CHARACTERISTICS OF AERODYNAMIC FIVE-HOLE-PROBES IN TRANSONIC AND SUPERSONIC FLOW REGIMES

by

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SUMMARY:

Four different aerodynamic five-hole-probes were calibrated in high subsonic and supersonic flows.

It was found that large instabilities in the calibration curves occur for these flow conditions where the bow shock is positioned in the neighbourhood of the pressure tappings.

Other instabilities may also occur, due to unpropitious arrangement of the pressure tappings. In this case, the calibration curves are partially wavy, which may be explained by separations at the probe-head and by secondary flows in the pressure tappings. It is also not possible to repeat the calibrations with sufficient accuracy. This implies that the evaluation of measurements will not be unique.

However, with a modified probe, where the pressure tappings are drilled normal to the probe surface, these instabilities disappear. The calibration curves are in this case found to be, both in the subsonic, supersonic as well as the transonic flow regions, smooth, which implies a unique evaluation of measurements.

1. Introduction

Measurements in turbomachines and model-cascades are very often performed with aerodynamic pneumatic probes. Among the necessary conditions a probe must fulfill, two of the most important are the reproducibility of the calibration curves, as well as the unique evaluation of measurements with the aid of these curves.
It is well known (/1/, /2/) that these two conditions are not automaticly satisfied for all types of probes. This may imply large differences between the real flow and the flow quantaties evaluated from the measurements performed with this probe.
The present report will reveal an example of a "bad" probe, i.e. a probe that does not fulfill the two conditions above. It will further indicate a modification of this type of probe, in order to satisfy the two criteria.

2. Calibration procedure

The present experiments were, to a large extent, performed in the Lavalnozzle at the Laboratoire de Thermique Appliquée (LTA) (fig.1).
In this nozzle, four different probes were investigated (fig. 2 - 3). The first of these probes is a wedge probe, of a type that is used at the LTA for annular cascade tests (fig. 3a). The second type (CP1) is normally employed in linear cascades (fig. 3b).
The probes III (R 15) and IV (R 15*) are real machine probes, both with the same dimensions, but with differences in the drilling of the pressure tappings (fig. 3c, 3d).
At the LTA, calibration coefficients that are made dimensionless with measured pressures only, are employed. The definition of these coefficients is given in fig. 4. The denominator for all four calibration coefficients is a measured, more or less dynamic, pressure, $\left(P_1 - (P_2 + P_3) / 2\right)$.

3. Results of the calibrations

3.1 Shock-induced instabilities at L-type of probes

In supersonic flow, the bow shock from the stem of the probe, may, depending upon the type of probe, interfere with the pressure tappings at the probe head. It is clear that, in the case of a wedge probe, the bow shock will never interfere directly with the pressure tappings, as the probe head always is situated behind this shock (see fig. 5).

For a L-type (fig. 2b, c, d) of probe, however, this bow shock will always, for one Mach number or another, impinge upon the probe head. As can be seen on Fig. 6, this is the case, for the probe R 15, at a flow velocity of about M~1.4. Below and above this Mach number, the bow shock does not directly influence the pressure readings. At this critical Mach number, however, large pressure fluctuations may appear, and the shape of the calibration curves may alter significantly.
It is therefore advisable to design a L-type of probe so that the bow shock always lies upstream or downstream of the pressure tappings, for all the flow conditions of interest.

3.2 Calibration curves

The calibrations of the wedge probe indicated that the curves obtained were both reproducable and smooth. This smoothness was remarkable, not only in the subsonic and supersonic regions, but also in the transonic flow regime. An example of the calibration factors for total pressure (K_2) and static pressure (K_3) as a function of the flow-velocity is given in fig. 7.
The cone probe, CP1, indicated however some irregularities. It was retained that the curves did not show a unique development over the yaw-and pitch-angles (fig. 8). Furthermore, it was noted that these curves were not reproducable within the expected accuracy and that the pressure fluctuated somewhat.
As regards the probe R 15, the above mentioned irregularities increased heavily. The calibrations could not be reproduced any more, and the pressures fluctuated to a much larger extent than on the probe CP1.
An example of the calibration factor for the yaw angle (K_4) at a high subsonic flow velocity (M=0,78) is given in fig. 9, where the wavyness and the nonreproducibility of the calibrations can be retained.
It is obvious that the calibration curve shown in this figure can not be used if a unique evaluation of measurements is expected.

4. Modification of probe R 15

As can be seen on the figures 3b (probe CP1) and 3c (probe R 15), the pressure tappings on these two probes are drilled parallel to the flow direction at zero yaw- and pitch-angles. This implies that the opening of the pressure tappings towards the flow is very large. In fig. 10, it is seen that this area is much larger for probe R 15 than for probe CP1. The reason therefore lies both in the different dimension of the pressure tappings (Ø 1mm

and 0,5mm resp.) and in the different cone angles (40° and 60° resp.).
It was assumed that the pressure fluctuations as well as the irregularities in the calibration curves were due to local unsteady separations in the pressure tappings.
The head of the probe R 15 was then modified so that the pressure tappings were drilled normal to the probe surface, as indicated in fig. 3d.
An example of the calibration curves for this modified probe R 15* is given in fig. 11 (compare fig. 9). It is seen that the calibration curve shows a monoton increase as the yaw-angle increases. Secondly, the values are reproducable to a high degree of accuracy, and no sign of pressure fluctuations were noticed.
It can therefore be conclued that a cone probe with the pressure tappings drilled normal to probe surface hold better characteristics than if the tappings are parallel to the flow direction.
In order to visualize the flow in the pressure tappings, an enlarged model (scale 20:1) of the probe R 15 was investigated in water (fig. 12). It was then clearly seen how the pressure (i.e. the water level) fluctuated in the case were the tappings were parallel to the probe head, and how stable the water level was when the tappings were drilled normal to the probe head surface.

