C.P. No. 1016

C.P. No. 1016

MINISTRY OF TECHNOLOGY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Forces on Cone Cylinders at M = 3.98

by

K. C. Moore

LONDON: HER MAJESTY'S STATIONERY OFFICE

1968

PRICE 4s 6d NET

U.D.C. 533.6.013.13 : 533.6.013.152 : 533.696.34 : 533.6.011.5 : 518.4

C.P. 1016*
November 1967

FORCES ON CONE CYLINDERS AT M = 3.98

by

K.C. Moore

SUMMARY

Normal force and pitching moment have been measured on a number of cone cylinder combinations at a Mach number of 3.98 in the 3 ft × 4 ft High Supersonic Speed Tunnel. The results are presented graphically. Comparison is made with theoretical predictions for the same quantities at small incidence based on second order generalized shock expansion theory, and with semi-empirical estimates based on the Data Sheets of the Royal Aeronautical Society.

* Replaces R.A.E. Technical Report 67301 - A.R.C. 30294.

CONTENTS

	Page
1 INTRODUCTION	3
2 MODEL GEOMETRY	3
3 TEST CONDITIONS	3
4 PRESENTATION OF RESULTS	4
5 DISCUSSION	4
Table 1	6
References	7
Illustrations	Figures 1-2
Detachable abstract cards	-

1 INTRODUCTION

A series of bodies of revolution, each consisting of a right circular cone (the nose) followed by a circular cylinder of the same diameter (the body) has been tested in the 3 ft × 4 ft tunnel (High Supersonic Speed Tunnel) at R.A.E. Bedford[1,2] at a Mach number of 3.98. An internal strain gauge balance was used to measure normal force and pitching moment*. The tests were not completed, but such results as were obtained are presented herein.

2 MODEL GEOMETRY

The shapes tested had four nose shapes each combined with a number of bodies of different lengths. Body diameter was 4 inches in all configurations. Two of the noses consisted of cones of length 8 and 16 inches (2 and 4 diameters); the other two were obtained from these shapes by rounding the apex to a spherical cap of radius 0.4 inches to which the basic cones are tangential. Typical configurations are illustrated in Fig.1. The configurations tested are listed in the Table.

Some of the configurations were tested both with and without a roughness band consisting of $\frac{1}{4}$ inch width of 36 grade carborundum grit at a distance of 1 inch from the apex of the nose. These are referred to as "transition fixed" and "transition free". This roughness had no significant effect on the quantities presented here.

3 TEST CONDITIONS AND ACCURACY

The models were tested at a Mach number of 3.98, a total pressure of 220 in.Hg and a total temperature of 313°K, giving a Reynolds number based on body diameter of 3.3×10^{6}.

Angle of incidence is measured in the 3 ft by 4 ft tunnel to an accuracy of $\pm 0.05^{\circ}$. Fluctuations in tunnel stagnation pressure which the Midwood manometer is unable to follow produce errors in its measurement of about 0.25 in.Hg at 220 in.Hg or about 0.1%. Static calibration of the strain gauge balance and the self balancing potentiometer system shows them to have an accuracy better than 1%. However, the accuracy was also estimated under dynamic conditions by repeating a number of readings at the same nominal conditions. The standard deviation of the differences of the normal force coefficients was 0.009, or 0.6% of the maximum value for that particular

---

*Axial force also was measured, but because of errors in base pressure measurement the results do not warrant publication.

model, and this is a rather larger value than would be expected from the estimates of static error given above. The difference is probably due to unsteadiness of the flow direction in the working section, which has been observed as an unsteady signal on the self balancing potentiometers but has not been measured accurately. These dynamic measurements lead one to expect random errors of greater than 0.027 in normal force coefficient to occur on 5% of the readings.

4 PRESENTATION OF RESULTS

Fig.2 consists of plots against incidence of normal force coefficient based on body cross sectional area (C_Z = (normal force)/(kinetic pressure) × (cross sectional area)) and centre of pressure position in body diameters behind the nose (C.P. = (pitching moment)/(normal force) × (body diameter)). The reference point on the models with rounded noses is the (virtual) apex of the conical portion of the nose (see Fig.1). Also presented are the normal force and centre of pressure positions for the pointed configuration calculated by the second order generalized shock expansion method of Syvertson and Dennis[3] (chained lines), and the centre of area of the configuration projected normal to the axis (dotted line); and the normal force and centre of pressure positions predicted for these shapes over the range of incidence by Ref.4 (continuous line).

Results for both round nosed and pointed versions, where these have been determined, are plotted on one graph. So also are the "transition fixed" and "transition free" results.

5 DISCUSSION

Over the linear range of incidence ($\pm 5^{\circ}$ say) shock expansion theory is seen to give a good prediction of the normal force. Its prediction of centre of pressure position is also thought to be good, though this is less obvious because of the large errors in the experimental determination of centre of pressure at low incidence and small normal force.

Above about 5° incidence non-linear effects are apparent and on the more slender configurations can contribute more than 50% of the normal force. The semi-empirical method of Ref.4 agrees well with the measured normal force results over this range, particularly for the less slender configurations. The centre of pressure positions given by Ref.4, though better than the estimates by shock expansion theory, are good only for order of magnitude predictions, differing by as much as half a diameter from the measured positions in some cases.

The centre of projected area is included on the plots of centre of pressure since one might reasonably expect the two to coincide at 90° incidence. However it seems to have little significance over the range of incidence tested.

Table 1

LIST OF CONFIGURATIONS TESTED

Designation	Nominal Nose length (body diameters)	Body length (body diameters)	Nose type
22 P	2	2	Pointed
22 R	2	2	Round
23 P	2	3	Pointed
24 P	2	4	Pointed
25 P	2	5	Pointed
25 R	2	5	Round
26 P	2	6	Pointed
26 R	2	6	Round
28 P	2	8	Pointed
42 P	4	2	Pointed
42 R	4	2	Round
43 P	4	3	Pointed
44 P	4	4	Pointed
45 P	4	5	Pointed
45 R	4	5	Round
46 P	4	6	Pointed
46 R	4	6	Round

REFERENCES

No.	Author	Title, etc.
1	D.R. Andrews	Some notes on the model testing facilities afforded by the high-supersonic-speed wind tunnel at R.A.E. Bedford. R.A.E. Technical Note Aero 2582 (A.R.C. 20922) (1958)
2	D.R. Andrews C.S. Brown	Calibration of the flow in the Mach 4 working section of the 4 ft by 3 ft high-supersonic-speed wind tunnel at R.A.E. Bedford. R.A.E. Technical Note Aero 2820 (A.R.C. 24279) (1962)
3	Clarence A. Syvertson David H. Dennis	A second-order shock-expansion method applicable to bodies of revolution near zero lift. NACA Report 1328 (1957)
4	Royal Aeronautical Society	Aerodynamics Data Sheets Vol. 4

