TRANSONIC CALIBRATION CHARACTERISTICS OF DISC STATIC PRESSURE PROBES

by

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At NEI Parsons, disc type static pressure probes are used when making measurements in low pressure steam turbines. The original selection of a disc type design was made since a sensing head was required which was largely insensitive to the variations of pitch angles likely to be encountered. An early design of probe, designated 'stem mounted' is shown in Figures 1B and 2. The probe was a double chamfered disc, 10 mm diameter by 1.8 mm thick, a wedge angle of 44^{o} and separate pressure tappings on each face. The probe could then be turned into the flow direction to equalise the tapping pressures and hence also give an indication of flow yaw angle.

Although calibration in the steam tunnels at Parsons indicated that the probe was relatively insensitive to pitch angle in flows of high subsonic Mach number this was not the case in supersonic flows (Figure 3). Additional calibration work in the wet steam transonic tunnel at CERL, Leatherhead also showed that interpolation between the two curves to obtain the calibration factor at intermediate Mach numbers was not valid. Indeed, as Figure 4 indicates these was a marked Mach number effect.

To determine the reason for these effects a Schlieren visualisation study was conducted over a range of pitch angles (Figure 5). The photographs clearly show a stem shock - head shock interaction disturbance which passes across the sensing hole at $+8^{o}$ pitch and moves back behind the probe head with increasing positive pitch. This links in with the 1.22 Mach number calibration curve which exhibits a distinct change at a pitch angle of $+10^{o}$, and suggests that the flow regime between the leading edge shock and the interaction disturbance is stable.

Subsequently an attempt was made to minimise the undesirable features of this probe by modifying the mounting configuration (Figures 1A and 6). The double chamfered disc was retained and mounted on a sting ahead of the support tubing shaped in such a way that the sensing head was in line with the axis of the probe stem enabling point measurements to be made in the flow. A Schlieren study at a Mach number of 1.29 (Figure 7) over a pitch angle range from -10^{o} to $+30^{o}$ showed that the shock pattern, although complex did not seem to exhibit any undesirable effects in the vicinity of the probe head pressure tappings. However, during the preliminary calibration programme on this probe, difficulty was experienced in finding a consistent null point where the probe lined up with the flow. The yaw characteristic of the probe was therefore investigated over an angle range of $\pm 10^{o}$ at a Mach number of 0.89 (Figure 8). The results based on the individual probe pressures P-left and P-right showed that the local static pressure at the probe sensing holes responded in such a way as to give null points at three different values of yaw angle. Consequently with the probe positioned on the central null point, rotation in the clockwise direction (positive yaw) produced a falling P-left and an increasing P-right pressure, which was the reverse of the yaw angle response in lower subsonic and higher supersonic flows. A detailed study of the probe's yaw angle characteristic over a range of increasing Mach number showed that it reverted to a single point pattern at a Mach number just above 1.2. Hence by mounting the sensing head on a sting in an attempt to reduce the adverse pitch angle effects, the unique yaw angle null characteristic was lost in transonic flows.

At this stage of the investigation the undesirable yaw angle effect was thought to be caused by the probe head shape, and the chamfered disc probe was replaced by a similar instrument with an elliptical profile head (Figure 1C). Unfortunately the theory foundered when the calibration factor at a Mach number of 0.887 still exhibited a triple null characteristic over a yaw angle range of $\pm 10^{o}$ (Figure 9). The characteristic also returned to a single null pattern in supersonic flows just above Mach 1.2.

When compared with the chamfered disc probe, however, the calibration factor patterns did appear to be more symmetrical. A possible explanation is that a more stable flow develops around the elliptical curved surface compared to the chamfered disc surface which imposes sudden changes of flow direction. It was also noticed that the calibration factor based on the average of the left and right pressure tappings was reasonably constant over a yaw angle range of $\pm 4^{o}$ about the central null position. Consequently if the probe can be aligned approximately with the flow direction it will indicate a pressure level that can be used for further detailed calibration study.

