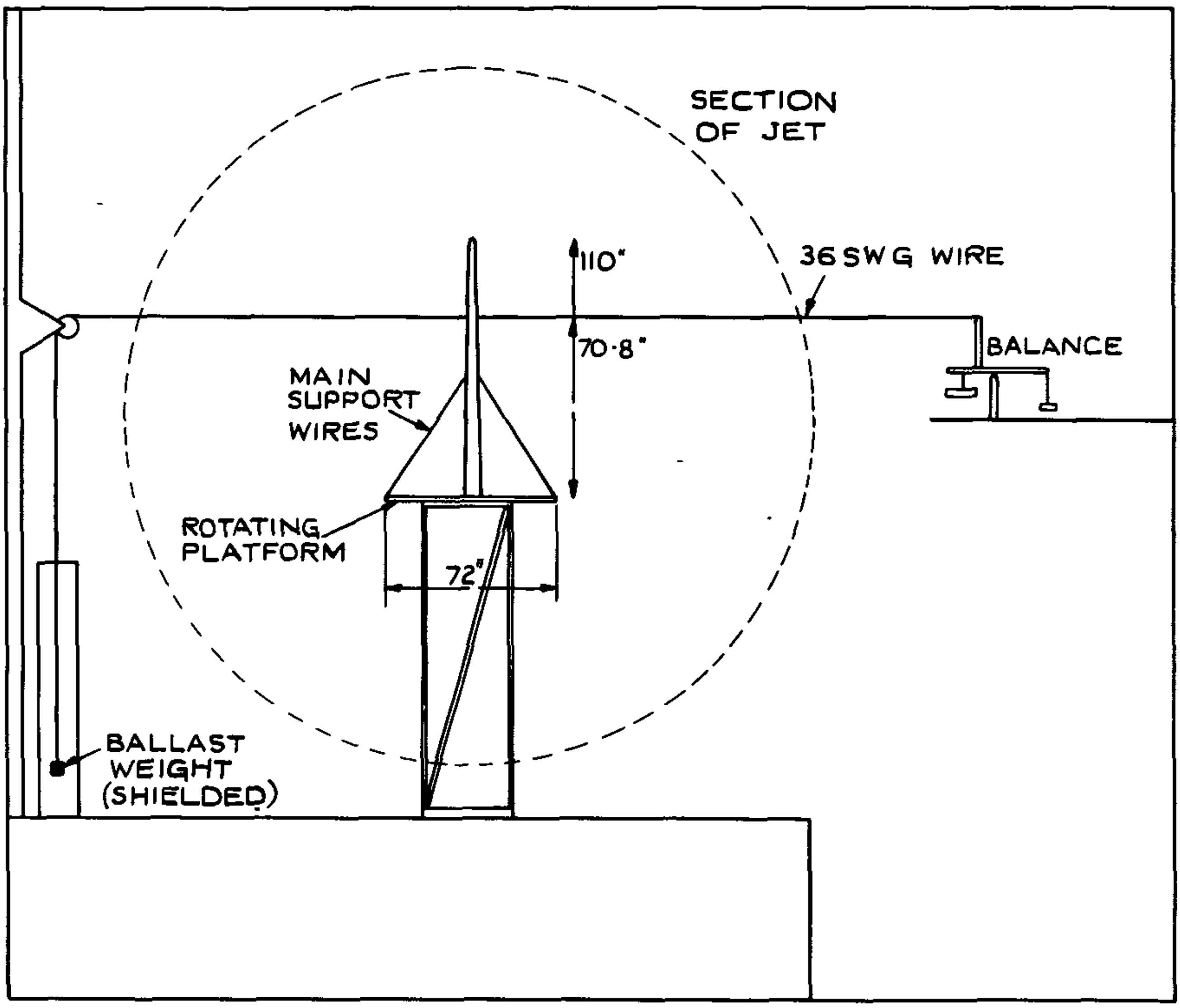


FIG. 2. MODEL INSTALLATION IN 24 FT. TUNNEL.