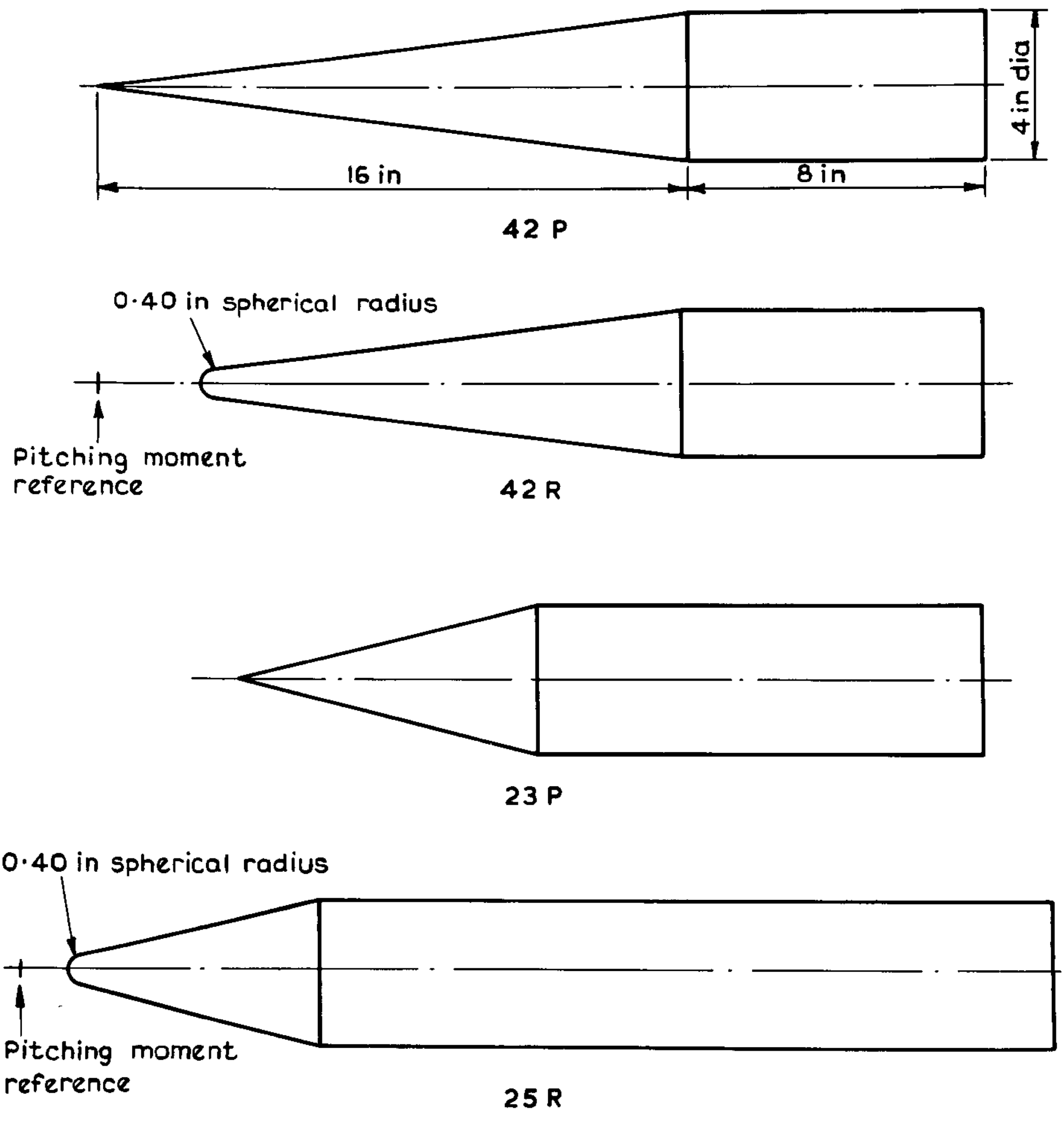

Fig.1 Typical model configurations

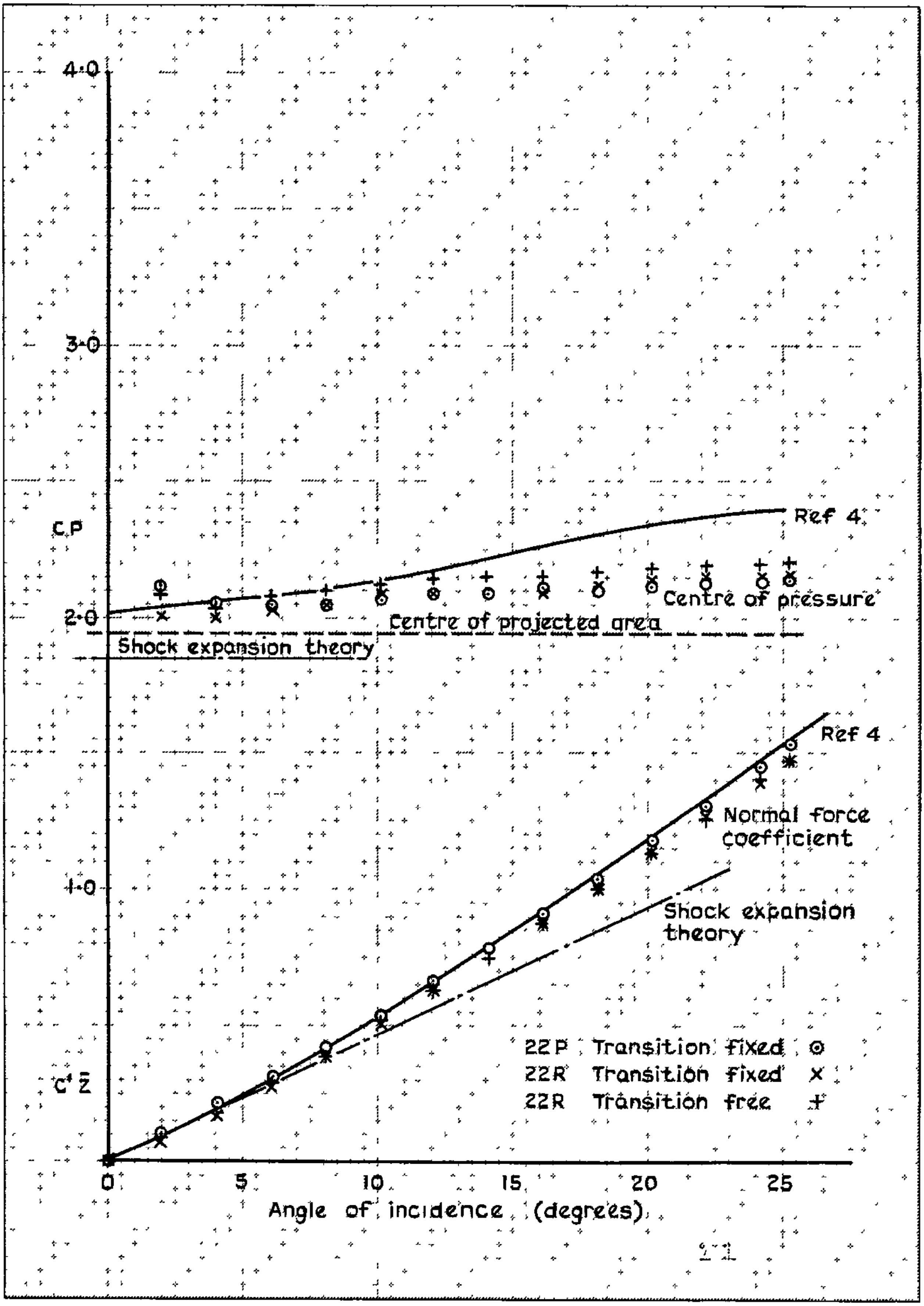

Fig. 2 Normal force and centre of pressure
