CONFIRMATION OF CHOICE OF REFERENCE CONDITIONS FOR PROBE CALIBRATIONS IN THE TRANSONIC TEST SECTION OF THE CERL WET STEAM TUNNEL

- by -

N.B. Wood
CEGB Technology Planning and Research Division,
CERL, Leatherhead, UK
and
R.A. Goodrick
University of Salford, UK

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ABSTRACT

Following discussions at the European Workshop on Probe Calibrations, the determination of reference conditions in the transonic test section of the CERL Wet Steam Tunnel has been checked. The sidewall static pressures, used for reference, were compared with the static pressures obtained by a probe mounted along the tunnel centreline. Within the accuracy of measurement, the sidewall and centreline static pressures were found to be in agreement.

The subsonic blockage of the ventilated test section was examined and found to be not greater than half that estimated for a closed wall tunnel with the same dimensions.

1. INTRODUCTION

As part of the European Workshop on Probe Calibrations, the results of calibrations in different transonic wind and steam tunnels were discussed at the Symposium in Aachen in September, 1983 (Broichhausen and Fransson, 1984). One of the main recommendations to arise from the discussions was that participants should check their reference conditions to aid the understanding of the differences found in the calibrations.

In the CERL steam tunnel reference conditions are obtained by measuring the longitudinal static pressure distribution along a side wall and pitot pressures on the centreline at selected positions. Examples of the pressure distributions obtained with the EPF-L Wedge Probe (WP-11) in position are shown in Fig. 1.

The reference static pressure is obtained from a region just upstream from the probe where the longitudinal pressure distribution is found to be uniform. This reference region is chosen at different positions for different Mach numbers because the development of the flow along the nozzle and (for subsonic conditions) the upstream disturbance caused by the probe vary with Mach number.

For the calibration of the WP-11 probe the total pressure was measured at two stations upstream from the probe (see Fig. 2) via retractable pitot probes. The reference total pressure was then chosen as that nearer to the position where the reference static pressure was obtained. The reference Mach number was obtained from the reference total and static pressures as described by Wood and Langford (1984).

2. TECHNIQUE FOR CHECKING REFERENCE CONDITIONS

Assuming that the general procedure adopted for determination of reference conditions in the CERL tunnel is valid, then the required check involves confirming that the presure distribution measured on the wall is representative of centreline conditions in the region where reference conditions are obtained.

In order to do this a 6 mm diameter cylindrical probe was constructed which could be mounted with its axis set along the test section centreline. Its nose was positioned upstream of the contraction and it extended downstream from the control flaps of the transonic test section. The probe was supported on diagonal cross braces near its nose and tail, as shown in Figs. 2 and 3. The cross braces wave made from flat brass strip, profiled to subsonic aerofoil shape (7.5 × 1.5 mm) at the upstream position and to wedge shape (12.5 × 3 mm) at the downstream position.

Four pressure tapping holes were provided at a single axial position at 90° intervals around the circumference of the centreline probe. The probe could be positioned axially so that its pressure tappings could be set at the range of axial locations chosen for measuring the reference conditions. Thus the probe could be used for measuring the centreline static pressure for comparison with the adjacent side wall pressure.

For the present experiment, it was desirable to position a WP-11 probe in the tunnel to provide similar blockage to that in the original tests. Because of the presence of the centreline probe the WP-11 could not, of course, be positioned with the sensing head on the centreline, but in the original calibrations the probe was tested both with its sensing head on the tunnel centreline (75 mm from the wall) and at 37.5 mm from the side wall. An example of the WP-11 probe was still avilable (kindly loaned to CERL by T. Fransson of EPF-L) and this was mounted in the tunnel in the latter configuration, as shown in Figs. 2 and 3.

3. RESULTS

The side wall static pressure distributions were similar to those obtained previously for similar tunnel conditions and with the WP-11 probe head inserted to 37.5 mm from the wall, i.e. as shown in Fig. 1.

