BALLISTIC RESEARCH LABORATORIES

REPORT NO. 627

Calibration of Wright Field Pitot Static Tube

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SUBJECT: **Forwarding of Report**

TO: Superintendent of Postgraduate School
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There is **forwarded herewith the following**: one copy of
BRL Report No. 627, "Calibration of Wright Field Pitot Static Tube,"
by Joseph Sternberg.

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BALLISTIC RESEARCH LABORATORIES

REPORT NO. 627

Sternberg/hlh
Aberdeen Proving Ground, Md.
23 July 1947

CALIBRATION OF WRIGHT FIELD PITOT STATIC TUBE

ABSTRACT

Wind tunnel tests have been carried out in the Aberdeen Bomb Tunnel to calibrate a specially designed high speed pitot static tube which is to be used in the calibration of the Wright Field Ten Foot (High Speed) Wind Tunnel. Static and total pressure readings were checked for M's from .2 to .86 and at M = .86, up to an angle of attack of $5°$. Within the experimental accuracy of the tunnel calibration, the static pressure reading of the pitot tube was equal to the static pressure of the air stream at the static hole location. No shock waves around the pitot tube were observed at any of the test M's.

LIST OF SYMBOLS

P = Local static pressure

P_F = Static pressure in the free stream

P_S = Pitot tube static pressure

P_o = Supply section pressure

P_T = Pitot tube total pressure

P_{65} = Tunnel wall reference pressure 17"
         upstream of the window center line

ρ = Local air density

u = Local velocity

a = Local speed of sound

q = Dynamic Pressure = $\frac{1}{2}\rho u^2$

$M = u/a$ = Local Mach number, M

M_s = Calculated M using P_S/P_o

C_P = Pressure coefficient = $\dfrac{P - P_F}{q_F}$

INTRODUCTION

In order to calibrate the Wright-Field Ten Foot High Speed Wind Tunnel a pitot tube was needed which could be used for speed determination up to approximately M = .9. Accordingly, R. Hensel[1] calculated the shape of a possible pitot tube using a constant line source distribution in an incompressible fluid. These calculations indicated that the maximum velocity would occur at 1" from the nose of a .4" dia tube, and that the static holes could be put at 3" from the nose where the incompressible coefficient was only -.003. The pitot tube is shown in Fig. 1 and 2.

The calibration of the tube was carried out in the subsonic nozzle of the Bomb Tunnel using two different supports, referred to as the Wright Field (W.F.) and the Aberdeen (A) supports. As shown in Figures 5 & 6 the tube was tested in two different axial and cross-sectional positions.

SUBSONIC NOZZLE

The subsonic nozzle is overexpanded in allowing for boundary layer growth so that the maximum velocity is obtained about 50" upstream of the center of the test section (referred to hereafter as $\mathbb{d}$) where there is an effective throat. With M = 1 at the throat, the $M_{\mathbb{d}}$ is about .85. For higher compression ratios, the flow becomes supersonic after the throat, then going through an almost normal transition shock wave to a subsonic speed at some position downstream of the throat. When $M_{\mathbb{d}}$ = .87, the highest Mach number used in these tests, the shock wave is about 22" upstream of the $\mathbb{d}$ (not in view in the window). Even with this shock wave, the flow conditions are steady enough at this speed, to permit testing. For still higher compression ratios, the supersonic region increases until at $M_{\mathbb{d}}$ = .95, the shock wave is in the upstream half of the window and testing cannot be done satisfactorily.

The subsonic nozzle has been calibrated through the speed range using a 1/2" diameter tube with pressure holes at a fixed axial position; the tube extended from upstream of the throat to the end of the test section where it was supported on the balance system strut. The tube was moved axially to obtain the survey and so had to be horizontally displaced from the tunnel $\mathbb{d}$ to prevent interference with the vertical windshield (See Fig. 4). Fig. 5 shows the position of the tube in the tunnel cross section. With a model present in the test section, at high subsonic speeds, the wall pressure in the region of the model is affected. It has been found experimentally that the pressure at Tap 65 (or P_{65}) 17" upstream of the $\mathbb{d}$ is unaffected even when there are strong tunnel blocking effects so this pressure was used as a reference for the nozzle calibration.

With the overexpansion of the nozzle described above, there is an axial pressure gradient through the test section as shown in Fig. 6. Figures 7 and 8 are cross plots of Fig. 6 and show the tunnel static pressure at the nose and at the static holes location for both the W.F. and the A installations. These calibration curves are good to better than 1/2% in pressure ratio or .003 in Mach number at the highest speed.

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[1]   AAF, Wright Field, TN-TSEAC-11, "Design and Calibration of a High Speed Pitot Static Tube", R. W. Hensel.

WRIGHT FIELD INSTALLATION

With the W.F. support shown in Figures 2 and 3, the tunnel choked slightly above Md = .78 because of the supports comparatively large cross-sectional area. Also, (see Fig. 3) it developed that the airfoil support was not directly lined up with the flow, which was not directed along the tunnel axis because of the presence of the windshield. The airfoil support was attached to the floor by a single bolt and the air forces on it rotated it out of its proper position placing the pitot tube at an angle of 2-1/2° with the flow. However, later tests with the A support showed that this angular error should not influence the result. The tube position in the tunnel cross section is shown in Fig. 5.

ABERDEEN INSTALLATION

With the Aberdeen support, shown in Fig. 4, the maximum M_d was .87. Apparently, at this Mach number, with the entropy rise in the transition shock ahead of the test section, the region around the support effectively becomes a second throat, fixing the flow in the test section, and preventing any further increase of speed there. The A support, which was similar to that used for the axial survey tube where it is attached to the strut, was designed so that the tube could be rotated in a horizontal plane to line it up with the airstream. Rotation in the vertical plane was achieved by using the balance system's angle of attack mechanism, since the tube was supported on the balance system strut. The pitot tube was lined up with the flow with these two adjustments and actually was found to be insensitive to variations in angle of several degrees.

TEST RESULTS

The testing procedure was to record the total and static pressure readings as functions of the reference pressure P_{65}/P_0 where P_0, the supply pressure, was maintained at a constant 95 cm Hg absolute. Both flash and steady schlieren pictures were taken at each speed.

The calculated pressure coefficient at the pitot tube static hole location is -.003. At the highest speed P/P_0 (static holes) = .616 (from tunnel calibration) so that for a pressure coefficient of -.003 (incompressible) the pressure ratio would be reduced by .001 to .615 (about -.002 in M). This variation could not be determined because it is within the experimental accuracy of the tests.

