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Tests on the Effect of Incidence on some Pressure Heads at High Subsonic Speeds

By

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21st July, 1950

Summary

Tunnel measurements have shown that up to at least $M = 0.75$ the loss in total head on a Venturi-shrouded pitot was less than 0.5% for incidences of up to about 40°. This compares with a limit of 9° at $M = 0.7$ to 0.85 for 0.5% loss on the pitot section of a standard Mk.VIIIA instrument and 17° at $M = 0.7$ to 0.9 on the small pitot heads in general use in the N.P.L. High Speed Tunnels.

The corresponding incidence limit for the static side of the Mk.VIIIA instrument was about 7°, compared with 5° for the standard tunnel static tube.

Introduction

At the request of the A. & A.E.E., Boscombe Down, some brief tests were undertaken in the 20" x 8" N.P.L. High Speed Tunnel to measure the effect of incidence at compressibility speeds on a full-size venturi pitot tube and a Mk.VIIIA pitot-static head. In addition the small pitot and static tubes normally used in the tunnel were tested on the same rig.

Experimental Details

Diagrams and principal dimensions of the four tubes tested are given in Fig.1.

The venturi pitot tube and the Mk.VIIIA+ pitot-static head are standard full-size instruments supplied for test by the A. & A.E.E.; the small pitot and static tubes are those generally used for exploration in the tunnel. All instruments were mounted in the centre of the tunnel on a strut passing through a bush in the tunnel wall. The angle of incidence was varied by rotating the strut and was measured by an inclinometer. Pressure measurements were made on a water manometer, the instrument total head being read against the total head in the tunnel intake and the static pressure against a hole in the tunnel wall opposite the model static holes. The reading of the wall hole appeared to be independent of the model incidence at all Mach numbers tested.

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+ The only difference between the Mk.VIIIA and Mk.VIIIB heads is that they have 12 and 24 volt heating elements respectively. The present results therefore are equally applicable to the latter type.

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The flexible walls of the tunnel[1] were set to give at each Mach number constant pressure along the tunnel in the absence of the model. In reducing the observations no allowance was made for the constraining effect of the walls either on free-stream Mach number or on the pressure field around the model. In the former case preliminary measurements suggested that the error in Mach number was negligible; the latter effect, although difficult to estimate accurately, was also considered small enough to be neglected for the present range of testing. Further, previous explorations have shown that the variation of total head and static pressure in the working section near the model positions is small enough to be ignored.

The venturi pitot head is an open-ended tube 0.18 in. external diameter pointing up stream and fixed along the axis of a venturi-shaped shroud. The method of mounting (similar in this case to that employed on an aircraft) proved quite rigid, but at speeds above $M = 0.6$ the measuring tube vibrated badly without however apparently affecting the readings. The maximum usable angle of incidence was determined by the tunnel blowing pressure, which became unduly high at large angles of attack.

The Mk.VIIIA pitot-static head was fitted to the end of a tubular sting and secured to the supporting strut by means of an adjustable sleeve. The static slots were positioned so that two of the six were in the plane of rotation. When measuring total head with this model it was found that the distance between the leading edge of the strut and the pitot orifice was unimportant in the present cases, but it was thought desirable to choose the maximum possible distance (16.9 in. or 20 tube diameters), from the strut to the static slots. This length of sting restricted the maximum angle of incidence to about 20°. No reliable readings at incidence could be obtained for Mach numbers above 0.84 due to choking of the tunnel downstream from the model position. Throughout the tests the leak hole between the pitot and static sides, provided for drainage purposes, was sealed, and the electric heater disconnected.

For the same reasons, the maximum angle of incidence and Mach number for the tunnel pitot and static tubes were about 30° and 0.90 respectively. In addition, the limiting angle was further reduced by the angular deflection of the tube and support under load at the higher Mach numbers but this amounted to less than a degree for incidences smaller than 20°. During the tests on the static tube two of the four static holes were in the plane of rotation.

Results

The experimental results for a range of Mach number are plotted in Figs. 2(a) to (h)+ as a proportion of the true total head (H_o) or wall static pressure (p_w).

(a) Venturi Pitot Tube

It is immediately apparent that at incidence up to the highest speed at which a comparison can be made $(M = 0.75)$ the venturi pitot tube is far less sensitive to incidence than either the Mk VIIIA or the small tunnel pitot. For example at a Mach number of 0.75 the latter two instruments read 0.5% low at $\alpha = 9°$ and 17° respectively, whilst the venturi still measures full total head even at 40° incidence. At lower Mach numbers, the increase in range is even more striking.

A/

+ Only the results at positive incidences are given, although extensive observations were taken of negative angles to check the symmetry of the curves. Except for some of the static readings, this was extremely good.

A venturi attachment to an ordinary total head tube has been tested in Germany[2] at low speeds; a comparison with the present results (Fig.3) suggests that the British instrument has a slightly greater range.

(b) Mk VIIIA pitot-static Head

From the results given in Fig.2, the percentage error in the measurement of the free-stream velocity can be worked out; this is done in Fig.4, which shows that for most of the present test range the error is under 1% and is probably negligible up to incidences of about 10°. Fig.5 gives the variation with Mach number of tunnel free-stream velocity, sonic speed and Reynolds number per inch of model.