5. Conclusions

Four different probes were calibrated in the subsonic, transonic and supersonic flow regions. Among the results can be mentioned:

- A wedge probe of the type shown gives smooth calibration curves, both in subsonic, transonic and supersonic flows.
- With L-shaped type of probes, the bow shock will always, for one Mach number or another, impinge upon the pressure tappings. Large pressure fluctuations may then appear, and the shape of the calibration curves may alter.
- Unpropitious arrangement of the pressure tappings may lead to pressure fluctuations and nonreproducable calibration curves. If the pressure tappings were drilled normal to the probe surface, these irregularities disappeared for the present probe.

References

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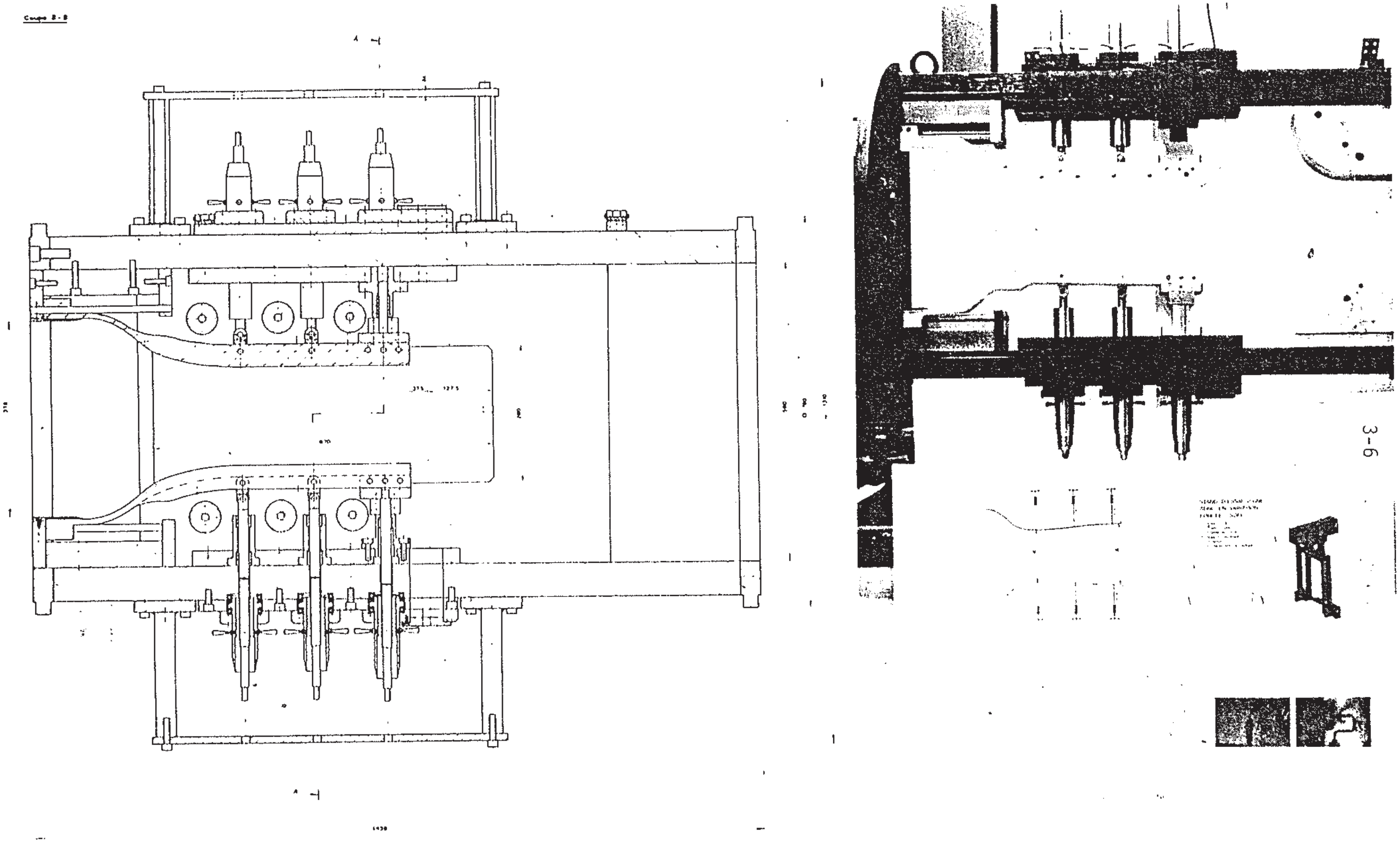
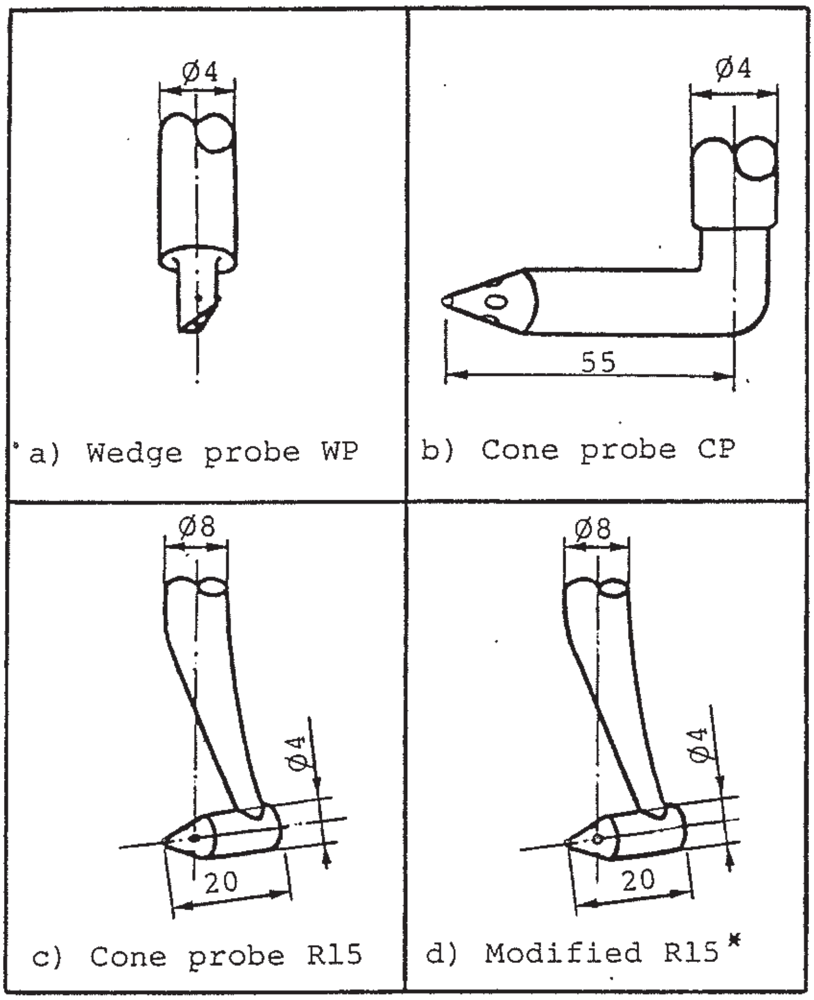


