C.P. No. 305
(17,755)
A.R.C. Technical Report

C.P. No. 305
(17,755)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Note on the Effect of Size and Position of End Plates on the Lift of a Rectangular Wing in a Wind Tunnel

By

A. S. Halliday, Ph.D., B.Sc., D.I.C., and Miss D. K. Cox, B.Sc.,
of the Aerodynamics Division, N.P.L.

LONDON HER MAJESTY'S STATIONERY OFFICE

1956

Price 2s 6d net

C.P. No. 305

Note on the Effect of Size and Position of End Plates on the Lift of a Rectangular Wing in a Wind Tunnel.

- By -
A. S. Halliday, Ph.D. B.Sc., D.I.C.
and Miss D. K. Cox, B.Sc.
of the Aerodynamics Division, N.P.L.

16th July, 1955

SUMMARY

Experiments have been made in a wind tunnel to determine the minimum size of end plate which would be effective in producing approximately two-dimensional flow conditions past an aerofoil at low incidence.

It is concluded that the lift distribution at the centre section is obtained within 10% if

(1) the end plates are at least $\frac{4}{3}$c in chordwise extent,

(2) the height of the end plates is at least 2c above and below the centre line.

End plates on the pressure surface only are ineffective, but on the suction surface only they may over-correct so as to give lift in excess of the two-dimensional value.

Experiments with inboard plates showed that two-dimensional conditions could only be obtained if they were placed on both surfaces. There was no reduction in the height of plate for which 90% of the two-dimensional lift was obtained.

The variation of effective aspect ratio with size of plate is considered. Theoretical and rough experimental aspect ratio factors are confirmatory.

1. Introduction

The end plates used for earlier Whirling Arm experiments on a rectangular wing of 48 in. span and 18 in. chord were 12 in. high and 27 in. long in a chordwise direction.

It was found that two-dimensional flow could not be simulated under the conditions of steady pitching. This conclusion was supported by the theory of Ref.1 (Küchemann and Kettle, 1951), which suggested that the effect of these end plates would be to increase the aspect ratio by a factor of 1·47, that is from 2.67 to 3.92.

In order to decide the size of end plates, effective in producing approximately two-dimensional flow conditions at the centre section of the wing, experiments were made in the N.P.L. 7 ft No.3 wind tunnel.

2./

Published with permission of the Director, National Physical Laboratory

2. Details of Model and Tests

The model used for the wind tunnel experiments was the one on which the Whirling Arm experiments had been made; it had a chord(c) of 18 in. and a span (b) of 48 in. In order to have a standard with which to compare the results obtained by varying the size of end plates, the span was made up to the full breadth of the 7 ft tunnel and the pressure plotted centre section taken to represent two-dimensional conditions.

The end plates were made in sections so that the height could be varied in steps of 6 in. above or below the centre line of the wing section. Initially the plates were 36 in. wide projecting 6 in. forward of the leading edge and 12 in. behind the trailing edge. The length was subsequently reduced to 24 in. with projections of 3 in. forward and behind. The spanwise position of the plates was also varied from the end positions, 48 in. apart, to symmetrical inboard positions 24 in. apart.

The model was assumed to be at zero angle of incidence when its attitude to wind was such that the pressures on the upper and lower surfaces at 0.10c from the leading edge were equal. As there was limited time available, the experiments were confined to an incidence of $\alpha = 2^\circ$. Complete pressure plotting of the section was done for particular cases only; for the remainder, pressure differences between upper and lower surfaces were taken at the two stations at 0.10c and 0.65c. Table 1 gives a list of the experiments made, except for the pressure measurement at 0.65c, the results of which have been omitted as they confirmed those at 0.10c.

3.1 Results

Fig.1 shows the pressure plotting results for 2° incidence in the two-dimensional and three-dimensional cases without end plates. The integrated lift coefficients (C_L) are 0.218 and 0.124 respectively.

End plates 36 in. wide extending from roof to floor of the wind tunnel were then placed in position at the tips of the 48 in. span model; Fig.2 gives the pressure distribution curve which is integrated to give $C_L = 0.208$ being just over 95% of the value obtained from the two-dimensional model.

Fig.3 shows the distribution when the end plates are moved to symmetrical inboard positions 24 in. apart. The value for $C_L = 0{\cdot}212$ was close to the two-dimensional one of 0.218.

Removing the plates from the lower or pressure surface of the wing gave a distribution shown in Fig.4 and a value of $C_L = 0.198$, a relatively small reduction from $C_L = 0{\cdot}212$ for the complete plates. These results suggest that plates placed on the suction surface of the wing have more effect than those on the pressure surface.

4.1 Effect of Width of End Plates

For practical reasons it is desirable to keep the size of end plates as small as possible and the effect of reducing the width is seen by comparing the results shown in Fig.2 with those of Fig.5, the width of the plates having been reduced from 36 in. to 24 in. This reduction in width resulted in only a small drop in C_L from 0.208 to 0.202 which is 93% of the two-dimensional value.

4.2 End Plates of Variable Height

As it would have taken too long to investigate the effect of varying the height of the end plates by complete pressure plotting,

it/

it was thought sufficient for a rough indication to take pressure differences between top and bottom surfaces at a distance 0.1c from the leading edge. The results are plotted against height of end plate in Figs. 6 and 7 for end plates of 36 in. and 24 in. chord respectively.

It is not claimed that these curves give more than a very approximate indication of the effect of end plates. From Figs. 6 and 7 it appears that plates at the wing tips on the upper surface only over-correct, having more effect than the complete end plates. This unexpected result is supported by the fact that end plates on the lower surface only produce a slight loss of lift.

4.3 Effect of Spanwise Position

Fig. 8, when compared with Fig. 6, shows the effect of moving the plates inboard so that they are spaced 24 in. apart or 12 in. from each wing tip. It will be seen that complete plates produce approximately the same effect as when they are placed at the tips of the wing. However, when the half plates are moved inwards, the upper plates have less effect and the lower ones much more, so that the upper and lower plates become of approximately the same importance.

5. Comparison with Theory

Küchemann and Kettle[1] give theoretical curves to show the influence on effective aspect ratio (A/κ) of variation of height of end plates.

The following rough procedure was used to compare the experimental results with calculations of Ref. 1. Fig. 9 was first drawn by plotting the pressure differences at 0.1c for infinite aspect ratio and for the three-dimensional wing without end plates ($A = \frac{8}{3}$), and by supposing ($p_u - p_l$) to be linear in $1/A_e$, where A_e is the effective aspect ratio. The pressure differences in Figs. 6-8 were thus related to an effective $1/A_e = \kappa/A = 3\kappa/8$ and the quantity κ was plotted to give the full curves in Figs. 10-12.

