PROBE INVESTIGATIONS IN THE PROXIMITY OF A WALL IN SUPERSONIC FLOW

by

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SUMMARY:

The response of one wedge-probe and one cone-probe in the proximity of a wall was investigated in supersonic flow. Due to the shock-boundary layer-interaction it is found that, as the probe approaches the wall, the detached bow shock lies further upstream than was the case with the probe in the middle of the nozzle. This change in shock-configuration around the probe does not, however, change the probe pressure readings appreciably.

Closer to the wall, the reflection of shocks back into the probe pressure holes, as well as the shock-interaction with the boundary layer, may alter the response of the pressure readings.

The performed tests, at Mach numbers M=1.2 and M=1.5 respectively, indicated that the presence of the wall influences the probe pressure response at a larger distance for the higher flow-velocity.

In order to evaluate the probe-measurements closer to the wall than about five probe diameters, a "two-dimensional evaluation process" is recommended. The probe is thereby turned into the yaw-direction of the flow, and the pressures are evaluated considering the flow to be parallel to the wall.

1. Introduction

Experiments have been performed with transonic turbine and compressor cascades in the annular wind tunnel at the EPF-Lausanne. Some of the probe measurements affectuated in the supersonic flow region yielded impossible pressures and flow angles. In some cases, the evaluation program even indicated "overpressures", i.e. local total pressures that were higher than the effective upstream total pressure.
It was found that the discreapancies between the real and the evaluated flow quantities increased as the probe approached the channel wall.
The response of two types of probes usually employed by the Laboratoire Thermique Appliquée, wedge probes and cone probes, were therefore investigated as the distance between the probe and the wall decreased.

2. Test facility for probe-wall-interaction

The present investigation was performed in the Lavalnozzle at the LTA (fig. 1). A plate with the flat lower side parallel to the supersonic flow was introduced into the Lavalnozzle, and the probe can approach this simulated wall (fig. 2).
The shock configuration around the wedge probe without the presence of the wall can be seen in fig. 3. This shock configuration corresponds more or less with the conditions during the calibration of the probe.
Two different types of probes, one wedge probe and one cone probe (fig. 4), were employed in the present tests; the response of the probes as well as the shock configuration around the probe heads were compared at two different supersonic flow velocities, $M \sim 1.2$ and $M \sim 1.5$.

3. Results

3.1 Wedge probe

The first tests were performed at a low supersonic flow velocity, $M \sim 1.20$ (fig. 5). The visualization of the flow around the probe head indicated that the bow shock from the stem changed form from an oblique to a straight shock at a distance of about 7 probe diameters from the wall (compare fig. 5a, c).
At this distance no appreciable change in the response of the
pressure tappings at the probe could be noted (fig. 6a). The in- (1)
fluence of the wall on the pressure readings is instead noted at a distance of about three probe-diameters from the wall.

This wall-influence is first remarked on the pressure P_4 and thereafter, to a much lesser extent, on the two pressures P_2 and P_3 (fig. 6a). The pressure P_1, which is an indicator on the total pressure, is hardly not affected.
It can therefore be concluded that, at this low supersonic Mach number ($M \sim 1.2$), the bow shock from the wedge probe lies far upstream of the pressure tappings and is relatively weak (fig. 5d). This bow shock does therefore not appreciably change the probe pressure readings. The large pressure increase for the pressure P_4 may instead be explained by the fact that the flow becomes guided as the probe approches the wall, which implies an increase in the dynamic part of the pressure measured with the forth pressure tapping. A further indicator that this pressure increase is not shock-induced is given, as the corresponding pressure distributions in high subsonic flow ($M \sim 0.8$) indicates the same trend as for $M \sim 1.2$.
For the higher flow velocity, $M \sim 1.5$, the pressures show completely different distributions (fig. 6b).
The distance at which the pressures P_2, P_3 and P_4 indicates an influence from the wall is now somewhat larger ($h/d = 4$). Further, this influence does not show the same characteristics as at the lower velocity, and it is seen that also the pressure P_1, i.e. the measured stagnation pressure, is influenced.
From the flow visualization at this higher Mach number (fig. 7), it can be concluded that the pressure readings are highly shock dependent. Both the increase, decrease and finally increase in the pressures P_2, P_3 and P_4, as well as the increase and subsequent decrease in pressure P_1 may be explained by the shocks seen on the Schlieren-photos and by shock-boundary layer-interactions.

3.2 Cone probe

The same investigation was performed with a L-shaped type of probe (fig. 4b) at the same flow velocities ($M \sim 1.2$ and $M \sim 1.5$ resp.). The pressure distributions are represented in fig. 8.
At the lower Mach number, the results in the neighbourhood of the wall resembles the ones measured with the wedge probe. The very sharp increase in the pressure P_4 close to the wall can not be noticed here, as it was not possible to approach the wall sufficiently with this probe (see fig. 4b).
Also at the higher flow velocity, the pressure distributions for the wedge probe and cone probe are similar. The pressures P_2, P_3 and P_4 are now influenced at a distance of about two probe diameters from the wall instead of about four diamenters,

which was the case with the wedge probe. The fifth pressure, P_5, which lies on the upper side of the probe head (i.e. further from the wall), is almost not influenced. This is also true for the measured stagnation pressure, P_1.
Also this shape of the pressure distributions can be explained with the aid of the Schlieren images (fig. 9), in the same way as with the wedge probe. As is seen on these images, the strong bow shock from the stem lies behind the probe pressure tappings at this Mach number, and influences therefore not the pressure readings. It is now instead the much weaker bow shock from the probe head that interferes with the pressure tappings (fig. 9d). This explains why the influence distance from the wall is shorter, at a Mach number of M=1.5, with the cone probe (fig. 9) than with the wedge probe.