The results of the tube static pressure measurements are shown in Figs. 7, 8, and 10 (Fig. 10 presents the results at the lower Mach numbers). For both installations, the static pressure is the same as the static pressure in the tunnel at the same position within the accuracy of the calibration.

Fig. 9 shows the pitot tube total head readings, P_T/P_0, for both installations. The maximum $\Delta P_T/P_0$ is about .004 or less than 1/2% of the total head. Limited total head surveys show that there are variations of total head across the tunnel of this order of magnitude, and that the non-uniformities vary with the Mach No. This may be the reason for the variation of P_T/P_0 (Fig. 9) with Mach No. and with tube installation (tubes were in different cross-sectional positions, see Fig. 5).

Figures 11 and 12 show the schlieren pictures at the highest Mach number tested with each support system. No shock waves can be seen in any of the pictures which indicates that there are not important compressibility effects, which is in agreement with the pressure measurements.

The pitot tube was also run up to 5° yaw with no observable change in either the static or total lead pressures. However, with the tube at 5° yaw the static holes are at a different point in the tunnel where the pressure may differ by several millimeters, perhaps 1/2%.

HUMIDITY EFFECTS

Using the Wright Field Installation, the lowest supply temperature was $72°$ F. and the highest D.P. was $-19°C$. At $M_d = .78$, the largest speed obtained, the highest Mach number around the model was calculated to be .83. The highest speed in the channel was about .87, at the throat. For the above initial conditions, the air at M = .87 should only have a relative humidity of 50% so that there is no possibility of moisture condensation.

Using the Aberdeen Installation, the lowest supply temperature was $85°$F. and the highest D.P. was $-10°C$. At $M_d = .87$, the largest speed obtained, the highest Mach number around the model was calculated to be .92. At this tunnel speed there is a shock wave in the channel, as previously described, with the stream Mach number just before the shock equal to about M = 1.12. For the above initial conditions, the air at M = .92, should have a relative humidity of about 85%. However, the air at M = 1.12 is about 3-1/2 times supersaturated, and with the shock in the channel it is possible that there is condensation followed by reevaporation. With $M_d = .85$ the M at the throat = 1, and the air there is only 1.46 supersaturated and the moisture should not condense. Thus some condensation effects only seem possible at the highest speed point taken. But for the highest point, the total head reading of the tube did not show any noticeable decrease which would be expected to accompany significant condensation effects, so that it is concluded that condensation did not affect the results.

CONCLUSIONS

At the high speeds, the tunnel calibration was only good to about .003 in Mach Number. The theoretical calculations predicted a Mach No. at the static hole locations (for the highest speed) about .002 M. less than the free stream M, so that the tunnel calibration was not accurate enough to check the value of the static hole pressure coefficient. Within the calibration limits, the Mach No. at the static hole location was the free stream Mach No.

Joseph Sternberg

CONSTANT LINE SOURCE DISTRIBUTION
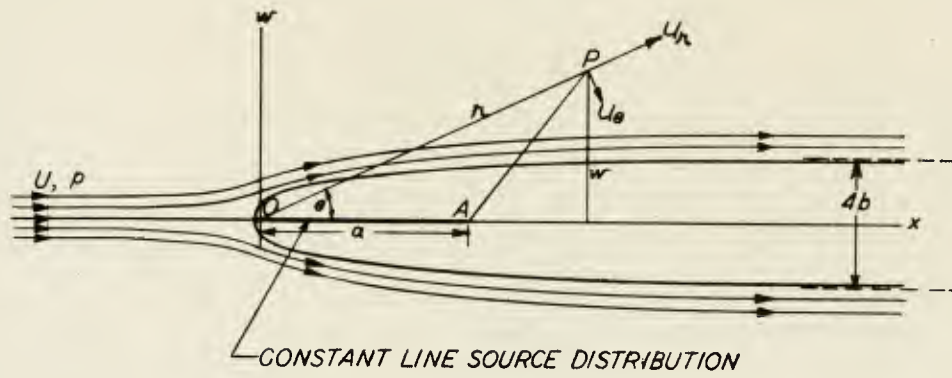
$$r^2 \sin^2\theta = 2b^2\left(r - \sqrt{r^2 + a^2 - 2ar\cos\theta} + 1\right)$$

FOR ACTUAL TUBE, $a = 1.00$, $b = .10$

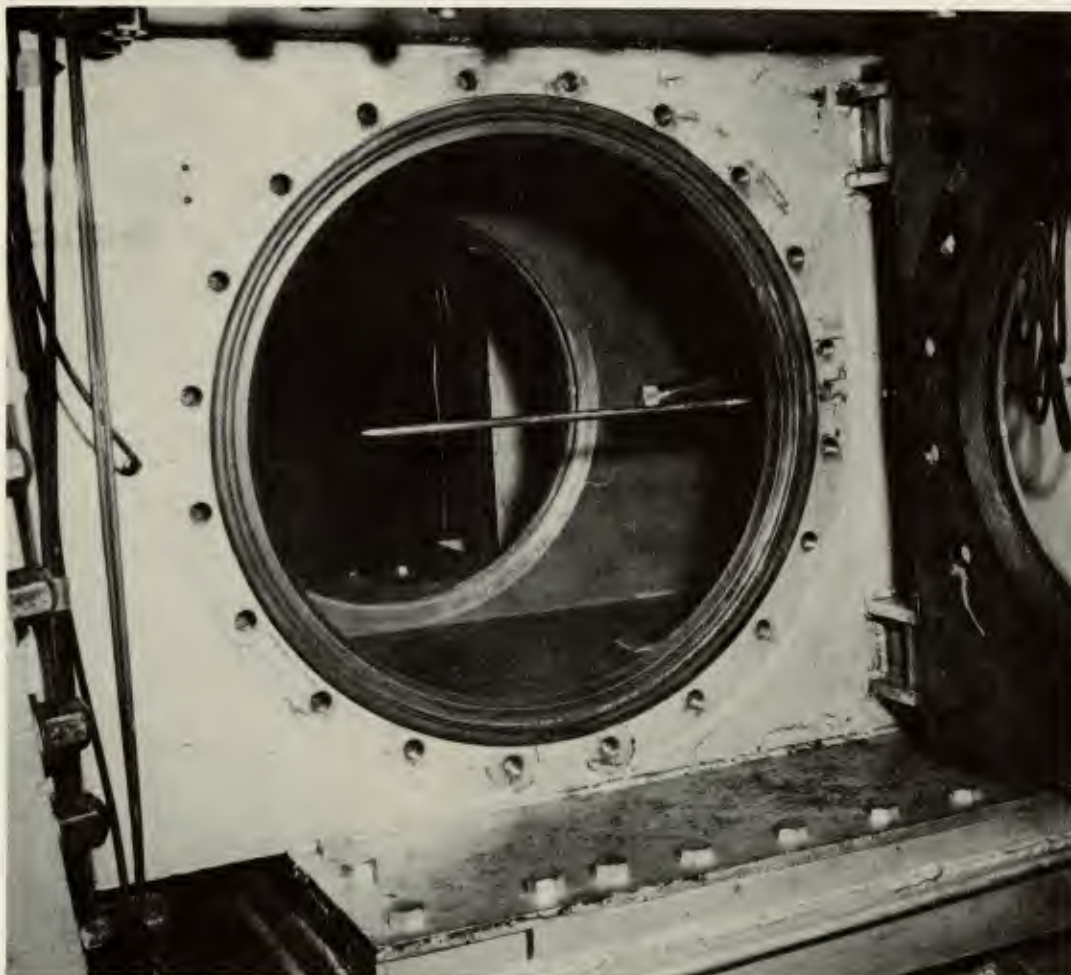Figure 1 - Pitot Tube Nose.