3.1 Accuracy

For the original calibrations in the CERL steam tunnel, the accuracy of the reference static pressure was given as ±0.87 mb to 99% probability. This included an allowance for the uniformity of the axial pressure distribution in the region chosen for reference (0.25 mb), the accuracy of the reference pressure gauge, used for the transducer calibration (0.83 mb) and the standard error of the linear regression through the transducer calibration (0.1 mb, or 0.26 mb to 99% confidence).

For most of the present tests, the transducer was calibrated with a reference gauge which had itself been calibrated to greater accuracy (0.091 mb to 99% confidence) than the gauge used previously. The accuracy of the regression line through the transducer calibration (2.6 standard errors) was 0.24 mb.

Although for the present investigation we are making comparison between a centreline pressure and one measured at the same axial location on the sidewall that sidewall pressure is representative of the pressure plateau chosen for determination of the reference static pressure. Therefore the variation in the uniformity of the plateau is still relevant. However, it was noticed during the present tests that there was some variation of tunnel conditions with time. Since the sidewall pressures were not measured simultaneously, the non-uniformity mentioned above must include temporal variations as well as spatial variations.

For each test condition, the centreline and adjacent sidewall pressures were measured before and after the scan of the sidewall pressure tappings. Taking all the test conditions included in this comparison, the standard deviation of the differences between the pairs of centreline readings and between the pairs of adjacent wall readings were calculated.

The results were:

Centreline 0.32 mb,
Adjacent sidewall 0.28 mb.

Each of these two results was for seventeen pairs of readings. These results must include also the transducer calibration accuracy. Therefore, the overall accuracy will be taken as given by these results.

For 99% probability the above results become:

0.73 mb for the sidewall;
0.83 mb for the centreline.

These magnitudes compare well with the accuracies quoted for the original calibration data.

3.2 Comparison Between Centreline Pressure and Adjacent Sidewall Pressure

Measurements were taken with the pressure tappings in the centreline probe positioned at three successive axial locations. For each location results were selected which covered the range of Mach numbers for which that position had been used to obtain the reference conditions. These were as follows:-

Axial Station	Mach No. Range	Number of Test Cases
19	0.62-1.00	6
22	0.90-1.08	6
25	1.07-1.13	5

Table 1: Details of 17 Test Cases Used for Evaluation of Results

For each test case there were two pairs of readings of centreline and sidewall static pressure, giving a total of 34 pairs of readings.

Fig. 4 shows one pair of readings for each test condition taken with the probe tappings opposite station 19. It can be seen that, within the accuracy of measurement, the readings lie on the line of equality.

Taking all 34 pairs of readings, the standard deviation of the differences between each pair was 0.30 mb, giving 0.78 mb for 99% confidence level. However, it can be seen from Fig. 4 that the wall static pressure tended to be slightly below the centreline pressure. Moreover, a regression line through all 34 points shows this result to be general, giving

$$p_{wall} = 0.4736 + 0.9947\, p_c \quad (88 \leqslant p \leqslant 178 \text{ mb})$$

with standard error = 0.26 mb.

Nevertheless, each pair of points gave agreement to the accuracy with which they could be measured.

The accuracies for total pressures, pressure coefficients and Mach numbers were as quoted by Wood and Langford (1984) for the original calibrations.

3.4 Blockage

It is clear from the wall pressure distributions presented by Wood and Langford (1984) that there was some subsonic blockage caused by the probe, despite the use of ventilated walls. The reduction in pressure in the neighbourhood of the probe is evidence of the acceleration of the flow in this region.

In the case of transonic Mach numbers, the existence of local supersonic regions on the probe, terminated by shock waves, makes the blockage effects more difficult to discern, whilst at supersonic Mach numbers the effect of the probe on the walls occurs downstream from the probe.