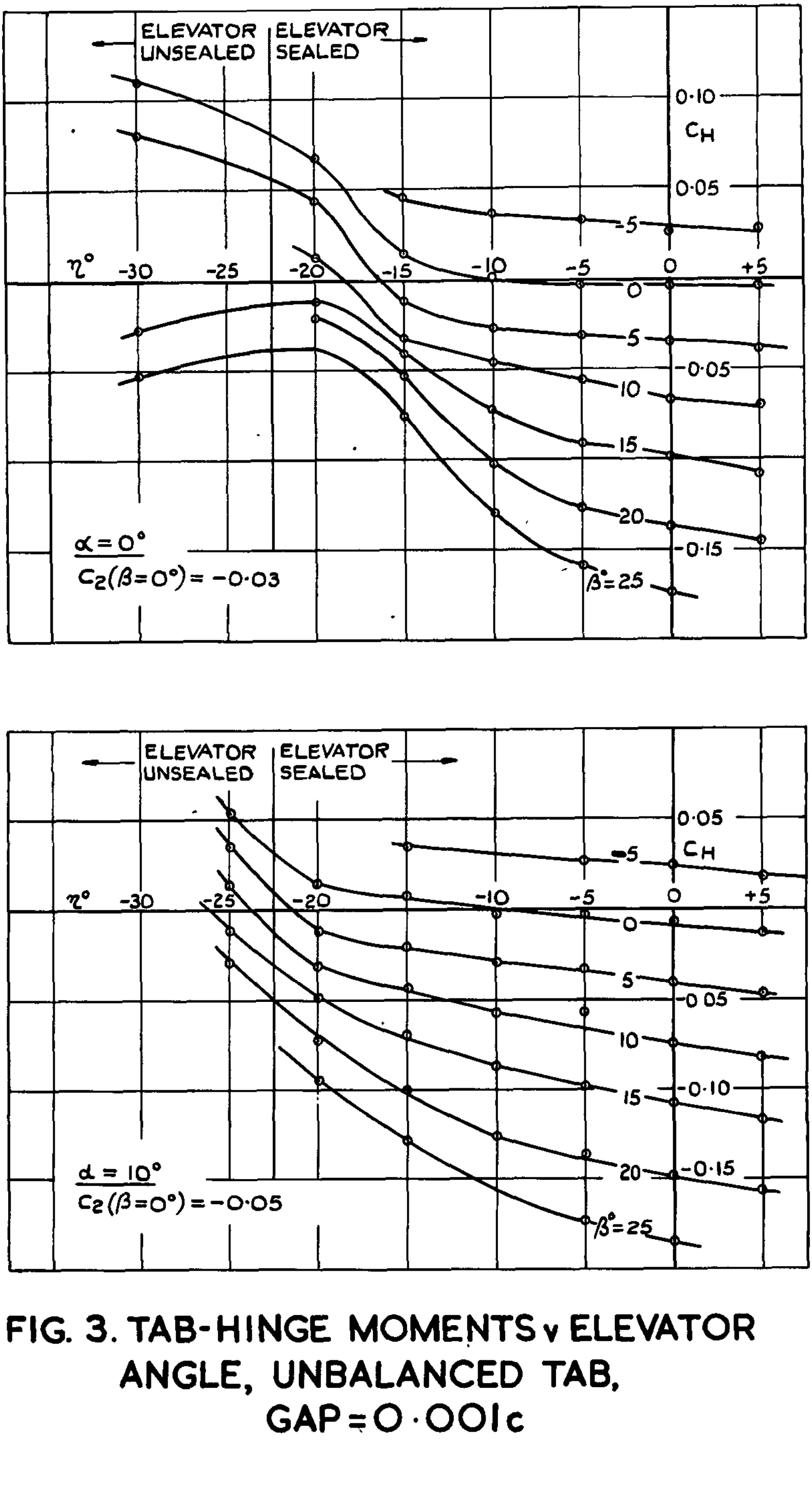
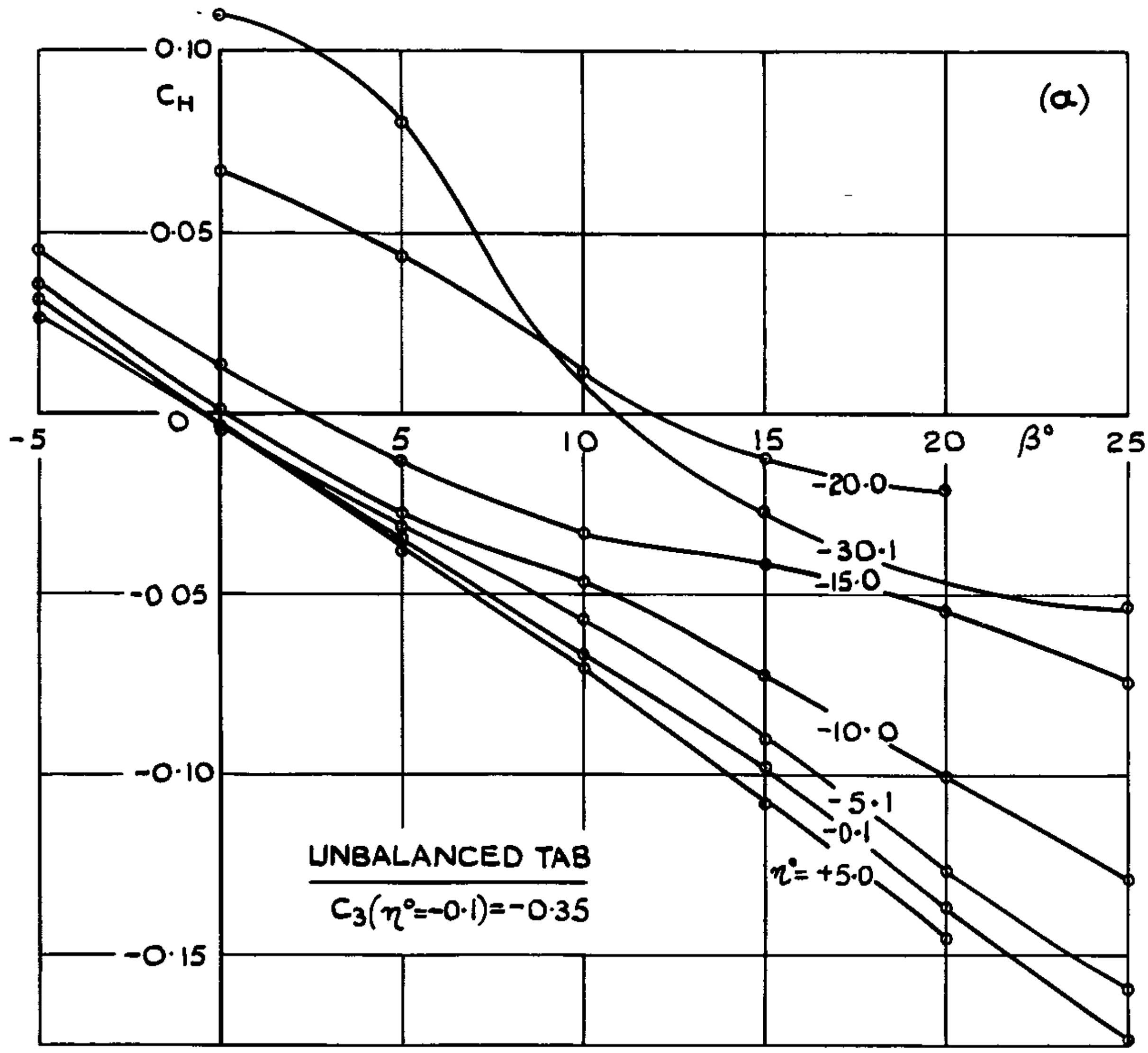