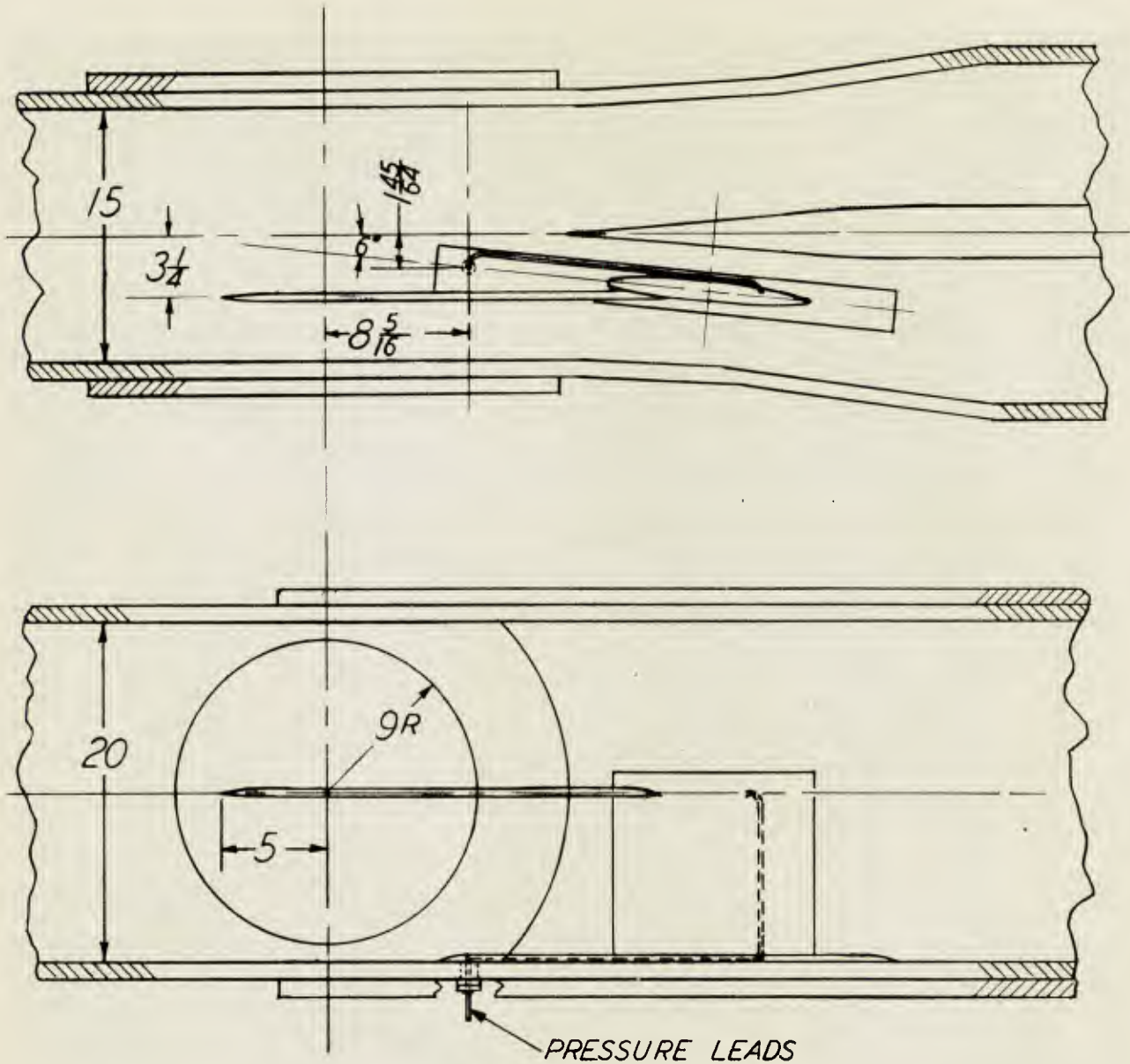
Figure 2 - Wright Field Installation.
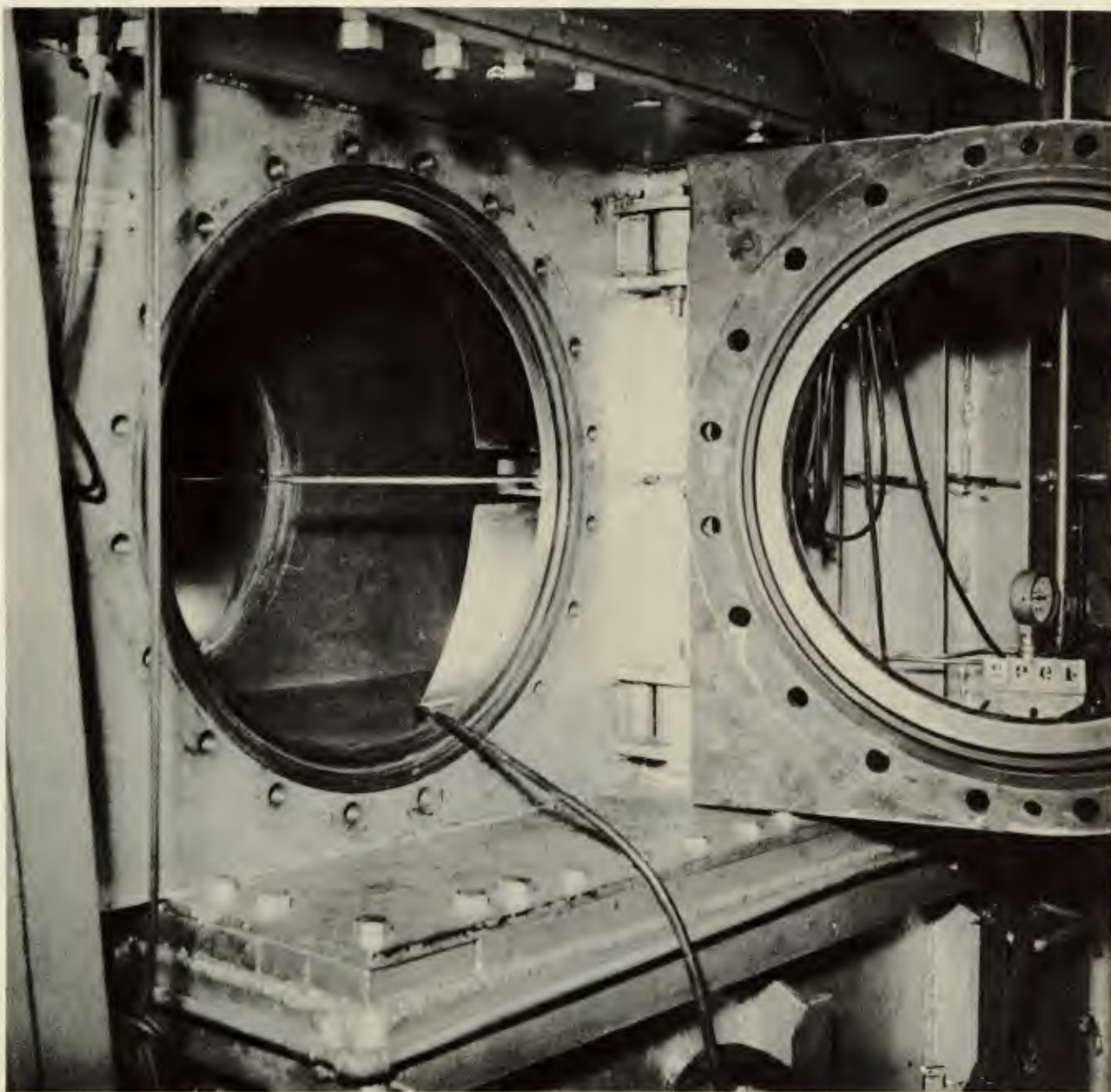
8

