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A.R.C. Technical Report

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Instrumentation Used in Measurement of the Three Dimensional Flow in an Axial Flow Compressor

By

J. H, Horlock

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Instrumentation Used in Measurement of the Three Dimensional Flow in an Axial Flow Compressor

- By -

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March, 1955

Summary

Measurements of total pressure, static pressure and yaw angle between the blade rows of an axial flow compressor have been made with a variety of previously calibrated instruments and the results of these investigations are compared.

Good agreement between the instruments is obtained except in the boundary layers near the walls of the compressor.

Introduction

In the course of the current work on an axial flow compressor test rig presented to Cambridge University by Rolls Royce, Ltd., main emphasis has been centred upon the measurement of axial velocity profiles between the blade rows under a variety of flow conditions. Most of these measurements have been made with a three hole Fecheimer tube, which records yaw angle, and is calibrated to record total and static pressure. Measurements made with this three hole tube have been compared with others obtained with a variety of calibrated instruments.

These comparisons have been made by traversing the instruments radially in between the guide vane row and an adjacent rotating row. The circumferential position selected was that mid-way between the wakes of the guide vanes at the mean radius of the blade, this mean radius being located at a radius equal to 0.762 of the tip radius. The compressor tip radius is 7.0" and the hub-tip ratio 0.4. The compressor was run at a ratio of entry velocity (c_{x_0}) to blade speed at mean radius (U_m) of $\frac{c_{x_0}}{U_m} = 0.500$.

The various instruments were previously calibrated at the centre of a 4" brass pipe. Air was drawn through an airmeter into the pipe, and at the calibration cross-section the static pressure at the walls of the tube was compared with that recorded by the instruments. Total pressure as recorded by the instruments was compared with the barometric pressure. The yaw angle zero of the instrument relative to the traversing gear frame holding it was obtained by measuring the inclination of the gear and the pipe to the horizontal.

Instruments

The axial clearance between the blade rows of the compressor is small, and all instruments are required to pass through a traversing ring of 0.250 in. axial thickness in the compressor wall. This limited the axial length of the instruments to 0.200 in. and prohibited the use of conventional type pitot and static instruments. All the instruments were made of 0.125 in. tube and this tube was carried in the traverse gear shown in Fig. 1.

A/

A frame carrying the instrument may be traversed circumferentially, moving both the instrument and the traversing ring, and may be locked in any circumferential position. This motion has three point support - two conical pins tracking in a circumferential groove, and a spring loaded ball. The frame is strapped to a circumferential track which is in turn carried on two bars parallel to the longitudinal axis of the compressor.

Radial movement of the instrument through the drilling in the traversing rings of the compressor casing is obtained with a friction drive and yaw is obtained by rotating the graduated instrument mounting. A fine and coarse control of this movement is available and a Vernier scale enables accurate reading of the yaw angle to be obtained. Split collets fitting in to the traversing ring (Fig. 2a) enable traverses in the main stream to be made without any disturbance of the flow near the wall, due to a cylindrical extraction hole. Other collets are used to seal the extraction hole when traverses in the boundary layer are made (Fig. 2b).

The instruments used are shown in Fig. 3, and are described below.

(1) <u>The Three Hole Fecheimer Tube</u>

Three hypodermic tubes are contained inside the 0.125 in. stock tube. Three 0.012 in. holes are drilled through to the hypodermic 0.250 in. from the rounded end of the tube at a spacing of 42° of arc. The middle hole points into the flow while the pressures recorded by the two outer drillings are balanced. The centre hole is calibrated to read total pressure and the two outer holes to read static. The errors in total and static are found to be proportional to the true dynamic head. The static pressure calibration curve is shown in Fig. 4. Another three hole tube of 0.050 in. outside diameter (O.D.) tube containing three 0.012 in. tubes was made but was found to be unsatisfactory due to the length of time required for readings to be steady.

(2) <u>The Conrad Yawmeter (See Ref. 1)</u>

Two 0.040 in. O.D. tubes are soldered side by side and chamferred off to form an included angle of 100°. When the pressures recorded by the two tubes are the same the instrument is pointing into the flow direction - the zero position. The instrument is calibrated over an angle of ± 15° from the zero position and $\dfrac{P_1 - P_2}{q}$ (curve A) $\dfrac{P_2 + P_1 - 2p}{2q}$ (curve B) are are plotted in Fig. 5.

Where P_1 is the pressure recorded by the first tube

P_2 is the pressure recorded by the second tube

q is the true dynamic head

p is the true static pressure

To obtain the total and static pressure in the compressor the instrument is rotated through a chosen angle, and the observed pressures recorded. The dynamic pressure q may then be obtained directly from calibrating curve (A) and then the static pressures from curve (B).

Another Conrad tube using small hypodermic tubing (0.024 in. O.D.) and a different wedge angle was found to be impracticable since the readings took a long time to become steady.