FIG. 3. TAB-HINGE MOMENTS v ELEVATOR ANGLE, UNBALANCED TAB, GAP = 0·001c

FIG. 4



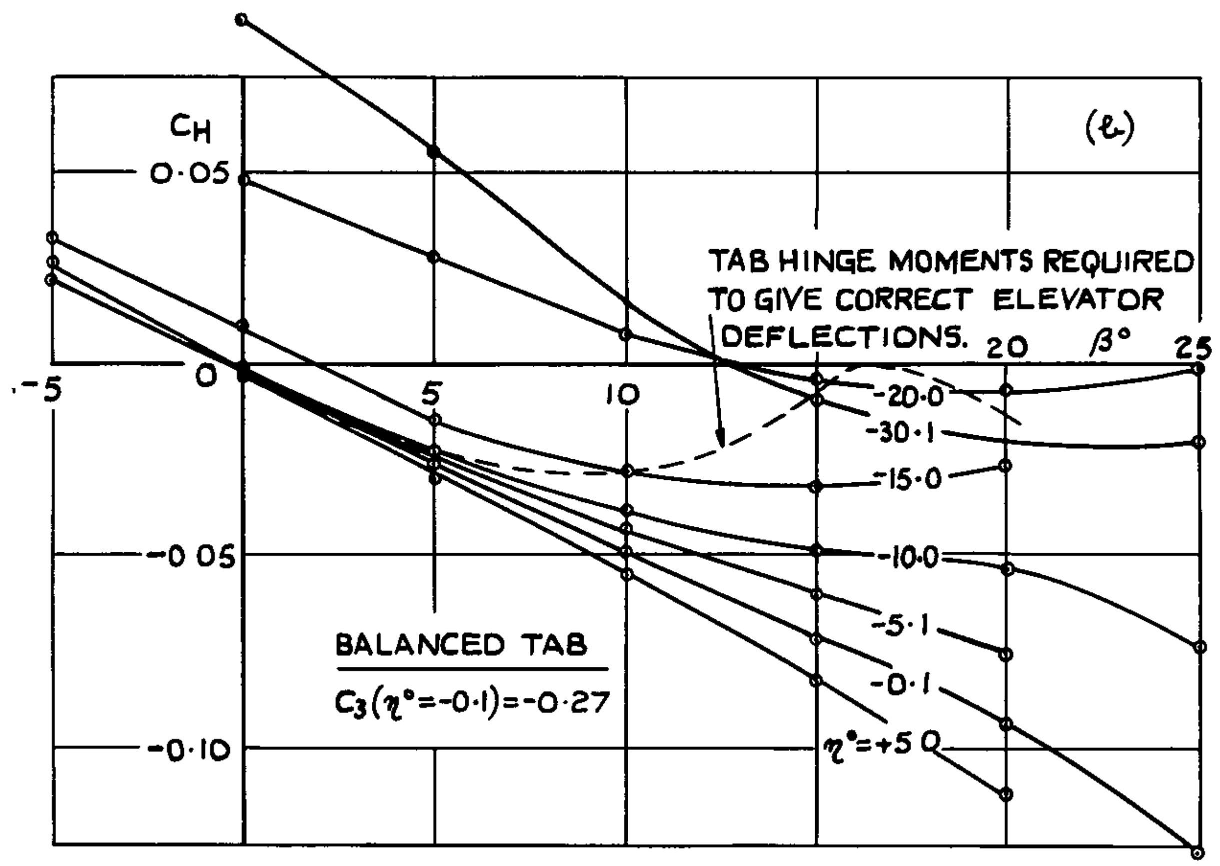