4. Conclusions

The present investigation was initialized in order to answer the question:
Up till which distance from the walls can we measure in an annular channel?
Among the results, the following points can be retained:

- With the wedge probe, the influence of the wall was noticed at a maximum distance of about four probe diameters for Mach numbers less than 1.5.
- With the cone probe, this influence was reduced to a distance of about two probe diameters from the wall. If measurements are performed in a channel, however, this type of probe will notice an influence both on the upper as well as on the lower wall (fig. 10b). The wedge probe, on the other hand, will not show this same influence at the lower wall (fig. 10a).
- A change in the characteristics of the pressure evolution from M~1.2 to M~1.5 can be explained by the alteration in shock-configuration around the probe for these different flow velocities.
- A simple solution to the question asked could be:
  + Turn the probe into the yaw-direction of the flow. (Because of the change in radial height if a cone probe is turned in an annular nozzle, we decided to use the wedge probe.)
  + Use a two-dimensional evaluation process at a distance shorter than five probe-diameters from the wall. This means that the flow should be considered parallel to the wall, and that the pressures for the pitch angle should not be used in the evaluation process.
  + Be very careful with the interpretation of the results of probe pressure measurements closer than about five probe diameters from the wall.

5. List of symbols

d	: Probe diameter for wedge probe	: $d = 4.$ mm
	Probe head diameter for cone probe	: $d = 4.$ mm
h	: Distance between wall and probe pressure tapping	
LP	: L-type of cone probe (see fig. 4b)	
M	: Upstream isentropic Mach number	
P_{ref}	: reference pressure = upstream effective stagnation pressure	
$P_1 \div P_5$	: Pressures Wedge probe; see fig. 6. Cone probe; see fig. 8.	
WP	: Wedge probe; see fig. 4a.	
α	: Yaw angle	
β	: Pitch angle	

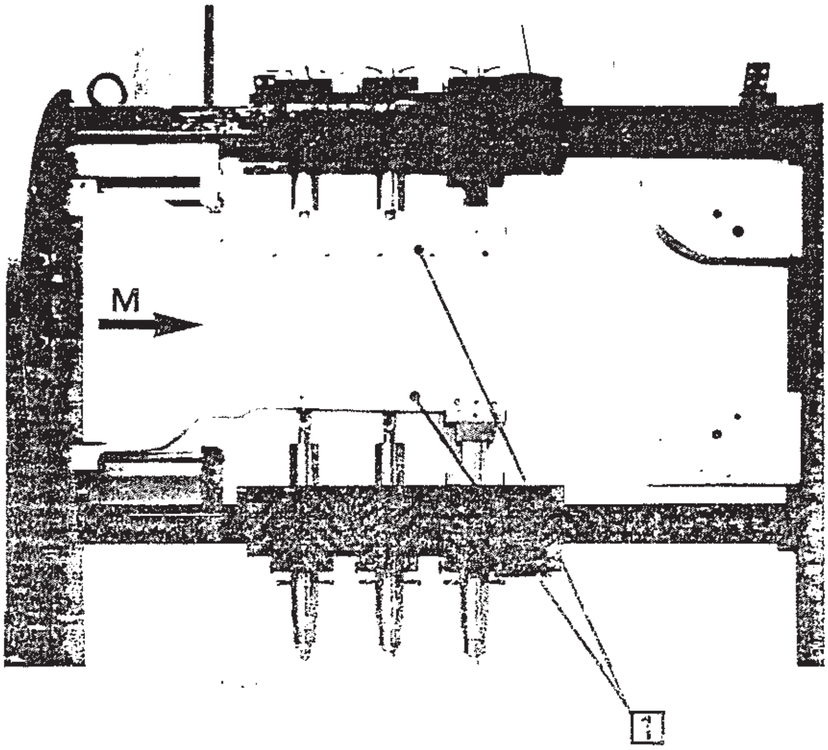


Fig. 1
Schematic view
of Laval Nozzle
"NEPTUN" at LTA.

[1] flexible liners.
[2] end of the flexible liners.
[3] plate.
[4] wedge probe head.