Fig. 1: Laval nozzle at L.T.A. / E.P.F.L.



a) Wedge probe WP

b) Cone probe CP

c) Cone probe R15

d) Modified R15*

Fig. 2: Four different probes

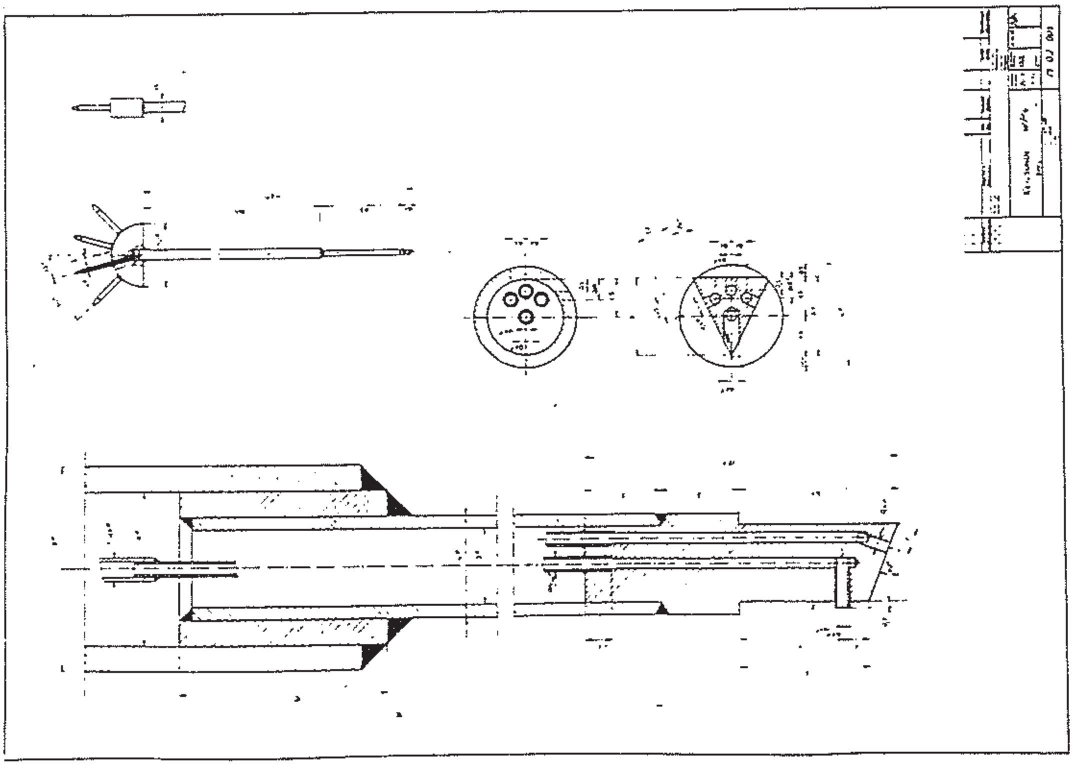