The percentage error in the measurement of dynamic pressure is plotted for various Mach numbers against incidence in Fig.6, the curves being of similar shape to those in Fig.4. As a comparison the low speed curve estimated by Yates and Bigg[3] for their proposed standard head is shown and agreement between this and the results obtained at $M = 0.4$ is quite good, despite minor differences in design.

A comparison of the present results at zero incidence with those obtained earlier[4] in the same tunnel on another full-scale Mk VIIIA pitot-static head, shows a similar trend with increasing Mach number, but the opposite sign for the error $p_1 - p_W$ at the lower speeds. The reason for this is not clear but may be due to differences in the method of support, to change of tunnel characteristics in the seven years between the tests, or to inherent differences in the two instruments.

(c) Tunnel Pitot and Static Tubes

The curves given in Fig.2 show that the tunnel pitot reads full total head at incidences up to about 9° for the Mach number range between 0.4 and 0.9. Above 9°, the instrument reads less than total head, but the rate of decrease of the ratio H_1/H_0 is much smaller than that measured on the Mk.VIIIA head. This may be due to the disparity in model size and shape but Merriam and Spaulding[5] found at low speeds that sensitivity to incidence decreased as the ratio of orifice diameter to external tube diameter increased; for the Mk VIIIA and tunnel pitots these ratios are 0.29 and 0.53 respectively.

The tunnel static tube is generally more sensitive to incidence than the Mk VIIIA instrument, and has little or no range where the ratio p_1/p_W is unity. For the higher Mach numbers (when the incidence is zero) the tube reads a static pressure greater than that on the tunnel wall. Though a comparison is difficult, a similar trend was observed by Walchner[6] in 1938 during his tests on a Prandtl tube. This rise in the ratio p_1/p_W with increasing Mach number was attributed in Reference 4 to the effect of the support.

General Remarks and Conclusions

When the incidence required for the instrument reading to fall to $0.995\ H_0$ or $0.995\ p_W$ is plotted against Mach number (as in Fig.7(a) and (b)), the effect of increasing the Mach number beyond about 0.7 is seen to be small; below this value, the angle increases with a decrease in Mach number. Four of the five sets of readings have curves of this type but for

the/

the venturi pitot it can only be inferred from the available results due to the high incidence required to produce this loss in total head. The figure further emphasizes the superiority of the latter instrument.

As noted earlier, the tunnel pitot has less sensitivity to incidence than the Mk.VIIIA pitot for the whole Mach number range; the reverse is true for the corresponding static results. The resulting error in either velocity or dynamic pressure when both components of the Mk.VIIIA pitot-static head are considered is fairly small even up to angles of 10°.

For the tests to be continued to higher speeds, it is obvious that smaller models of the flight instruments would be required, though it is possible that the results for the Mk.VIIIA head could be extrapolated to about M = 0.9 without serious error. In the case of the venturi pitot extrapolation from the present data is both difficult and undesirable and it is hoped that the manufacture and test of a smaller instrument will be possible later.

List of Symbols

H_o	Free stream total head as measured in the tunnel intake (almost equal to atmospheric pressure).
H_1	Total head measured by the instrument.
p_w	Static pressure at the tunnel wall measured by a hole directly opposite the model static holes or slots.
p_1	Static pressure measured by the instrument.
M	Free stream Mach number based on $H_o - p_2$, where p_2 is the pressure at the tunnel speed hole upstream of the model and nearly equal to p_w in every case.
V	Free stream velocity based on H_o and p_w.
δV	Difference between velocity measured by instrument and V (i.e. $V_1 - V$).
$\frac{1}{2}\rho V^2$	Free stream dynamic pressure based on H_o and p_w.
$\delta(\frac{1}{2}\rho V^2)$	Difference between dynamic pressure measured by instrument and $\frac{1}{2}\rho V^2$ (i.e. $\frac{1}{2}\rho_1 V_1^2 - \frac{1}{2}\rho V^2$).
α	Angle of incidence of instrument.