(3) The Wedge Static Probe

A pointed brass wedge is built round a flattened hypodermic tube and a 0.012 in. hole is drilled through the wedge. The instrument records a maximum pressure when pointing into the flow. Calibration shows that in this position the instrument records static pressure less 12% of the dynamic pressure.

(4) The Disc Static Probe

A disc is soldered onto the end of a hypodermic tube and a hole (0.012 in.) is drilled through the disc to the hypodermic tube. The instrument is calibrated in similar fashion to the wedge static and records static pressure less 9% of the dynamic head (see Fig. 6).

(5) The Needle Static Probe

A hypodermic tube (0.040 in. O.D.) is bent into the direction of flow and a 0.012 in. hole is drilled through the tube at right angles to the flow, 0.160 in. from the nose of the tube (which is filled in with solder and rounded off). This instrument is calibrated similarly to the wedge and disc static probes and records static pressure less 32% of the dynamic head.

(6) A Pitot Tube

A hypodermic tube is bent into the shape of a shepherd's crook to enable measurements to be taken near the wall. This is found on the calibrating rig to read true total pressure over a wide range of velocity.

Comparison of Measurement with Various Instruments

(a) Yaw Angle

Yaw angle measurements obtained with the three hole and Conrad tubes in a radial traverse between guide vanes and rotor are shown in Fig. 7. The maximum variation between the two sets of observations - between radial position $R = \frac{\text{radius}}{\text{tip radius}} = 0.5, 0.9$, is 40' at $R = 0.9$.

(b) Total Pressure

The measurements of total pressure made with the Conrad, Fecheimer and pitot tubes are plotted in Fig. 8 as a depression below atmospheric pressure expressed as a percentage of the mean inlet dynamic head to the compressor measured on a plane upstream of the guide vanes. These results show that the Conrad tube gives results with some scatter, and that the three hole tube readings are in doubt near the wall. If the Pitot tube readings are correct then the three hole tube suggests the wall boundary layer is thicker than is really the case.

(c) Static Pressure

Static pressures depressions below atmospheric pressure computed from measurements made with the Conrad tube and the three hole tube are shown plotted as a percentage of the dynamic head at inlet to the compressor (Fig. 8). The Conrad tube again shows considerable scatter. Also shown are corrected static pressure measurements made with the wedge, the disc and the needle statics (it being assumed that the total pressure is that measured by the pitot tube) and a static pressure obtained from a wall tapping.

These/

These results show that between the boundary layers $\left(R = \frac{\text{radius}}{\text{tip radius}} = 0.5 \text{ to } 0.9 \right)$ there is a maximum discrepancy of 4% of the dynamic head. This maximum discrepancy occurs at R = 0.5, 0.9 and is between the Conrad tube and the disc static measurements. Nearer the walls there are considerable variations and it is evident that none of the instruments with the possible exception of the wedge static is to be relied upon near a wall. It appears that the three hole and the Conrad tubes read too low a value of static-depression near the wall, while the disc static reads too high a value.

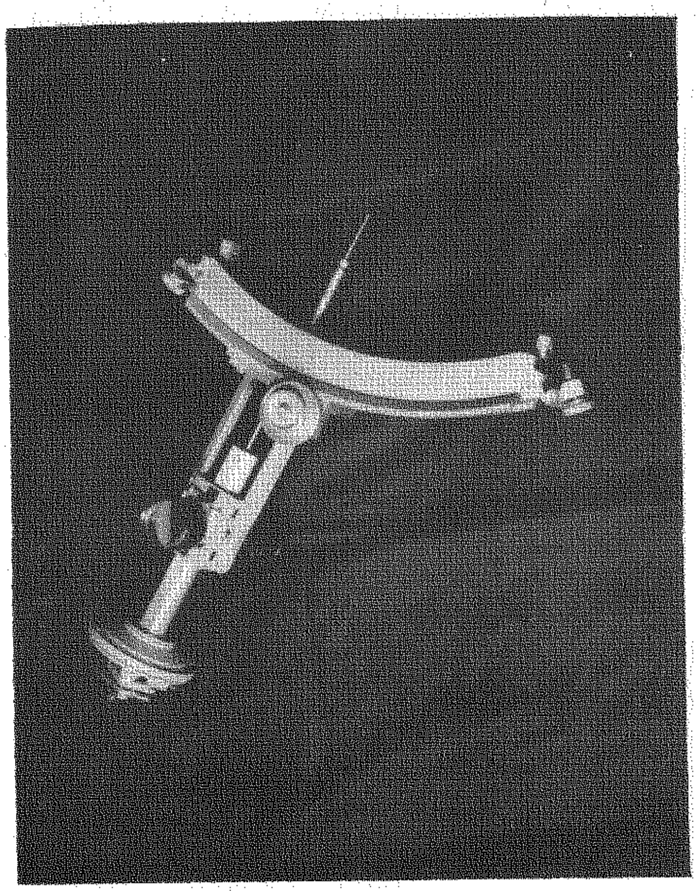
The fluctuations in the observed readings expressed as a percentage of the total dynamic head were approximately ± ½%