It is pointed out that Ref. 1 predicts identical curves for upper plates and for lower plates alone. With plates at the tips of the wing the present experimental results cast some doubt on this simplifying assumption as will be seen from the curves of Figs. 10 and 11. However, the results with complete end plates are of the order predicted and support the theoretical trends. Closer numerical agreement could have been obtained, had a more precise procedure been used to deduce the factor κ.

The theoretical curves for inboard plates have been obtained from Ref. 2 (Mangler and Rotta, 1947), from which the curves of Fig. 1 of Ref. 1 were taken. The aspect ratio factor (κ) is given for values of $2b_1/b_2$ up to 0.5 for complete plates and 1.0 for half plates. The value of $2b_1/b_2$ for the tunnel experiments was 1.0; the theoretical curve for complete plates shown in Fig. 12 was therefore obtained by extrapolation and that for half plates was taken direct from Fig. 12 of Ref. 2.

6. Conclusions

The experiments indicate that the end plates of chordwise extent $4c/3$ are satisfactory. If the plates are placed at the tips of the wing on the suction surface only, it appears that they will have slightly more effect than complete end plates. If, however, they are moved inboard the half plates are only partially effective. In order to obtain a lift coefficient of at least 90% of the two-dimensional value, the height of the tip plates need not exceed $3b/4$ on the suction

surface/

surface and 3b/4 on each surface in the case of the inboard plates. These results apply when the aspect ratio $A = \frac{8}{3}$. In general, the minimum ratio h/b will decrease rapidly with increasing aspect ratio, while the ratio h/c will decrease fairly slowly. As a general criterion it is deduced that the desired lift is obtained within 10%, provided that the total height of end plate exceeds $h = A\frac{3}{2}c = 4c$.

REFERENCES

No	Author	Title, etc.
1	Küchemann D. and Kettle D. J.	The effect of end plates on swept wings. C.P.104. June, 1951.
2	Mangler W. and Rotta J.	Aerofoils with tip plates. AVA Monograph F, 1.6, M.A.P. R.& T.1023, 1947, GDC/2533T. A.R.C. 11,553.

TABLE I/

TABLE I

Summary of Experiments

Case	Pressure Measurement	Chord of Plate	Vertical Span of Plate	Distance Between Plates	C_L	Fig.
1 (2-dim)	Complete	-	-	-	0.218	1
2 (3-dim)	Complete	-	-	-	0.124	1
3	Complete	36 in.	-42in. to +42in.	48 in.	0.208	2
4	Complete	36 in.	-42in. to +42in.	24 in.	0.212	3
5	Complete	36 in.	0 to +42in.	24 in.	0.198	4
6	Complete	24 in.	-42in. to +42in.	48 in.	0.202	5
7	0.1c	36 in.	-z to +z	48 in.	-	6
8	0.1c	36 in.	0 to +z	48 in.	-	6
9	0.1c	36 in.	-42in. to +z	48 in.	-	6
10	0.1c	36 in.	-z to 0	48 in.	-	6
11	0.1c	24 in.	-z to +z	48 in.	-	7
12	0.1c	24 in.	0 to +z	48 in.	-	7
13	0.1c	24 in.	-42in. to +z	48 in.	-	7
14	0.1c	24 in.	-z to 0	48 in.	-	7
15	0.1c	36 in.	-z to +z	24 in.	-	8
16	0.1c	36 in.	0 to +z	24 in.	-	8
17	0.1c	36 in.	-42in. to 0	24 in.	-	8

NOTE -z denotes that half plates have been built progressively from 0 to 42 in. below the lower (pressure) surface.
+z denotes that half plates have been built progressively from 0 to 42 in. above the upper (suction) surface.