References/

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1	Lock and Beavan	Tunnel interference at compressibility speeds using the flexible walls of the rectangular high speed tunnel. (September, 1944). R. & M.2005.
2	Bäuerle	AVA monographs. D_2. Model testing technique. II. Testing equipment and instruments. 3. Measuring instruments for pressure, velocity and direction measurements. MAP. VG251. 951.T. G.D.C. 470.T. (15th March, 1947). A.R.C. 11,222.
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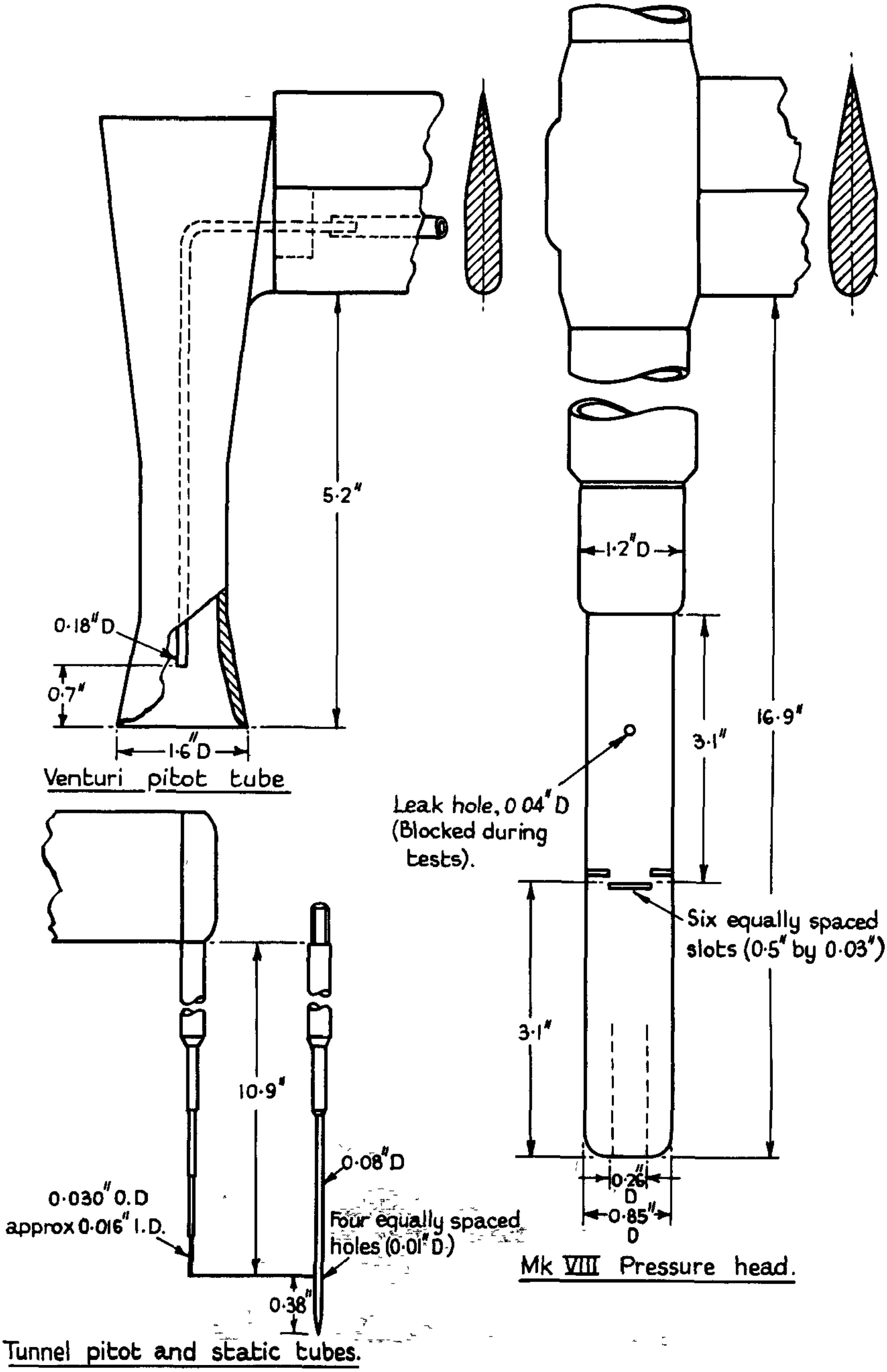
4	Lock, Knowler and Pearcey	The effect of compressibility on static heads. (January, 1943). R. & M.2386.
5	Merriam and Spaulding	Comparative tests on Pitot static tubes. NACA Tech. Note No.546. (November, 1935).
6	Walchner	On the effect of compressibility on the pressure readings of a Prandtl tube situated in flows at sub-sonic velocity. (Jahrbuch der deutschen Luftfahrtforschung 1938, Vol.1, pp. 578-82). Translated by K. M. M. Goggin. Air Ministry Translation No.962. A.R.C. 4181.



Models used in present tests.

