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Description of a Probe for Measurements of Two-Dimensional Wake Flow Quantities

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Summary

In the near wake of a two-dimensional cascade, the pressures vary in the circumferential direction and in the axial direction. It was designed a probe, which allows accurate measurements of flow properties in such a flow, whereby the Mach number should not exceed the transonic range. This probe has three separate sensing elements, which enable the pick-up of total pressure, static pressure and flow angle.

Some calibration results are shown in the Mach number range of $Ma = 0$ through 1 and in the Reynolds number range of $Re = wl/\nu = 1 \cdot 10^5$ through $7 \cdot 10^5$, where $l = 80$ mm. Furthermore a few examples of measurements with this probe are given. Lastly some flow angles, which were measured with different kinds of probes, are compared with one another.

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Symbols

a	local velocity of sound
$B = 300$ mm	width of test section
H	height of test section
l	blade chord
$Ma = w/a$	local Mach number
$Ma_{2th} = f(p_K/p_{o1})$	exit Mach number for isentropic cascade flow
p	static pressure
p_o	total pressure
$q = p_o - p$	dynamic pressure
$q_{2th} = p_{o1} - p_K$	dynamic pressure at exit for isentropic cascade flow
$Re = wl/\nu$	Reynolds number
t	pitch
u, z, r	coordinates in the test section
w	flow velocity
z_M	distance between blade trailing edge and measuring plane in the axial direction z
β	flow angle
β_S	blade angle

Indices

K	related to tank ("Kammer")
lo	open to lower side
p	related to probe

u	local value
up	open to upper side
1	inlet conditions
2	exit conditions

1. Requirements

The exit conditions of a two-dimensional wake flow of cascade profiles may be described by the three flow parameters total pressure, static pressure and flow angle. Fig. 1 shows as an example the flow through a turbine cascade. The boundary layers of the blade suction side and pressure side form a wake, which mixes downstream of the cascade with the undisturbed flow. With increasing distance from the cascade, the wake becomes broader and flatter. It is obvious, that the flow properties change in the circumferential direction (coordinate u) and in the direction perpendicular to the cascade front (axial direction coordinate z). They are constant vertical to the figure, because we assume two-dimensional flow.

In subsonic wake flow and at moderate pitch-chord ratios, the pressure gradients in the direction of u and z are less severe, if the wake is measured about one chord length downstream, that is at $z_{M''}$. There the flow angle is nearly equalized along one pitch, and the change of the static pressure in the axial direction is small. In this case, a lot of different probe constructions indicate correct results.

However, in transonic wake flow, the homogenization of the wake flow takes place further downstream. A shock system occurs in the cascade and downstream of it, and these shocks lead to pressure gradients between two neighbour wakes,too. Now the flow quantities have to be measured at the same point of the u, z-coordinate system. On the other hand the sensing elements may be located at different points of the third coordinate r perpendicular to the u, z-plane, if we have two-dimensional flow in this region.

2. Design

We designed a probe, which fulfills these requirements, see fig. 2. We called this probe "Neptun probe" because of its similarity with Neptun's fork. Here we have three single sensing elements: one for total pressure, one for static pressure and one for the flow angle.

Fig. 3 shows the details of this probe. The flow parameters are picked up along one line, which is adjusted parallel to the blade trailing edge. The directional sensing element consists of two parallel tubes, which are cut under an angle of 45 degrees against the tube axis. This arrangement allows angle measurements even at the existence of a varying pressure perpendicular to the slide plane, i.e. if a pressure gradient in the pitch-wise direction dp/du occurs.

The static tube has an elliptical head, and the stem is also elliptical. Both configurations were tested successfully in the National Physical Laboratory in Teddington [1]. The distance between the static holes and the stem was determined in such a way, that the displacement of the flow by the static tube is compensated by the upstream effect of the stem. We have only two holes, which are located in one line with the top of the other sensing elements. By this layout, the pressure gradients in the u, z-plane do not affect the static pressure reading.

The tube for the total pressure measurement has a ratio of inner diameter to outer diameter of 0.4. Values of 0.3 through 0.5 are recommended by DFVLR Göttingen or by the American Society of Mechanical Engineers (ASME) [1].