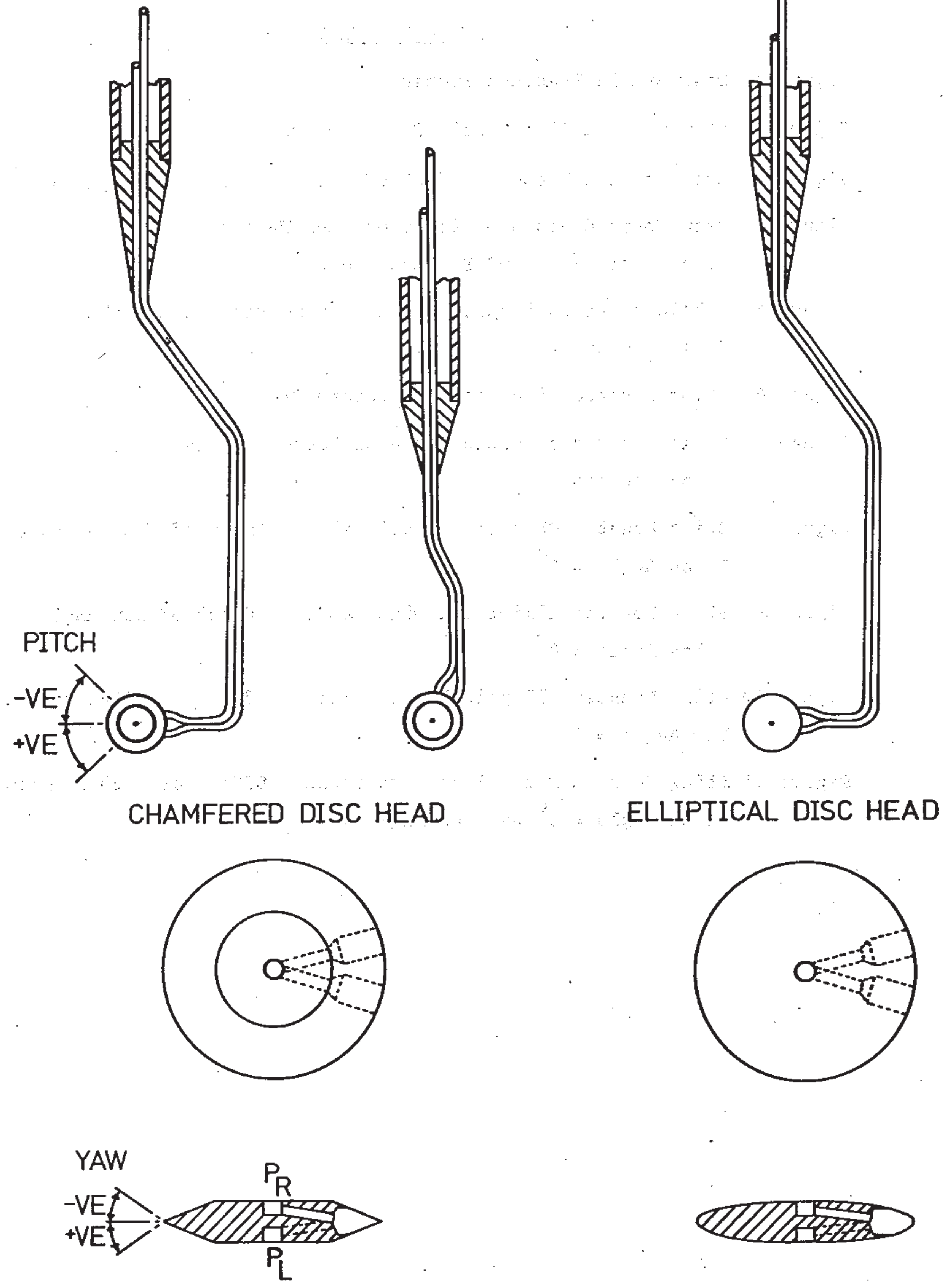
The effect of pitch angle showed a distinct improvement in that the influence on calibration factor was a lot less. Figure 10 shows results at the transonic Mach number limits which looked promising. However the transonic regime is still characterised by large changes in pressure at the probe sensing holes(Figure 11). There is a slight improvement over the stem mounted disc in that the amplitude of the variation is reduced by about half and the Mach number range of the irregularity is also less. The NEIP results at Mach 1 in the subsonic tunnel may be considered as being unrepresentative because of blockage effects.

Since the purpose of calibrating these probes is to study how they respond in transonic flows and ultimately use them to measure turbine flow patterns this must always be kept in mind. Conventional measurements involve alignment with the flow by rotating the probe head in the yaw plane until the pressures sensed at the left and right tappings are equalised. The probe pressure, which with this type of probe is normally lower than the local static is noted and the relevant calibration factor applied to gain the true static pressure. However, as the transonic calibration facilities revealed three null points, there is no reason to presume a similar behaviour will not occur in the turbine. Consequently the measurement of local yaw angles in the flow using an arrowhead probe and aligning the disc probe to this direction will be necessary. The probe static pressure may then be found by taking an average of the left and right tapping readings because this value has been found to be reasonably uniform within $\pm 4^{o}$ of the central null.

It should also be possible to define the central null point by the way the probe readings respond to small changes in yaw angle (i.e. if the probe is in the vicinity of the central null, clockwise rotation will cause the left tapping pressure to fall and the right to rise).