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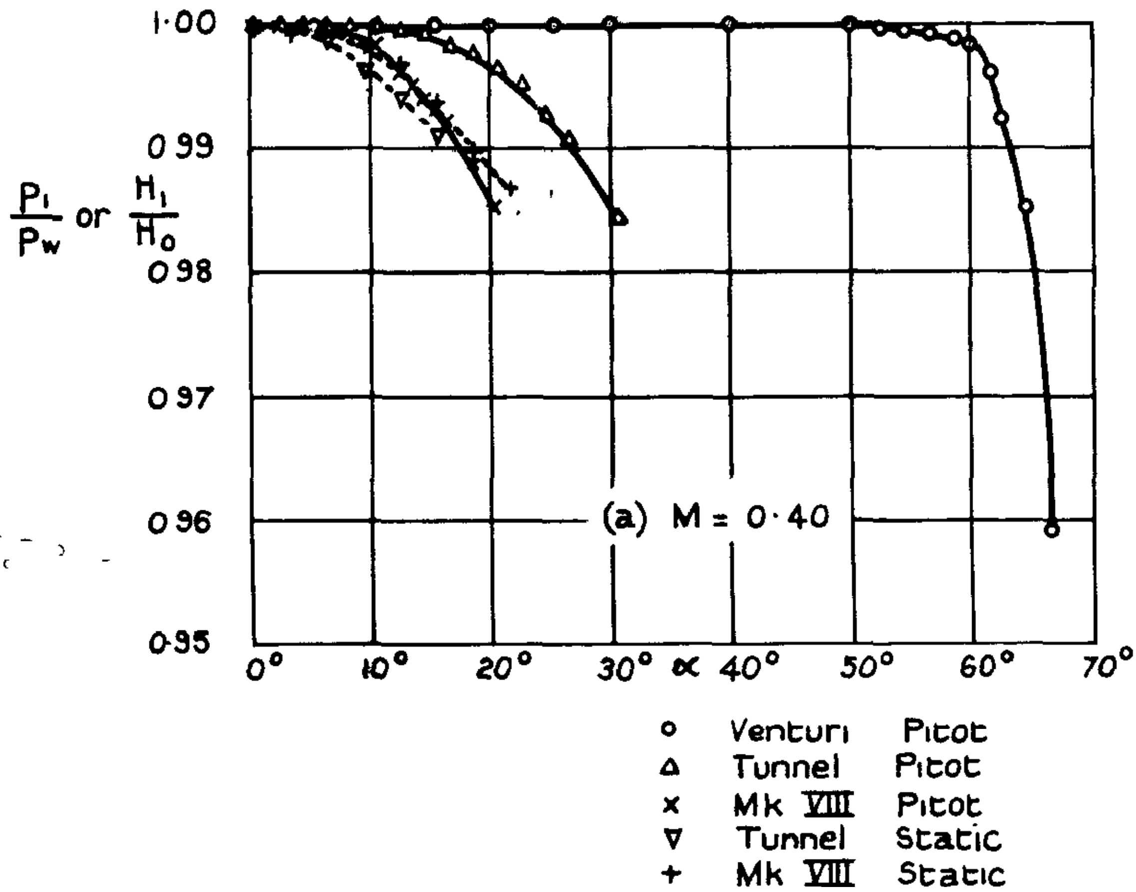