FIG. 4. TAB HINGE MOMENTS v TAB ANGLE, GAP = 0·001 c, α = 0°

FIG. 5

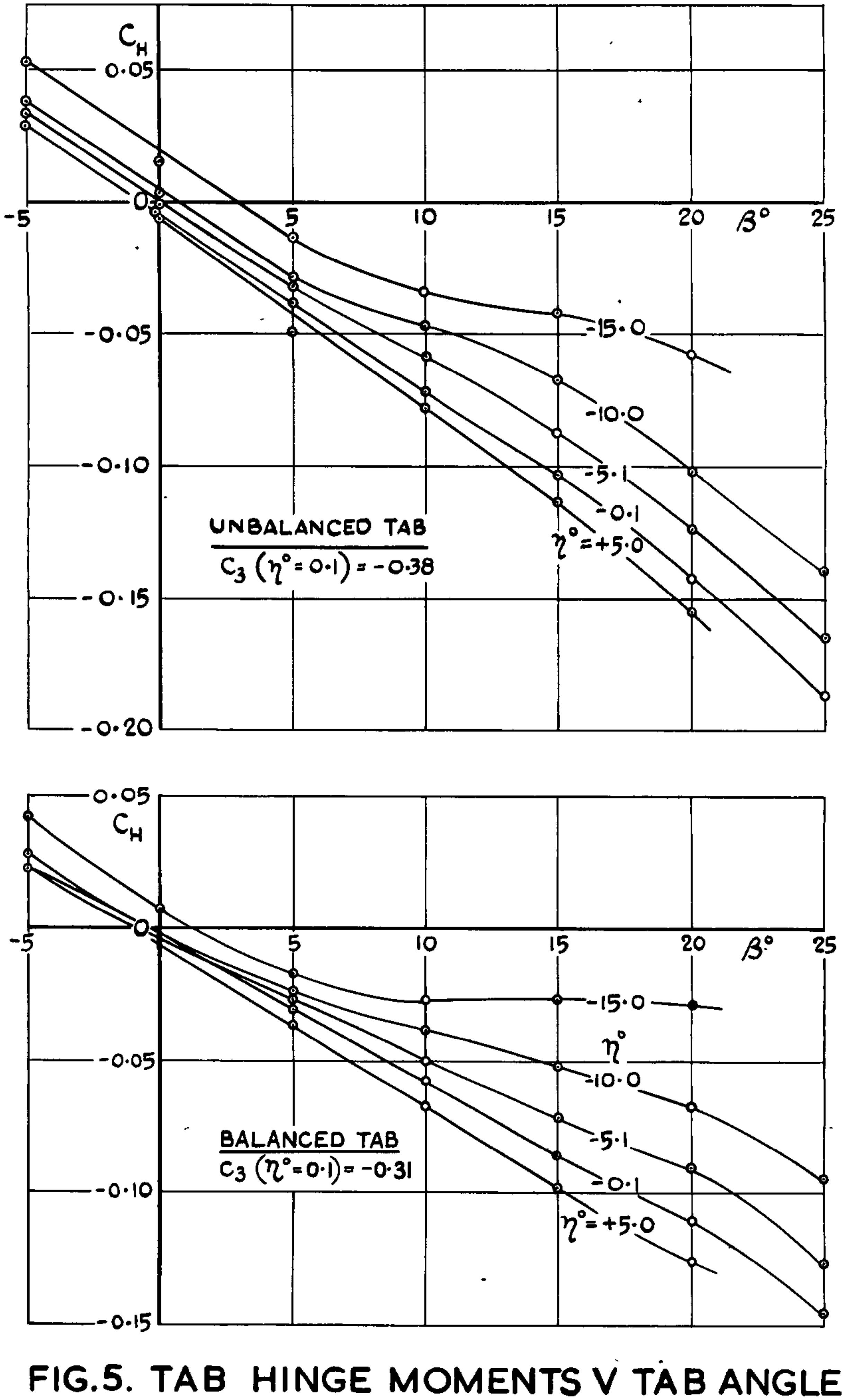