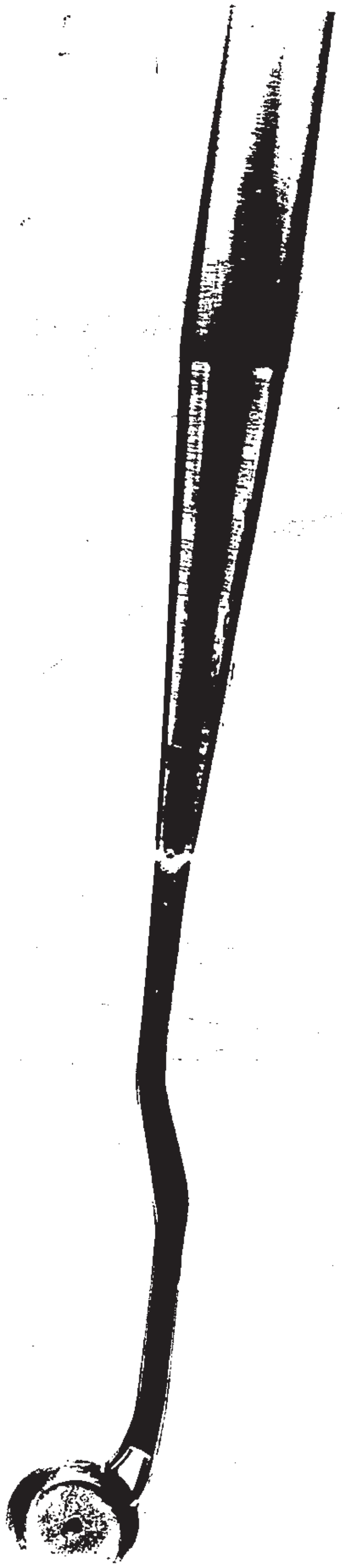
Care will be needed when taking readings at either end of the transonic region where the probe yaw characteristic reverts to a single null point pattern. Also some probe pressure instability may be encountered at $1.08<Mn<1.12$ where the pressure at the sensing head changes rapidly for a small change in free stream Mach number.

LIST OF FIGURES



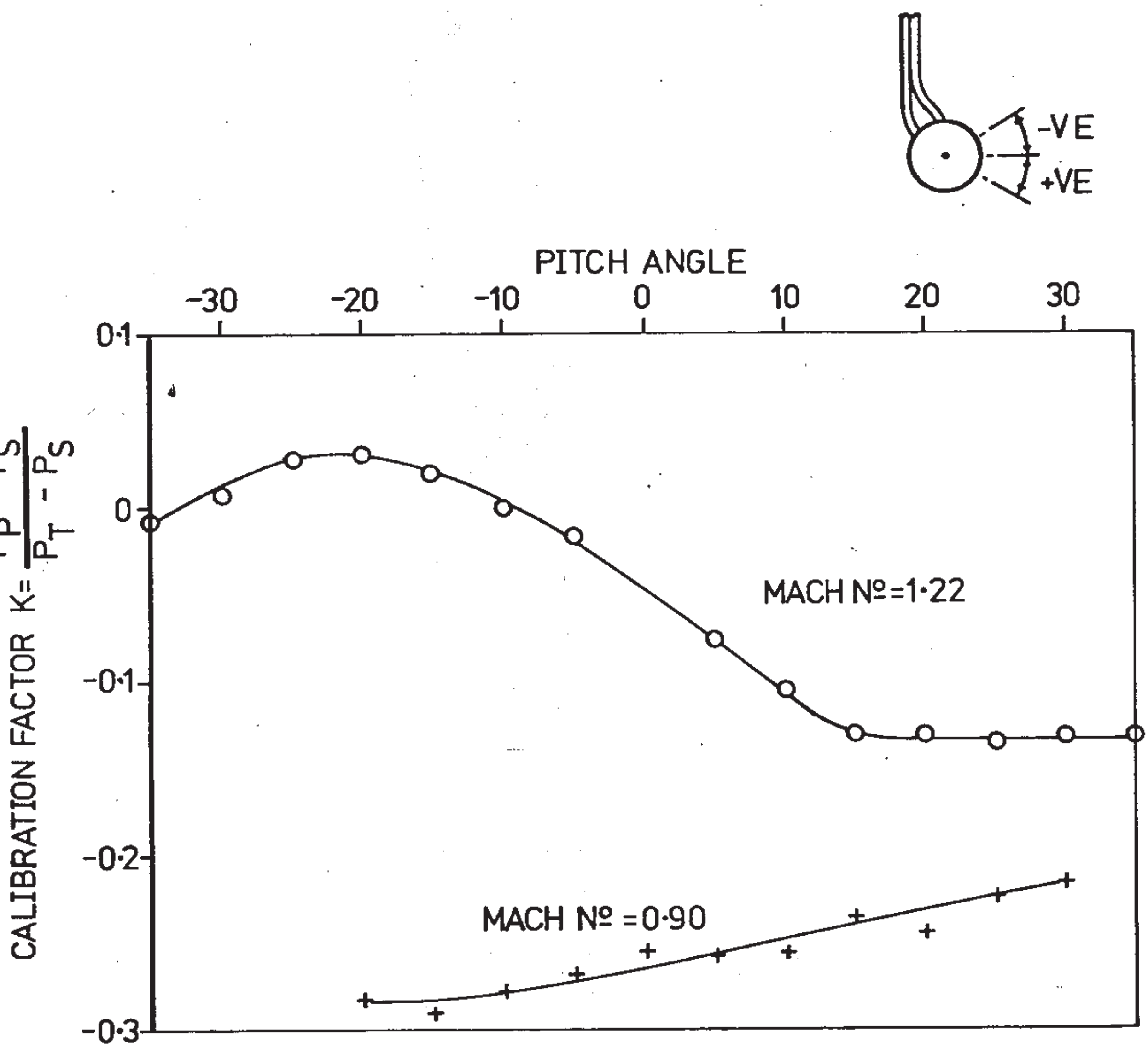
DISC STATIC PRESSURE PROBES

FIGURE 1.