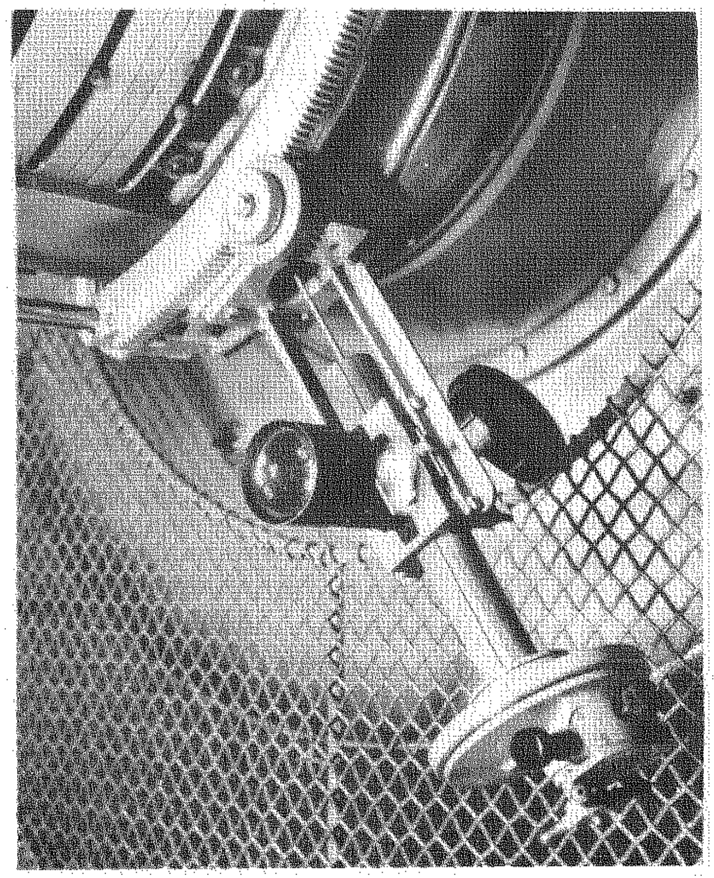
Conclusions

The results show that the maximum variation in observed axial velocity ($0.4 < R < 0.9$) using these different instruments may amount to ± 1% about a mean velocity mainly due to the variations in static pressure measurements. These maximum variations occur at R = 0.4, 0.9, i.e., the nearest positions to the annulus walls.

Reference

No.	Authors	Title, etc.
1	R.A.E. Aero Tunnel Staff	Appendix to Report "Pressure and boundary layer measurements on a 59° swept back wing at low speed". Current Paper No. 86.





TRAVERSING GEAR

FIG.I.

Z.9439.R.

