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WALL PROXIMITY EFFECTS ON THE MEASURING ACCURACY OF WEDGE PROBES

M.V.A.Murthy and S.Soundranayagam+

Scientist, Propulsion Division,
National Aeronautical Laboratory, Bangalore, India.
+Professor, Mechanical Engineering Department,
Indian Institute of Science, Bangalore, India.

ABSTRACT Wall proximity effect on the calibration constant of a wedge probe was studied by carrying out tests in a specially built calibration tunnel. The test results showed distinct effects of wall proximity on the wedge probe constants. The extent of error caused by neglecting such effects in a turbine test was estimated and found to be as high as 12% in evaluating parameters like loss coefficient in the vicinity of the hub and casing walls.

1. Introduction

Measurements of flow within a turbomachine have often to be done in a very confined environment where the probe dimensions are not negligible compared to the lateral distance between the flow surfaces. This has often led to difficulties in interpreting the results even qualitatively. There is a growing feeling amongst turbomachine engineers that measurement probes should be calibrated in geometries not very unlike those in which they are meant to work.

The calibration constants of small wedge probes have been found to be dependent on the dimensions of the open jet in which they were calibrated [1]. Wall proximity effects have also been noticed by some workers [2 - 4] though no results have been given of their actual effect in evaluating turbomachine parameters.

This paper deals with calibration tests carried out on a wedge probe with special emphasis on wall proximity effects and its subsequent use in a model turbine.

2. Probe Calibration Rig and Test Procedure

A sectional view of the calibration rig is shown in Fig. 1. The height of the test section across which the probe moved was kept the same as that of the annulus of the test turbine. The probe to be calibrated was inserted into the test section through the top wall.

Figure 1 also shows the measuring planes and instrumentation of the calibration rig. The wedge probe to be calibrated was located in plane IV. In this plane wall static pressure tappings were provided both on the top and bottom walls and on the side walls of the test section to check the uniformity of wall static pressure over the range of test Mach numbers. During the calibration tests the wall static pressure measured on the side wall was taken to be the true static pressure P_{sa} in the test section, since the presence of the probe in the test section did not materially influence this reading. The total pressure P_o at the probe location was measured by the total pressure tapping of the wedge probe. The pressure readings P_o and P_{sm} of the wedge probe from total pressure tapping and from the pressure tapping on the wedge surface were taken in the aligned

condition of the probe in the direction of flow. From these readings the wedge probe constant B was evaluated over the range of flow Mach number as

$$B = (P_o - P_{sm})/(P_o - P_{sa})$$

Initial calibration tests at centre height were carried out both in the actual turbine annulus and in the calibration rig and were found to be in good agreement.

Figure 2 shows the dimensions of the combination wedge probe calibrated. The location of the total pressure tube and the pressure tapping on the wedge surface of this probe was offset by 2.0 mm from the constructional point of view due allowance being made for this in processing the data.

3. Results and Discussion

The calibrations carried out on the wedge probe at different heights from the test section wall showed a strong effect of wall proximity on the probe constant as can be seen in Fig. 3. The variation of probe constant was also not symmetric along the height of the test section. This is due to the flow distortion similar to the one observed in [2] in presence of the probe stem.

Measurement errors, in the vicinity of wall arise because of two effects. One is due to the redistribution of the potential flow around the probe and its stem. The other is due to the velocity gradient around the probe if immersed in the wall boundary layer. The flow distribution around a spherical probe in the vicinity of a wall was studied by Heneka and Bubeck[3] through tests in a flat water channel on a simplified two dimensional model. The flow visualisation around the model in the vicinity of wall indicated a redistribution of potential flow resulting in local change in the direction of the stream line and an error in pitch angle, with a low pressure region at the pressure tapping situated away from the wall compared to pressure at the tapping situated near the wall. The wall proximity effect on pitch angle measurement was also studied by Heikal [4] on spherical probes. His results were contrary showing the error in pitch angle measurement in the opposite direction. The trend observed in the results of Heikal [4] could be due to the predominant effect of wall boundary layer and associated velocity gradient resulting in higher surface pressure at the tapping situated away from the wall on the probe head. The wall proximity effects observed in the present calibration tests on the wedge probe appear to be due to the potential flow redistribution over the probe and its stem indicating probe constant being highest near the bottom wall and reducing towards the top wall (Fig. 3) in the flow Mach number range upto about 0.75.