STEM MOUNTED DISC STATIC PRESSURE PROBE

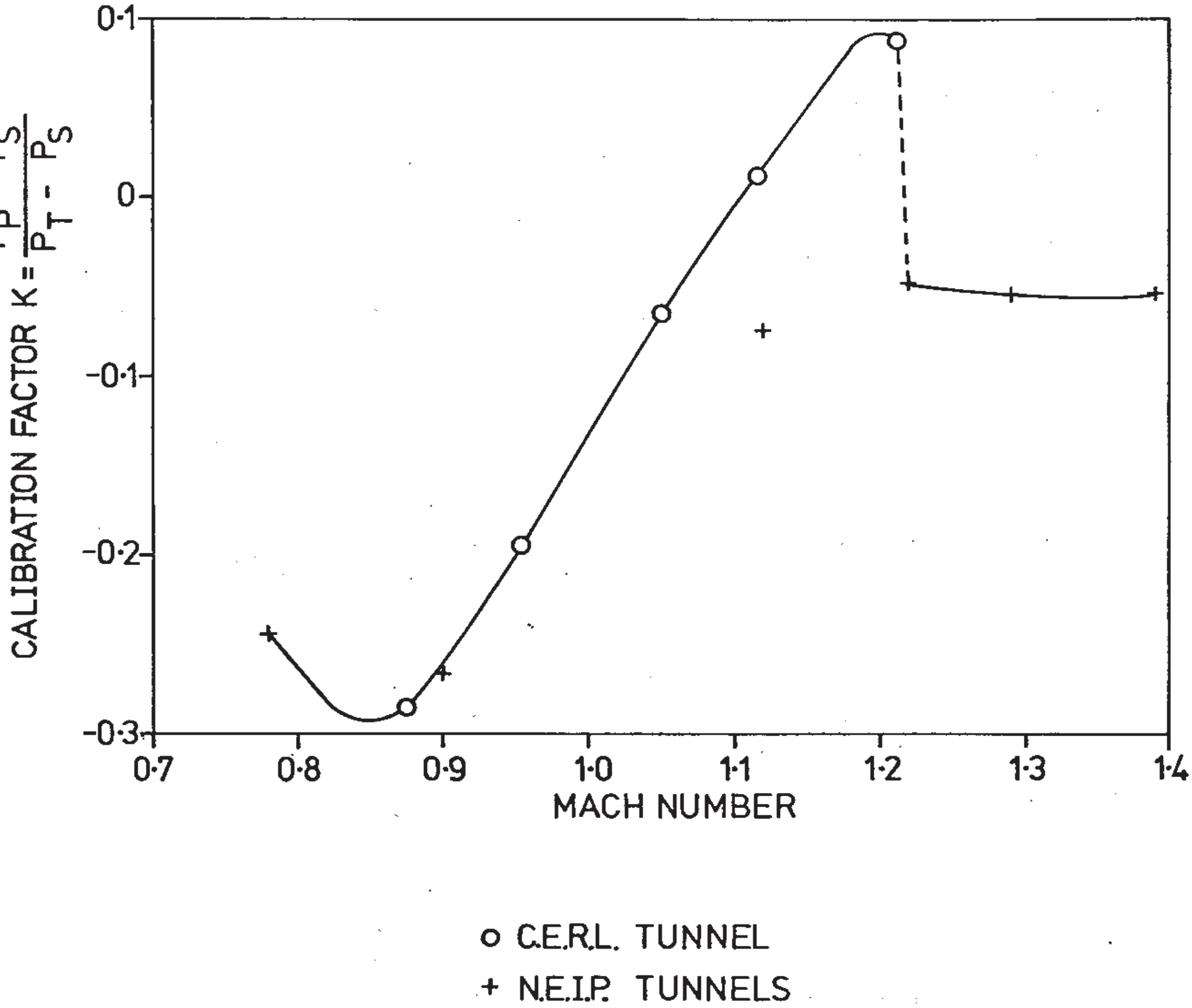
FIGURE 2



STEM MOUNTED PROBE - EFFECT OF PITCH ANGLE.

YAW ANGLE = 0°

.FIGURE 3



STEM MOUNTED PROBE-EFFECT OF MACH NUMBER.