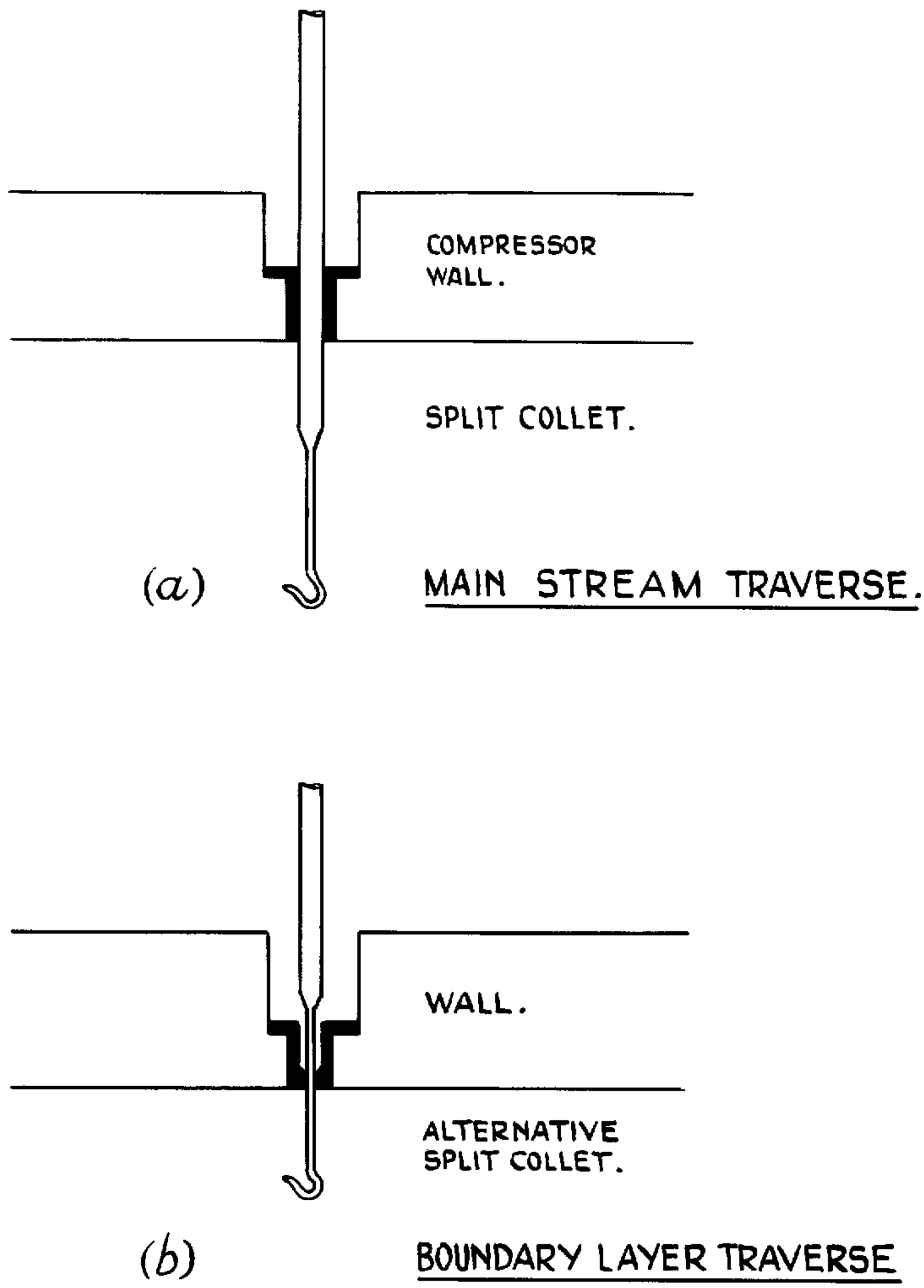
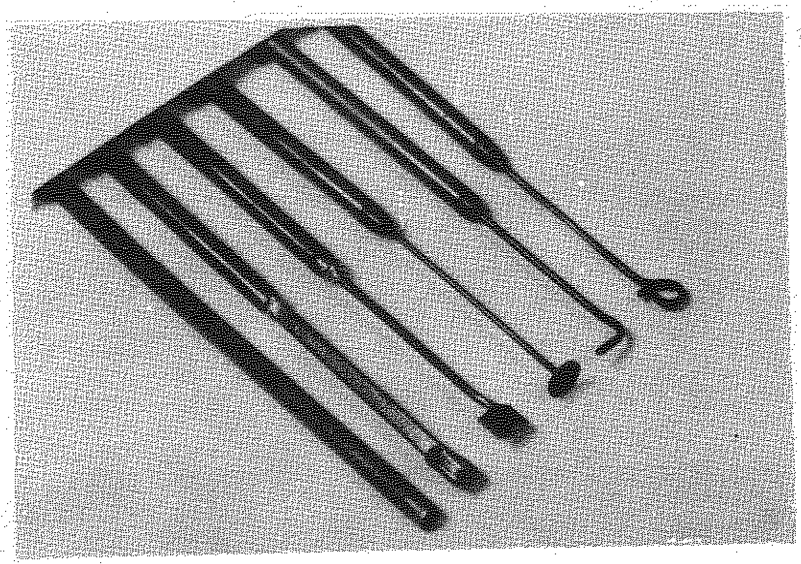

COMPRESSOR
WALL.
SPLIT COLLET.
(a)
MAIN STREAM TRAVERSE.
WALL.
ALTERNATIVE
SPLIT COLLET.
(b)
BOUNDARY LAYER TRAVERSE

FIG. 2

Z.9439.R.



INSTRUMENTS FIG.3.

Z.9439.R.