Returning to the subsonic blockage, this was discussed by Broichhausen (1984). However, he concluded that the CERL tunnel, which had the largest cross-section of any of the calibration channels participating in the workshop, as well as ventilated walls, displayed the greatest blockage. This is exceedingly unlikely.

Broichhausen applied blockage results quoted by Wyler (1975), who found additionally that the blockage effect in an open jet was equal and opposite to that for a closed channel. Therefore, a ventilated tunnel would be expected to give a blockage which is between the open and closed channels, and ideally approaching zero.

For the present discussion a simple one-dimensional blockage analysis has been carried out, in which the change in pressure resulting from the change of area at the probe has been calculated.

The expression used was

$$\frac{A}{p}\frac{dp}{dA} = \frac{dp/p}{dA/A} = -\frac{2\gamma M^2\left(1+\frac{\gamma-1}{2}M^2\right)^{-1}}{(\gamma+1)M^2\left(1+\frac{\gamma-1}{2}M^2\right)^{-1}-1} \qquad \ldots (1)$$

and gives results of similar magnitude to those obtained by Wyler.

The results obtained are shown in Table 2. The experimental results are from the measurements of Wood and Langford (1984), where the pressure change $(p_{27}-p_{19})/p_{19})$ is between the axially uniform wall condition upstream from the probe (station 19) and the wall pressure close to the plane of the probe (station 27).

Test No.	Length of Probe in Flow (mm)	M	$\frac{p_{27} - p_{19}}{p_{19}}$	$\frac{\Delta p}{p}$ (Calculated)
6	75	0.48	-4.4×10^{-4}	-0.0034
5	"	0.65	-0.0018	-0.0084
7	"	0.77	-0.0091	-0.0167
4	"	0.86	-0.0183	-0.0326
11	37.5	0.87	-0.0094	-0.0179

Table 2: Effect of Subsonic Blockage on Pressure in Plane of Probe. Test Numbers Are Those of Wood and Langford (1984). The Calculated Pressure Change is Obtained From Eq. (1), Calculated with $\gamma = 1.32$.

Whilst the pressure in the plane of the probe may not be uniform, it seems likely that a major reason why the experimental blockage effects were no greater than half those calculated was the use of ventilated walls.

It is likely that the blockage in the CERL tunnel was lower than that in other tunnels in the Workshop

(a) because the cross sectional area of the test section was larger;

(b) as a result of the ventilated walls.

4. CONCLUSIONS

Checks have been made on the method of obtaining reference conditions for probe calibrations in the CERL Wet Steam Tunnel. A static pressure probe, mounted along the centreline of the test section with its nose upstream from the contraction, was used to obtain pressure readings for comparison with pressures measured on the sidewall. The results showed that the pressures were in agreement within the accuracy of the measurements. This result is considered to confirm the method used to obtain reference conditions.

The subsonic blockage was examined and was found to be no greater than half that calculated from a simple analysis based on area ratio for a closed-wall test section. This gives an indication of the reduction in blockage achieved by the use of ventilated walls.