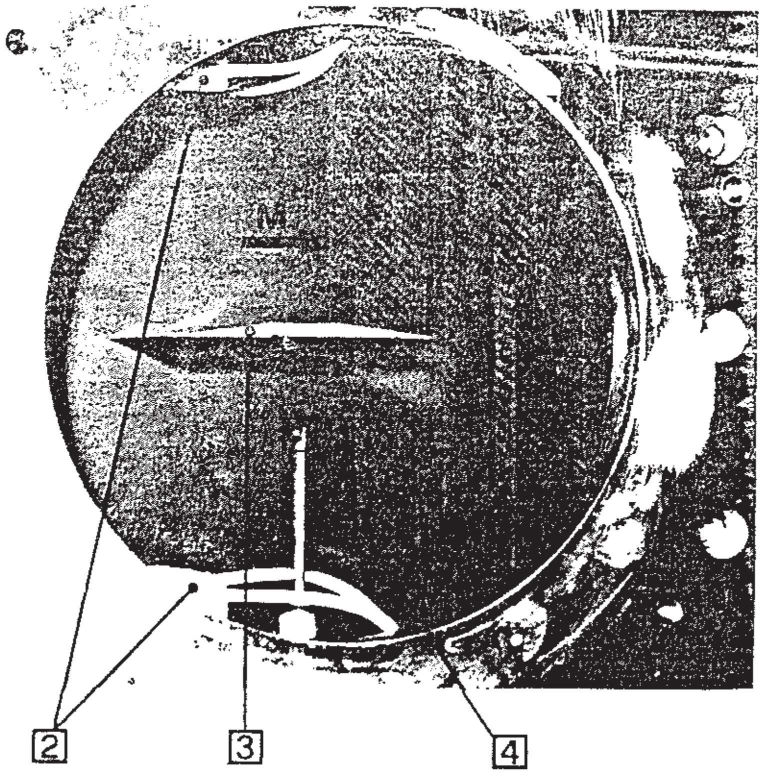


Fig. 2
Test facility
for probe-wall-
-interaction.

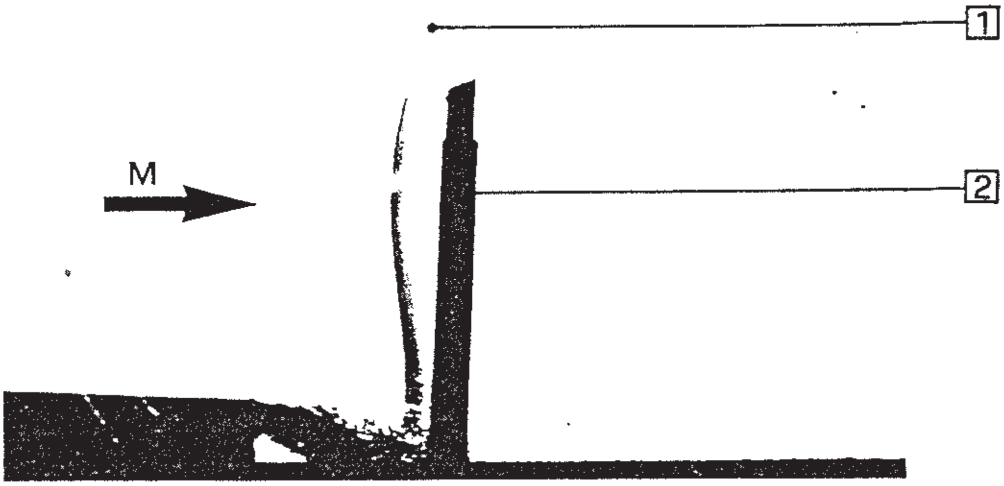
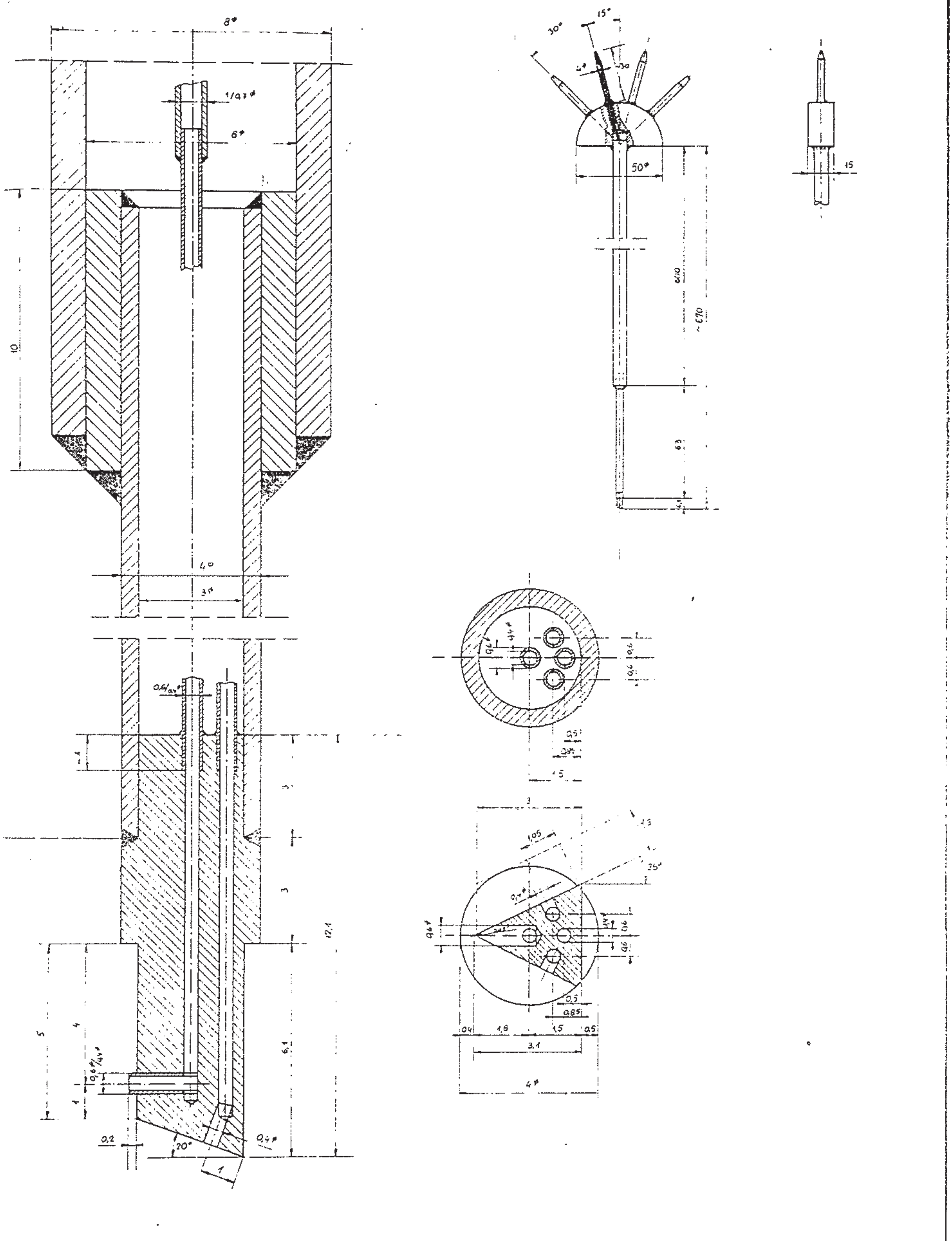