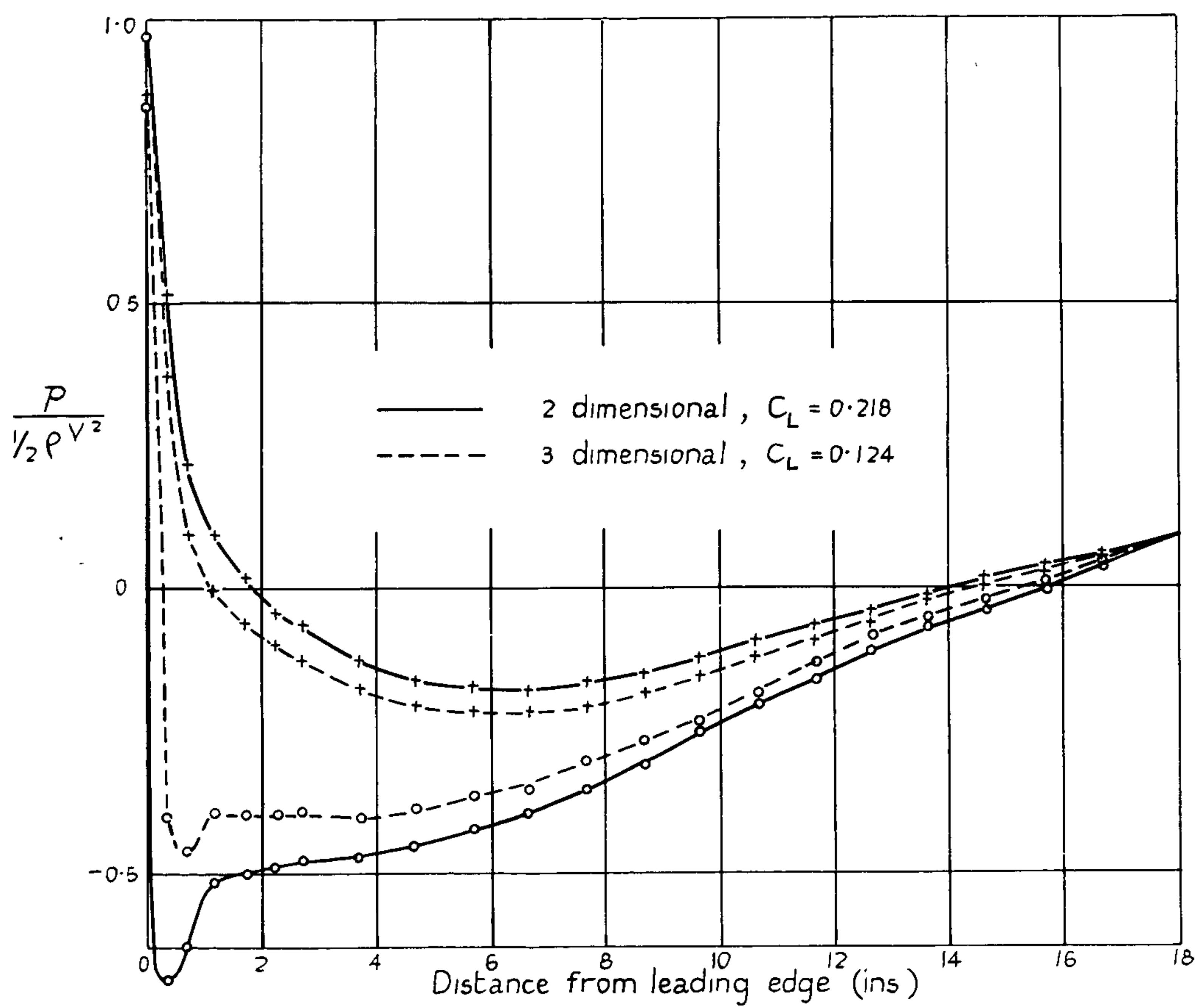
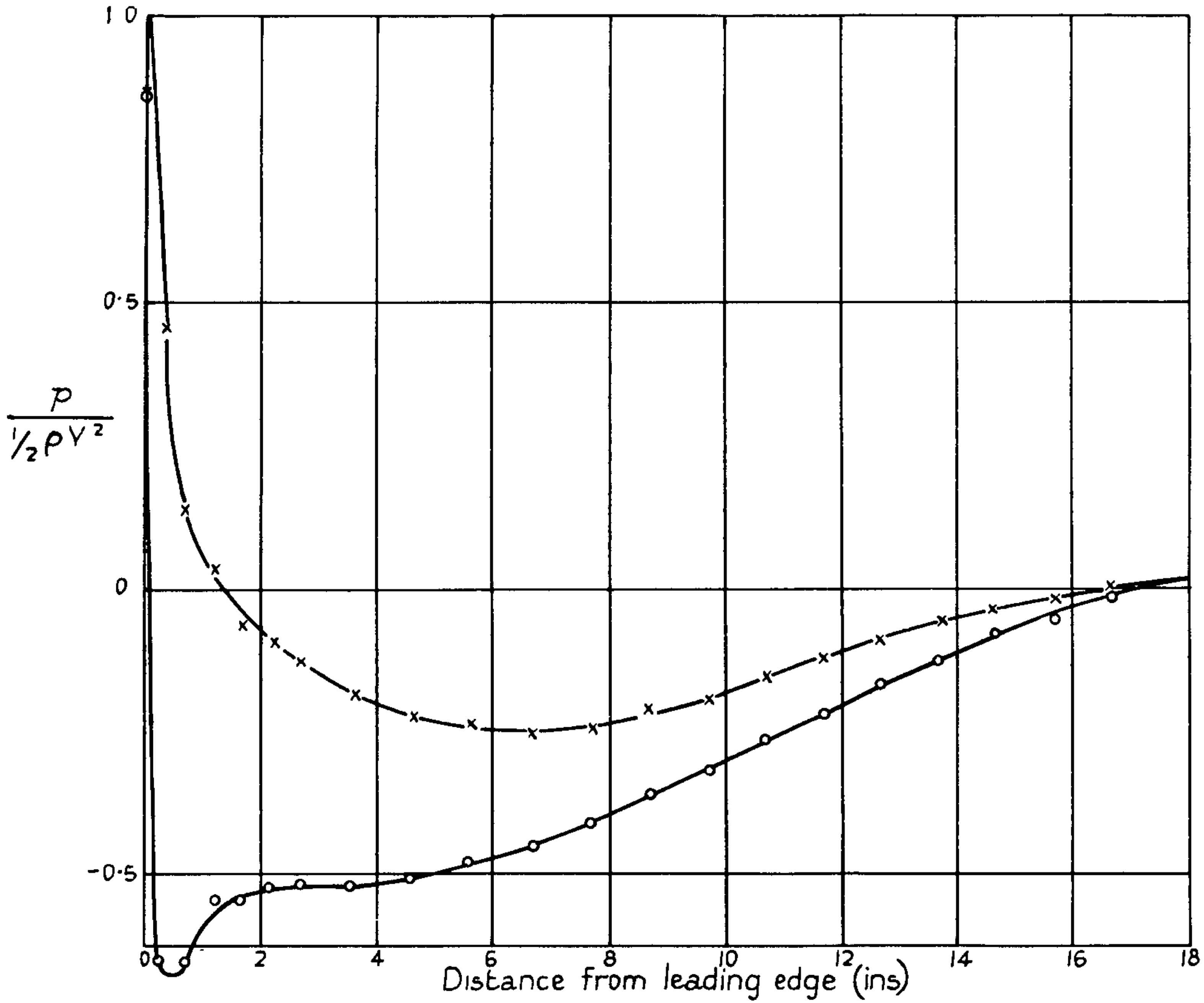


FIG 1.