Configurations 22 P and R

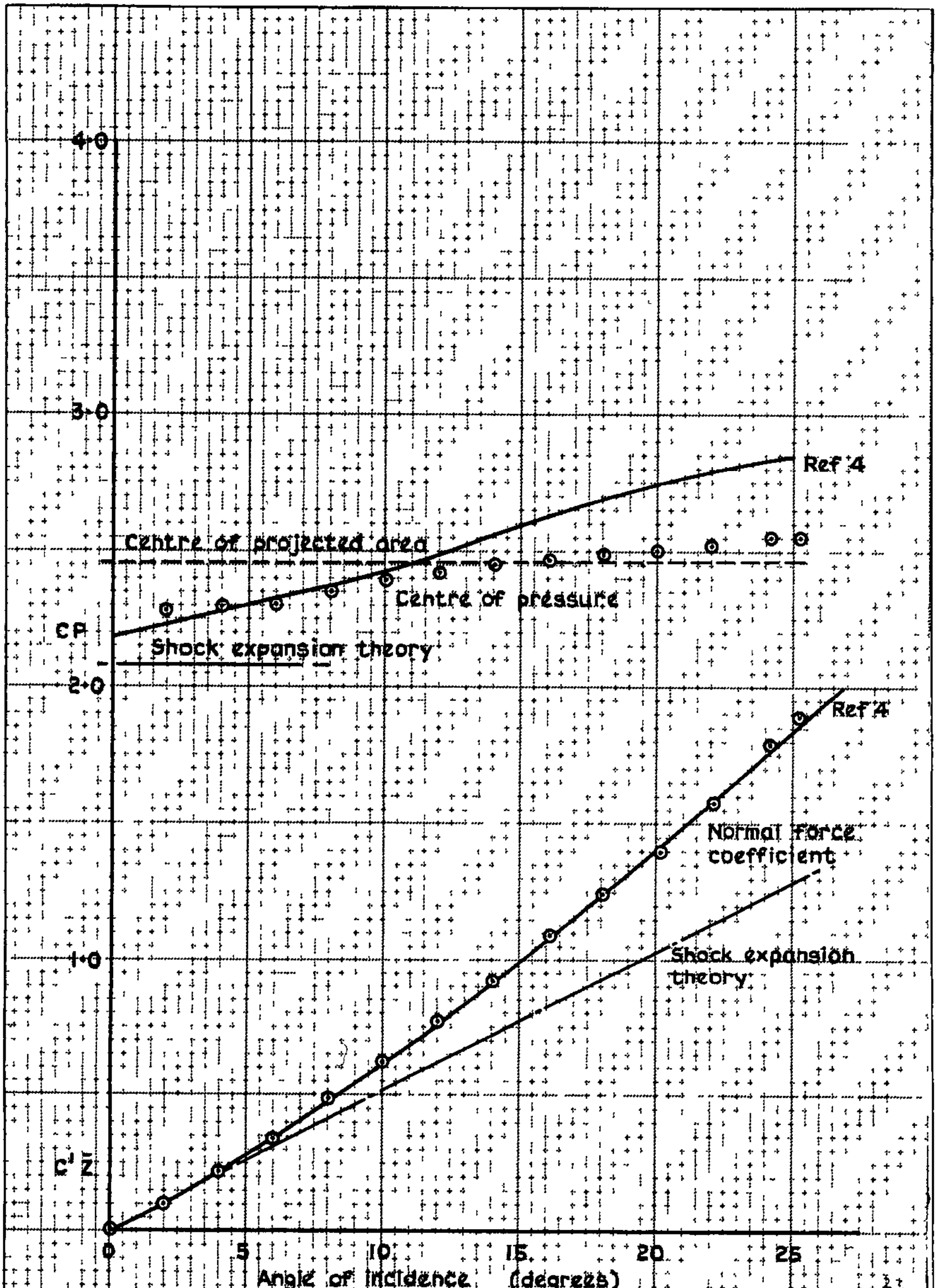

Fig. 2 contd Normal force and centre of pressure
Configuration 23 P transition fixed