Fig. 3a: Wedge probe WP4

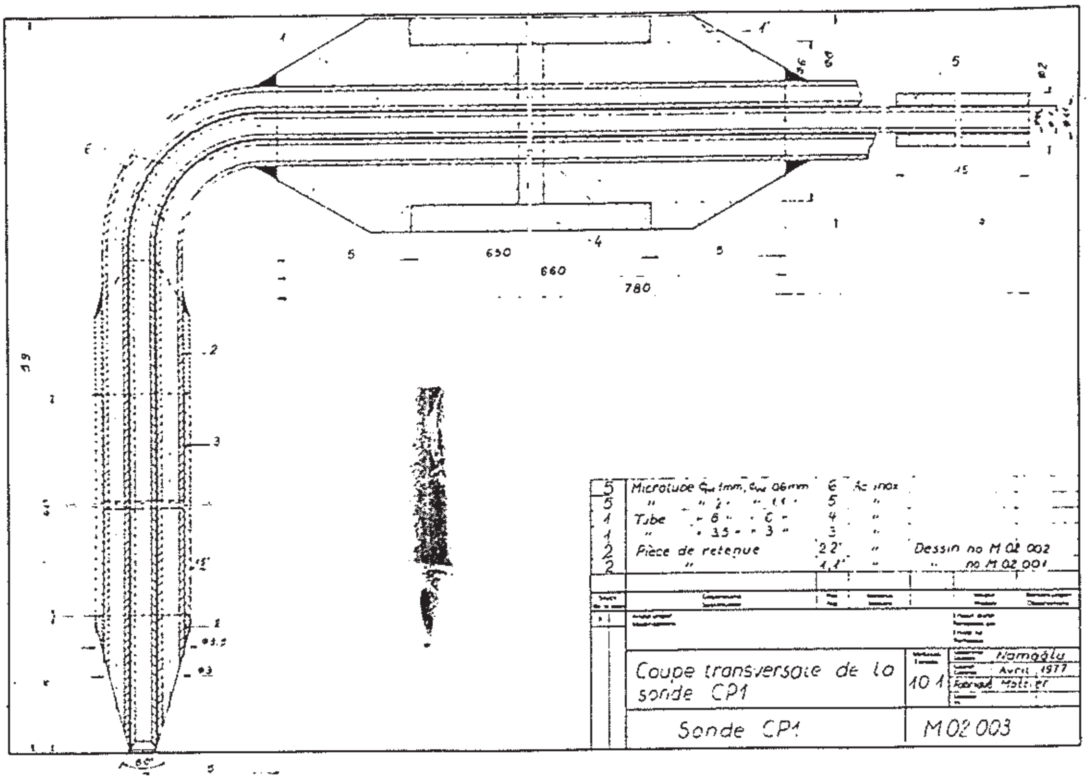


Fig. 3b: Cone probe CP1

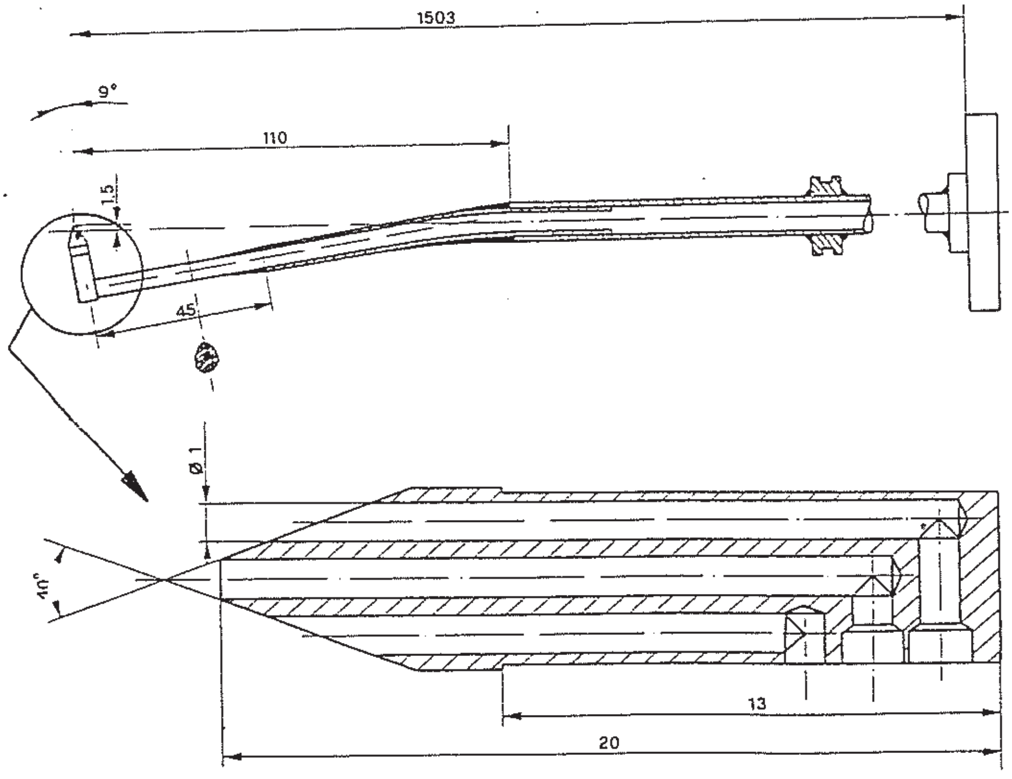


Fig. 3c: Cone probe R15

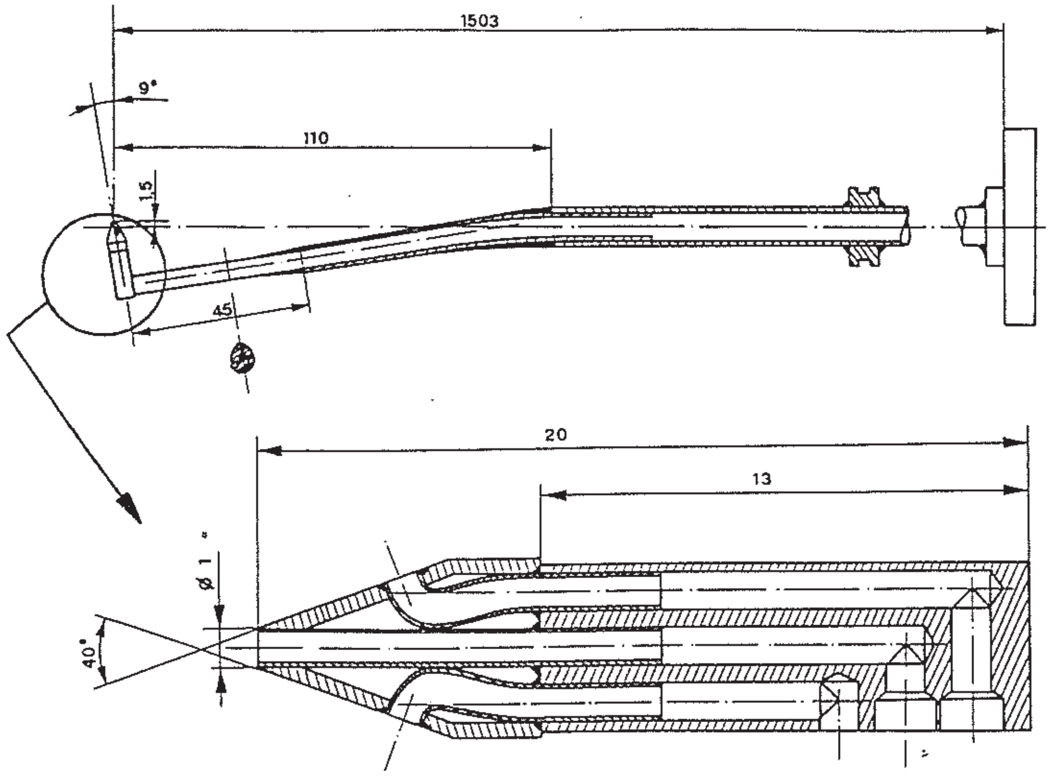