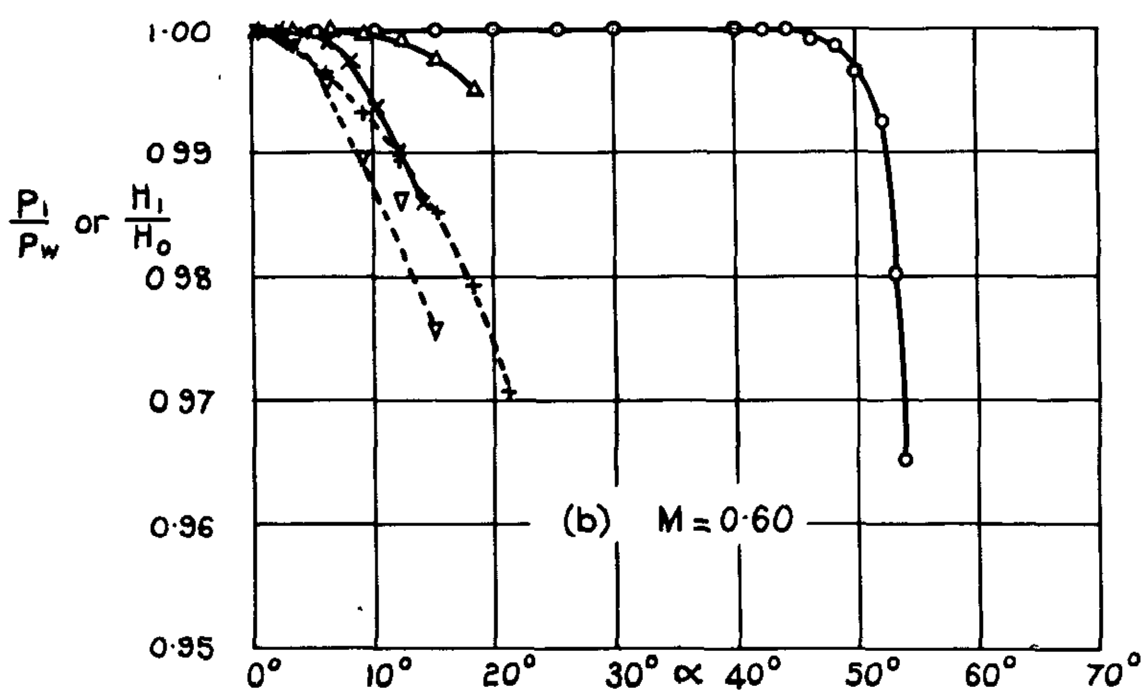
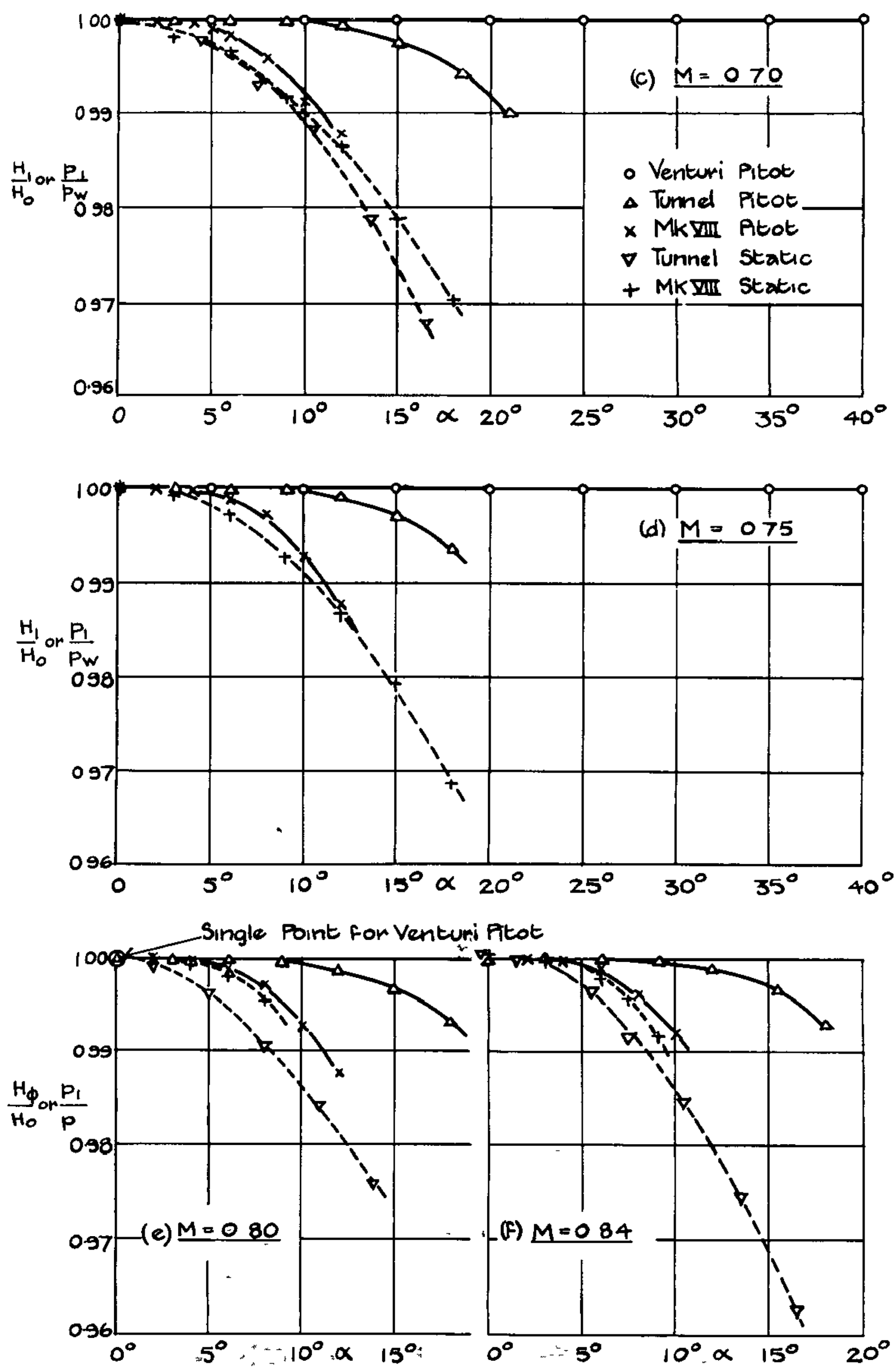