PITCH ANGLE = 0° & YAW ANGLE = 0°

FIGURE 4

PITCH ANGLE = +8°

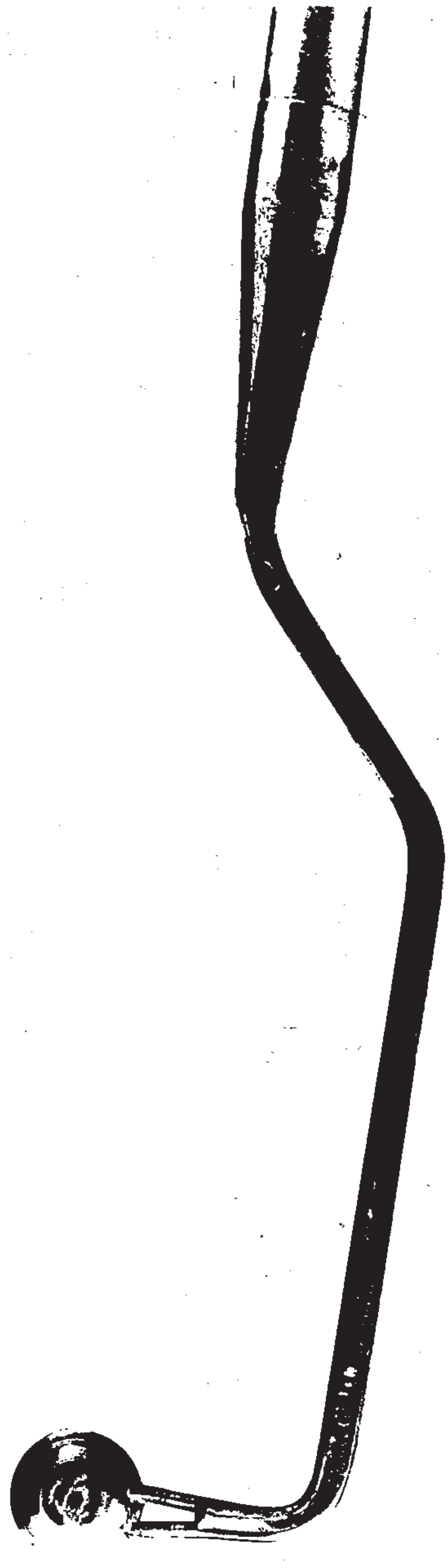
PITCH ANGLE = +15°

PITCH ANGLE = +20°

PITCH ANGLE = +30°

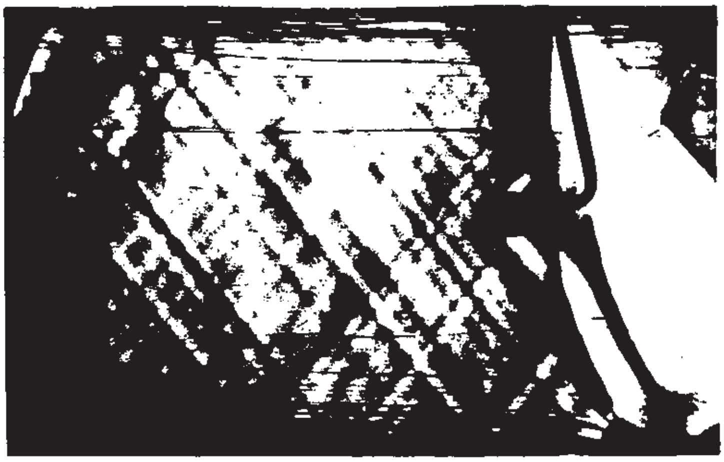
SCHLIEREN VISUALISATION OF FLOW ROUND
DISC HEAD PROBE. - STEM MOUNTED

FIGURE 5