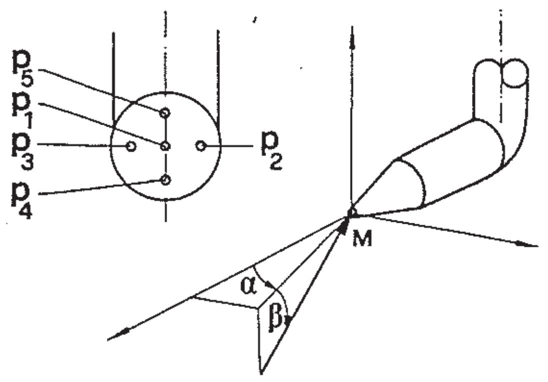


Fig. 3d: Modified cone probe R15*

Flow quantities:

$$M, \alpha, \beta, p_t, p_s$$

Measured values:



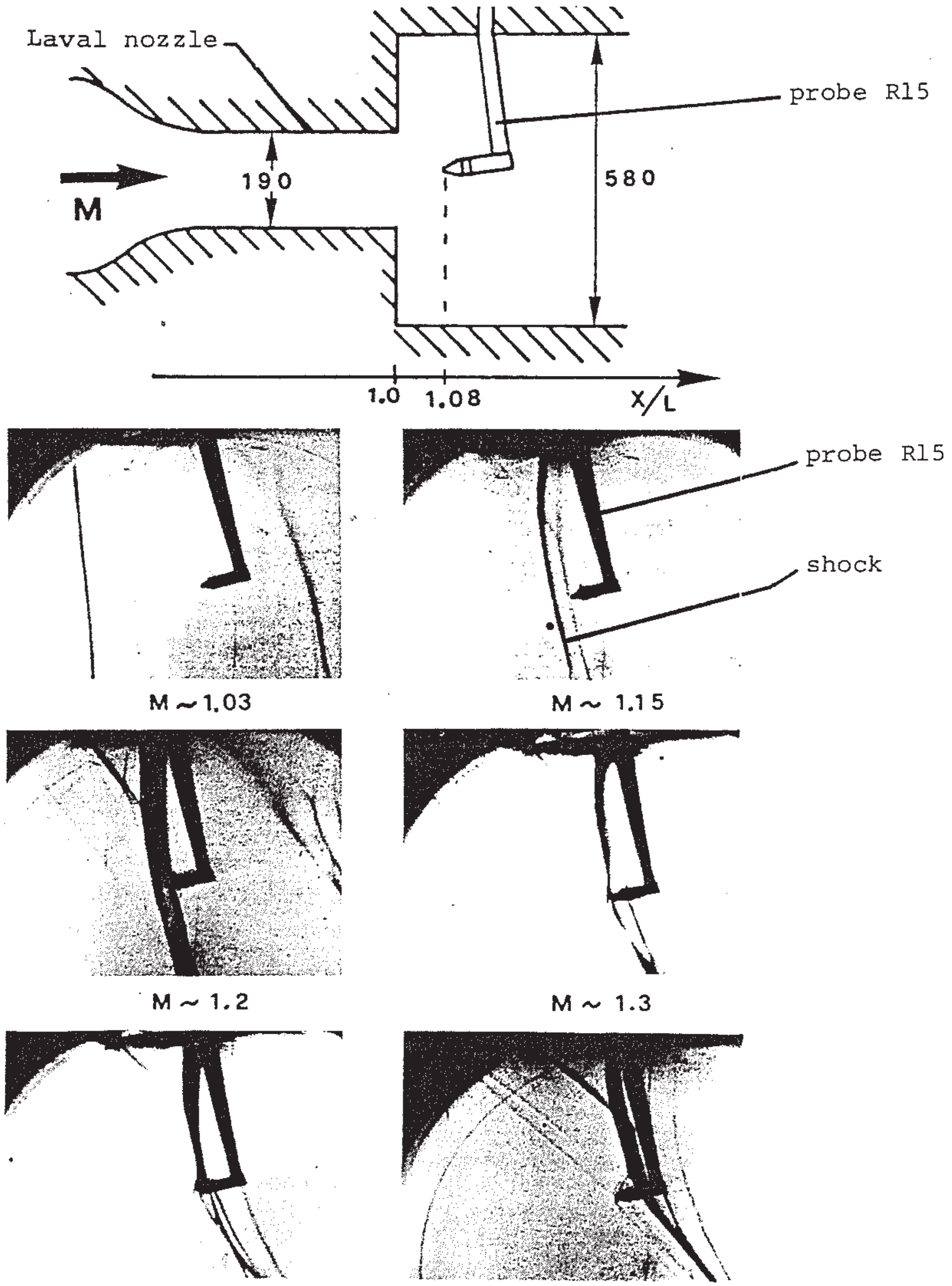
Calibration coefficients:

$$K_1 = \frac{p_4 - p_5}{p_1 - \frac{p_2 + p_3}{2}} \qquad K_2 = \frac{p_t - p_1}{p_1 - \frac{p_2 + p_3}{2}}$$

$$K_3 = \frac{p_t - p_s}{p_1 - \frac{p_2 + p_3}{2}} \qquad K_4 = \frac{p_2 - p_3}{p_1 - \frac{p_2 + p_3}{2}}$$

Fig. 4:
Calibration coefficients
with yaw and pitch
angle definitions

Fig. 5: Shock configuration around the probe WP4 ($M \sim 1.3$)

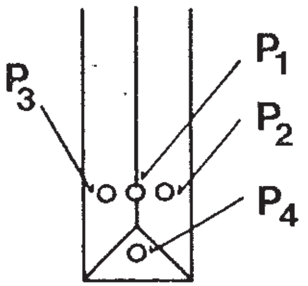


M ~ 1.03　M ~ 1.15

M ~ 1.2　M ~ 1.3

M ~ 1.4　M ~ 1.5

Fig. 6: Schlieren photos at different flow velocities (probe R15)



$$K_2 = \frac{P_t - P_1}{P_1 - \frac{P_2 + P_3}{2}}$$

$$K_3 = \frac{P_t - P_s}{P_1 - \frac{P_2 + P_3}{2}}$$

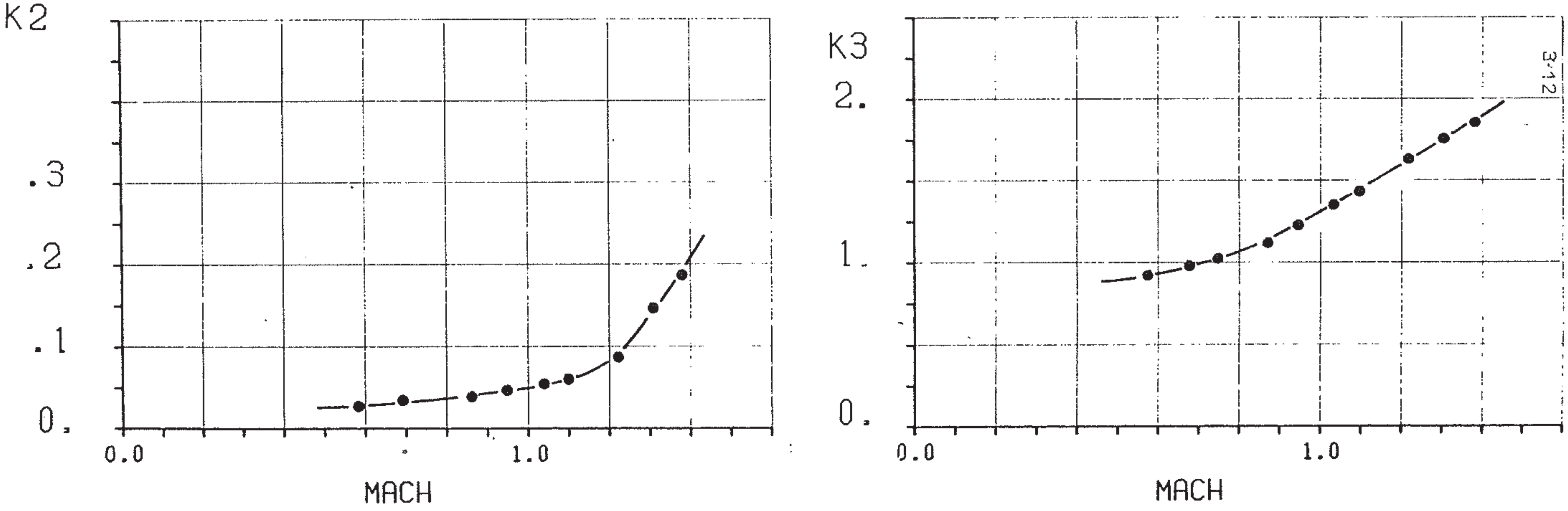
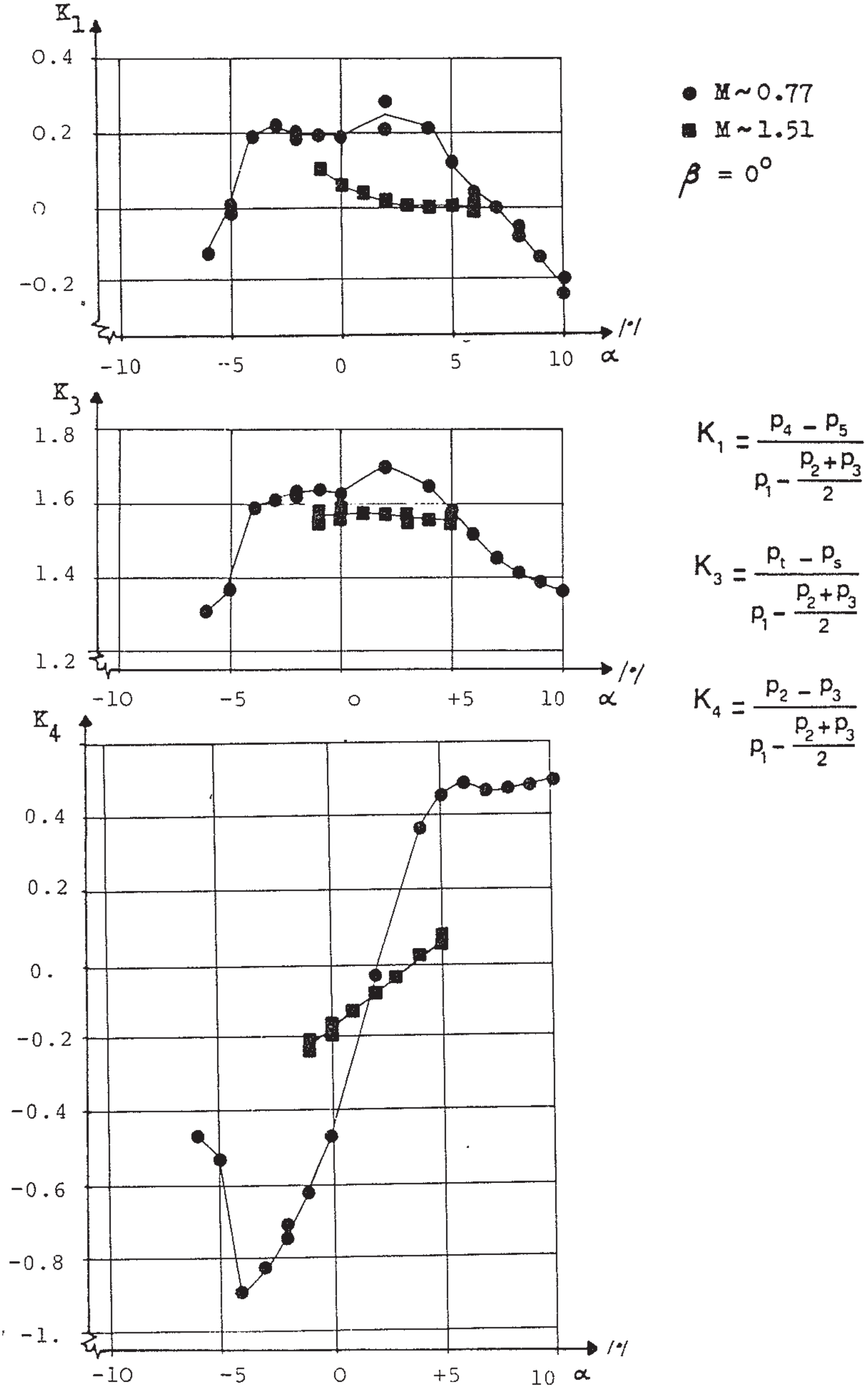