The lateral influence of one tube on another was also calculated. The measured velocity is only 0.1 % higher than in the free stream. Therefore this influence is negligible.

A similar probe, called "multipurpose survey probe", was designed at NASA Lewis Research Center in Cleveland, Ohio, in 1970 [2].

3. Calibration

The Neptun probe was calibrated in the test section of our High Speed Variable Density Cascade Wind Tunnel, see fig. 4 and [3]. This tunnel allows to vary the Mach number and the Reynolds number independently from one another. It operates continuously. The test section has a width of B = 300 mm. It is obvious, that the distance of the outer sensing elements (60 mm) is not too long compared with this tunnel width and with the aspect ratio of B/l = 3,75. Lateron an example is shown for the two-dimensionality of the flow in this region.

For the calibration, the probe "sensing line" was adjusted in the plane of the static wall tappings. These tappings were connected with the total pressure in the settling chamber far upstream. Lastly the flow angle was found by turning the probe around the "sensing line".

The influence of the probe support on the static wall tappings was also investigated. We picked up the readings of the tappings during installed probe and during removed probe. In both cases, we got the same results, i.e. there is no influence.

Fig. 5 shows some results of this calibration. In the left diagram, the deviation of the total pressure p_{op} at the probe location from the settling chamber pressure p_{o1} is given. The deviation is small up to $Ma_1 = 0.8$, but it takes a maximum of 1 % of the dynamic head in the high subsonic region. That means, that the true total pressure is 1 % smaller than that of the settling chamber in this case.

The right diagram shows the difference of the static pressures of the probe and of the wall tappings $p_p - p_1$. This parameter amounts less than 2 % of the dynamic head at $Ma_1 < 1$. These 2 % lie within the range of the different static wall tappings along the side walls. At $Ma_1 = 1.0$, the difference $p_p - p_1$ increases repidly, because a local shock exists in front of the holes of the static tube. This shock refers to a local increase in static pressure.

The influence of the probe support on the pressure readings was checked by the turning of the probe stem by 180°. The two results at $Re_1 = 3 \cdot 10^5$ do not deviate essentially.

Fig. 6 shows an example of the pressure readings at the inclination of the probe against the flow direction. $p_{up} - p_{lo}$ is the difference of the readings of the two tubes of the flow angle sensing element. This difference varies linear with the inclination angle β_p. The total pressure does not change in a range of ± 5°. The static pressure reading takes its maximum value just in that case, if the angle sensing element is turned into the flow direction. This result verifies, that all sensing elements are adjusted to each other properly. Therefore this probe can be used for measurements with constant angle setting, too.

It should be mentioned, that we usually turn the probe into the flow direction, and then the pressures are read. We correct the total pressure at all Ma-Re-combinations, but the static pressure results only at Ma = 1. Further we average the corrected local values by maintaining the momentum constant.

4. Example: turbine wake flow

Let's have a look on a practical example: In fig. 7, the local readings of the Neptun probe in the wake of a turbine blade are shown. The measurement was taken in a plane 15 % chord length downstream of the cascade. The exit Mach number was $Ma_{2th} = 1.0$. You can see the well-known wake, the local flow angle and the local static pressure rise along one pitch. This figure contains the results of three wake traverses: one traverse was conducted in the middle of the tunnel width or of the blade height ($2r/B = 0$), and the others relate to a line ± 30 mm out of the tunnel centre ($2r/B = \pm 0,2$). That is the distance between two neighbour sensing elements of the probe. It can be seen, that all results follow one line in each diagram. Now it is verified, that the flow is two-dimensional in the probe region.

The upper diagram of fig. 8 shows again the local flow angle β_{2u} along one pitch (symbol: triangle). But here it is compared with the reading of a wedge probe. The angle holes of that probe lie ± 0.9 mm out of the probe center line, see sketch on the left side. Therefore its reading cannot be accurate in the range of a pressure gradient as on the wake flank. In the range of u = 15 through 35 mm, a big difference between the readings of both probes is visible. Here the wedge probe indicates wrong values because of different total pressures at the position of the two holes. The mean values, which are area-averaged along one pitch, are also different.