STING MOUNTED DISC STATIC PRESSURE PROBE

FIGURE 6



PITCH ANGLE = -10°

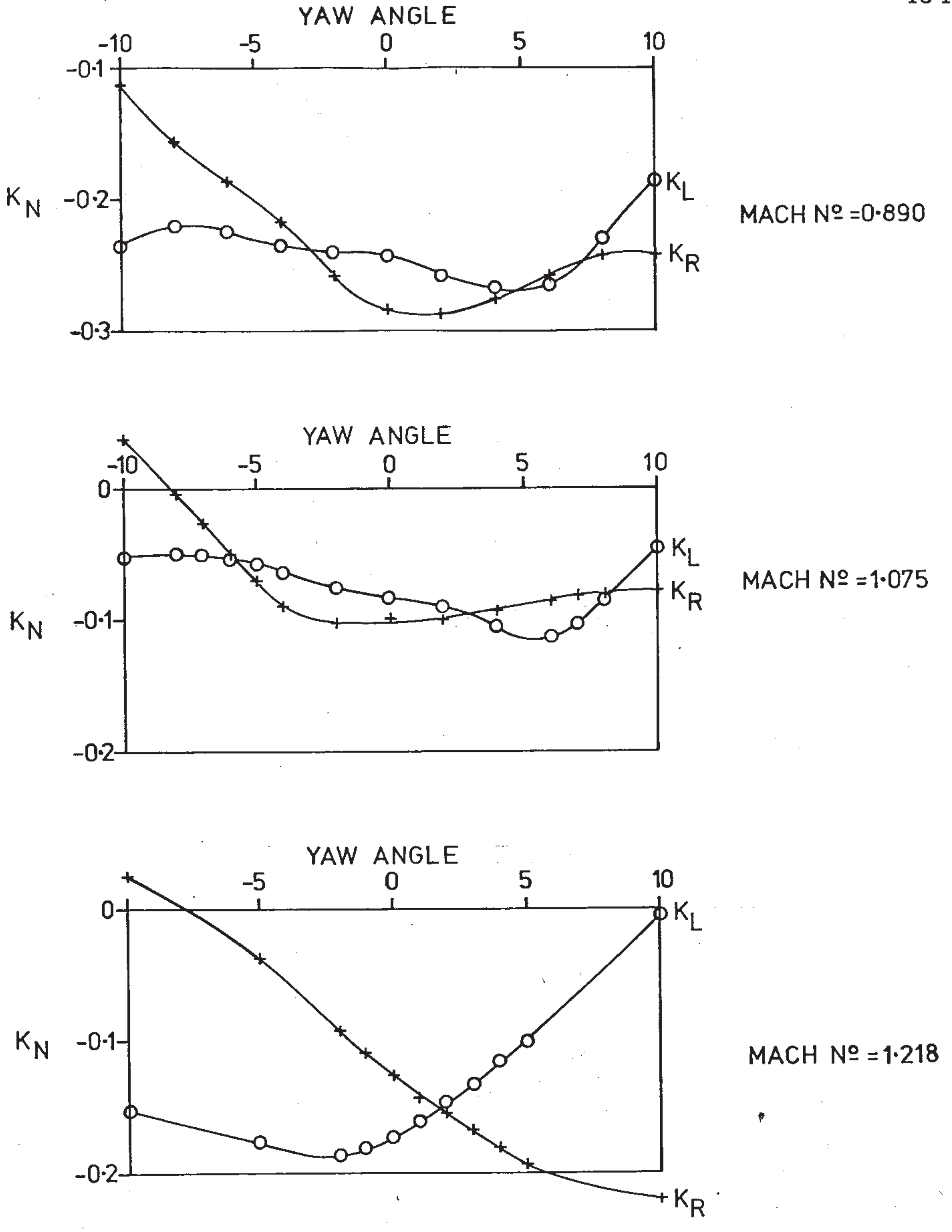
PITCH ANGLE = 0°

PITCH ANGLE = +15°

PITCH ANGLE = +30°

SCHLIEREN VISUALISATION OF FLOW ROUND
DISC HEAD PROBE - STING MOUNTED

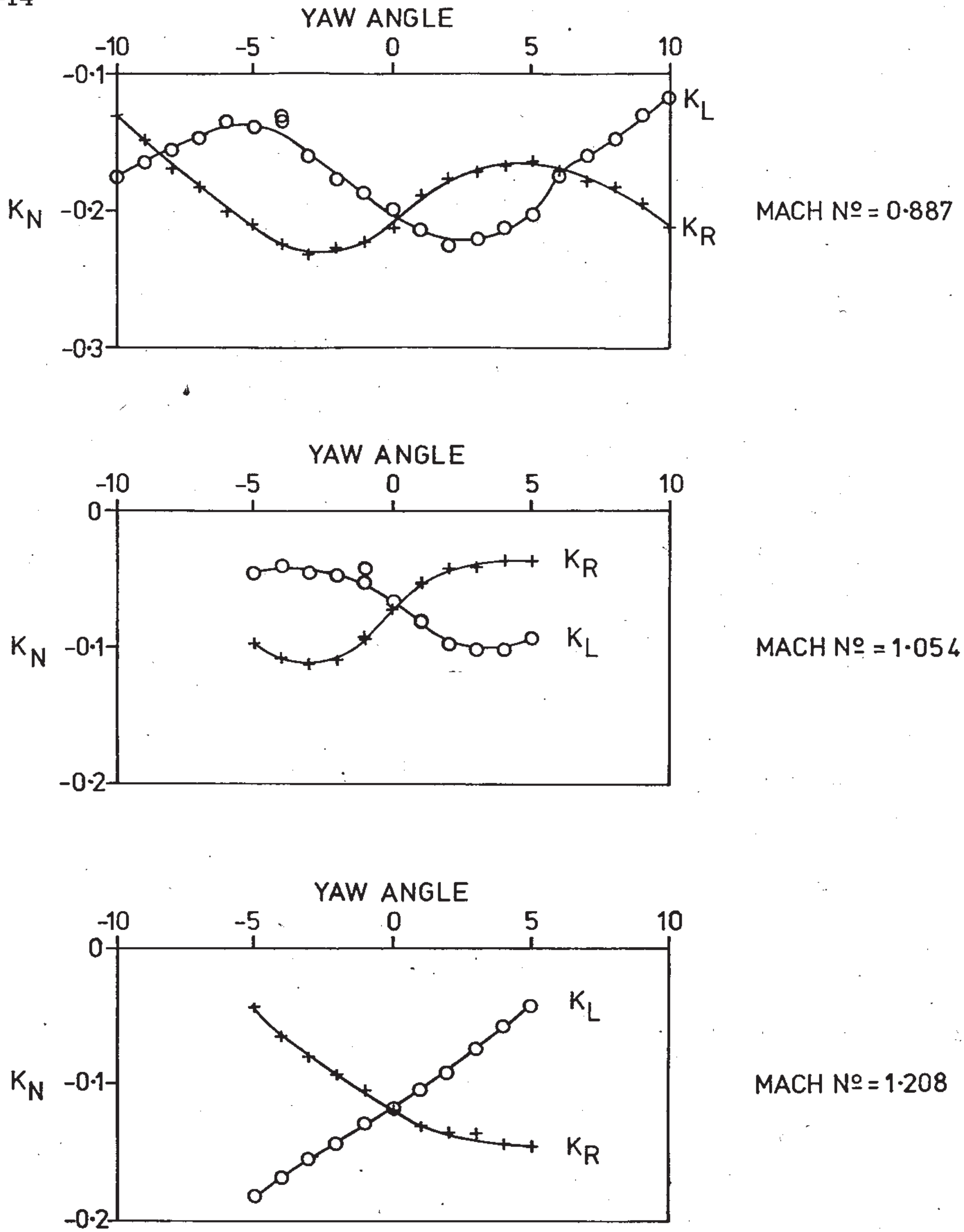