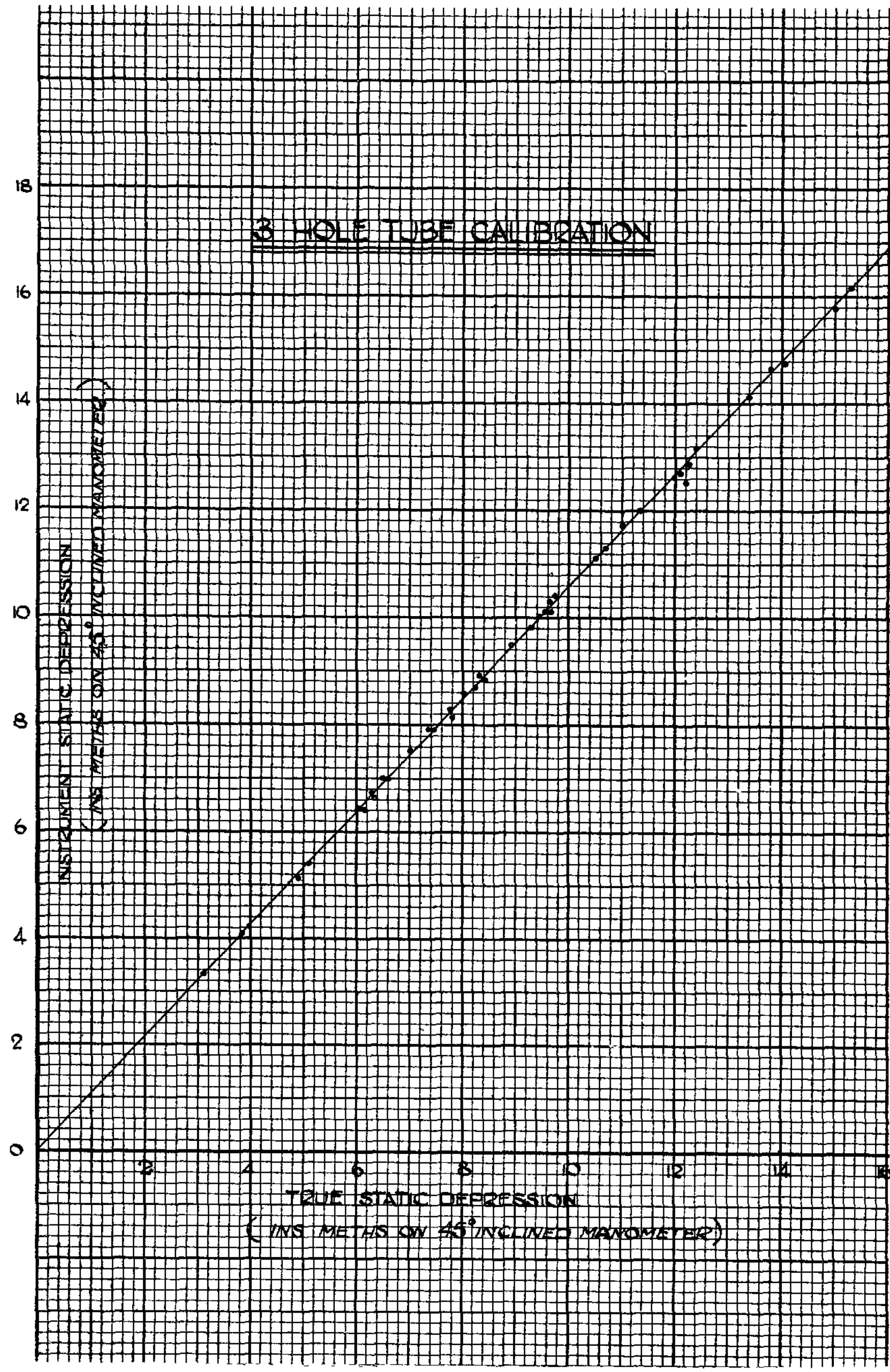

3 HOLE TUBE CALIBRATION
INSTRUMENT STATIC DEPRESSION
(INS METHS ON 45° INCLINED MANOMETER)
TRUE STATIC DEPRESSION
(INS METHS ON 45° INCLINED MANOMETER)
0
2
4
6
8
10
12
14
16
18

FIG 4

Z.9439.R.