Fig. 3

Shock configuration around the wedge probe.
(calibration conditions for about M~1.3)

[1] bow shock from the probe stem.
[2] wedge probe.



KEILSONDE WP4

M-02-005

Fig. 4a

Wedge probe WP4.

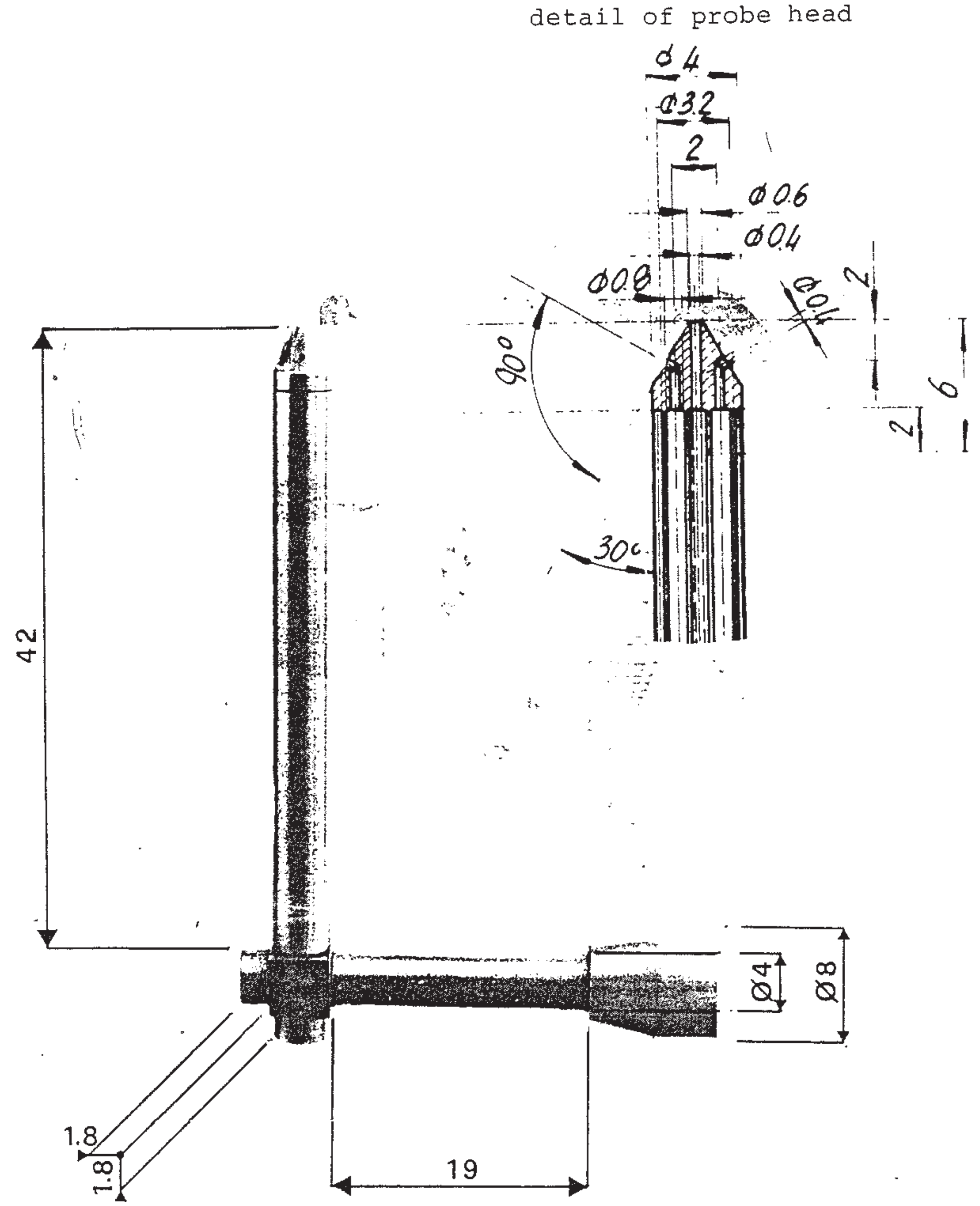


Fig. 4b

Cone probe LP3.