5. ACKNOWLEDGEMENTS

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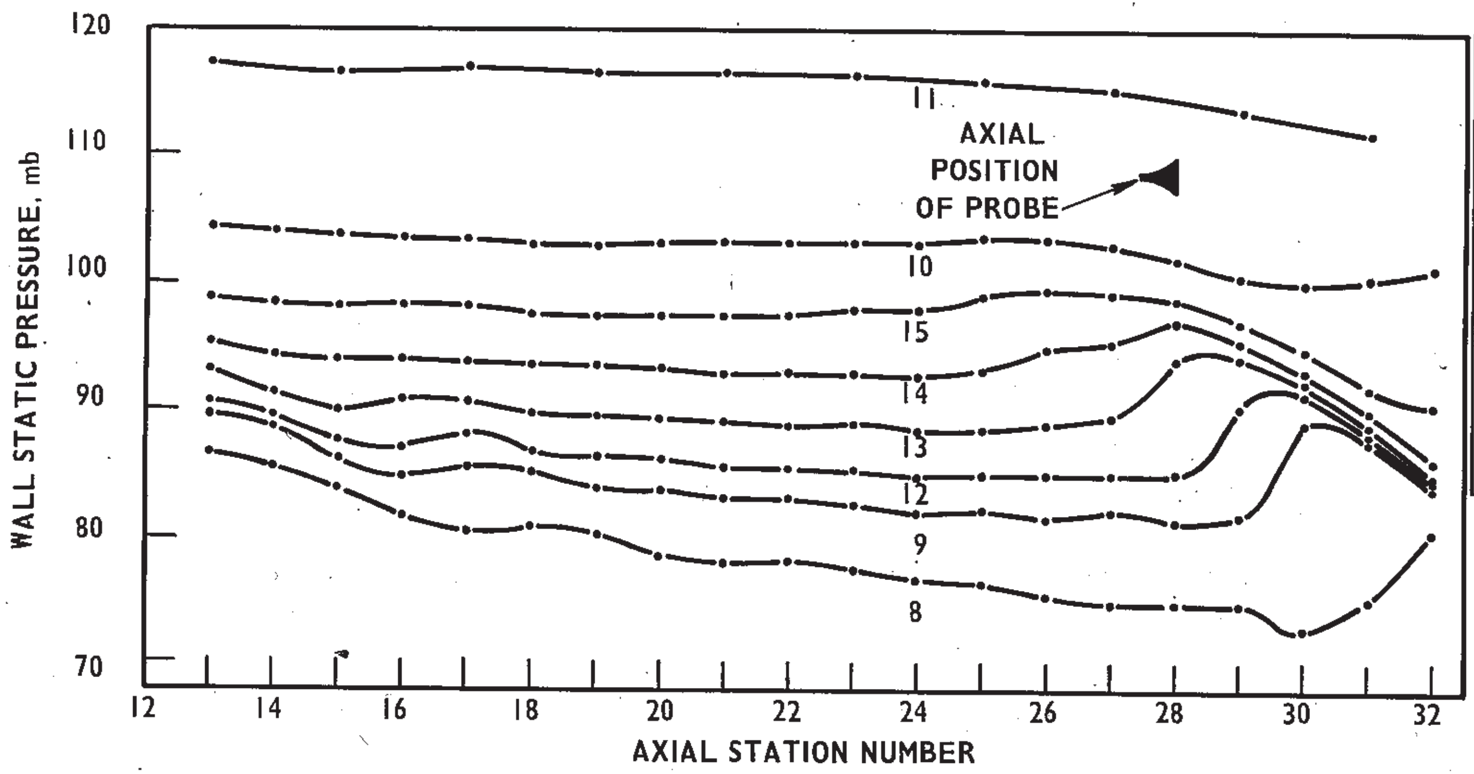

Test No.	Flap Angle (deg)	Mach No.
8	90	1.21
9	45	1.14
10	20	0.96
11	0	0.87
12	40	1.11
13	35	1.08
14	30	1.05
15	25	1.01