The lower diagram holds the momentum-averaged flow angle β_2 over the distance z_M between cascade and probe. At all measured distances, the Neptun probe yields a constant value of β_2, which is assumed to be correct. But the results of the wedge probe differ by 1° from those values of each side out of the wake. Even at $z_M/l = 0.4$, the difference between Neptun probe and wedge probe amounts 0.6°. Therefore z_M/l should be bigger than 0.4, if the wake is measured with a probe like this wedge probe.

5. Conclusions

A probe was designed for the measurement of two-dimensional wake flow properties. This probe can be used in a field of pressure gradients as it occurs in the subsonic and transonic exit flow of a turbine cascade. Three separate sensing elements enable the pick-up of total pressure, static pressure and flow angle.

The probe was calibrated in the same wind tunnel, where the probe is used. The Mach number range was Ma = 0 through 1, and the Reynolds number range was $Re = wl/\nu = 1 \cdot 10^5$ through $7 \cdot 10^5$ with $l = 80$ mm. For wake flow measurements, one turns the probe into the local exit flow direction and corrects the pressure readings. The correction of the total pressure amounts 1 % of the dynamic head or less. The static pressure only requires a correction at Ma = 1.

A comparison of flow properties, which were measured with this probe and with a conventional wedge probe, was made. It shows, that the wedge probe can be used in a distance of $z_M/l > 0.4$, in order to get accurate exit flow angles.

References

[1] WUEST, W. — Strömungsmeßtechnik.
Vieweg Braunschweig (1969)

[2] STABE, R.G. — Design and Two-Dimensional Cascade Test of Turbine Stator Blade with Ratio of Axial Chord to Spacing of 0.5.
NASA TM X-1991 (1970)

[3] SCHOLZ, N., HOPKES, U. — Der Hochgeschwindigkeits-Gitterwindkanal der DFL Braunschweig.
Forschung Ing. Wes. 25 (1959), S. 133 - 147

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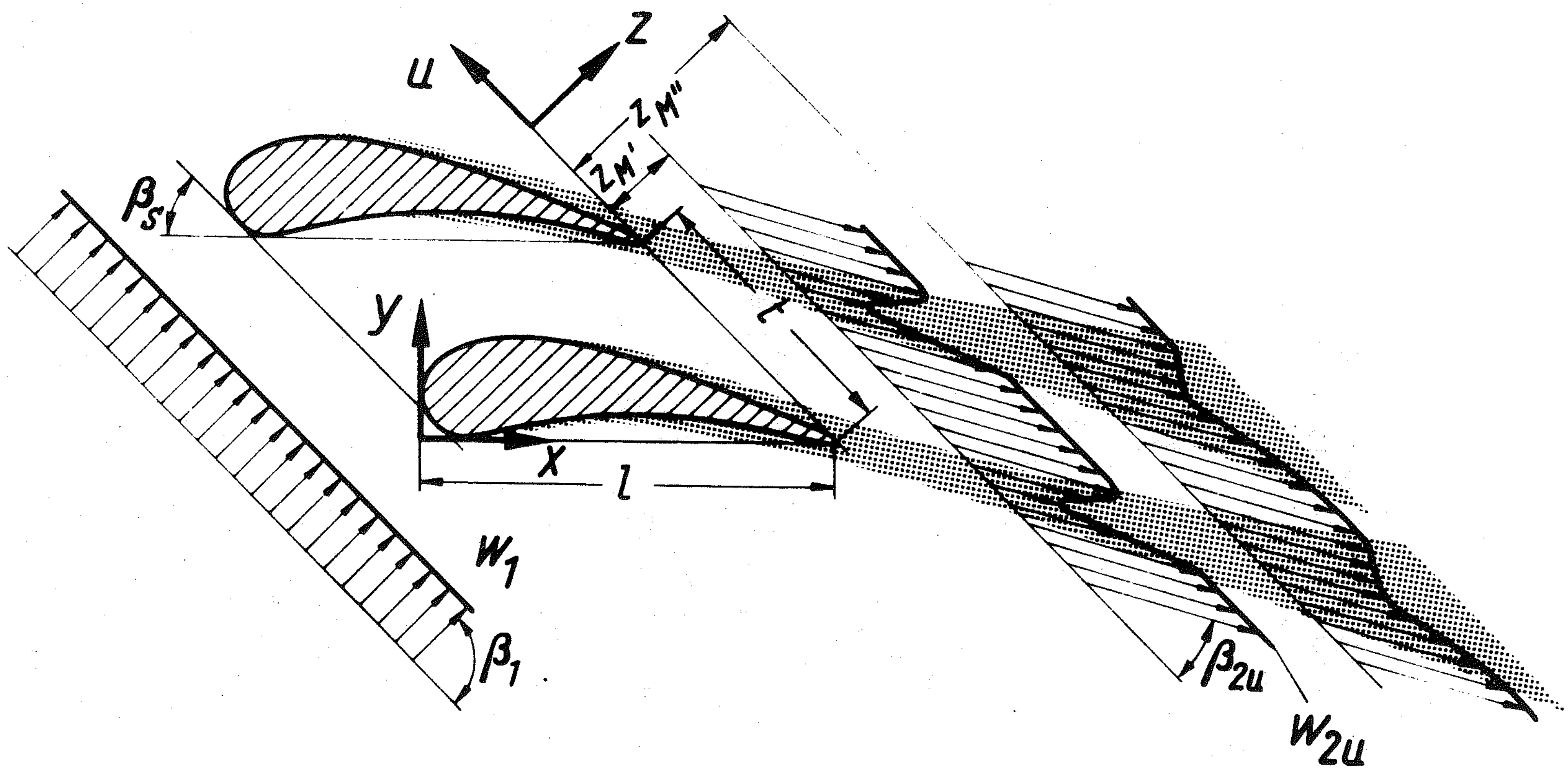