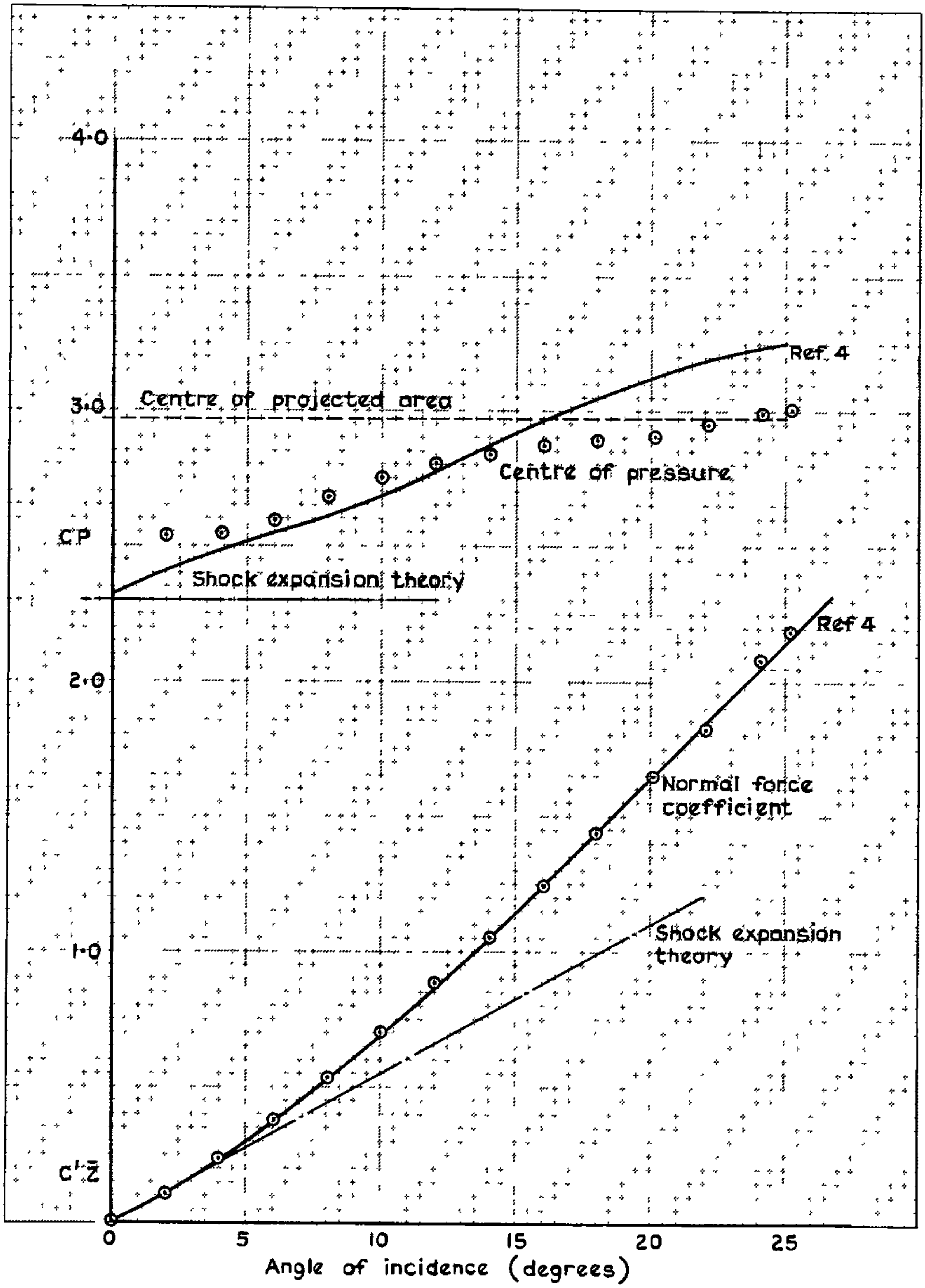

Fig. 2 contd Normal force and centre of pressure
Configuration 24 P transition fixed