Pressure plotting 18 in chord RAE 102
Angle of incidence 2 deg

FIG. 2

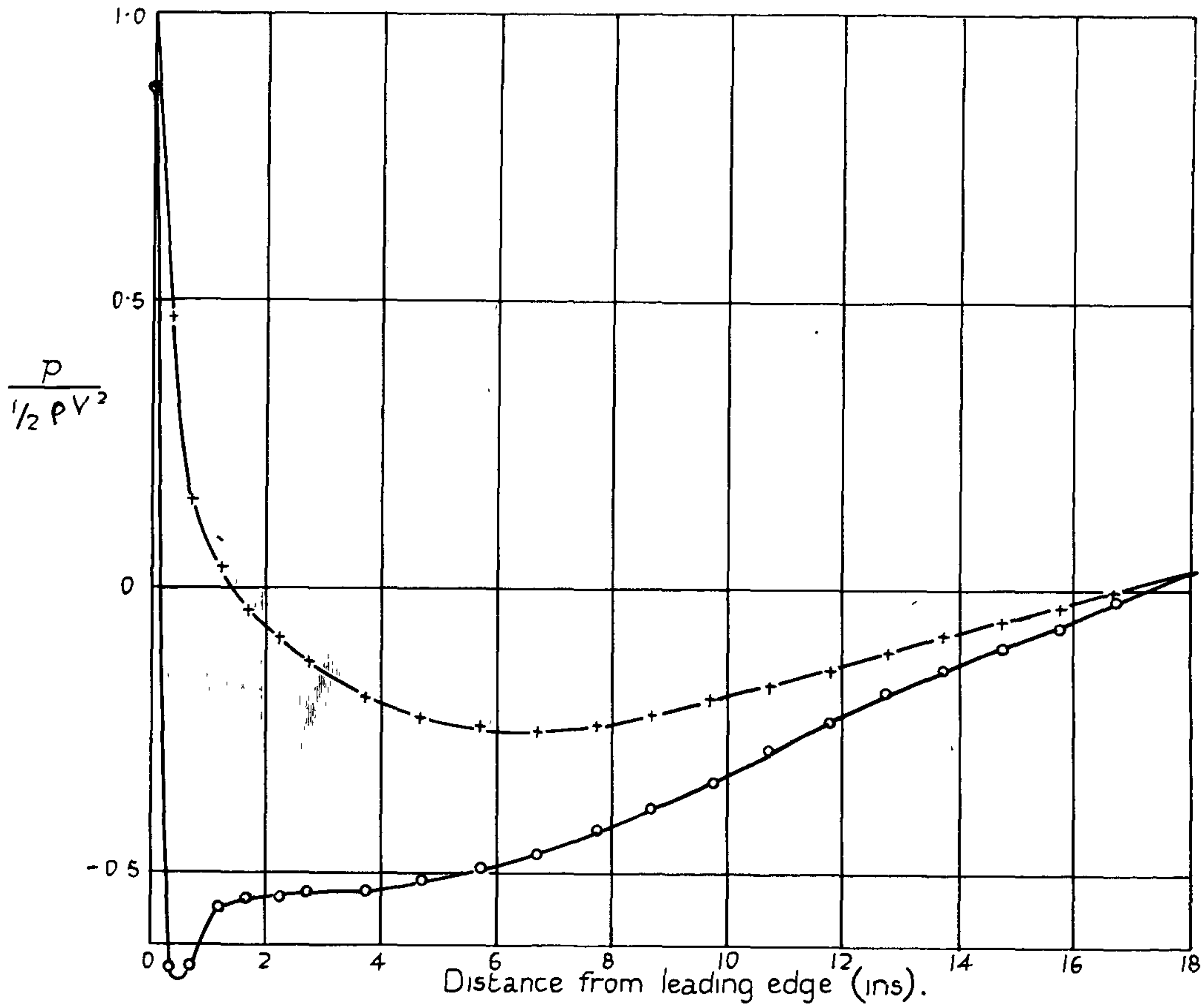


Pressure plotting RAE. 102

36 in wide plates from roof to floor at ends of wing

$C_L = 0.208$ $\alpha = 2°$

FIG 3.