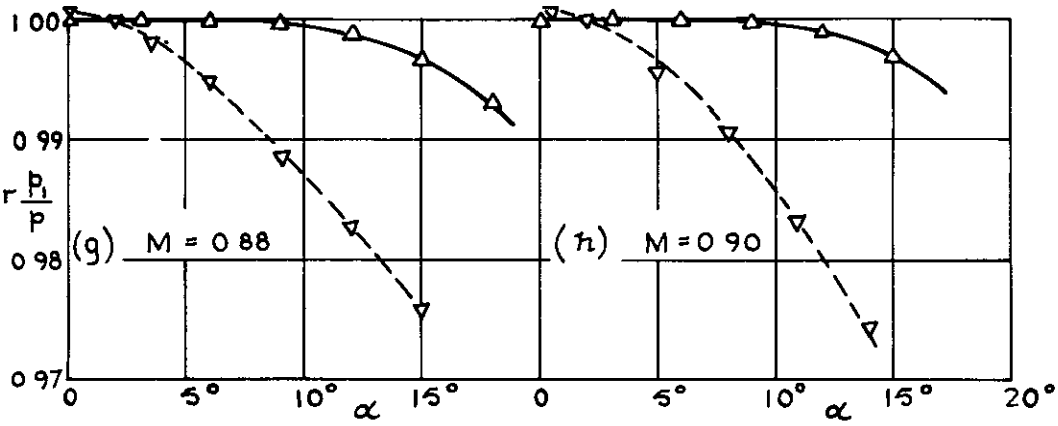


Results of Tests on Pitot and Static Tubes at Incidence



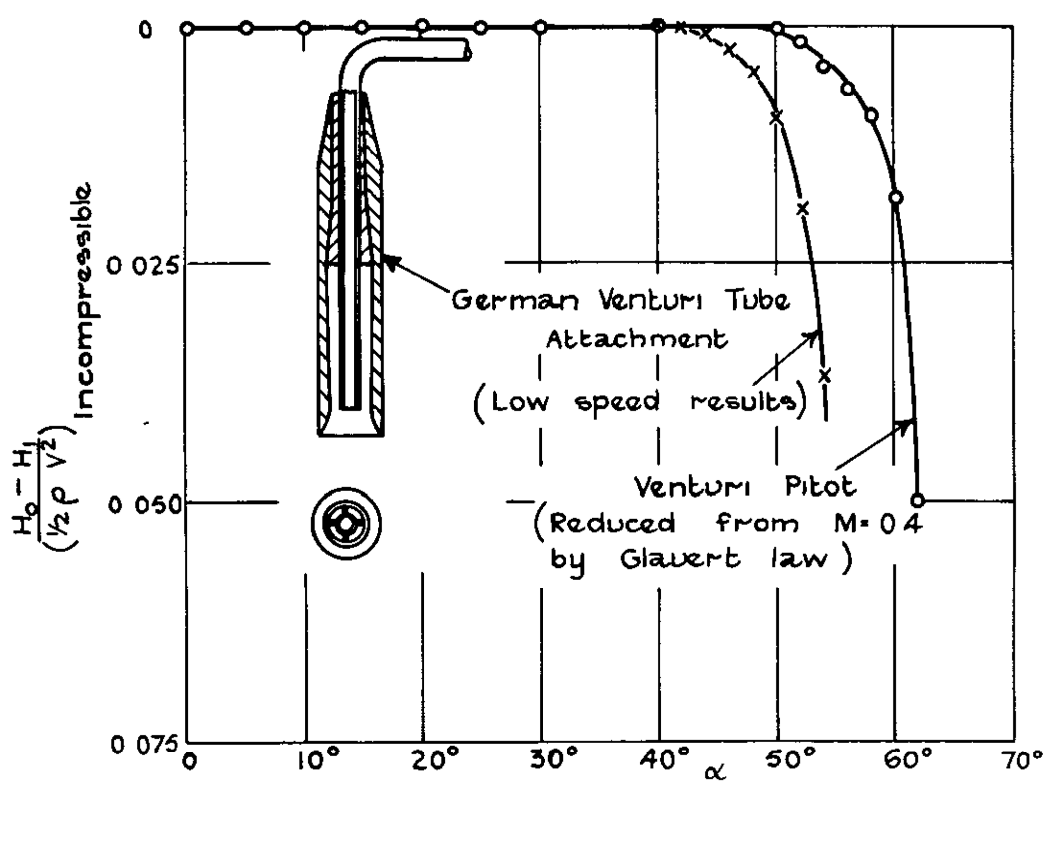
Results of Tests on Pitot and Static Tubes at Incidence

Fig 2



Results of Tests on Pitot and Static Tubes at Incidence

Fig 3



Comparison of Venturi Pitit Results with German Tests on a Similar Instrument

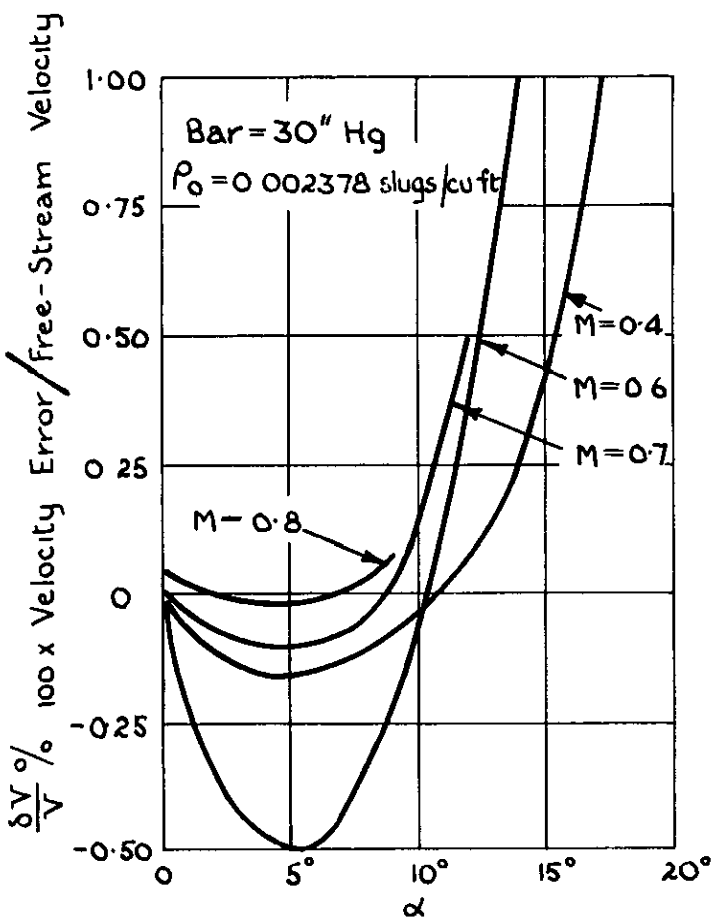


FIG 4

Errors in Measurement of Velocity due to Incidence of Mk VIII A pitot-static head in Tunnel