FIG. 1 AXIAL VARIATION OF WALL STATIC PRESSURE; $\beta = 0$, LENGTH OF PROBE IN FLOW 37.5 mm

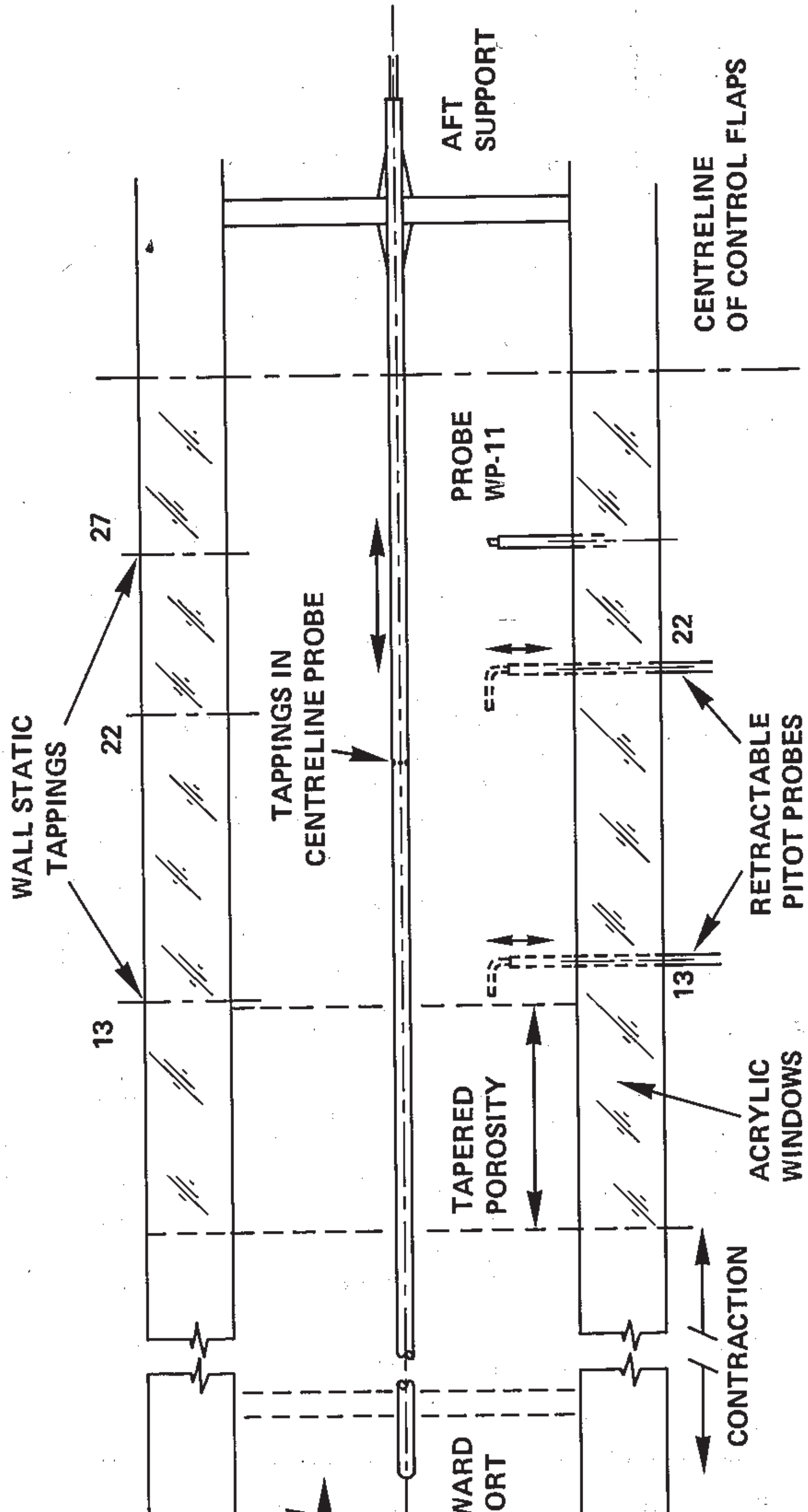

FIG. 2 PLAN VIEW OF TEST SECTION WITH WP-11 AND CENTRELINE PROBES INSTALLED (PROBE WP-11 SHOWN AT 37.5 mm IMMERSION)