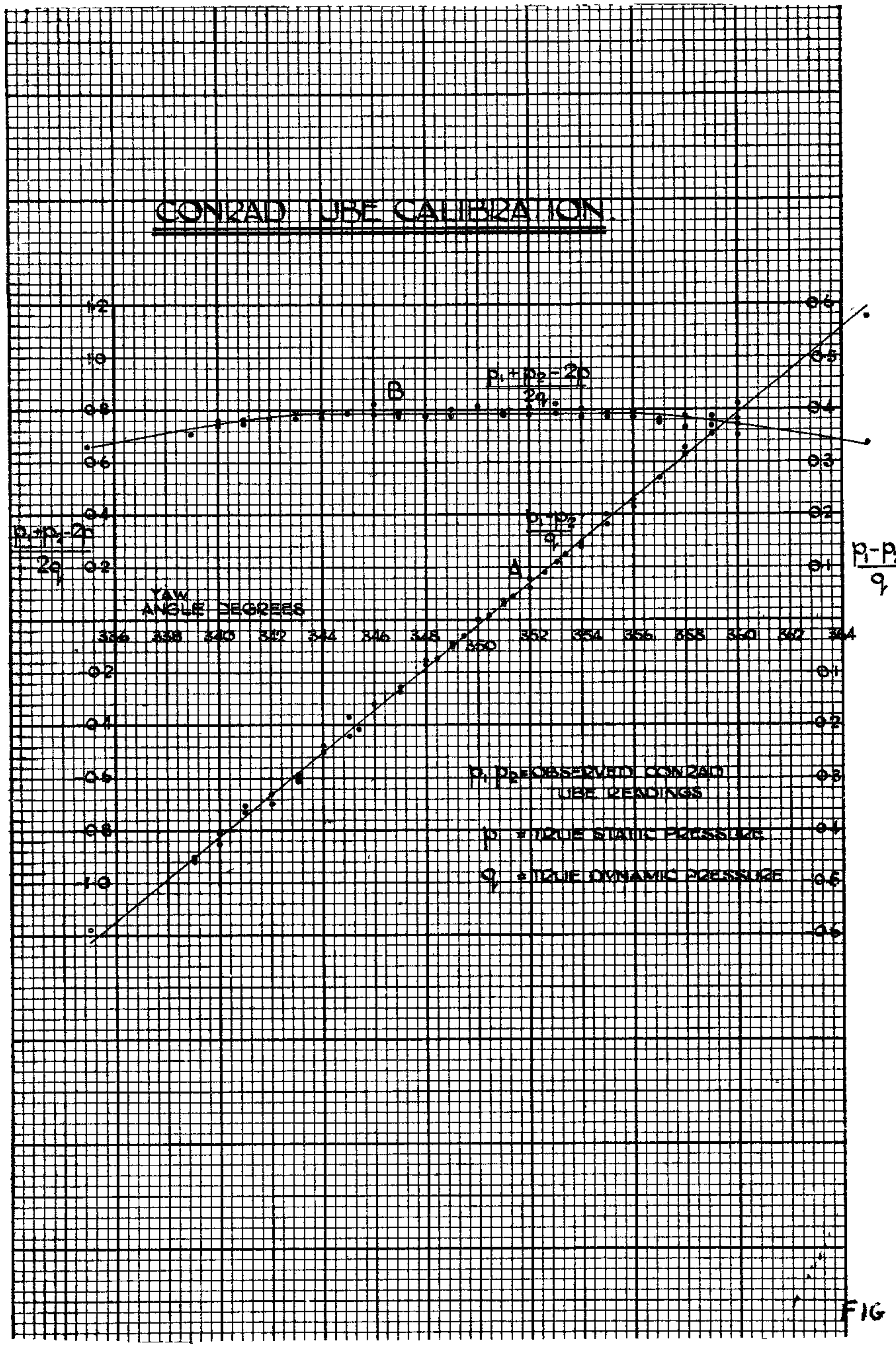

CONRAD TUBE CALIBRATION.
B
A
$\frac{p_1+p_2-2p}{2q}$
$\frac{p_1-p_2}{q}$
YAW ANGLE DEGREES
336
338
340
342
344
346
348
350
352
354
356
358
360
362
364
1·2
1·0
0·8
0·6
0·4
0·2
0·6
0·5
0·4
0·3
0·2
0·1
$p_1\ p_2$ = OBSERVED CONRAD TUBE READINGS
p = TRUE STATIC PRESSURE
q = TRUE DYNAMIC PRESSURE

FIG 5

Z.9439.R.