Figure 3 - Wright Field Installation.
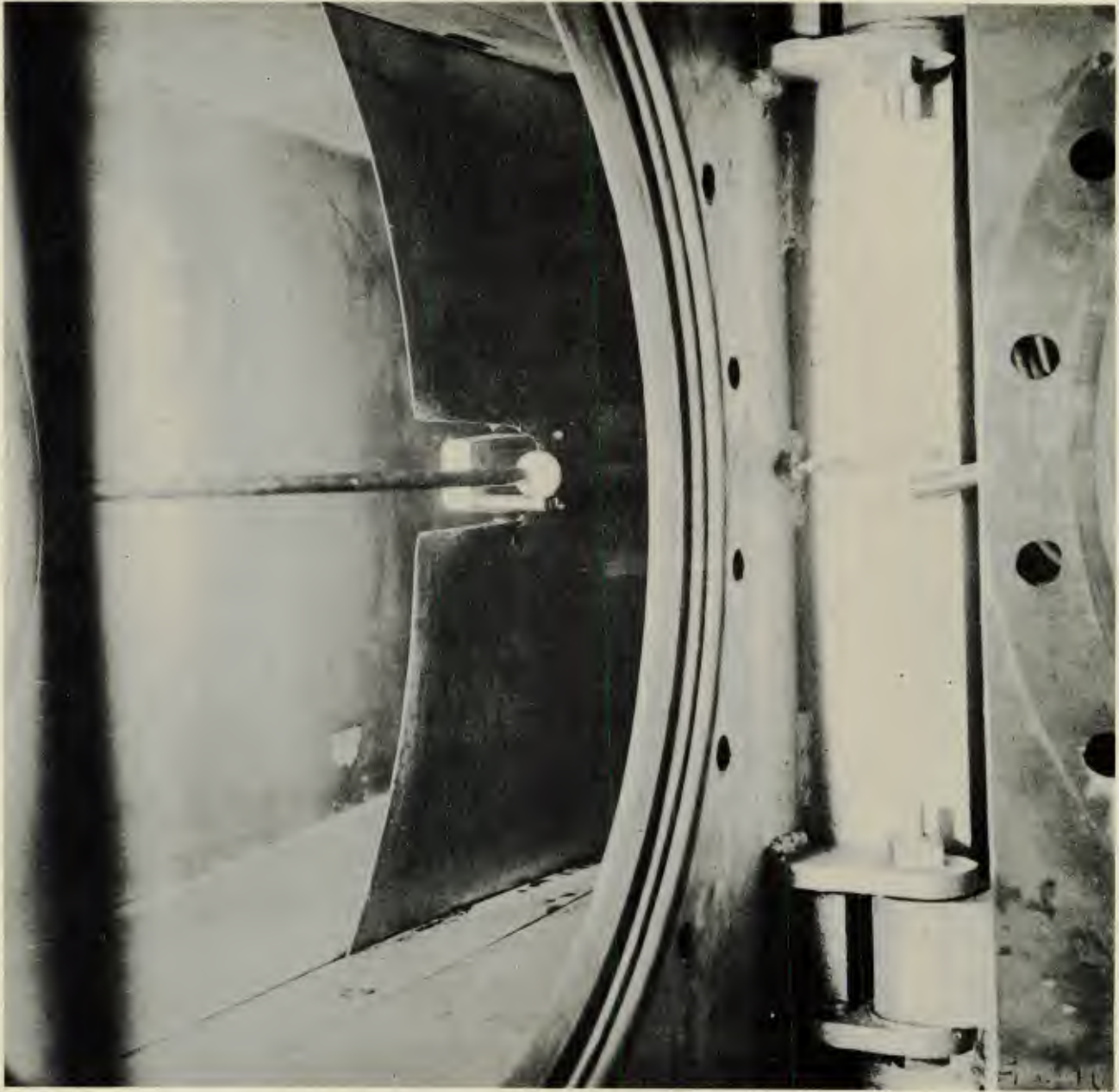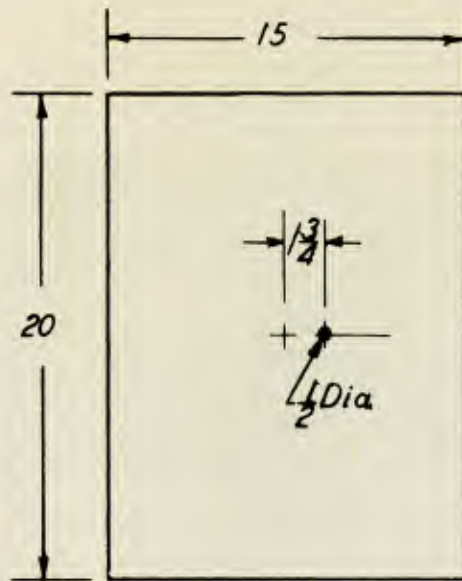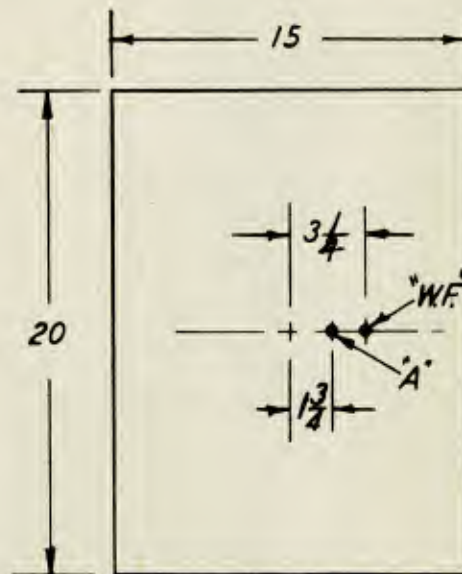
Figure 4(a) - Aberdeen Installation.