FIGURE 7



CALIBRATION FACTOR $K_N = \dfrac{P_N - P_S}{P_T - P_S}$

STING MOUNTED CHAMFERED DISC PROBE.

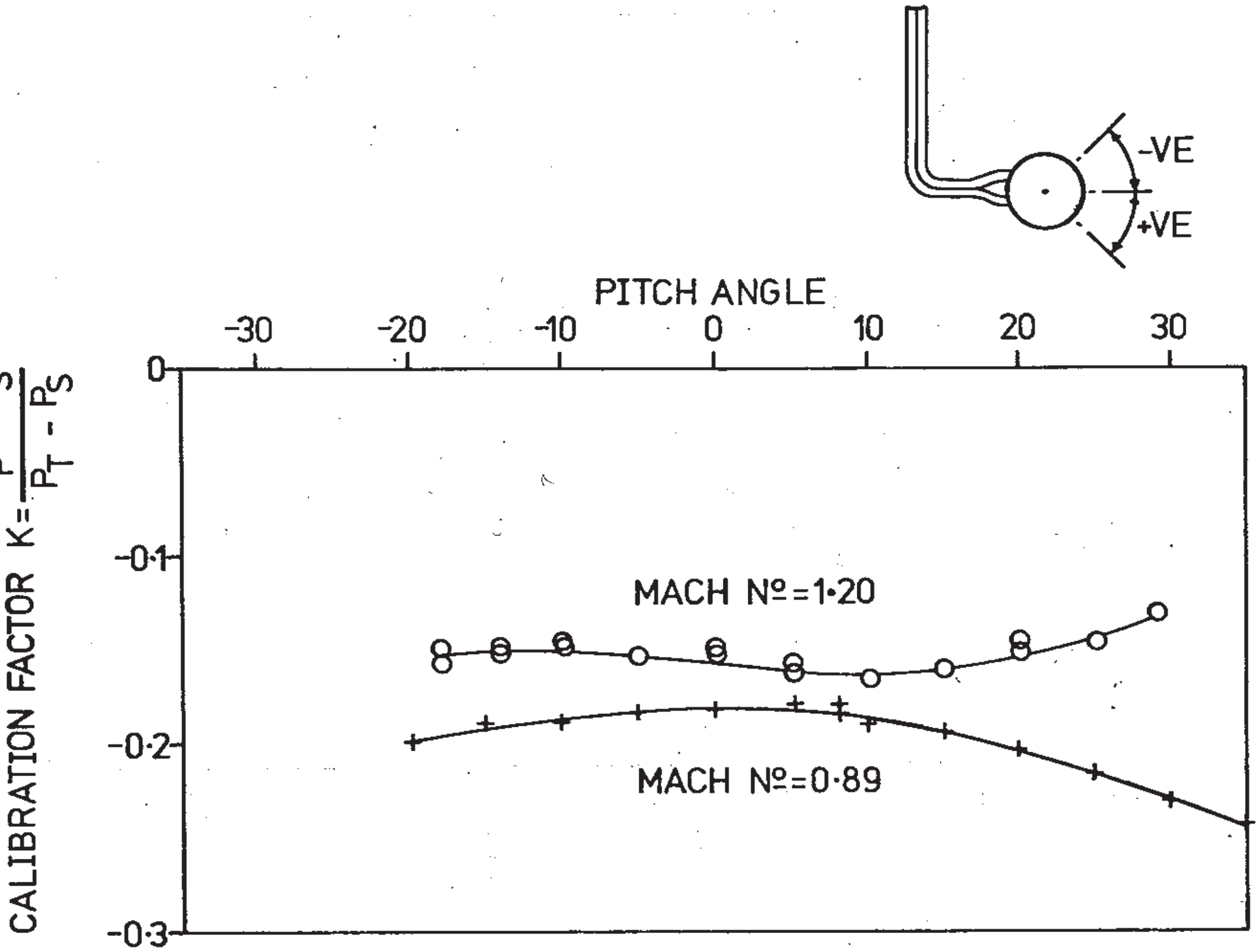
EFFECT OF YAW ANGLE. PITCH ANGLE = 0° FIGURE 8



CALIBRATION FACTOR $K_N = \dfrac{P_N - P_S}{P_T - P_S}$

STING MOUNTED ELLIPTICAL DISC PROBE.