FIG. 5. TAB HINGE MOMENTS V TAB ANGLE, GAP=0·0025c, α=0°

FIG.6

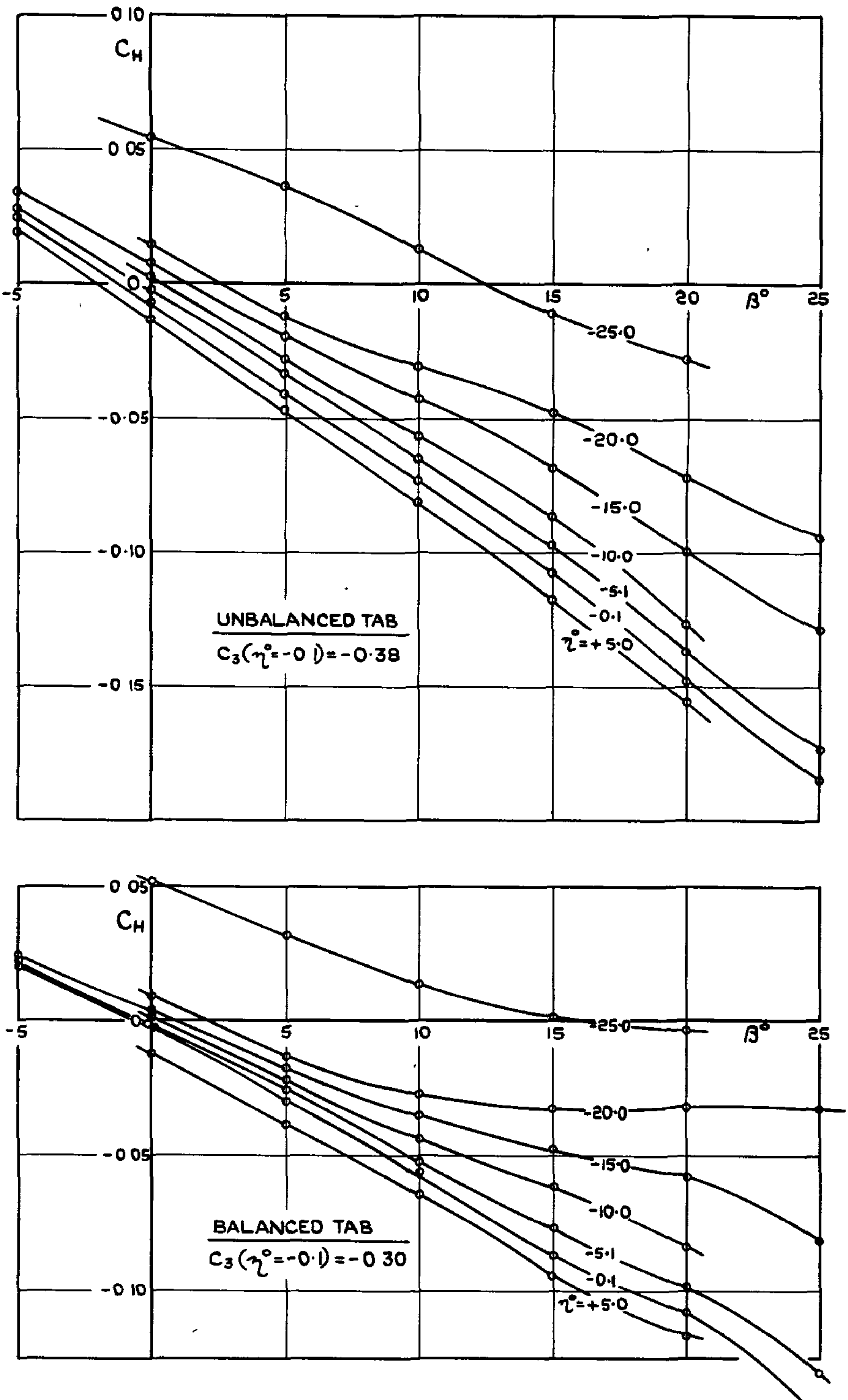
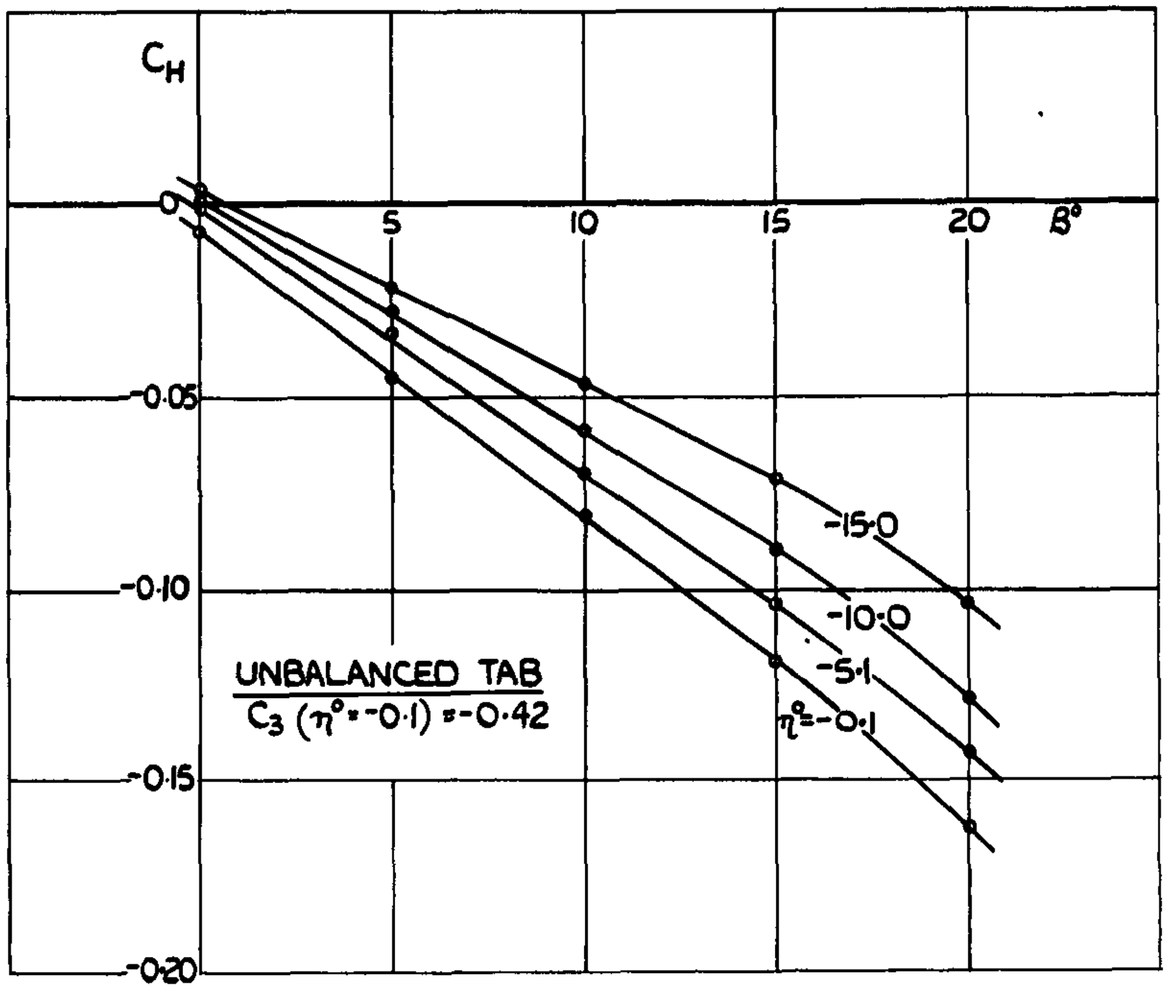