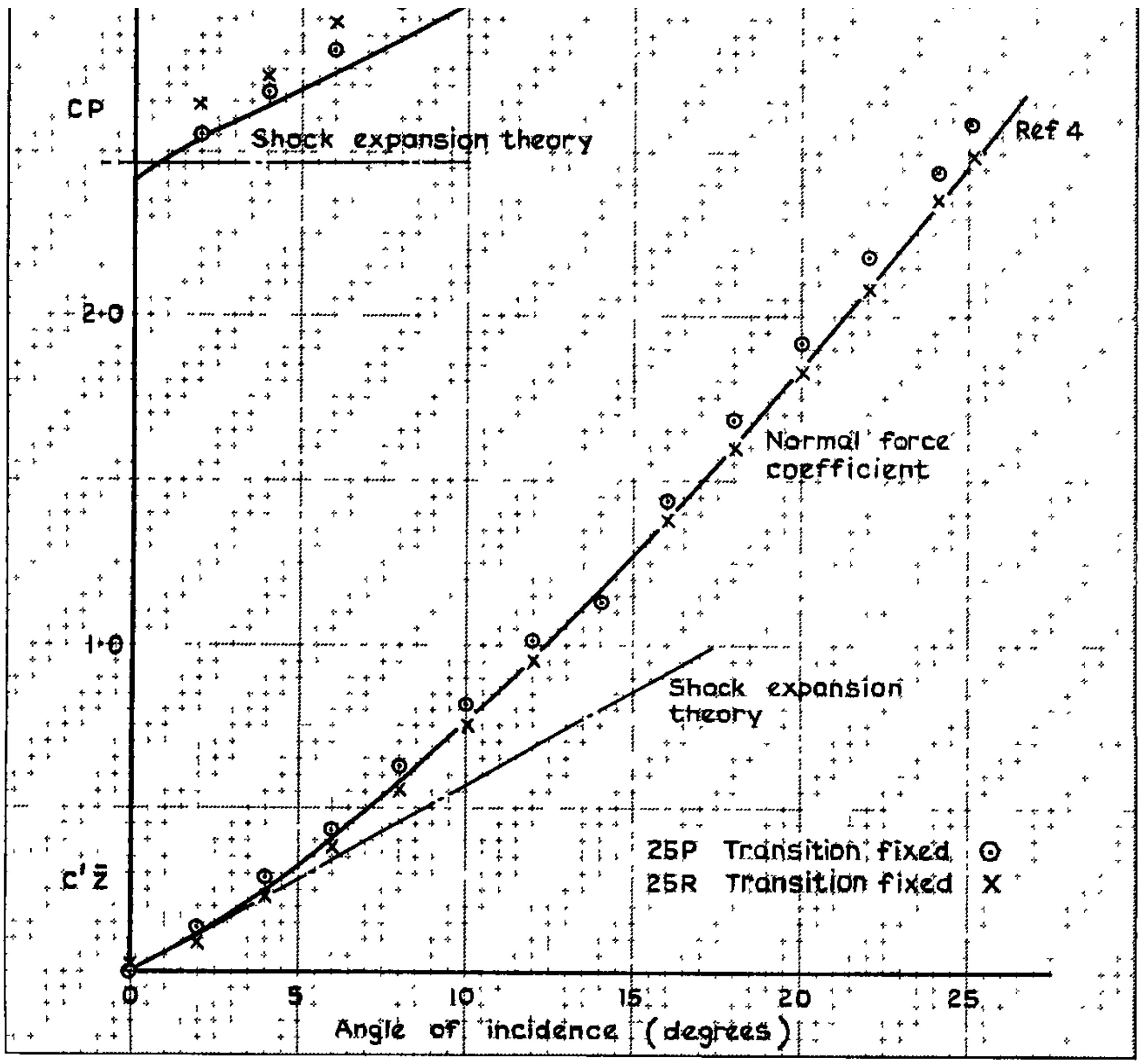

Fig. 2 contd Normal force and centre of pressure
Configurations 25 P and R

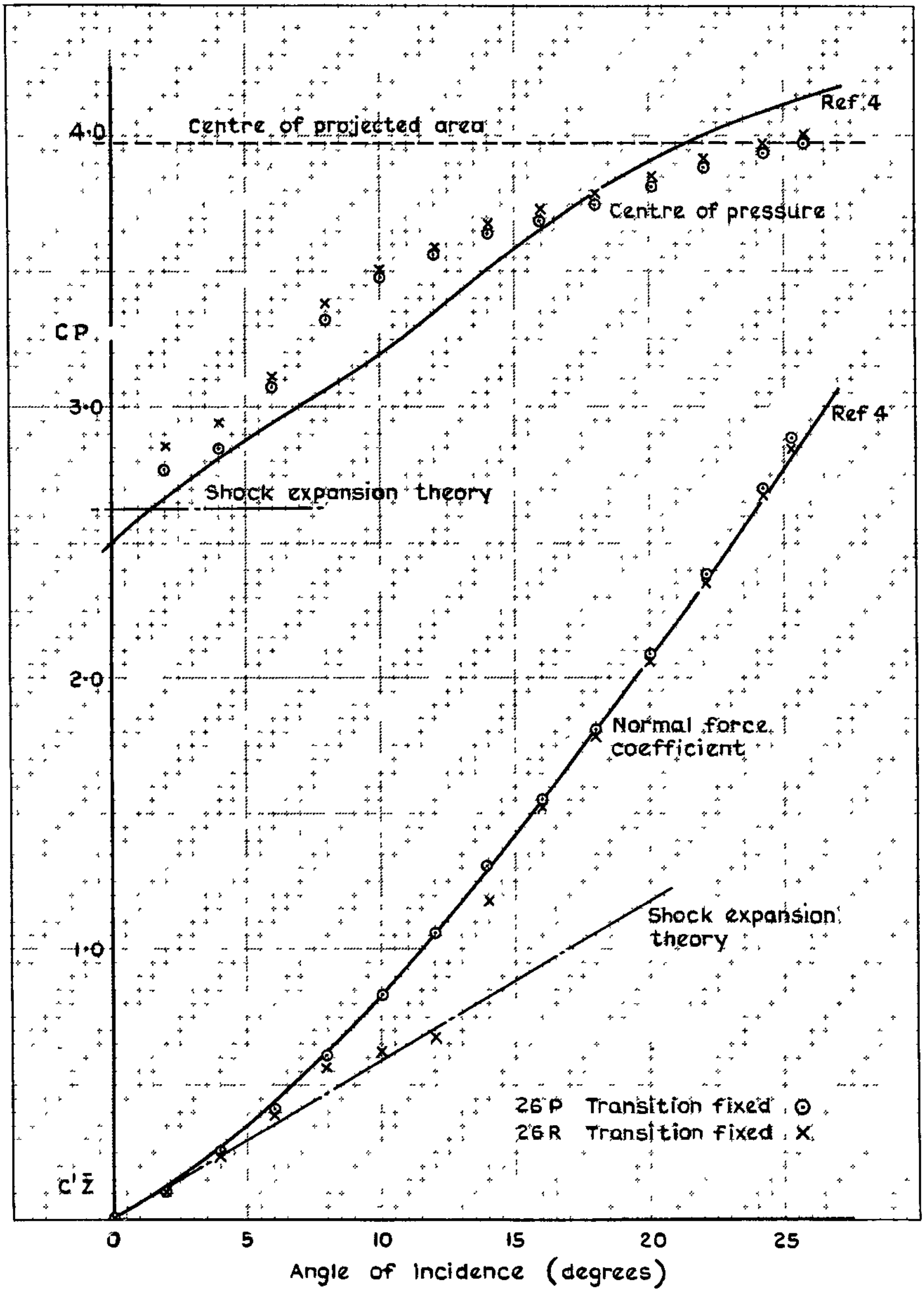