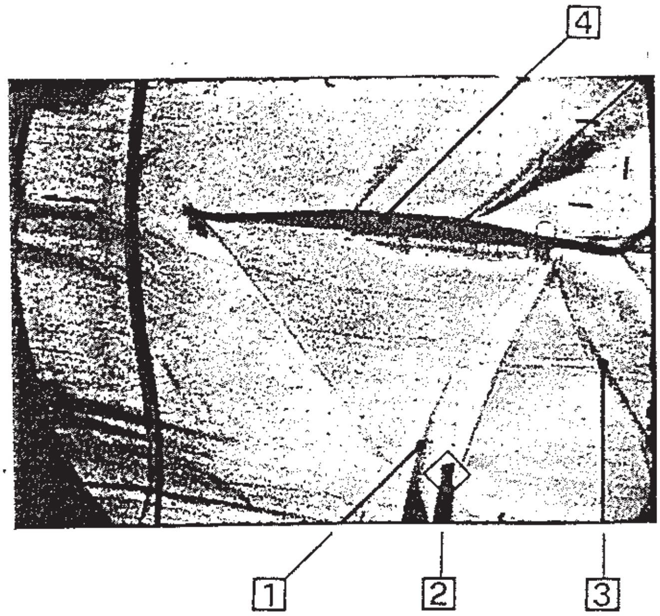


Fig. 5a

h/d ~ 11

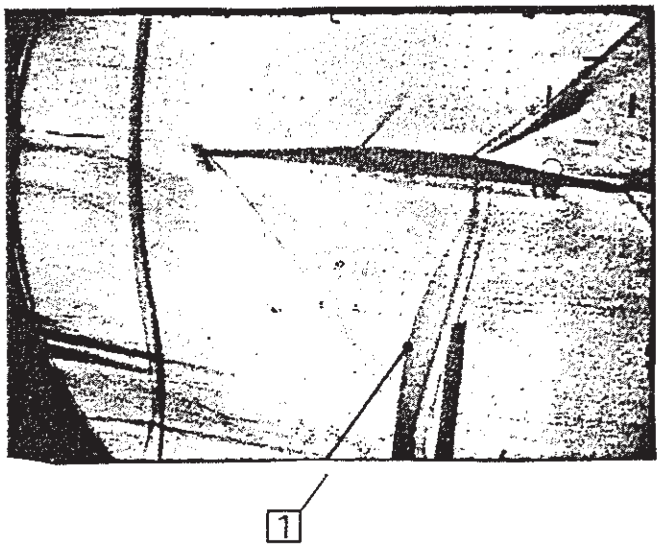


Fig. 5b

h/d ~ 7

1 bow shock from the probe stem.

2 wedge probe head.

3 reflection of the bow shock.

4 plate.

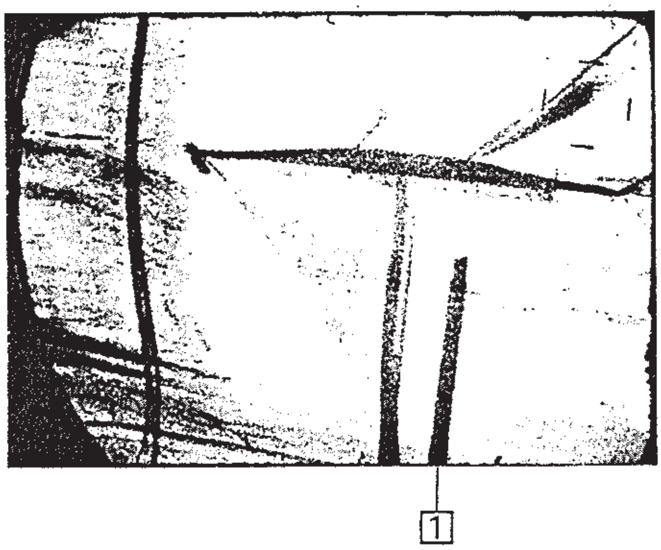


Fig. 5c

h/d ~ 3

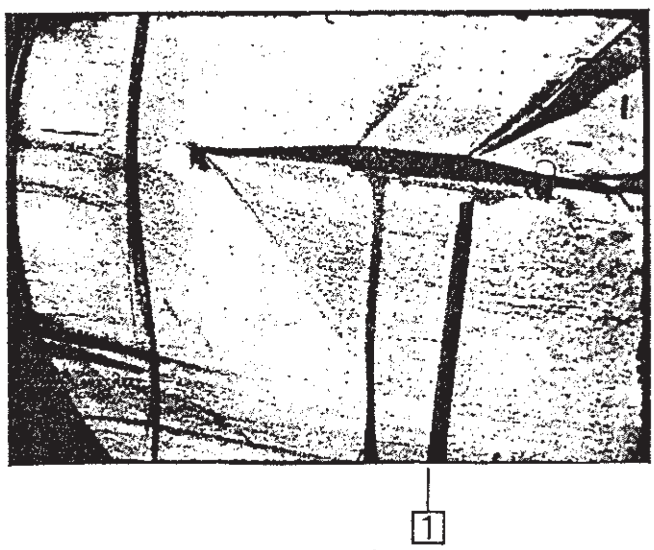


Fig. 5d

h/d ~ 1

Fig. 5

Shock configuration around the probe WP4 at different distances from a wall.