Figure 4(b) - Aberdeen Installation.

AXIAL SURVEY

ABERDEEN INSTALLATION AND WRIGHT FIELD
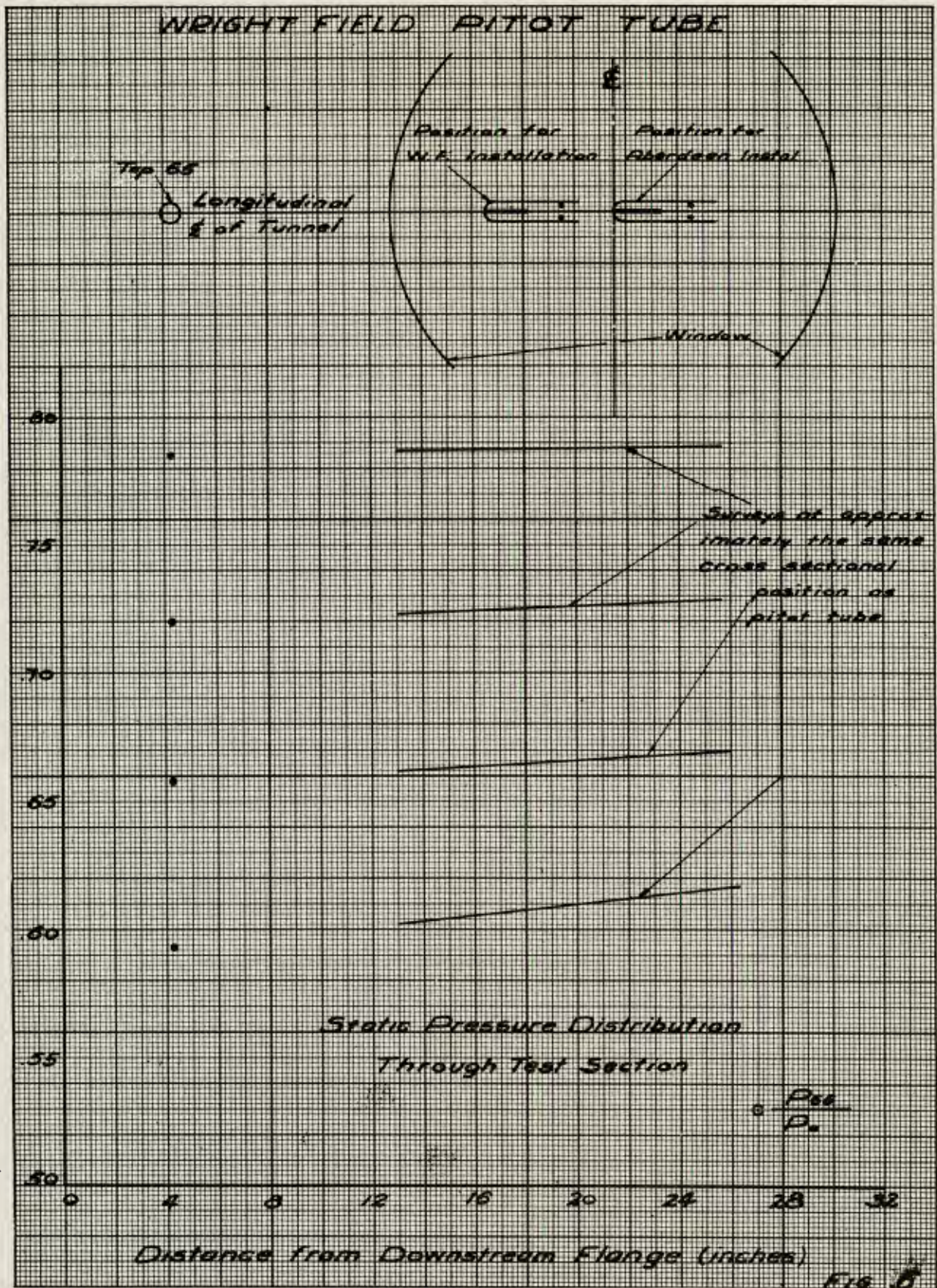
Figure 5 - Cross-Sectional Positions in Tunnel.
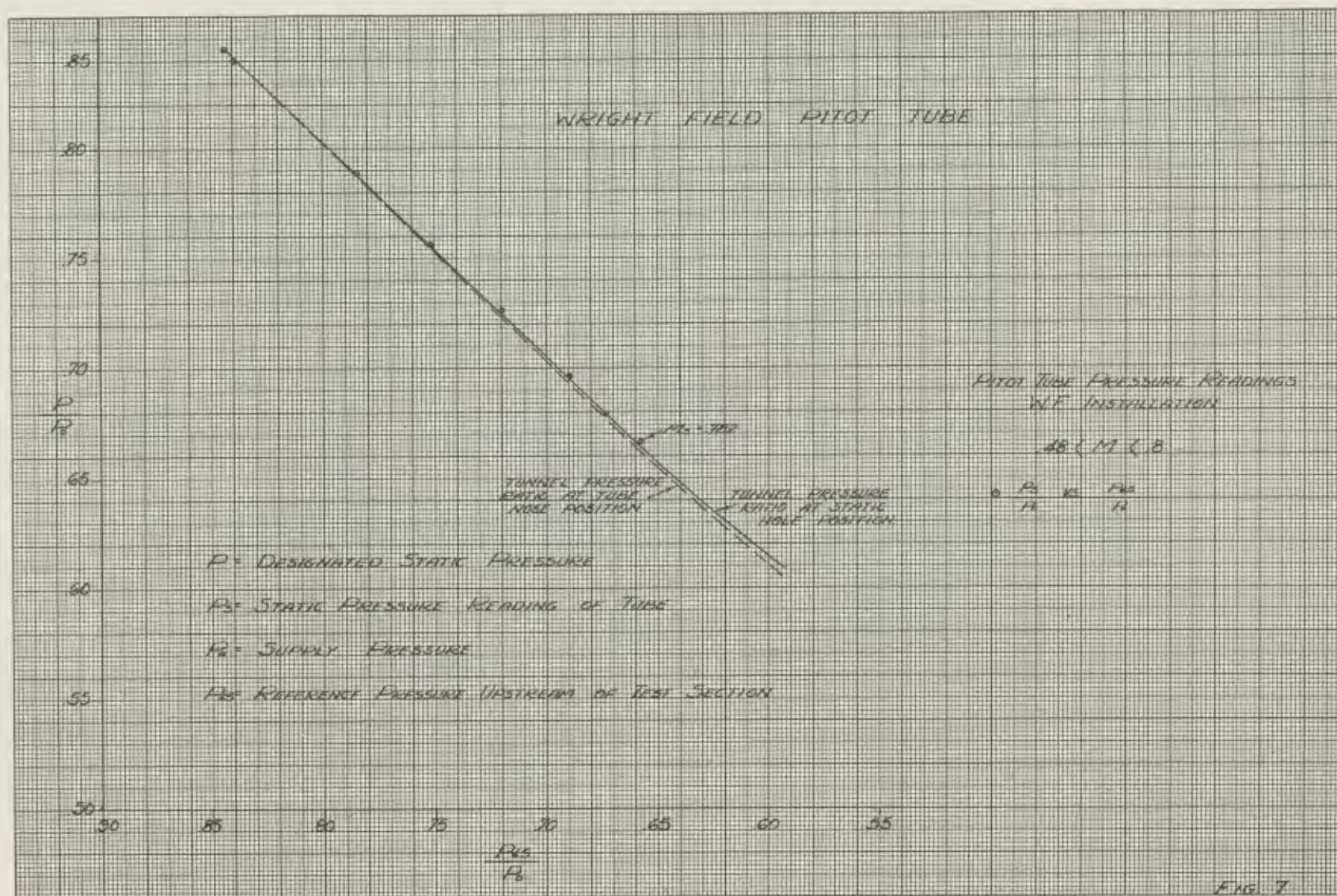
Figure 6 - Wright Field Pitot Tube.