Fig. 1: Cascade wake flow

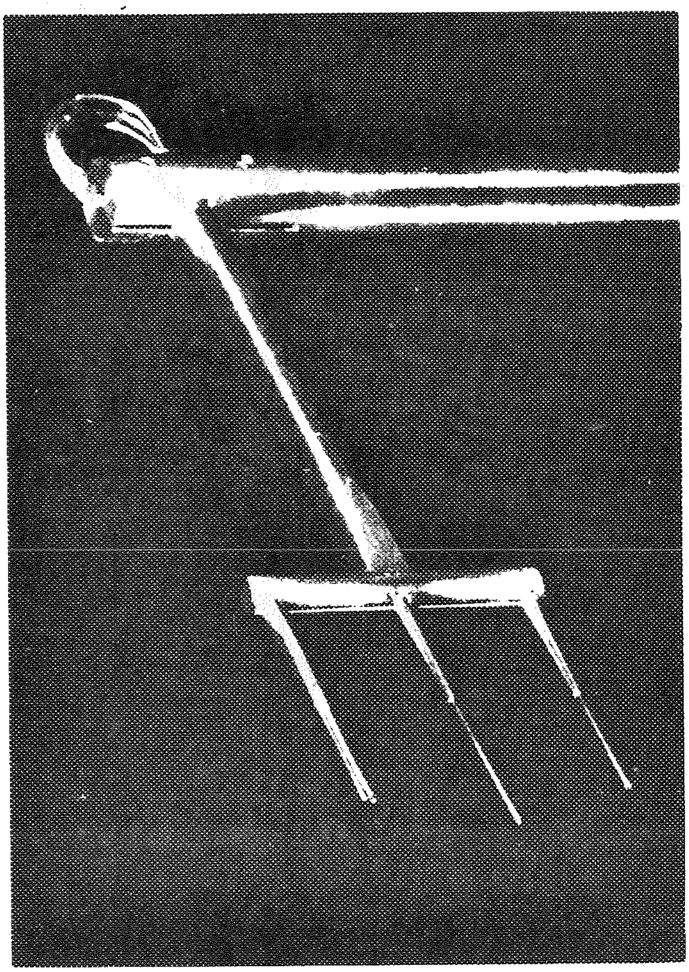

Fig. 2: View of Neptun probe

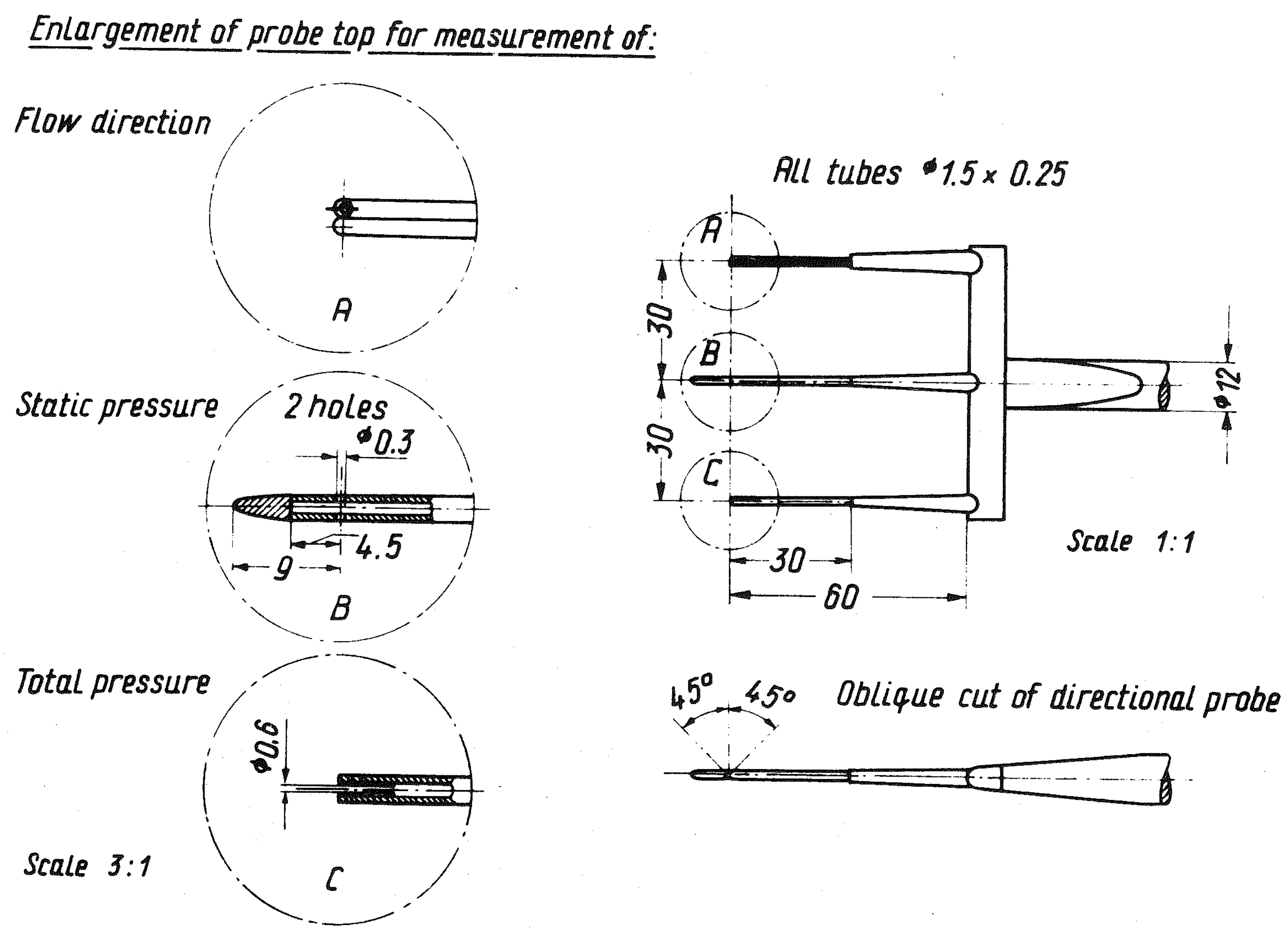