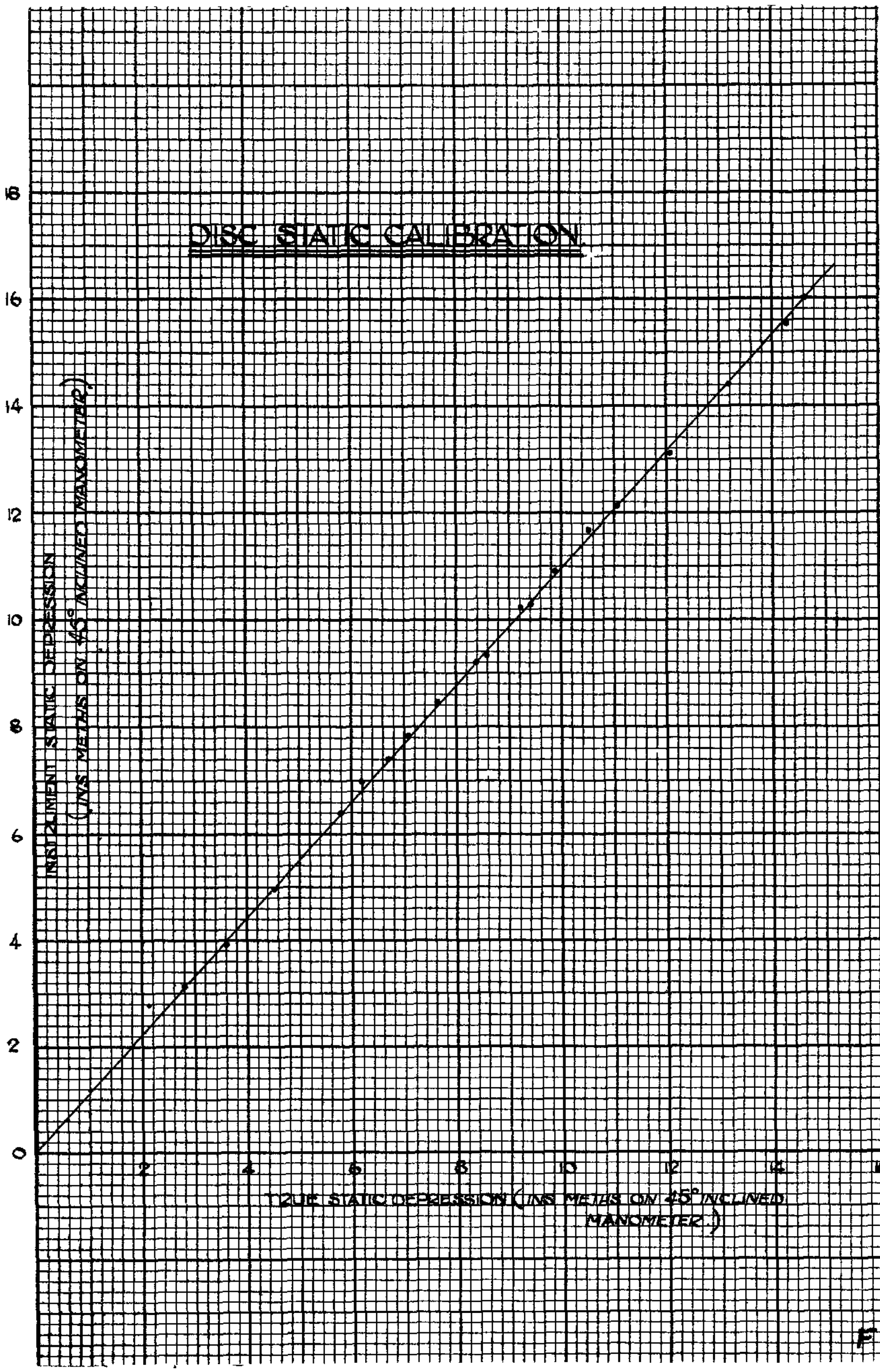
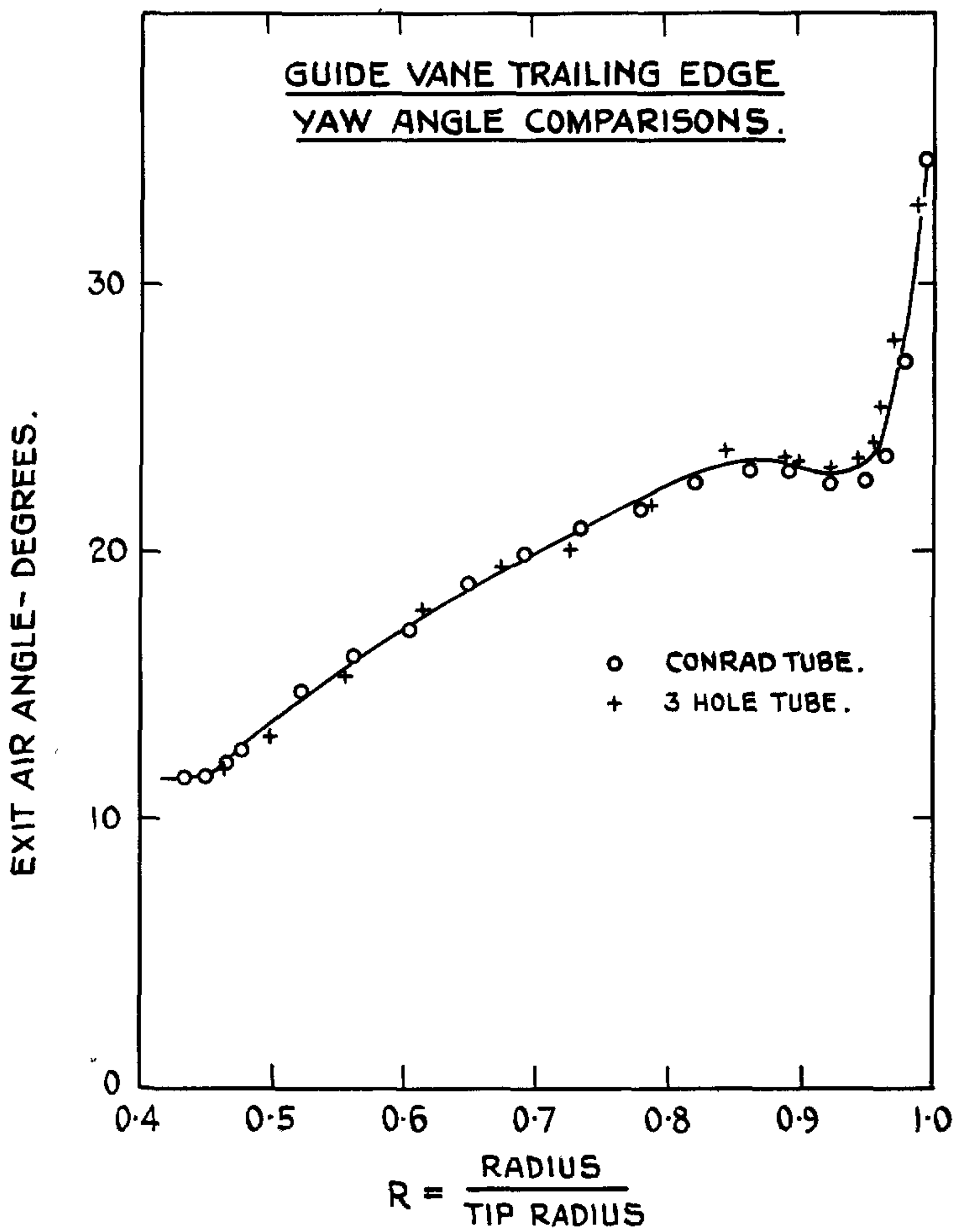