M ~ 1.2

Fig. 6a

Fig. 6b

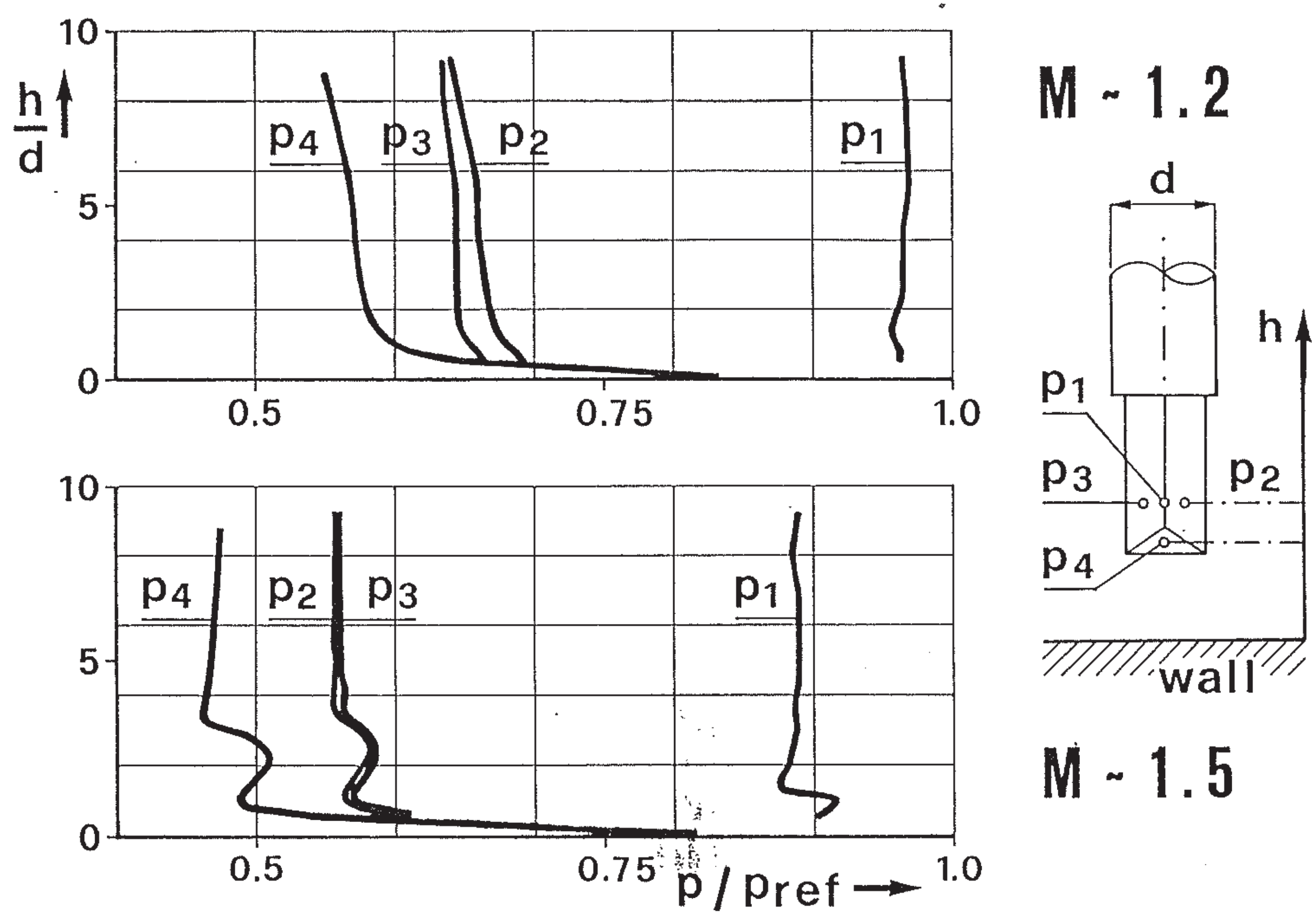


Fig. 6

Measured pressures with the wedge probe.

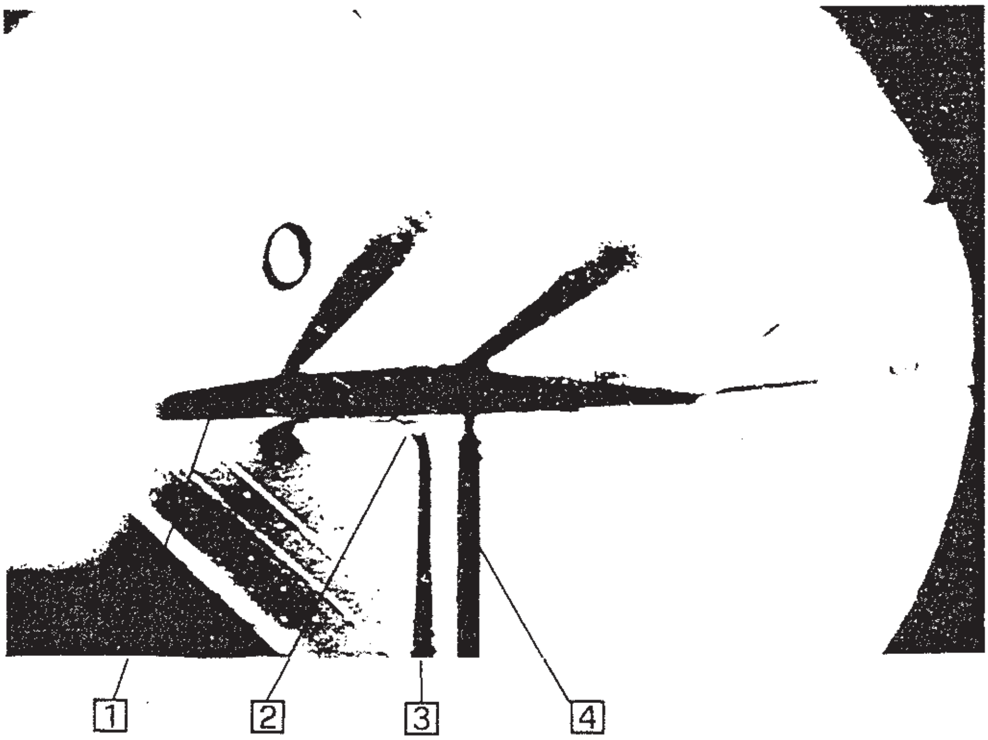


Fig. 7

Shock configuration around the probe WP4.