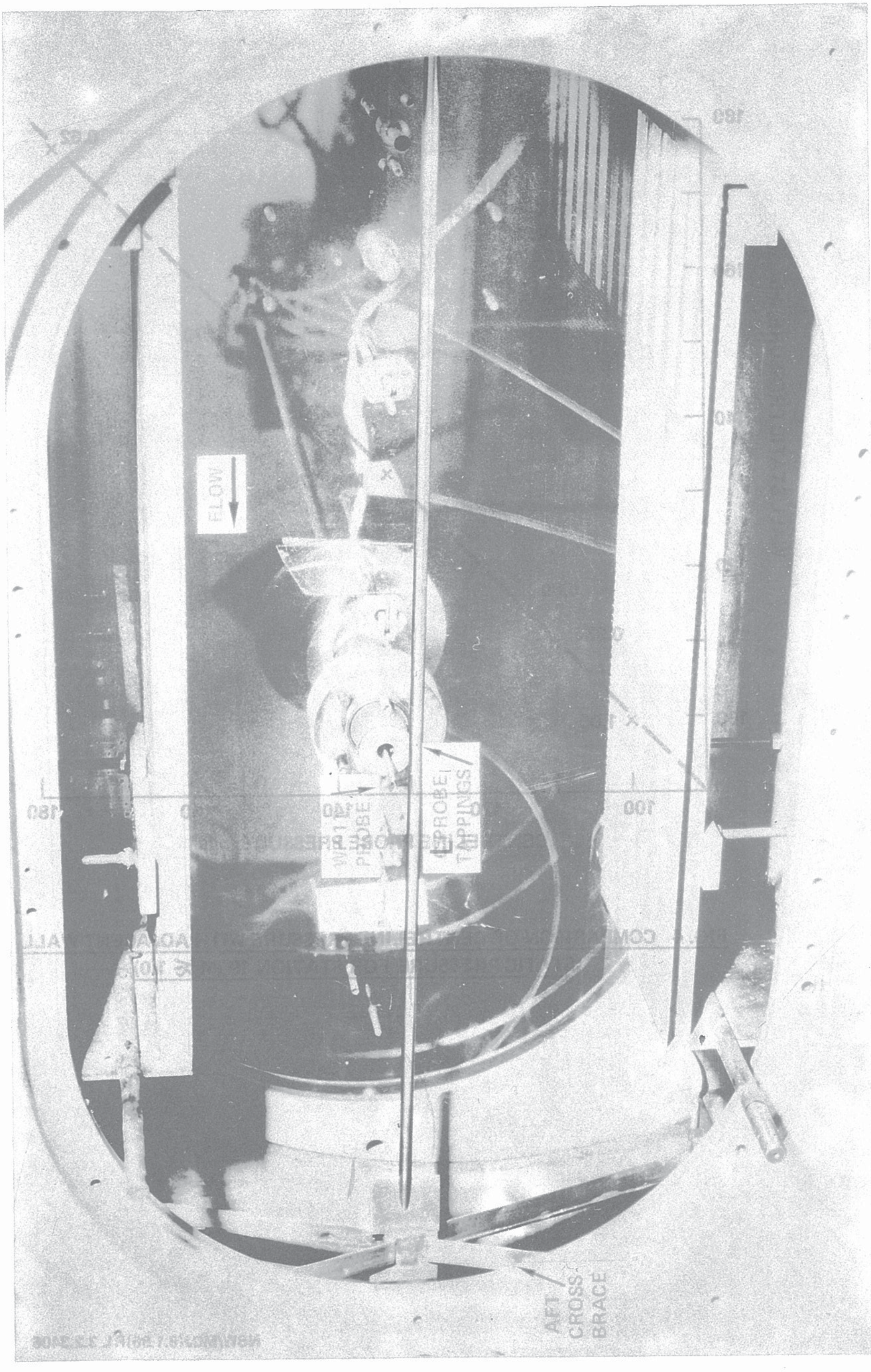

FIG. TRANSONIC TEST SECTION WITH WP - 11 AND CENTRELINE PROBES INSTALLED