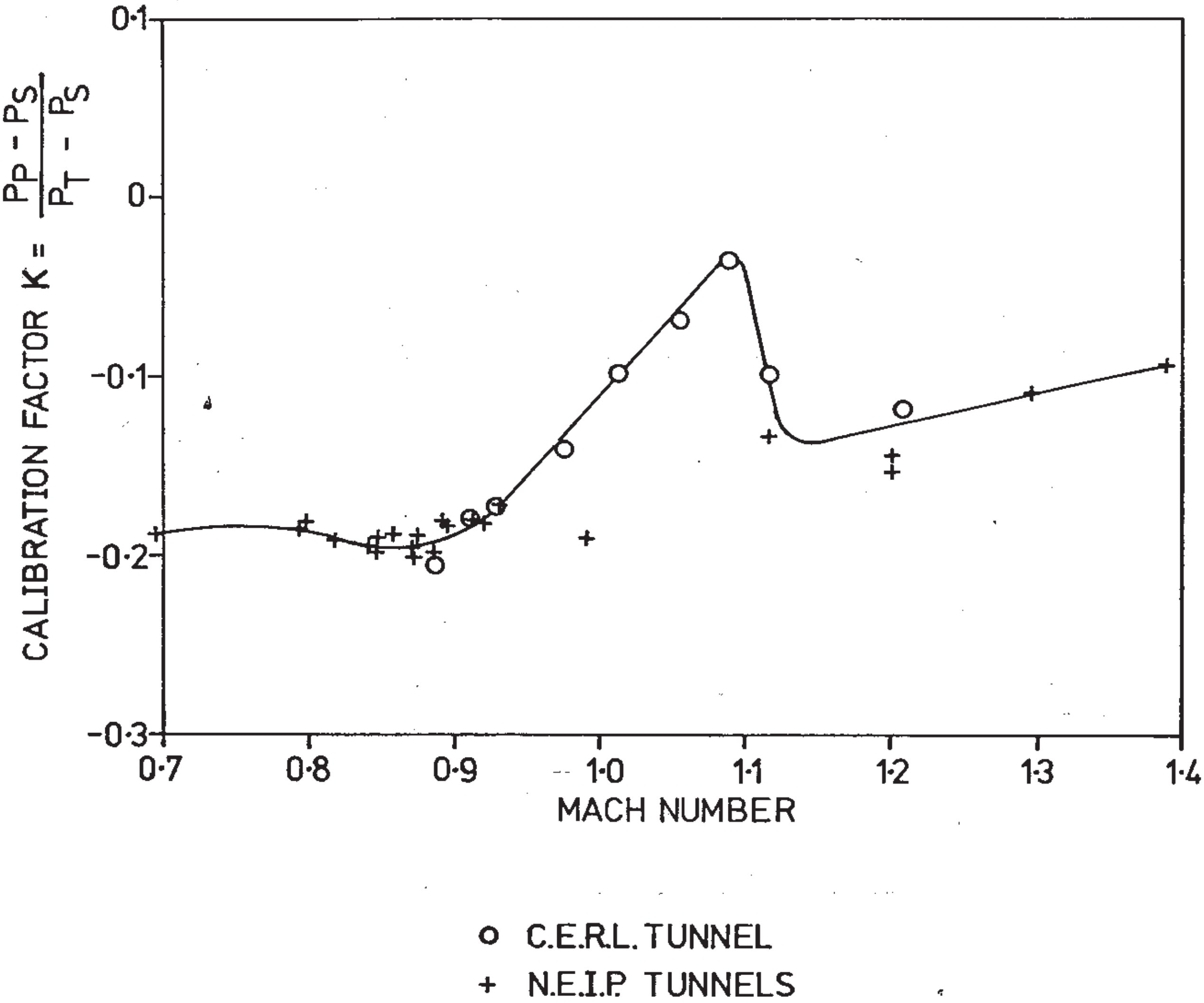
EFFECT OF YAW ANGLE! PITCH ANGLE =0°   FIGURE 9



STING MOUNTED ELLIPTICAL DISC PROBE.

EFFECT OF PITCH ANGLE. YAW ANGLE = 0°

FIGURE 10



STING MOUNTED ELLIPTICAL DISC PROBE.

EFFECT OF MACH NUMBER

PITCH ANGLE = 0° & YAW ANGLE = 0°

FIGURE 11