Fig. 7: Calibration curves for total (K2) and static (K3) pressures as a function of Mach numbers (probe WP4)



$$K_1 = \frac{p_4 - p_5}{p_1 - \frac{p_2 + p_3}{2}}$$

$$K_3 = \frac{p_t - p_s}{p_1 - \frac{p_2 + p_3}{2}}$$

$$K_4 = \frac{p_2 - p_3}{p_1 - \frac{p_2 + p_3}{2}}$$

Fig. 8: Calibration curves of cone probe CP1

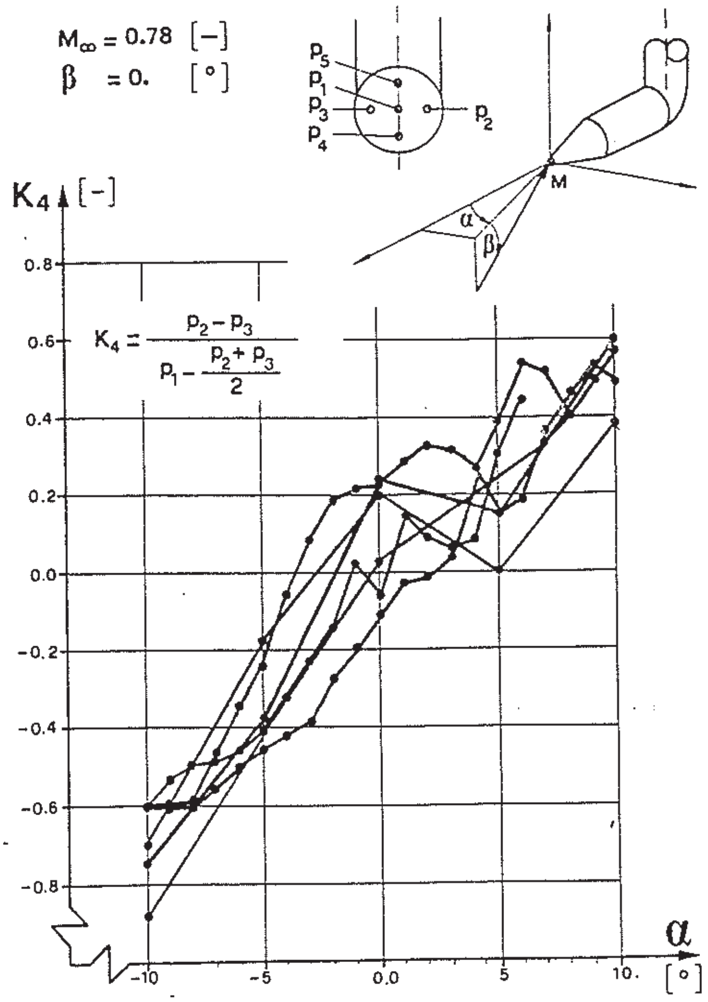
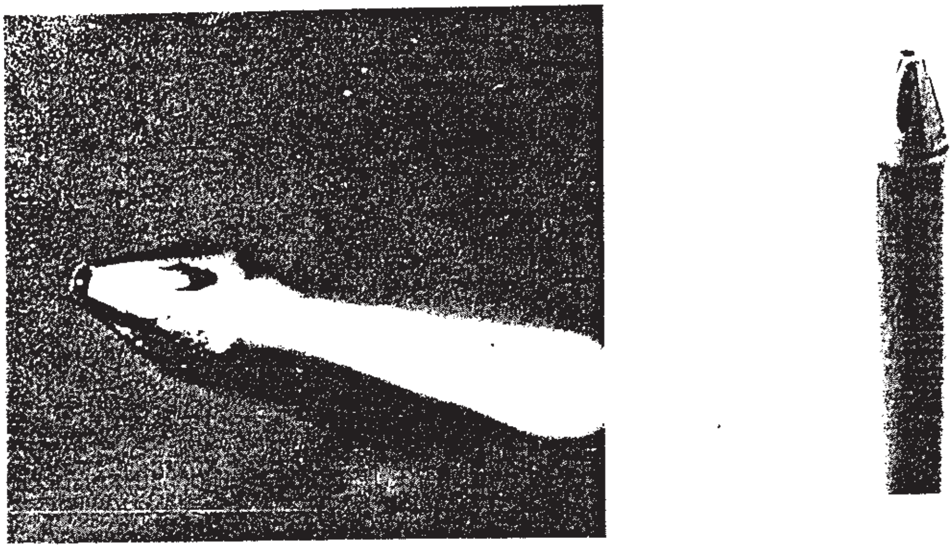