FIG.6 TAB HINGE MOMENTS v TAB ANGLE, GAP = 0·001c, $\alpha = 10^\circ$

FIG. 7.



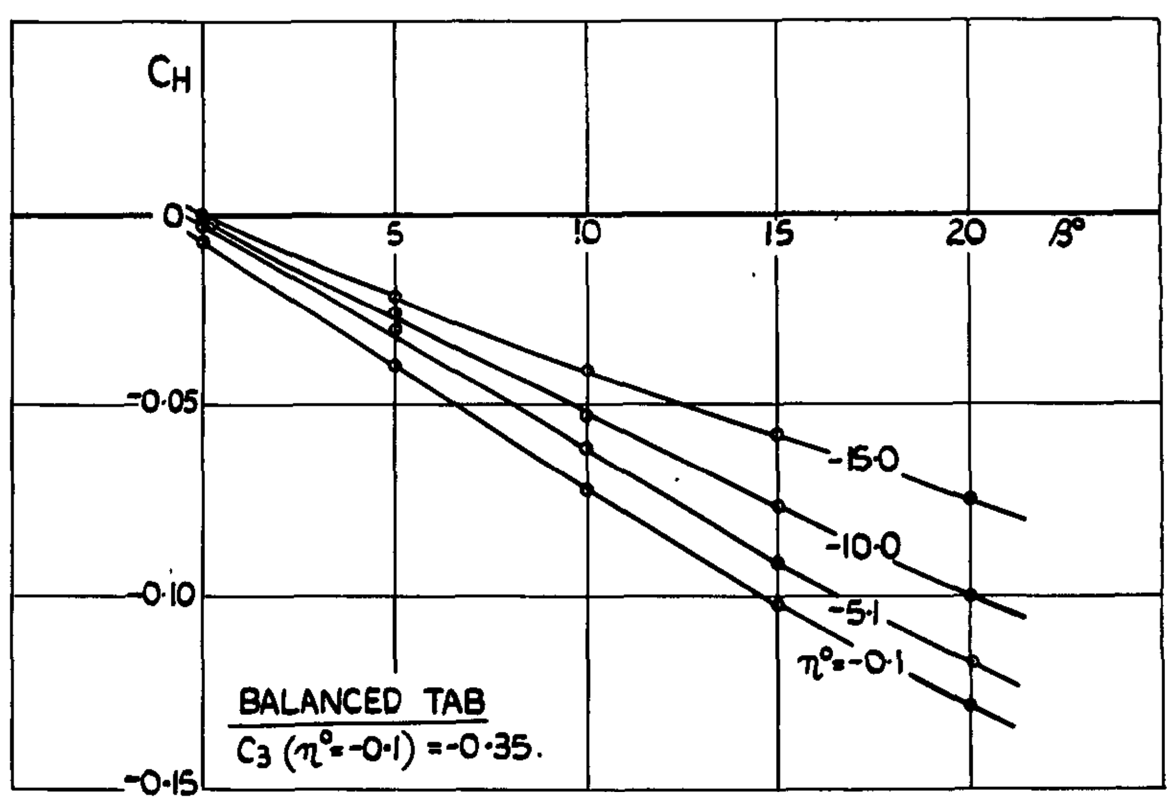


FIG. 7. TAB HINGE MOMENTS v TAB ANGLE, GAP = 0·0025c, α = 10°

FIG. 8.