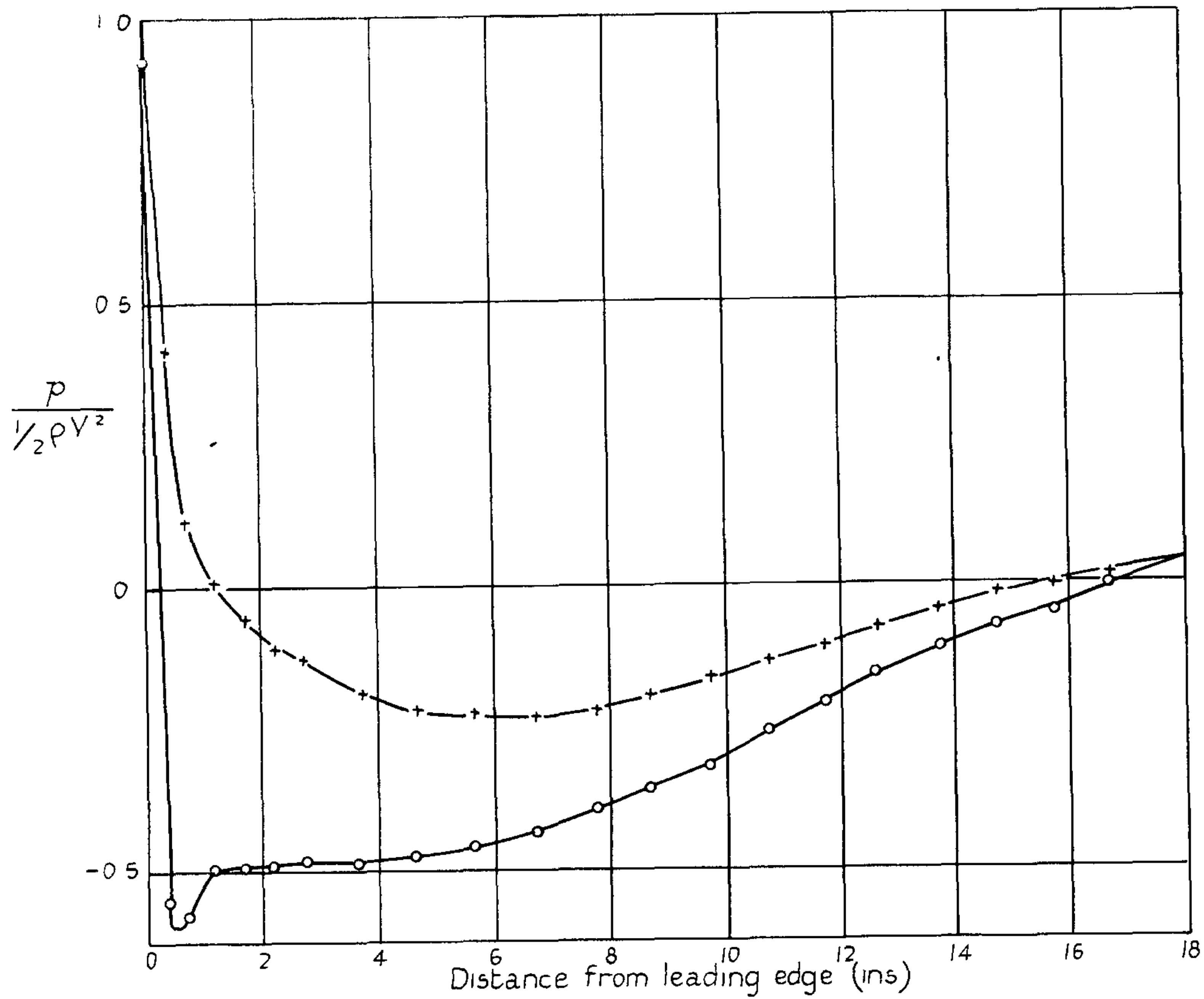


Pressure plotting R A E 102

36 in wide plates from roof to floor 12 in inboard from wing tips

$C_L = 0.212$, $\alpha = 2^\circ$

FIG 4

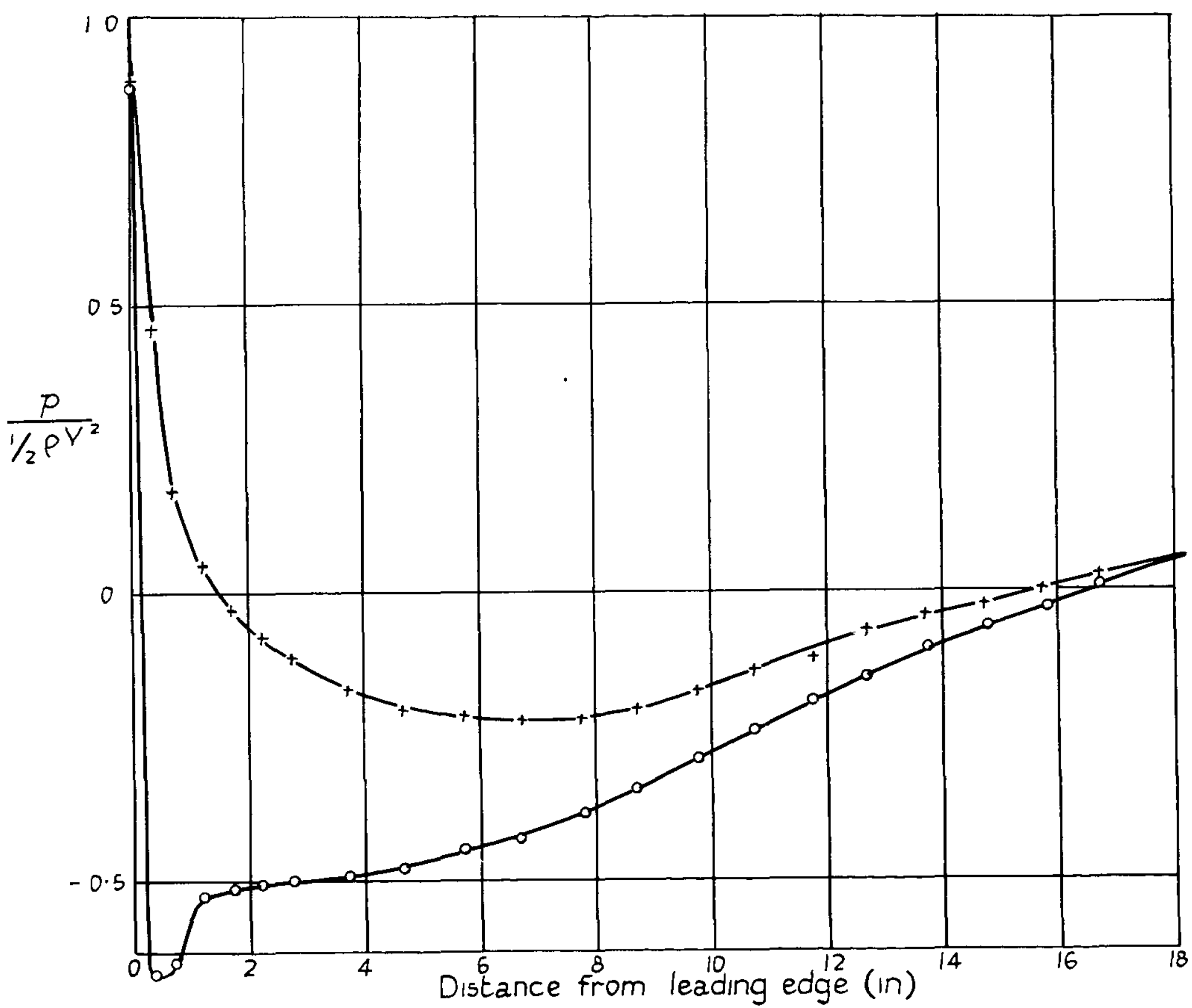


Pressure plotting R A E 102

36 in wide plates placed 12 in inboard extending from upper surface to roof of tunnel

$C_L = 0{\cdot}198$, $\alpha = 2°$

FIG 5



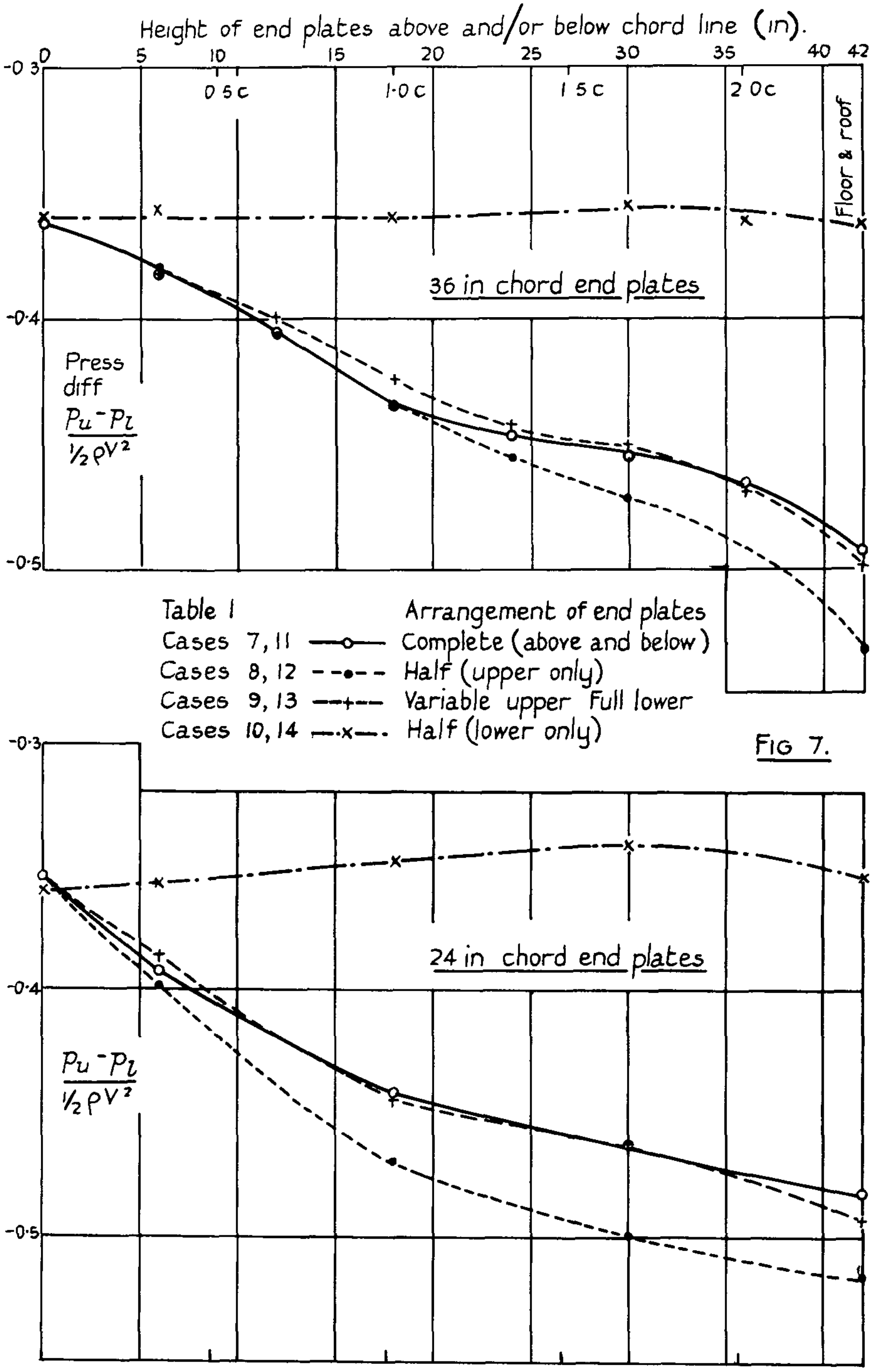
Pressure plotting R A E 102

24 in wide plates from roof to floor at ends of wing

$C_L = 0{\cdot}202$, $\alpha = 2^\circ$.