Fig. 2 contd Normal force and centre of pressure
Configurations 26 P and R

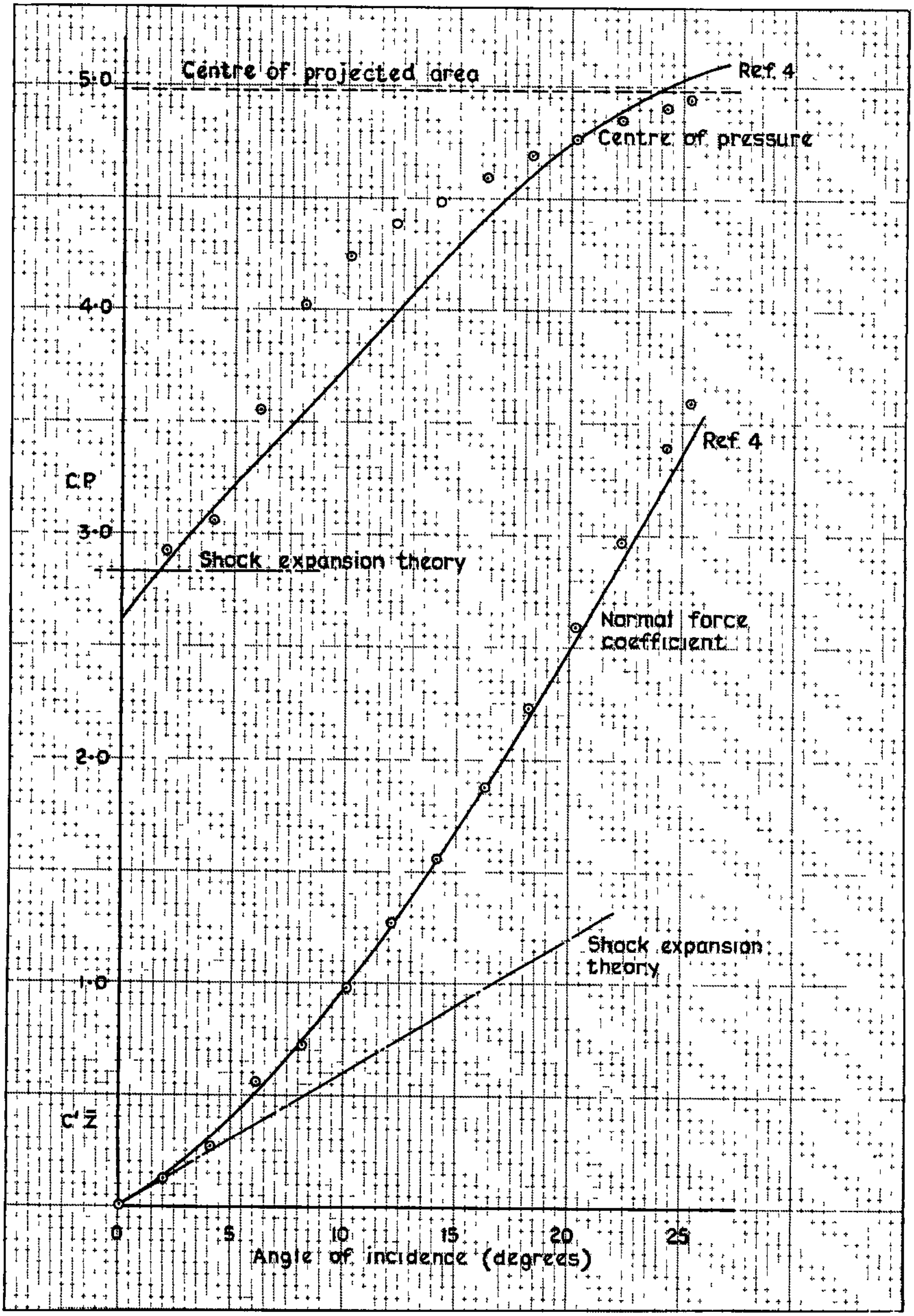

Fig.2 contd Normal force and centre of pressure
Configuration 28P transition fixed