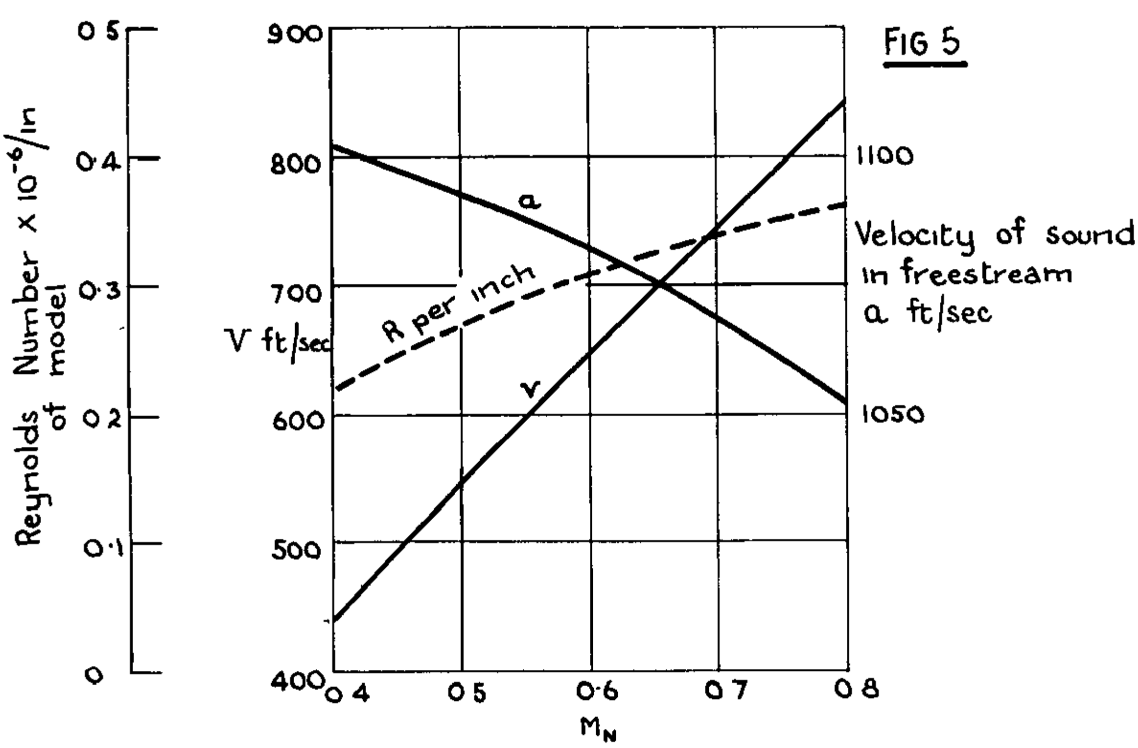
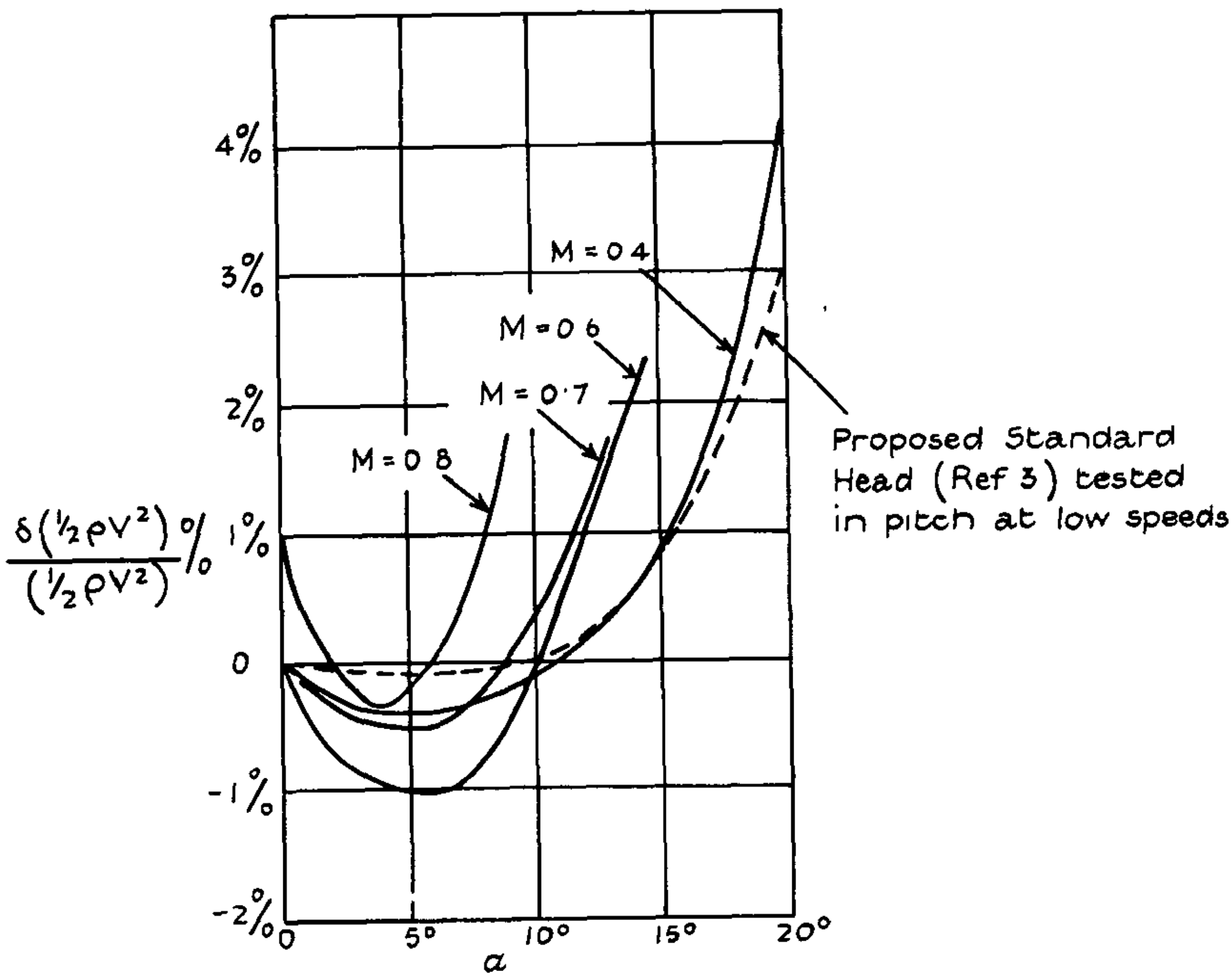