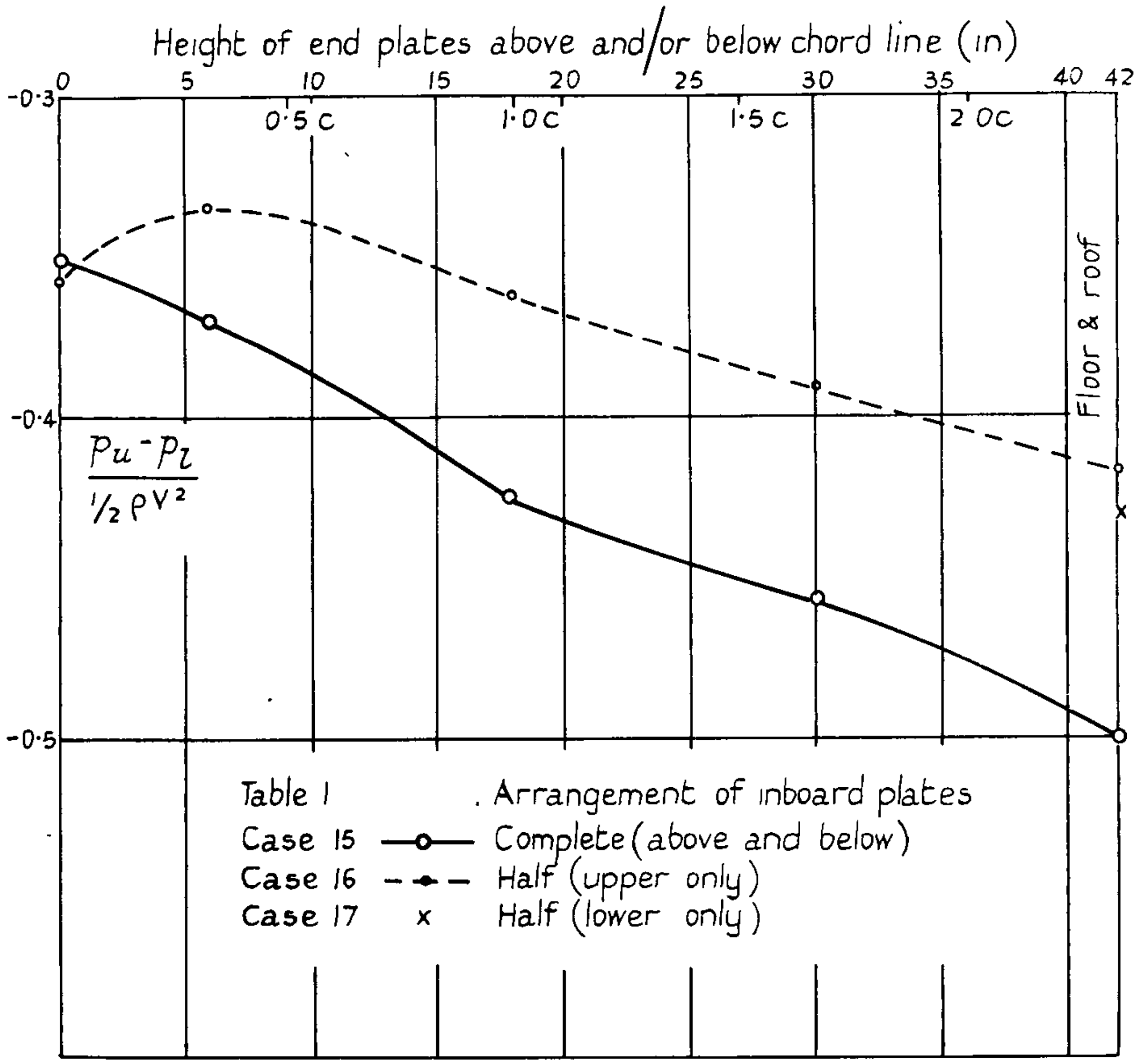
FIGS 6 & 7.

FIG 6.



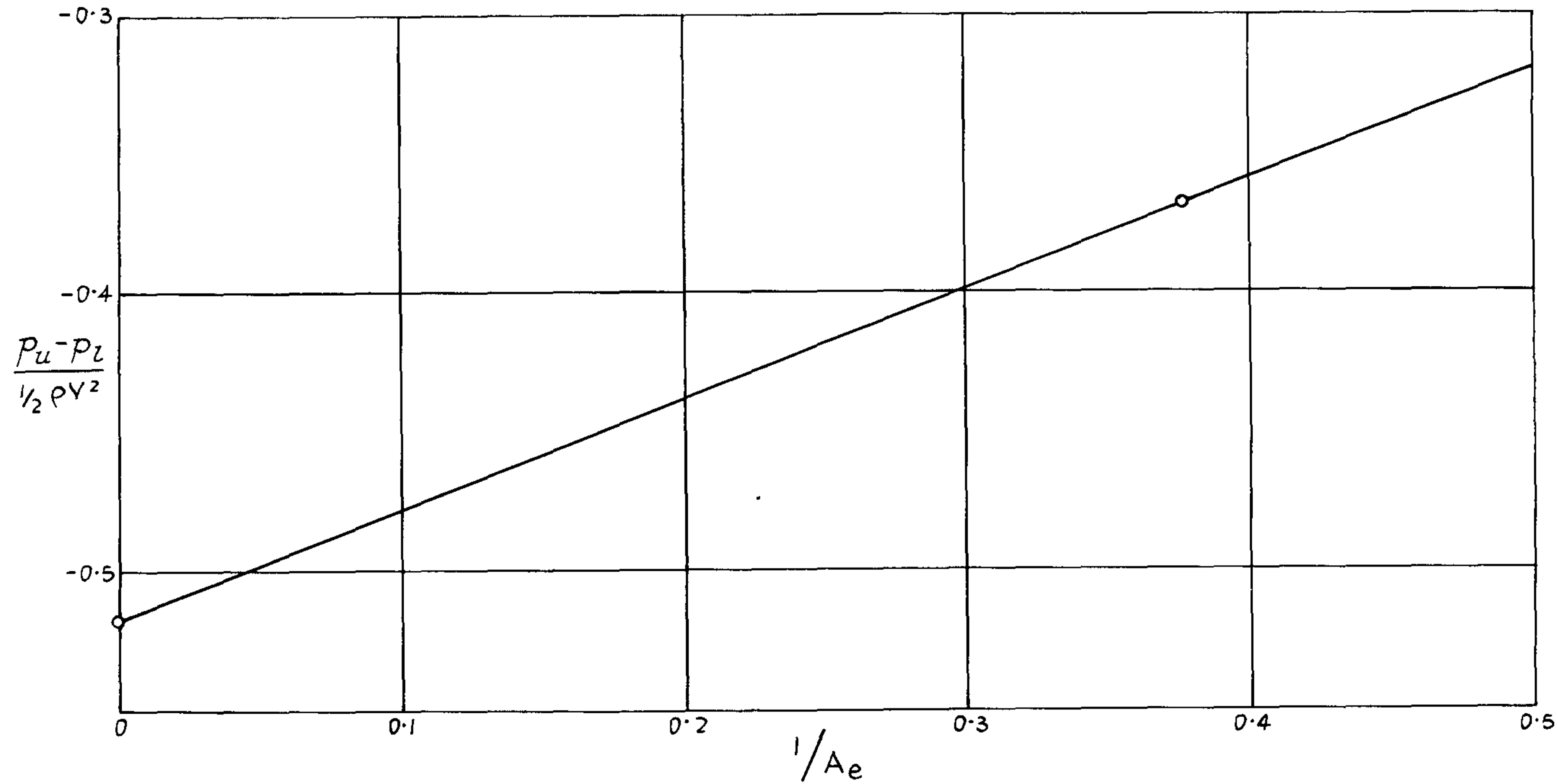
Effect of varying height of end plates on pressure differences at 0·1 c, α = 2 deg