The probe constant at any given height from the wall was nearly constant for flow Mach numbers upto about 0.75 (Fig. 3). This trend is also seen in Fig. 4 where the probe constant was normalised with respect to the value at the mid height and plotted as a function of probe height. For flow Mach numbers upto about 0.75, the curves in Fig. 4 collapsed to a single curve and the normalised probe constant B/B_{mid} could be related to the probe height h/H in this Mach number range by

$$B/B_{mid} = 1.08 - 0.16(h/H)$$

For flow Mach numbers above 0.75, the curves of B/B_{mid} deviated due to the presence of a local shock. The presence of a local shock for flow Mach numbers above 0.75 can be observed through its effect on the static pressure at the bottom wall in the probe plane as the probe approached the bottom wall (Fig. 5).

The calibrated wedge probe was used in a turbine annulus and the performance parameters of the turbine rotor were evaluated considering the wall proximity effects. These values were also compared with values obtained ignoring wall proximity effects to study the magnitude of the errors involved in ignoring these effects. It was observed that the wall proximity effects did not cause great error in the estimation of local Mach numbers etc., which depended on the pressure ratio. But they did cause significant error, as much as 12%, when quantities such as blade loss coefficient were estimated that depend on the difference of pressure (Fig. 6).

4. Conclusions

The study has shown that the wall effects have an important influence on probe calibrations in internal flows and that the calibration should be done in a channel of similar geometry to the flow field to be measured. Measurements in a typical turbine annulus have shown that wall effects should be considered in all such internal flows for evaluation of parameters that depend on the difference of pressure. However for the evaluation of parameters that depend on the ratio of pressures, it would appear that neglect of wall effects in most tests would not lead to great error.

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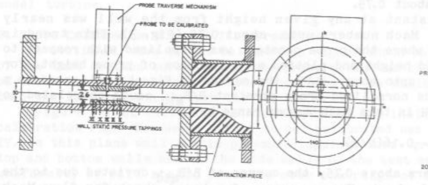

Fig. 1 Probe Calibration rig.

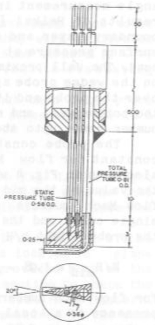

Fig. 2 Combination Wedge Probe

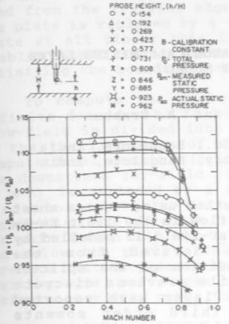

Fig. 3 Variation of the probe constant with Mach number and probe height

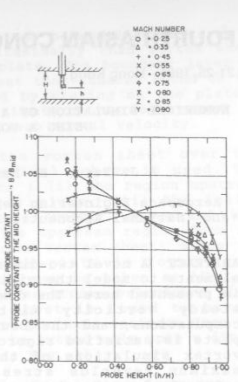

Fig. 4 Variation of the normalised probe constant with Mach number and probe height

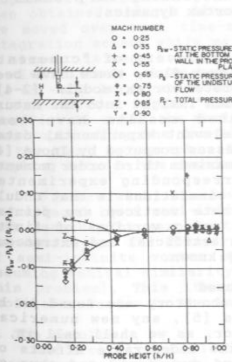

Fig. 5 Variation of static pressure in the probe plane on the bottom wall

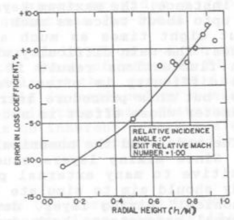

Fig. 6 Error in loss coefficient due to neglecting wall effects in a turbine test