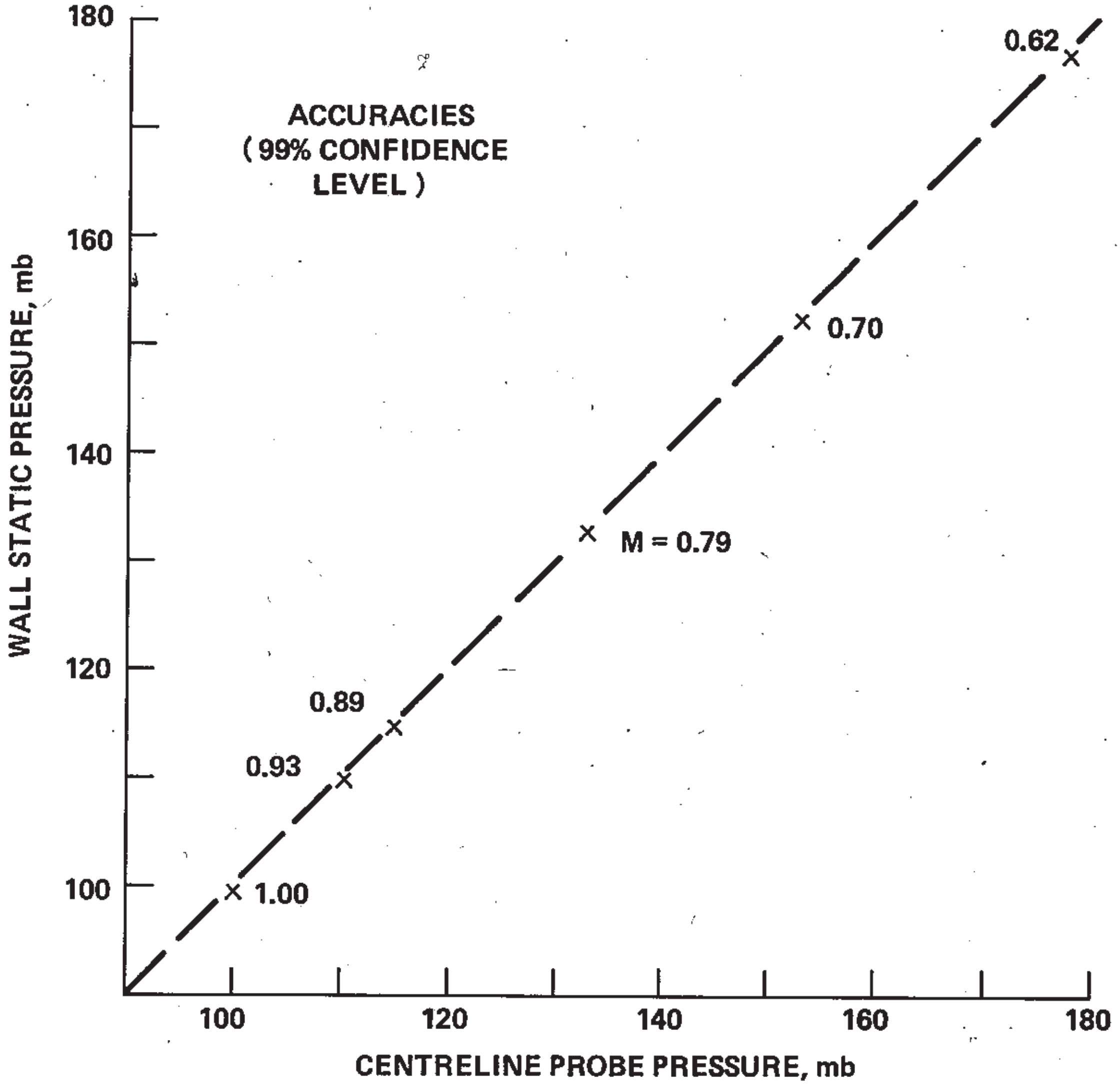

FIG. 4 COMPARISON OF CENTRELINE PRESSURE WITH ADJACENT WALL STATIC PRESSURE FOR STATION 19 ($M \lesssim 1.0$)