FIG. 8.

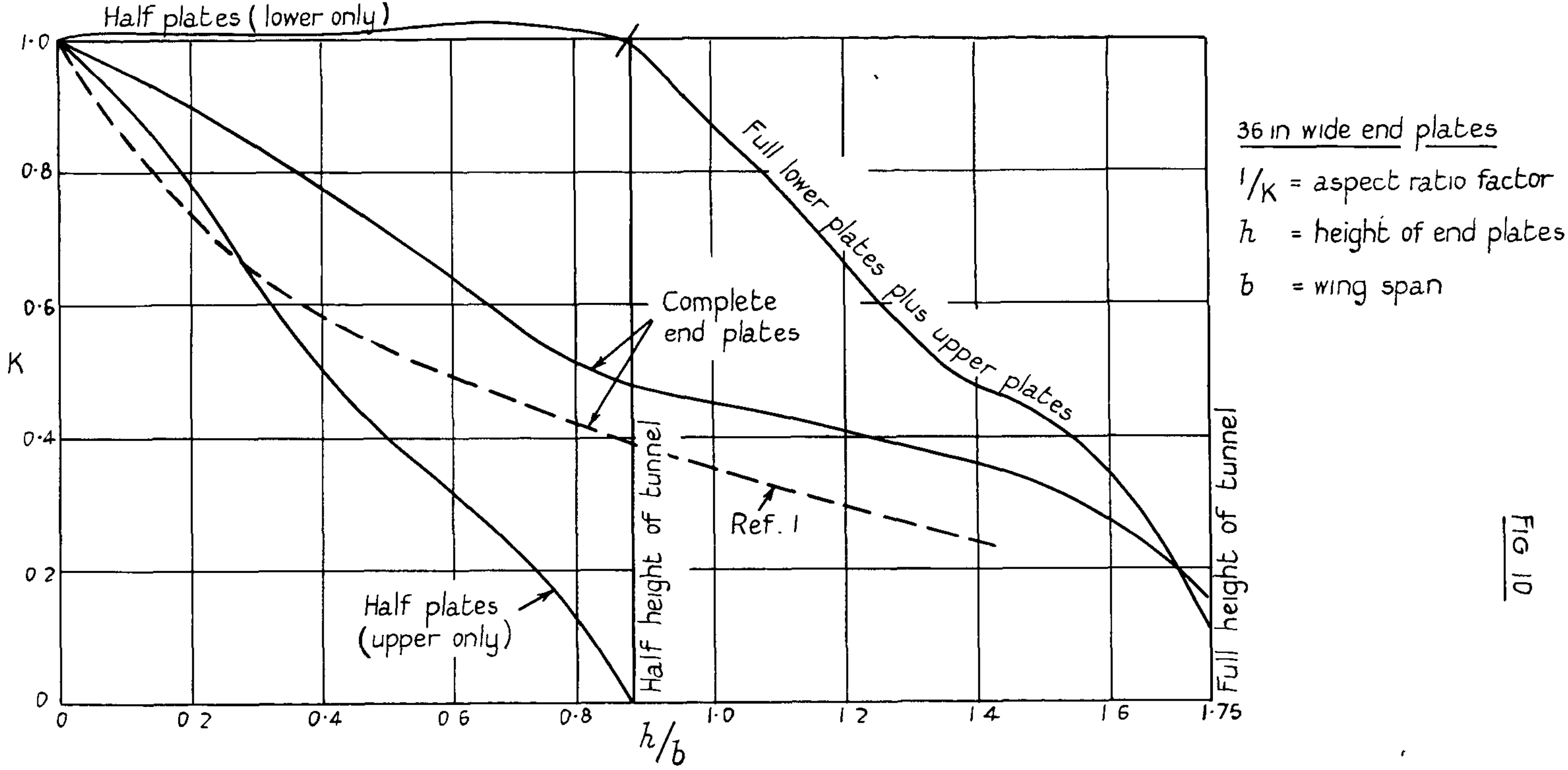


Effect of varying height of end plates on pressure differences at 0·1 c, α = 2 deg.