$M \sim 1.5$

$h/d \sim 0$

[1] plate.

[2] -shock.

[3] bow shock from the probe stem.

[4] wedge probe head.

Fig. 8a

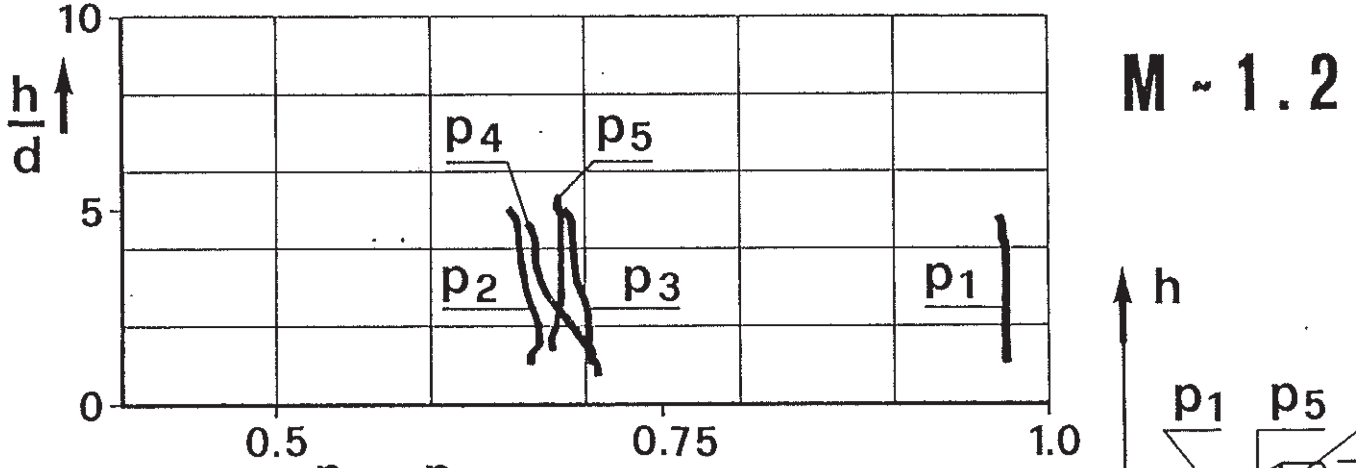
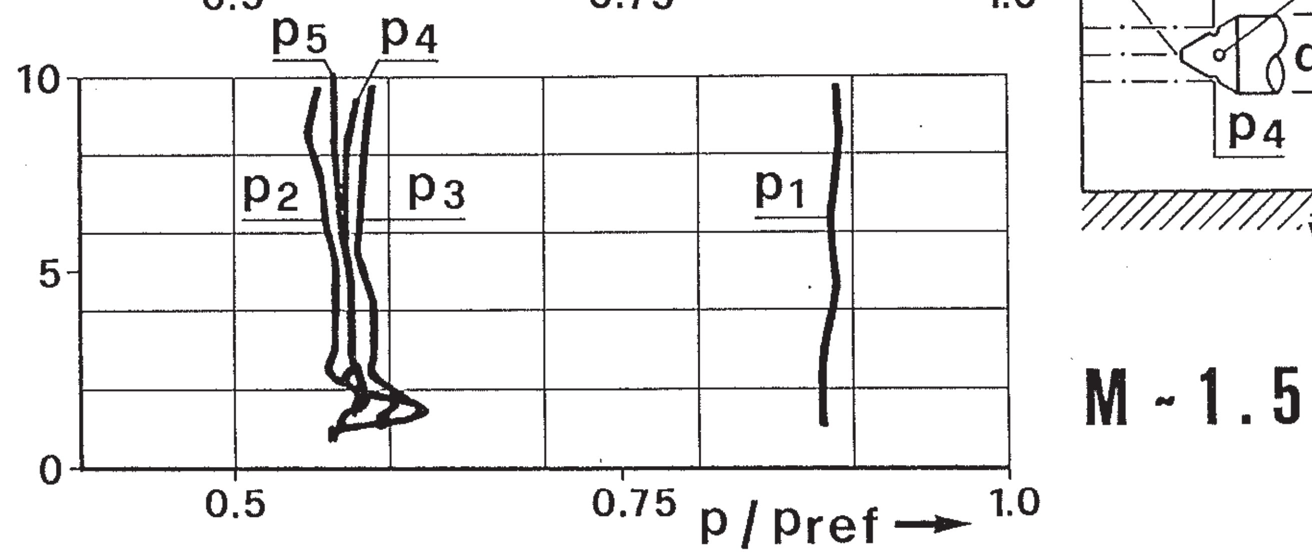


Fig. 8b



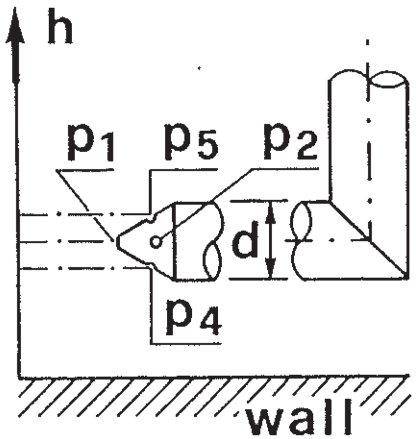


Fig. 8

Measured pressures with the cone probe.