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Figure 7 - Wright Field Pitot Tube.
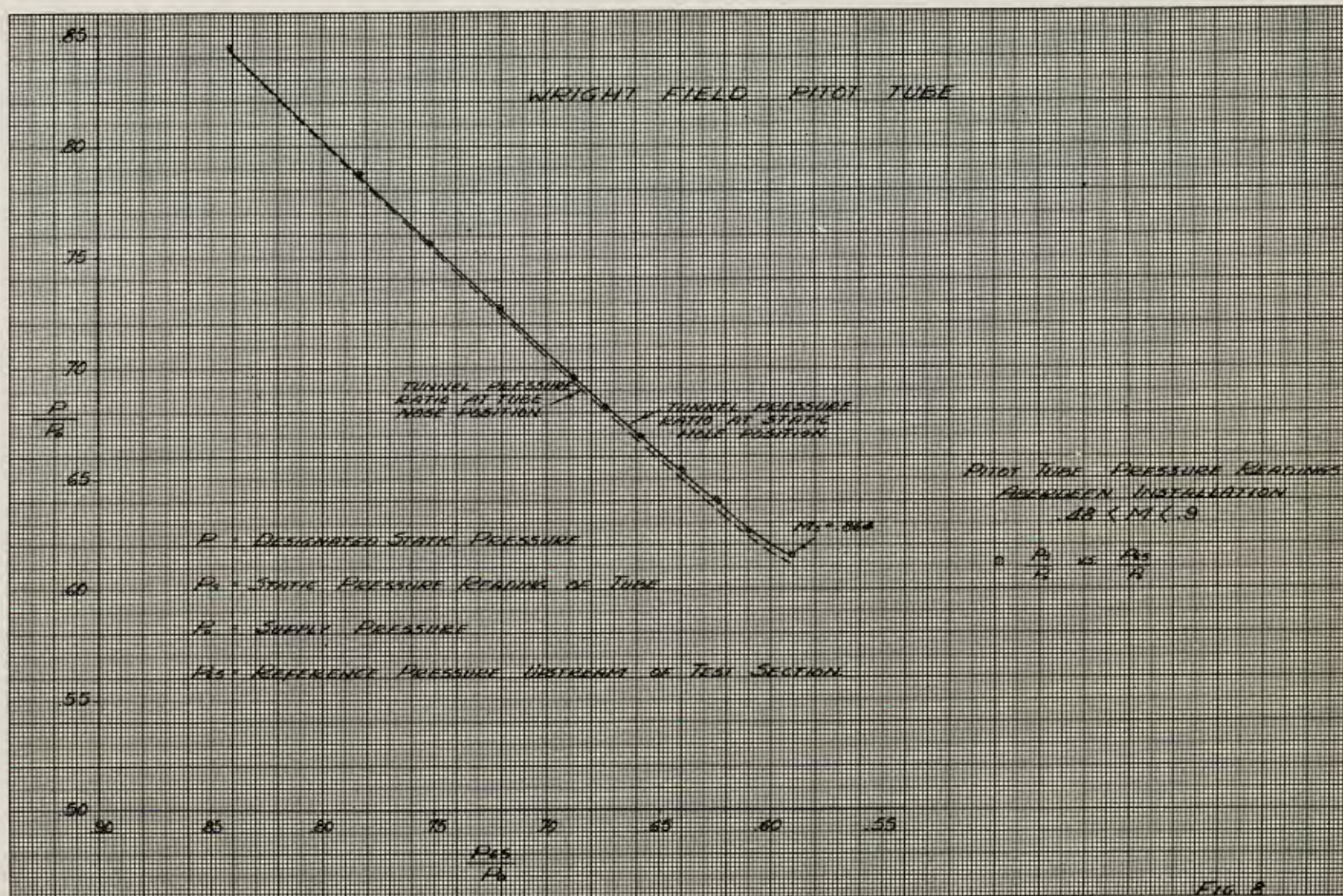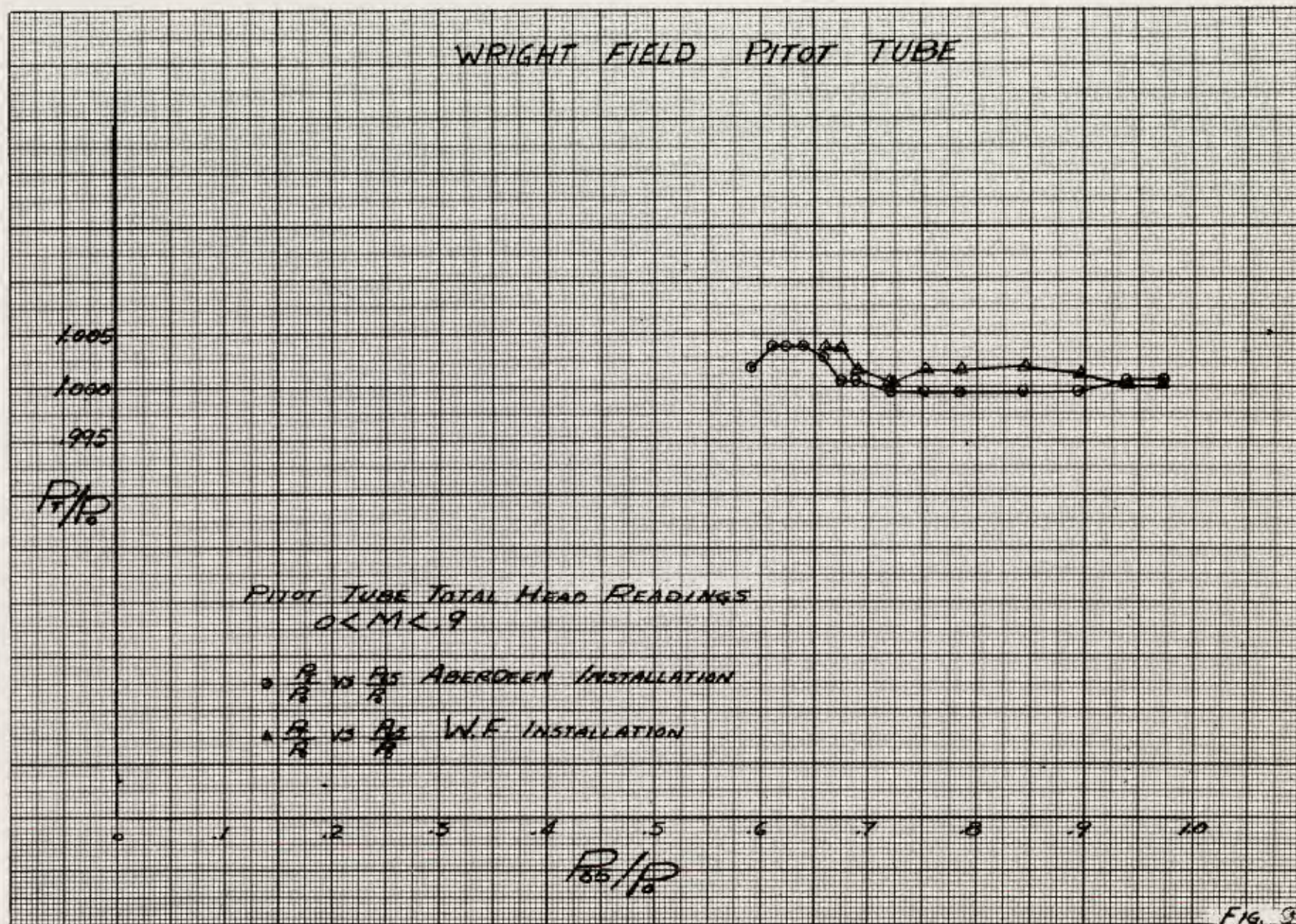
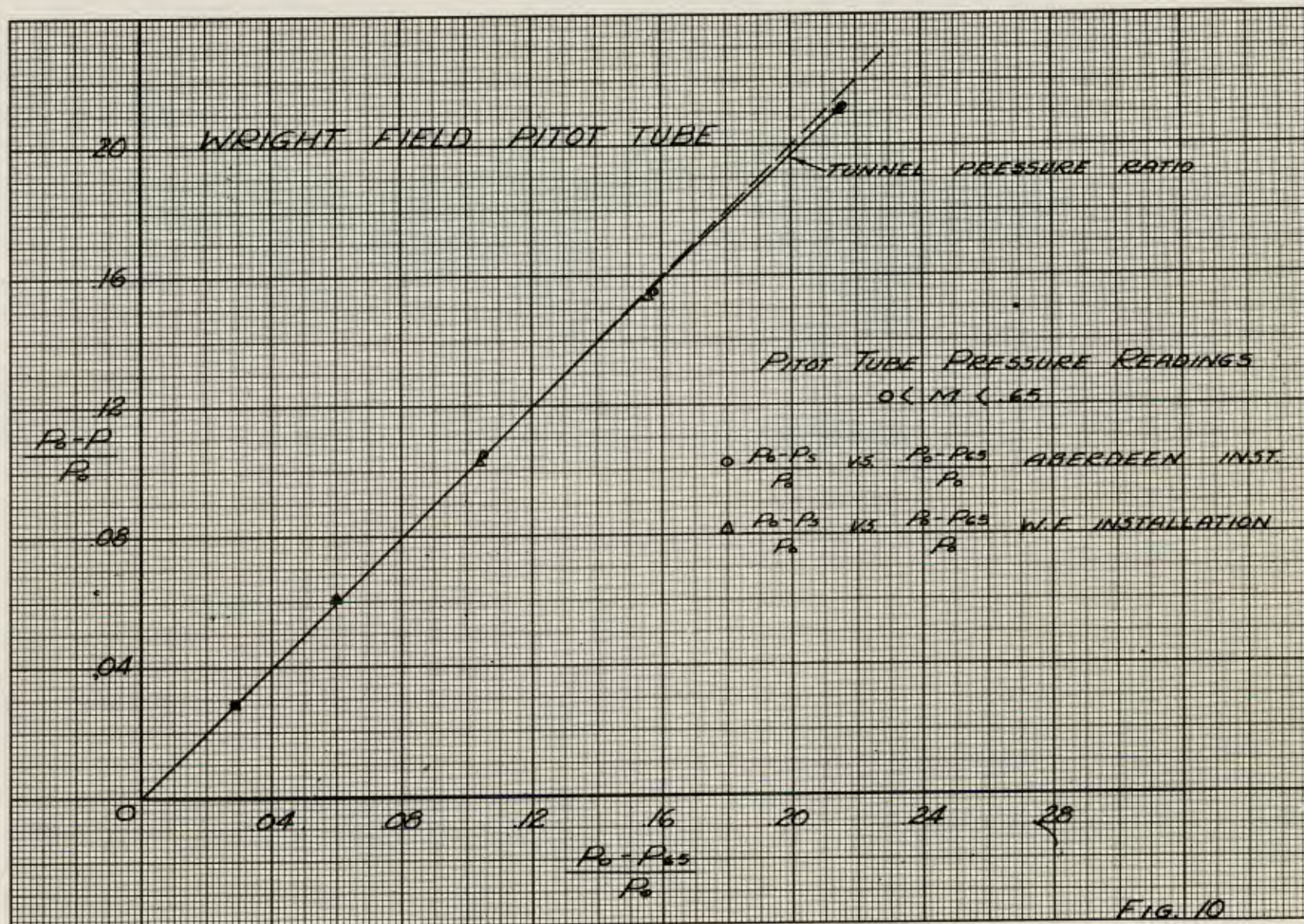Figure 