FIG 9

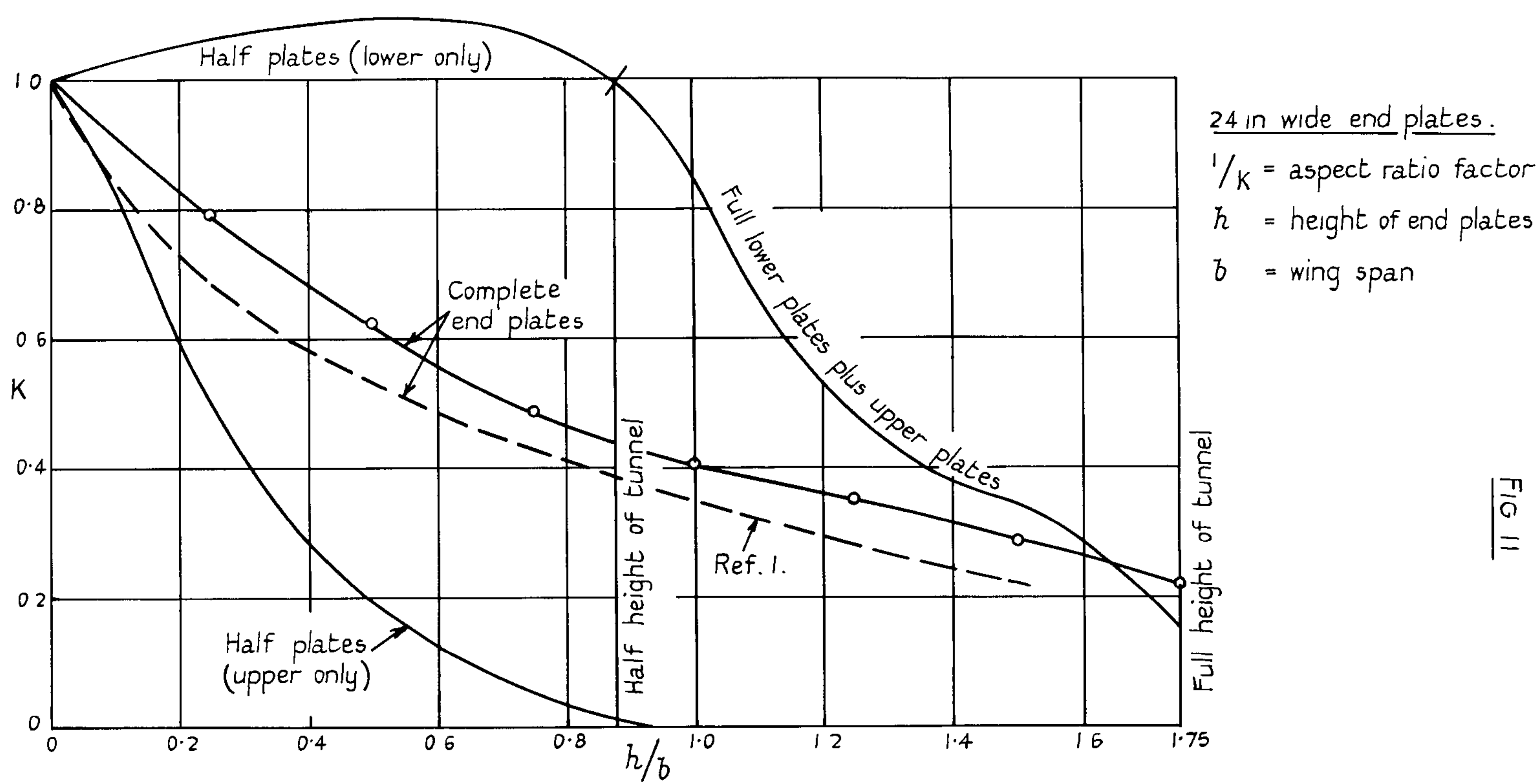


Variation of pressure differences at 0·1c with aspect ratio



Aspect ratio factor.

FIG 10



Aspect ratio factor.

FIG 11

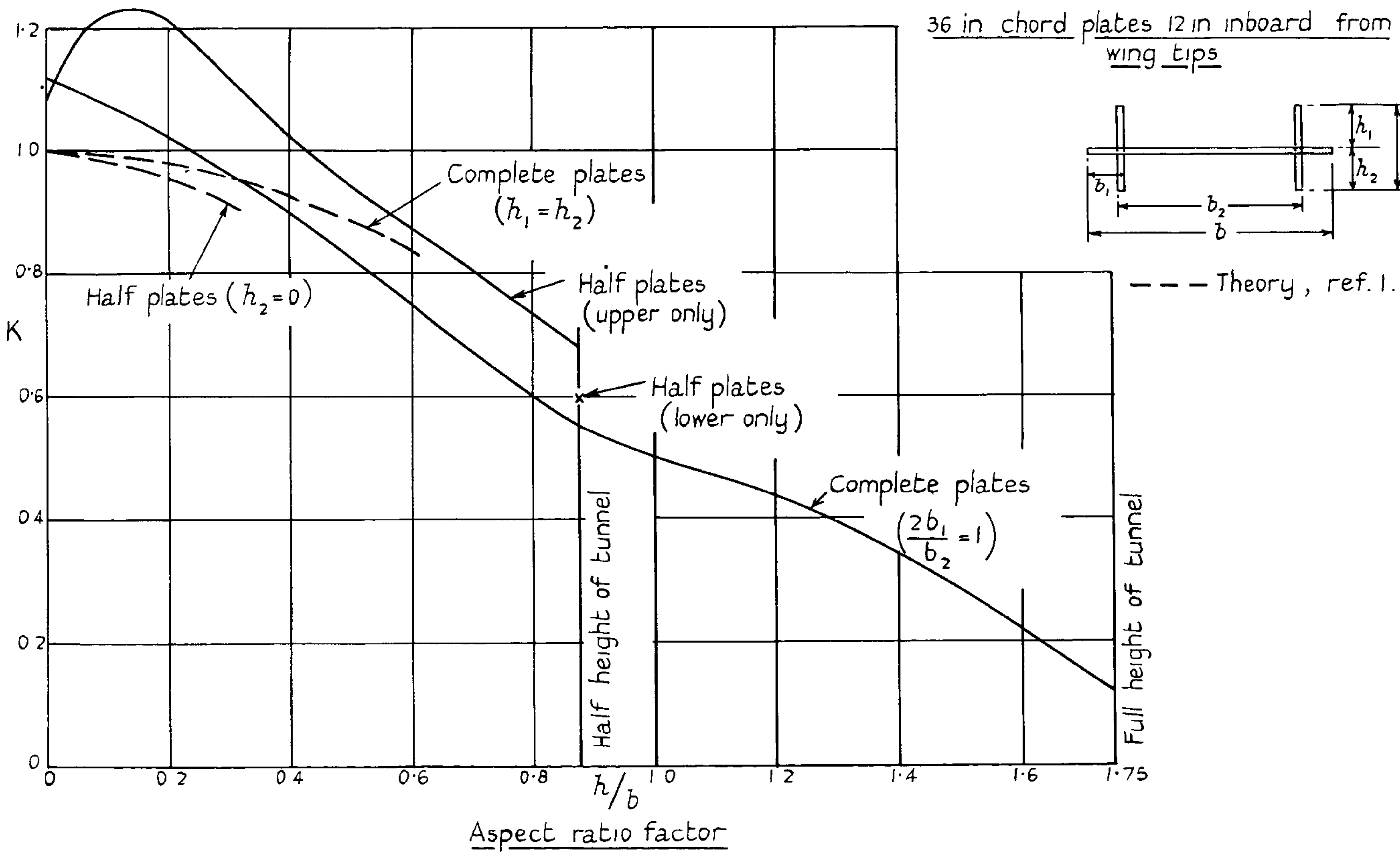

36 in chord plates 12 in inboard from wing tips
h_1
h_2
h
b_1
b_2
b
Theory, ref. 1.
Complete plates ($h_1 = h_2$)
Half plates ($h_2 = 0$)
Half plates (upper only)
Half plates (lower only)
Complete plates ($\frac{2b_1}{b_2} = 1$)
Half height of tunnel
Full height of tunnel
K
1·2
1·0
0·8
0·6
0·4
0·2
0
0
0·2
0·4
0·6
0·8
1·0
1·2
1·4
1·6
1·75
h/b
Aspect ratio factor

FIG 12.

C.P. No. 305
(17,755)
A.R.C. Technical Report

Printed and published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
P.O. Box 569, London S.E.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
Tower Lane, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast
or through any bookseller

Printed in Great Britain

S.O. Code No. 23-9010-5

C.P. No. 305