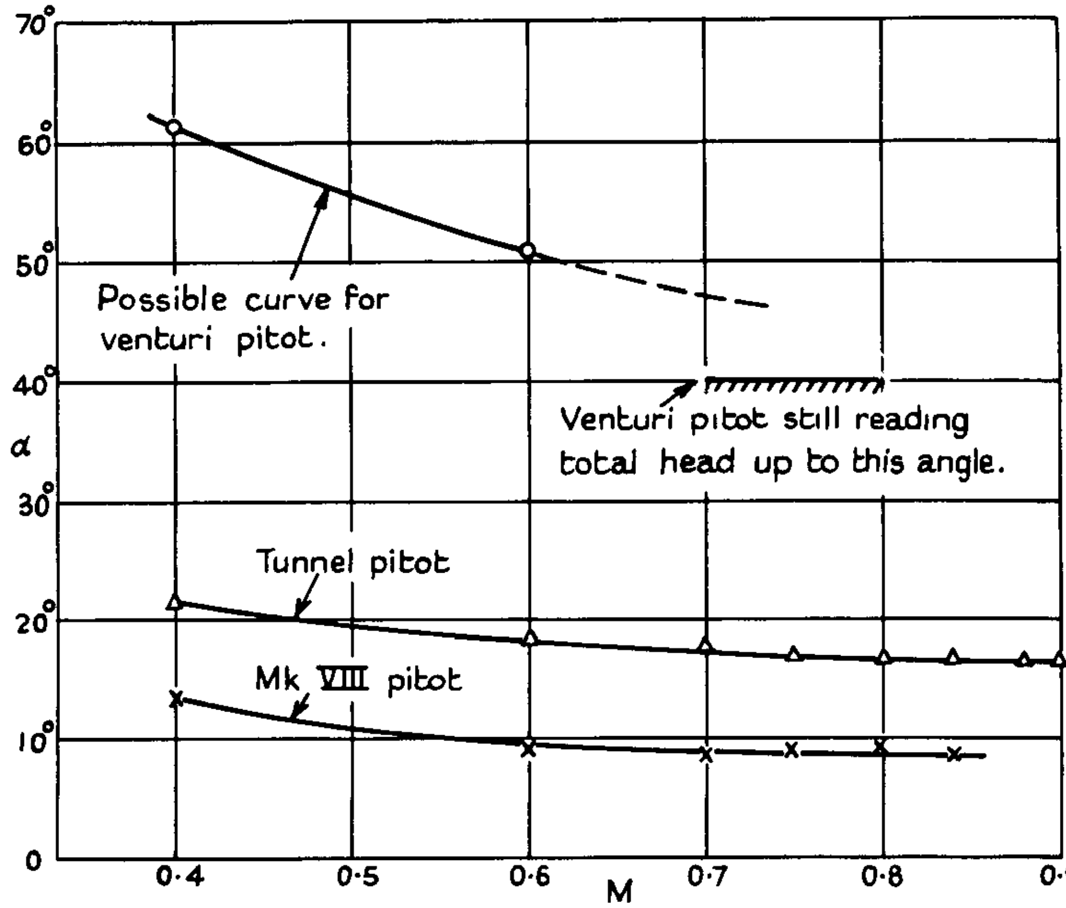
FIG 5

Variation of Tunnel Characteristics with Mach Number
(Induction Tunnel with atmospheric total head)



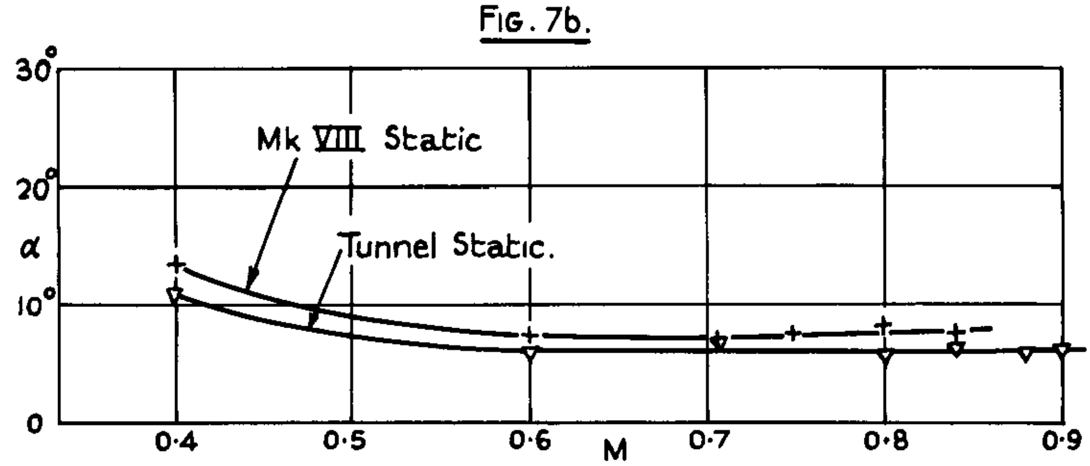
Errors in $\frac{1}{2}\rho V^2$ due to Incidence of Mk VIII A Pitot-Static Head in Tunnel.

FIG. 7a.



Variation with Mach Number of Incidence required for Instrument to read $0{\cdot}995\ H_o$.

FIG. 7b.



Variation with Mach Number of Incidence required for Instrument to read $0{\cdot}995\ p_W$

E.E.M.

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