8 - Wright Field Pitot Tube.
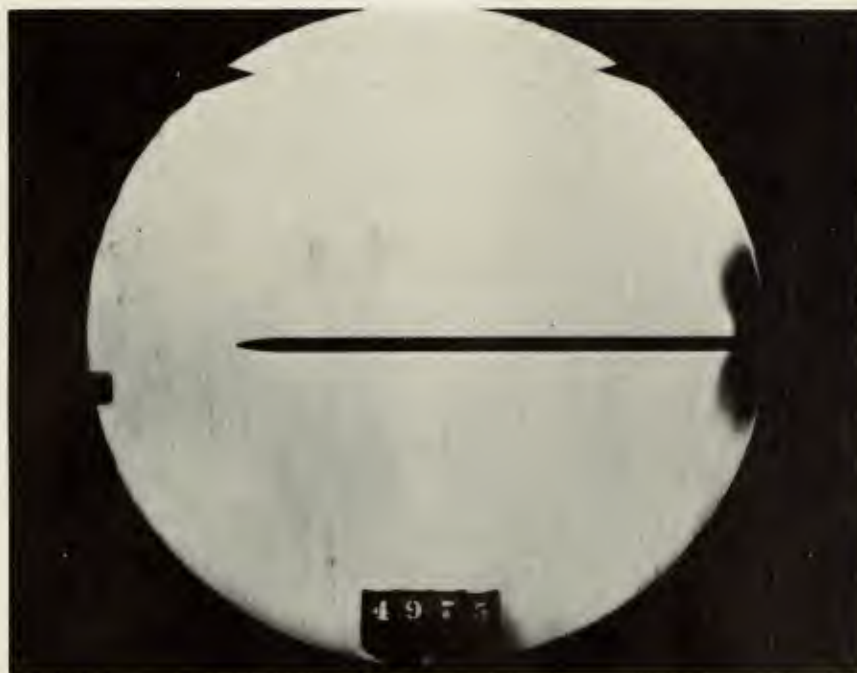
Figure 9 - Wright Field Pitot Tube.
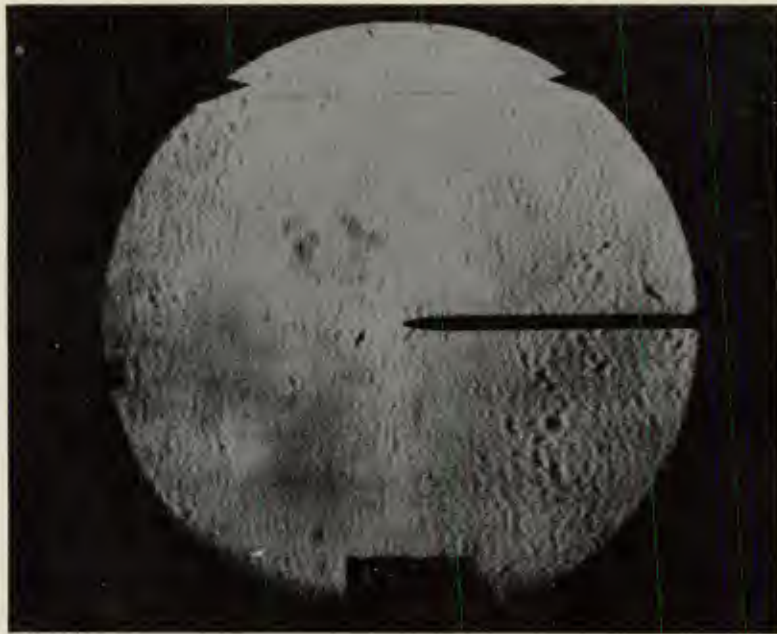
Figure 10 - Wright Field Pitot Tube.

Flash Vertical Knife Edge

Steady .01 Sec. Vertical Knife Edge

Figure 11 - M_d = .78 "WF" Support.

Flash Vertical Knife Edge

Steady .01 Sec. Vertical Knife Edge

Figure 12 - M_d = .87 "A" Support.