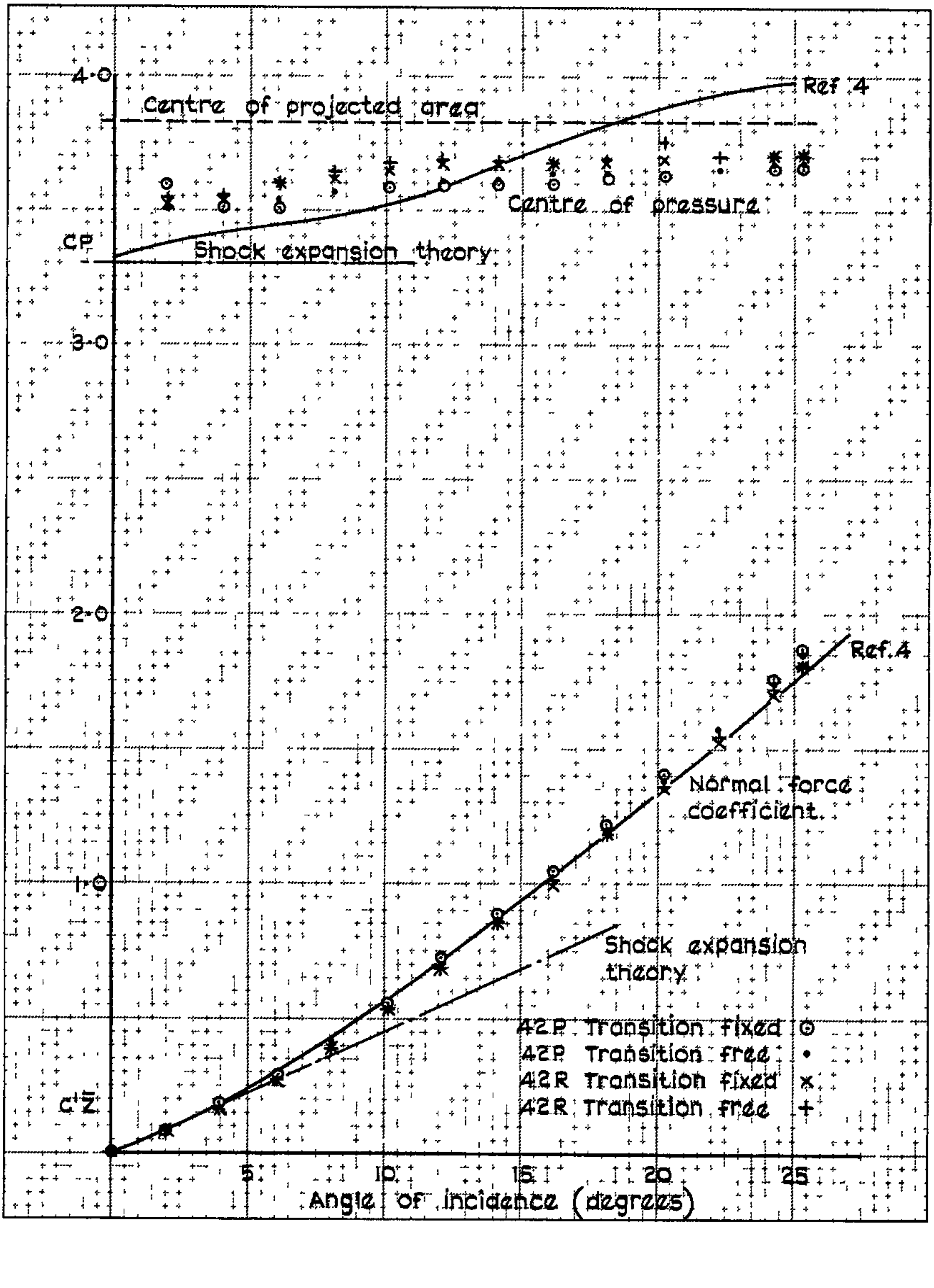

Fig. 2 contd Normal force and centre of pressure
Configurations 42 P and R

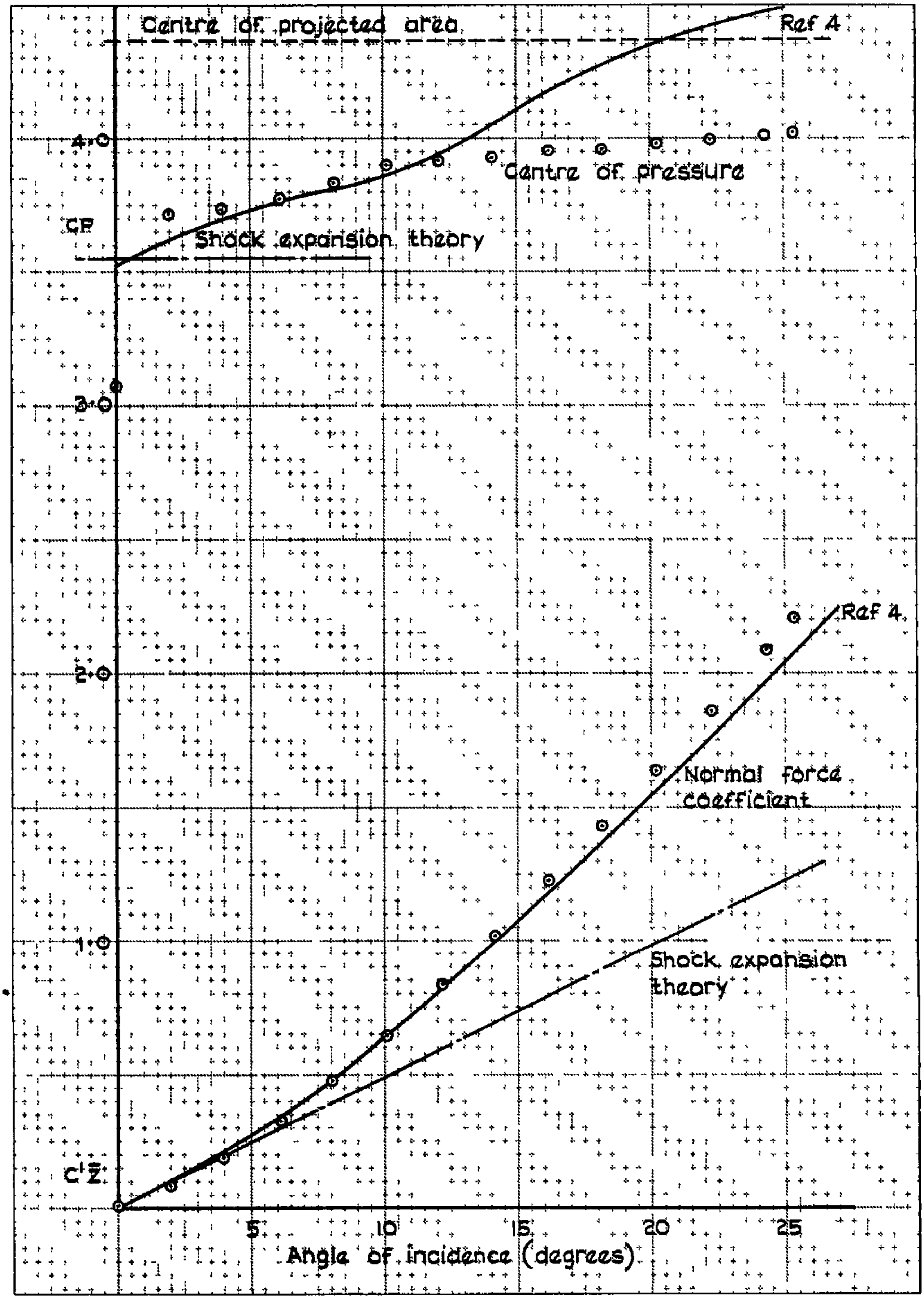

Fig. 2 contd Normal force and centre of pressure

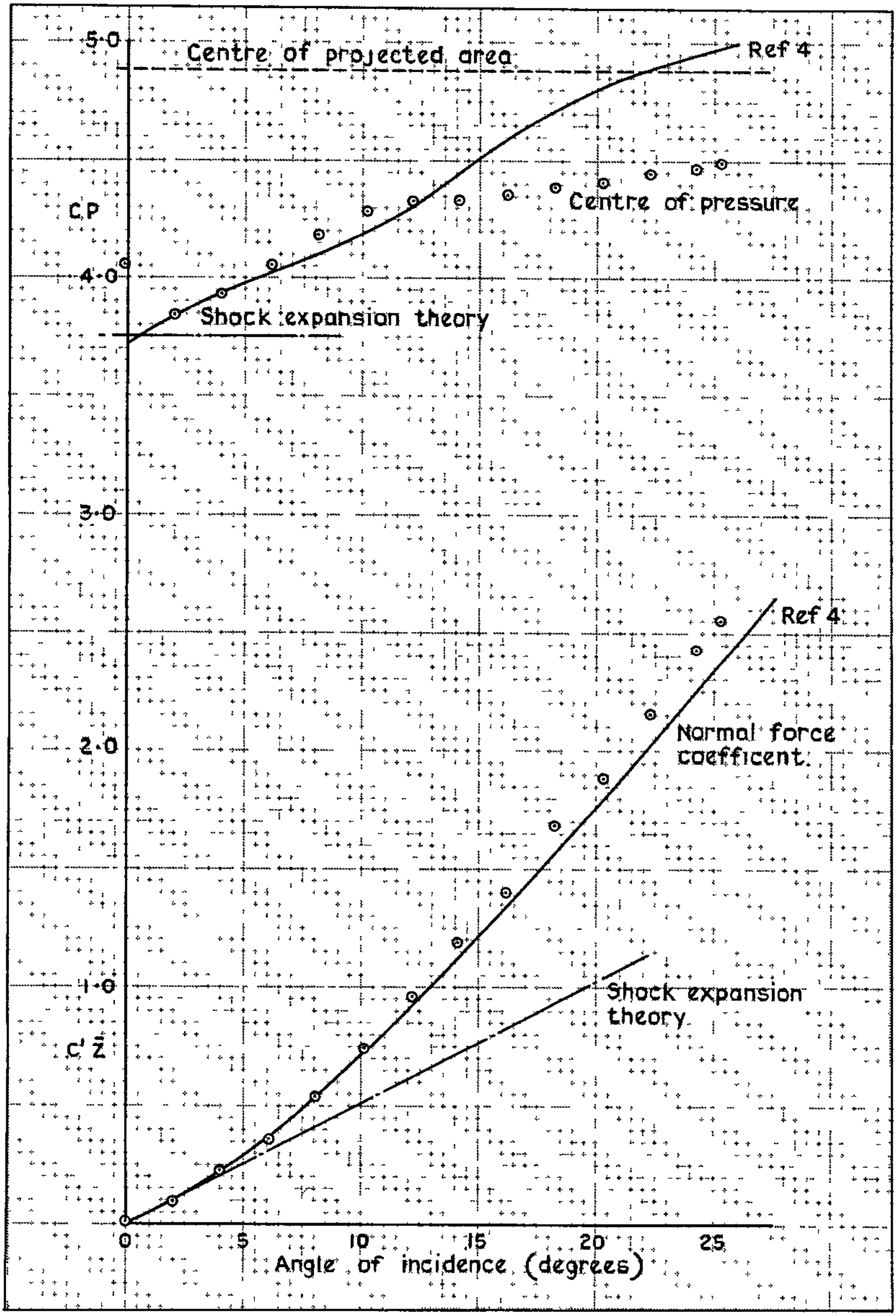

Fig. 2 contd Normal force and centre of pressure Configuration 44P transition fixed