Fig. 9: Six calibrations of probe R15



a) Cone probe R15

b) Cone probe CP1

Fig. 10: Enlargement of probe heads R15 and CP1

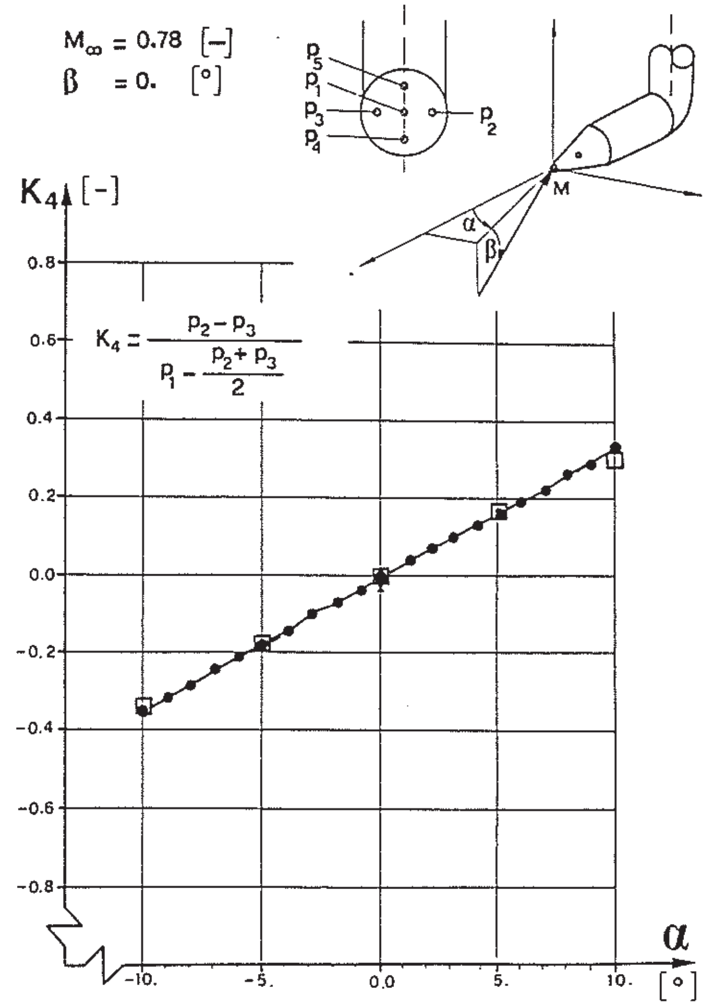


Fig. 11: Three calibrations of the modified probe R15*

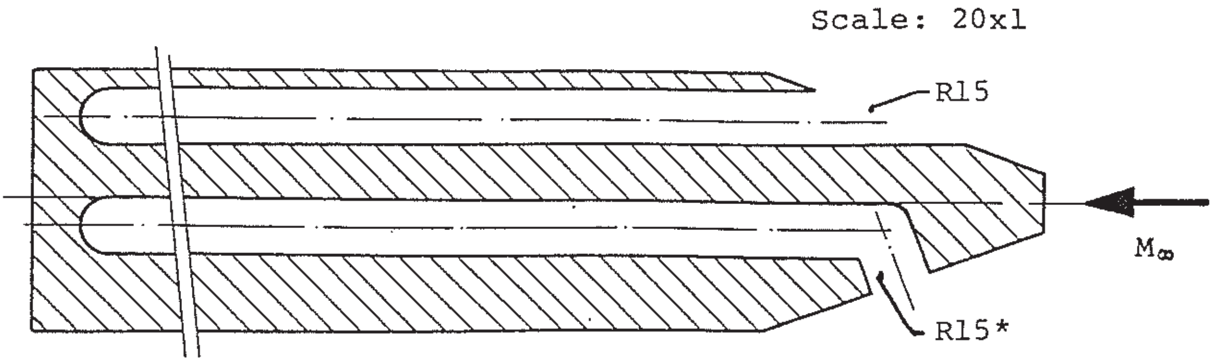


Fig. 12: View of 2-D model for visualization in water