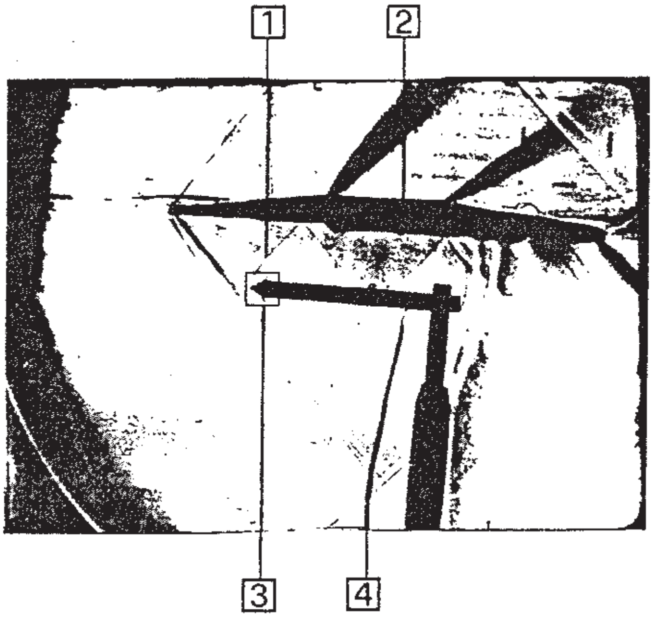


Fig. 9a

h/d ~ 5

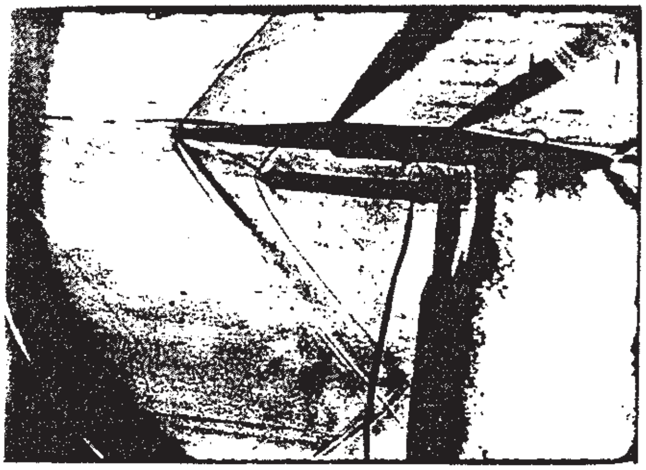
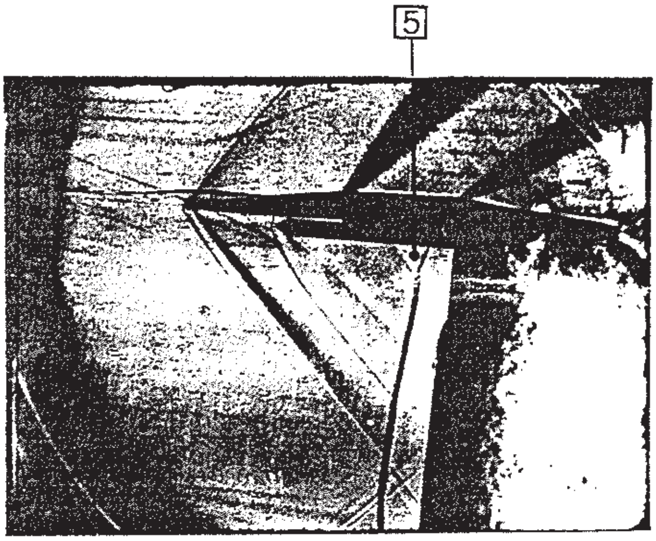


Fig. 9b

h/d ~ 2



1 bow shock from the probe head.

2 plate.

3 cone probe head.

4 bow shock from the probe stem.

5 λ - shock.

Fig. 9c

h/d ~ 0

Fig. 9

Shock configuration around the cone probe LP3 at different distances from a wall.

M ~ 1.5

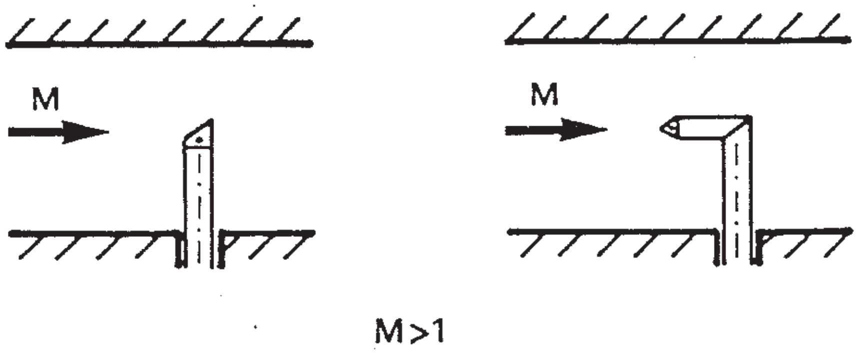


Fig. 10
Probe in a channel.