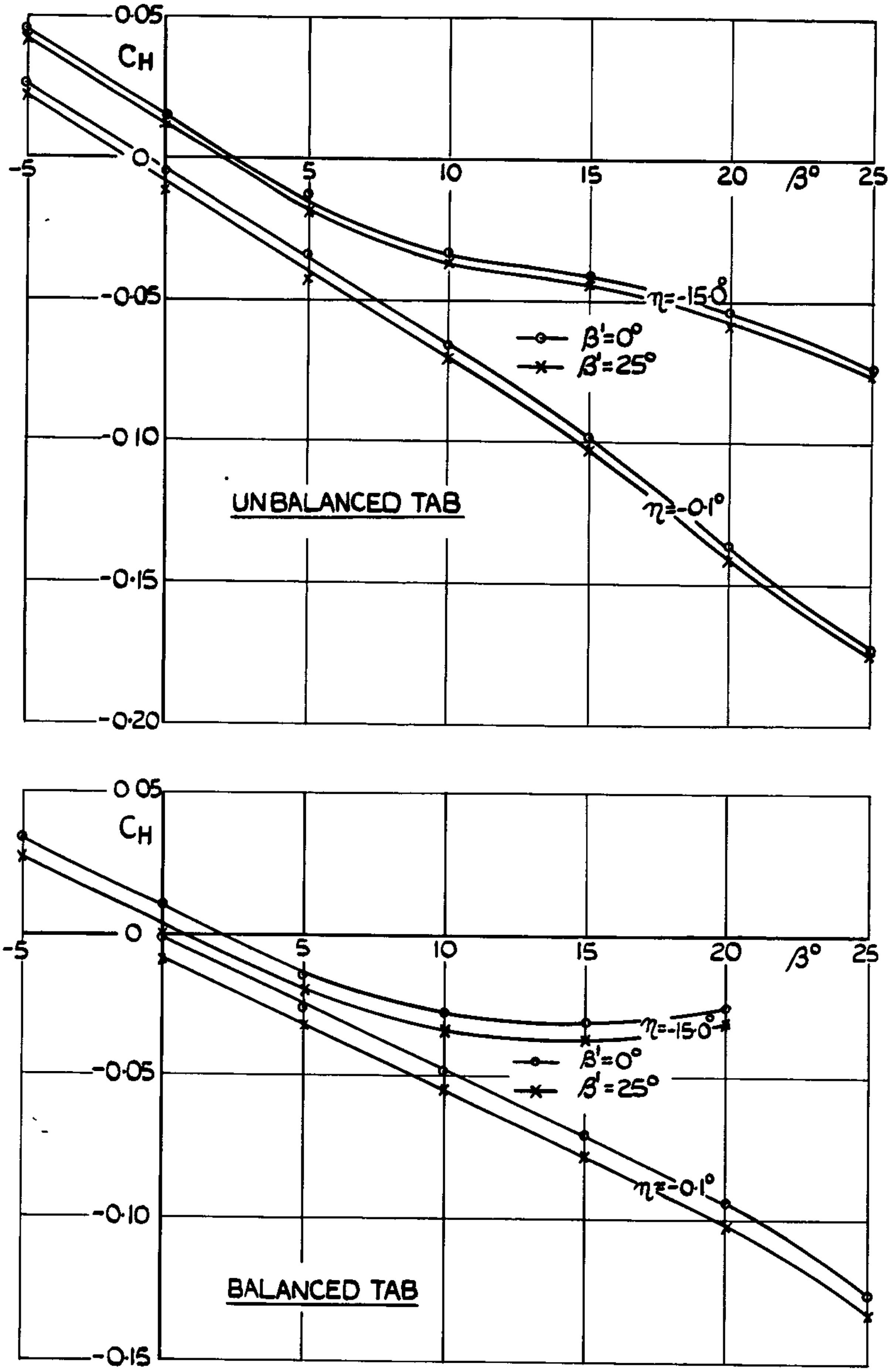
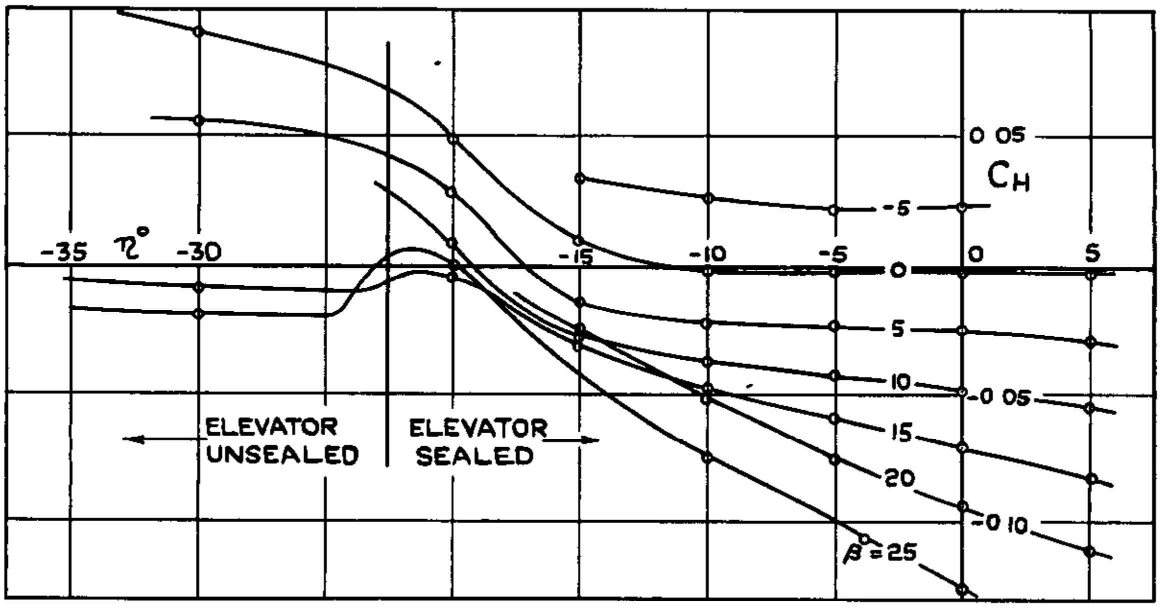
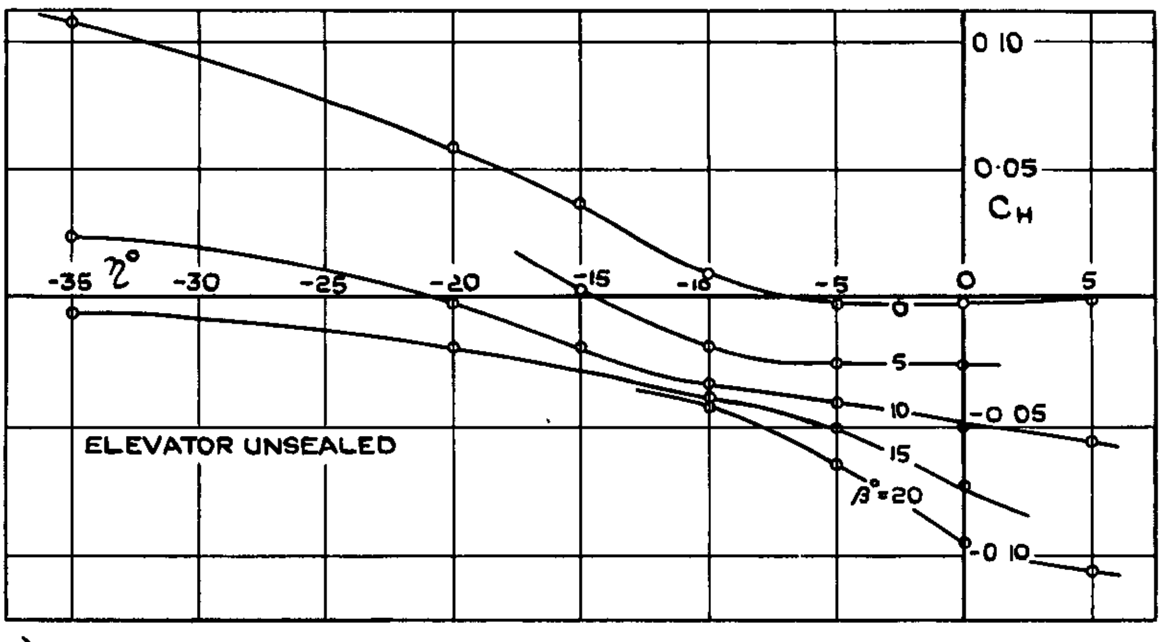


FIG. 8. EFFECT ON TAB HINGE MOMENTS OF SETTING, β', OF OTHER TABS GAP = 0·001c, α = 0°.



a) TAB HINGE MOMENTS v ELEVATOR ANGLE WITH ELEVATOR SEALED FOR DEFLECTION UP TO 20°.
TAB CHORD = 0·047c̄.



b) TAB HINGE MOMENTS v ELEVATOR ANGLE WITH ELEVATOR GAP OPEN.
TAB CHORD = 0 0425 c̄

FIG.9 EFFECT OF SEALING ELEVATOR GAP. BALANCED TAB, GAP = 0·001c, α = 0°

C.P. No. 112
(14,826)
A.R.C. Technical Report

PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE

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