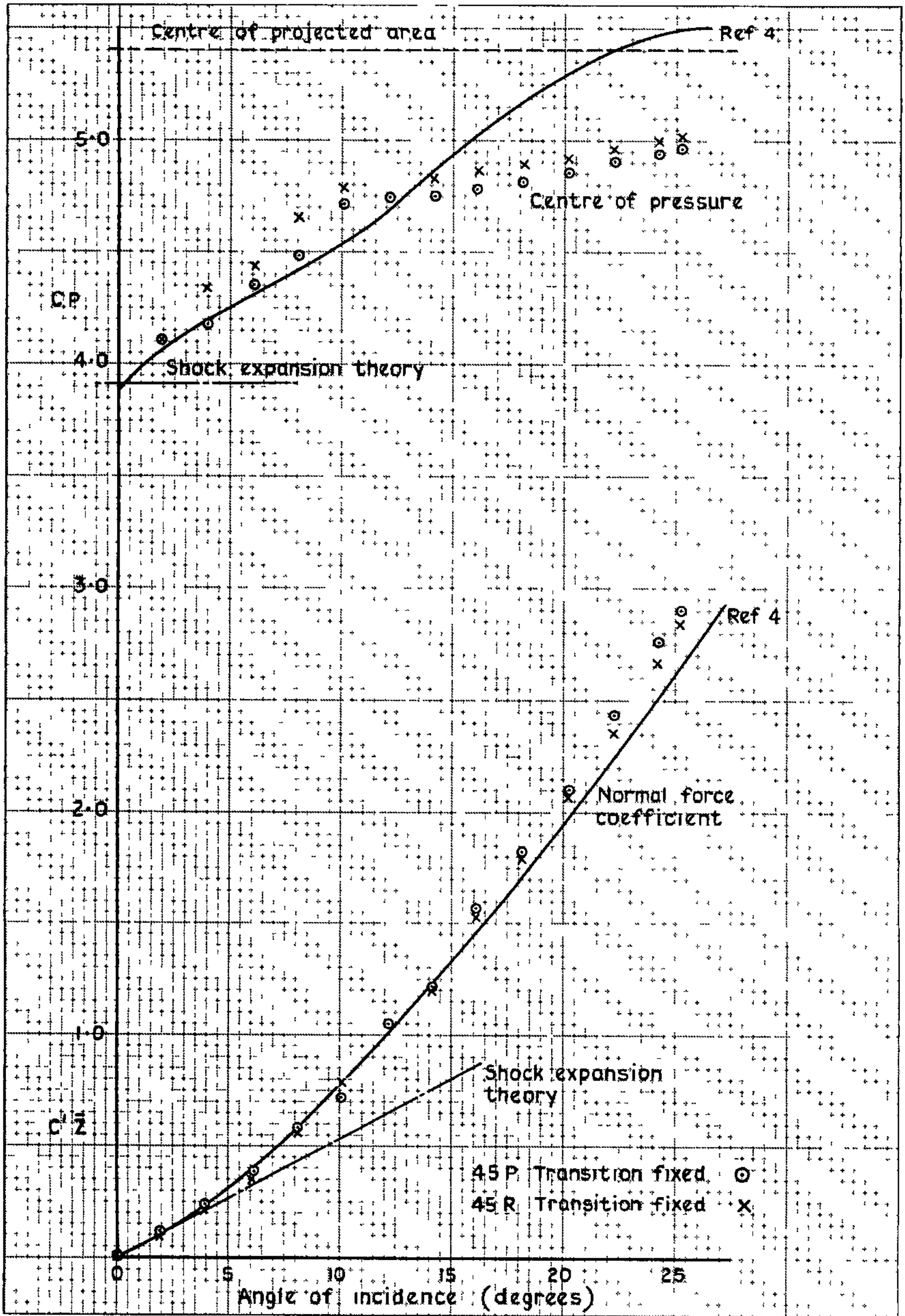

Fig.2 contd Normal force and centre of pressure Configurations 45 P and R

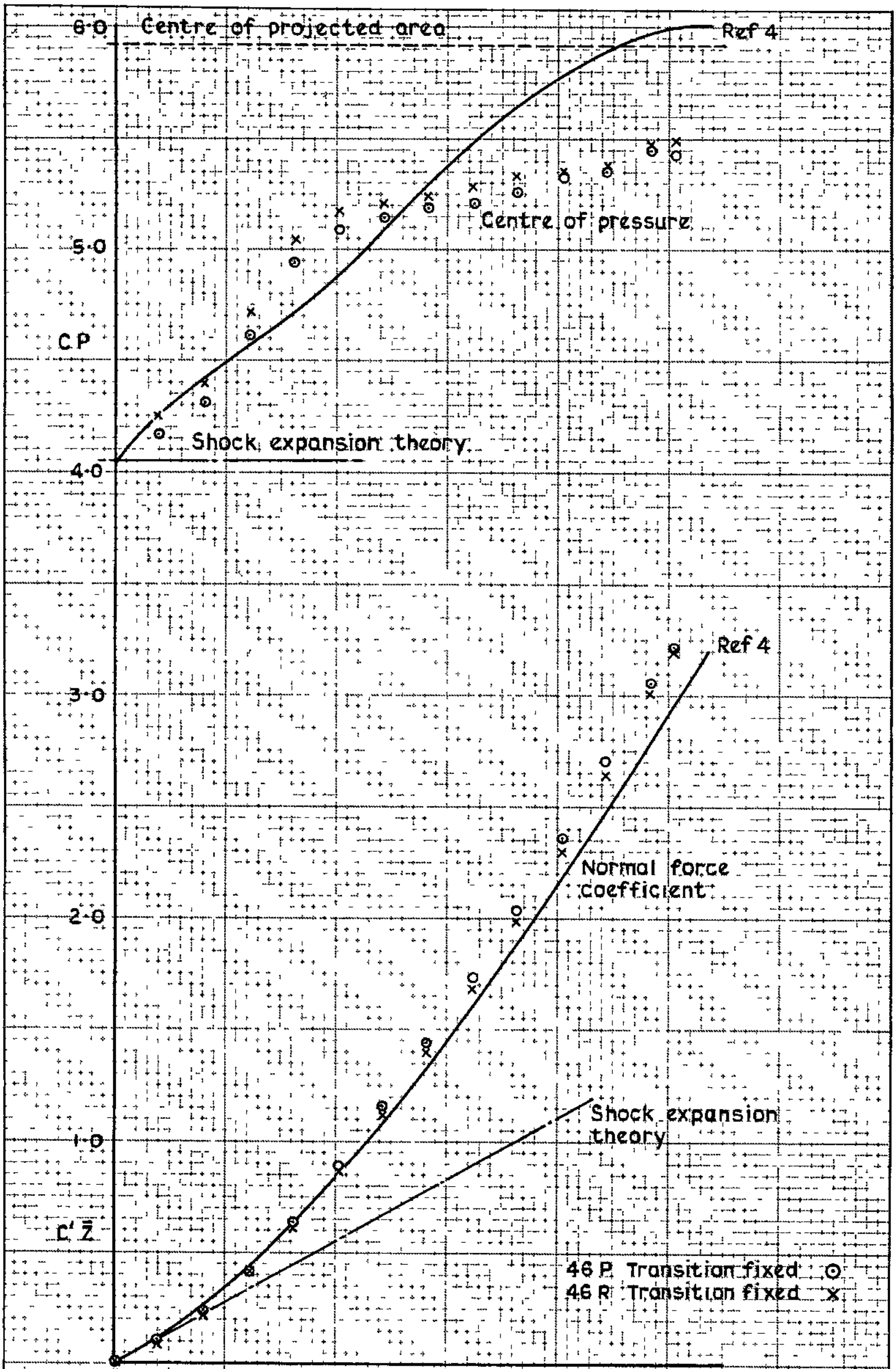

Fig.2 concld Normal force and centre of pressure Configurations 46 P and R

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. Dd.135645. K.3.

A.R.C. C.P. 1016
November 1967

533.6.013.13 :
533.6.013.152 :
533.696.34 :
533.6.011.5 :
518.4

Moore, K.C.

FORCES ON CONE CYLINDERS AT M = 3.98

Normal force and pitching moment have been measured on a number of cone cylinder combinations at a Mach number of 3.98 in the 3 ft x 4 ft High Supersonic Speed Tunnel. The results are presented graphically. Comparison is made with theoretical predictions for the same quantities at small incidence based on second order generalized shock expansion theory, and with semi-empirical estimates based on the Data Sheets of the Royal Aeronautical Society.

A.R.C. C.P. 1016
November 1967

Moore, K.C.

FORCES ON CONE CYLINDERS AT M = 3.98

Normal force and pitching moment have be
cylinder combinations at a Mach number o
Supersonic Speed Tunnel. The results ar
is made with theoretical predictions for
incidence based on second order generali
with semi-empirical estimates based on t
Aeronautical Society.

A.R.C. C.P. 1016
November 1967

Moore K.C.

FORCES ON CONE CYLINDERS AT M = 3.98

Normal force and pitching moment have be
cylinder combinations at a Mach number o
Supersonic Speed Tunnel. The results ar
is made with theoretical predictions for
incidence based on second order generali
with semi-empirical estimates based on t
Aeronautical Society.

Published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
49 High Holborn, London w c.1
423 Oxford Street, London w 1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
Brazennose Street, Manchester 2
50 Fairfax Street, Bristol 1
258-259 Broad Street, Birmingham 1
7-11 Linenhall Street, Belfast 2
or through any bookseller

C.P. No. 1016

S.O. CODE No. 23-9018-16