DISC STATIC CALIBRATION.
INSTRUMENT STATIC DEPRESSION (INS METHS ON 45° INCLINED MANOMETER)
TRUE STATIC DEPRESSION (INS METHS ON 45° INCLINED MANOMETER.)
0
2
4
6
8
10
12
14
16
18

FIG 6

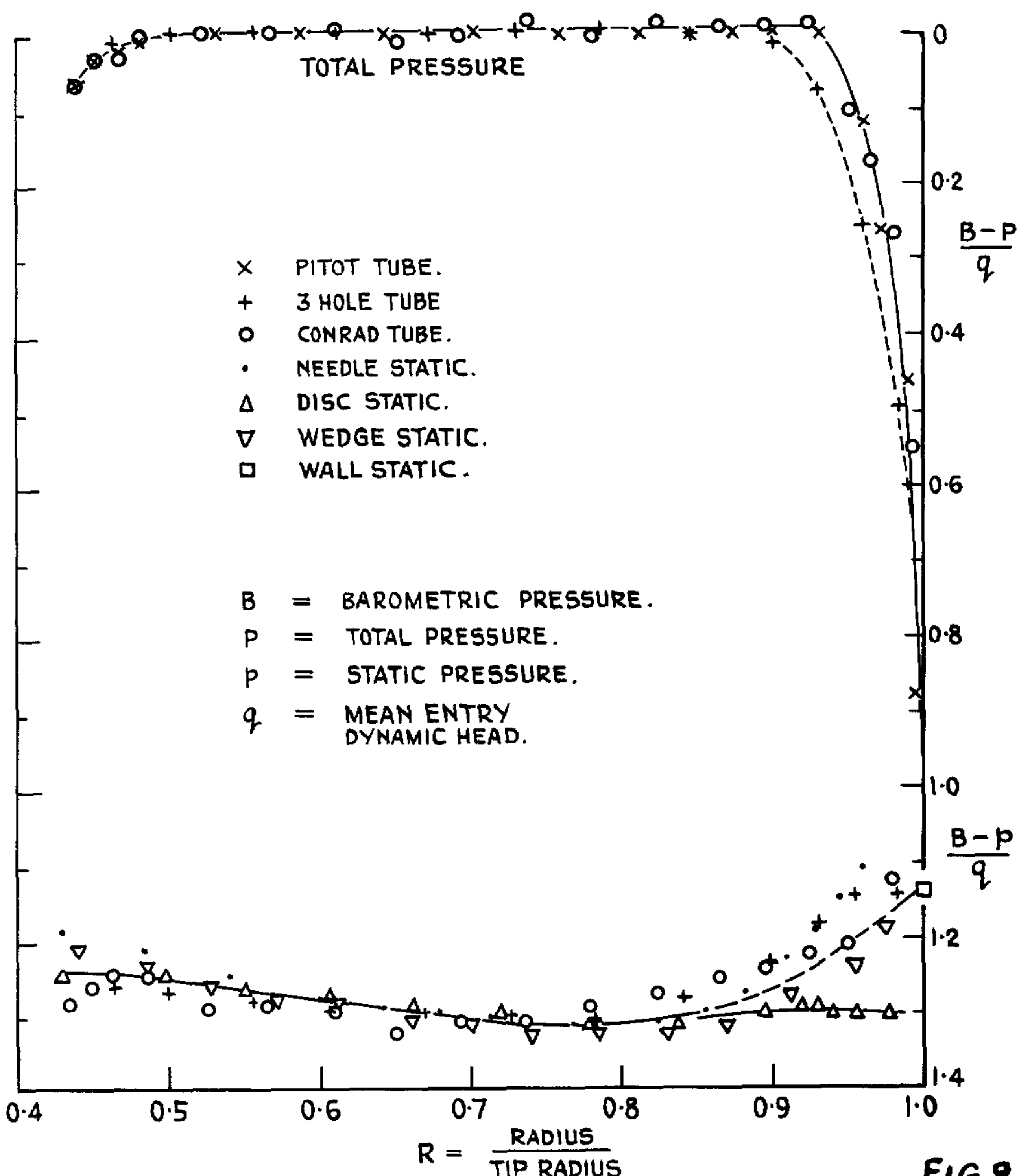
Z.9439.R.


GUIDE VANE TRAILING EDGE
YAW ANGLE COMPARISONS.
30
20
10
0
EXIT AIR ANGLE - DEGREES.
CONRAD TUBE.
3 HOLE TUBE.
0·4
0·5
0·6
0·7
0·8
0·9
1·0
R = RADIUS / TIP RADIUS

Z.9439.R.

FIG. 7.

GUIDE VANE TRAILING EDGE COMPARISONS OF TOTAL AND STATIC PRESSURE.



Z.9439.R.

FIG 8

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