Fig. 3: Neptun probe for wake traverse measurements in 2D-flow

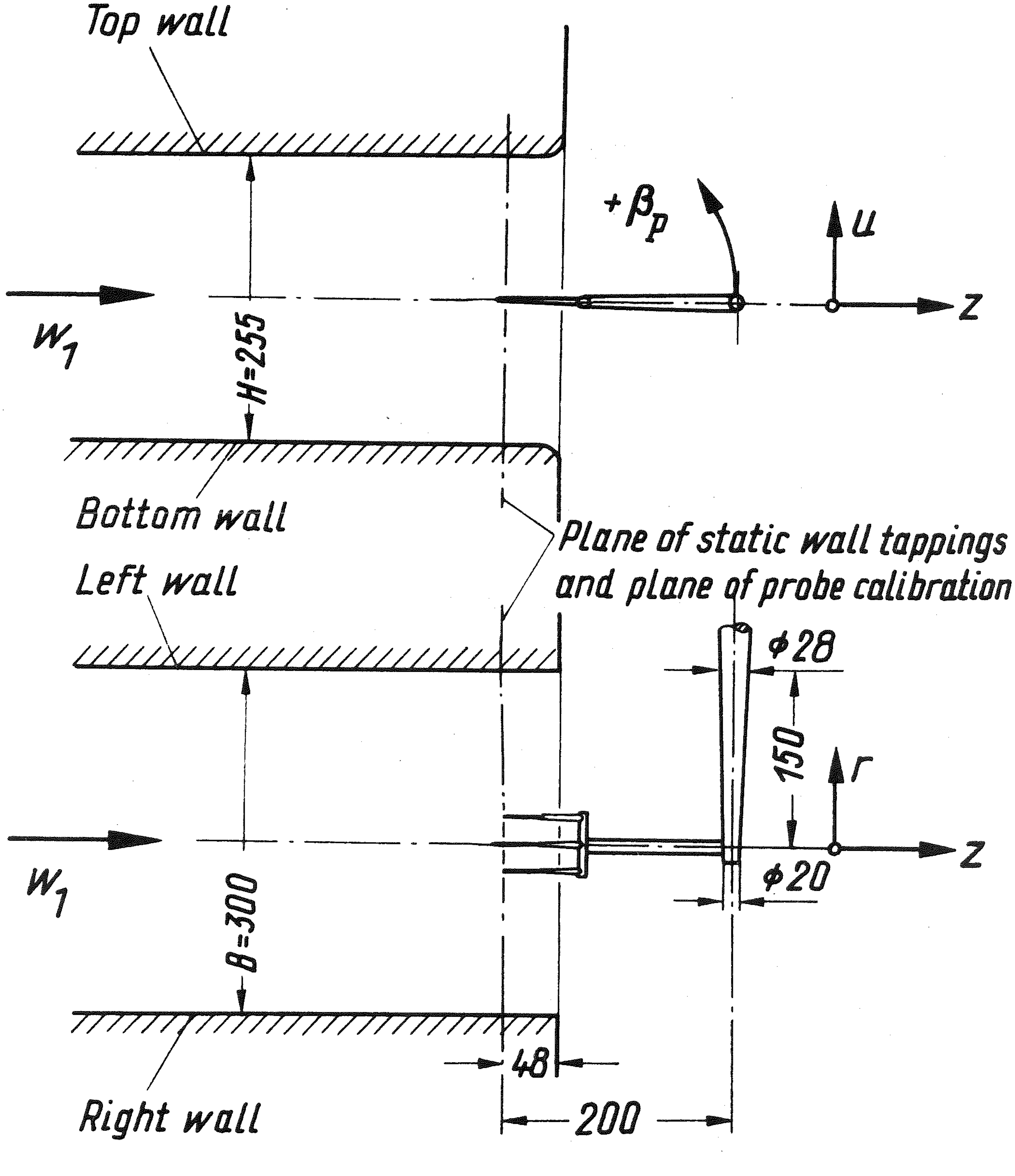

Fig. 4: Set-up for probe calibration

$$Re_1 = \frac{w_1 l}{\nu_1} \quad \text{with } l = 80\,mm$$

Different probe set-up at $Re_1 = 3 \times 10^5$	
Symbol	Probe set-up
△	p_{0P}
▲	p_{0P}

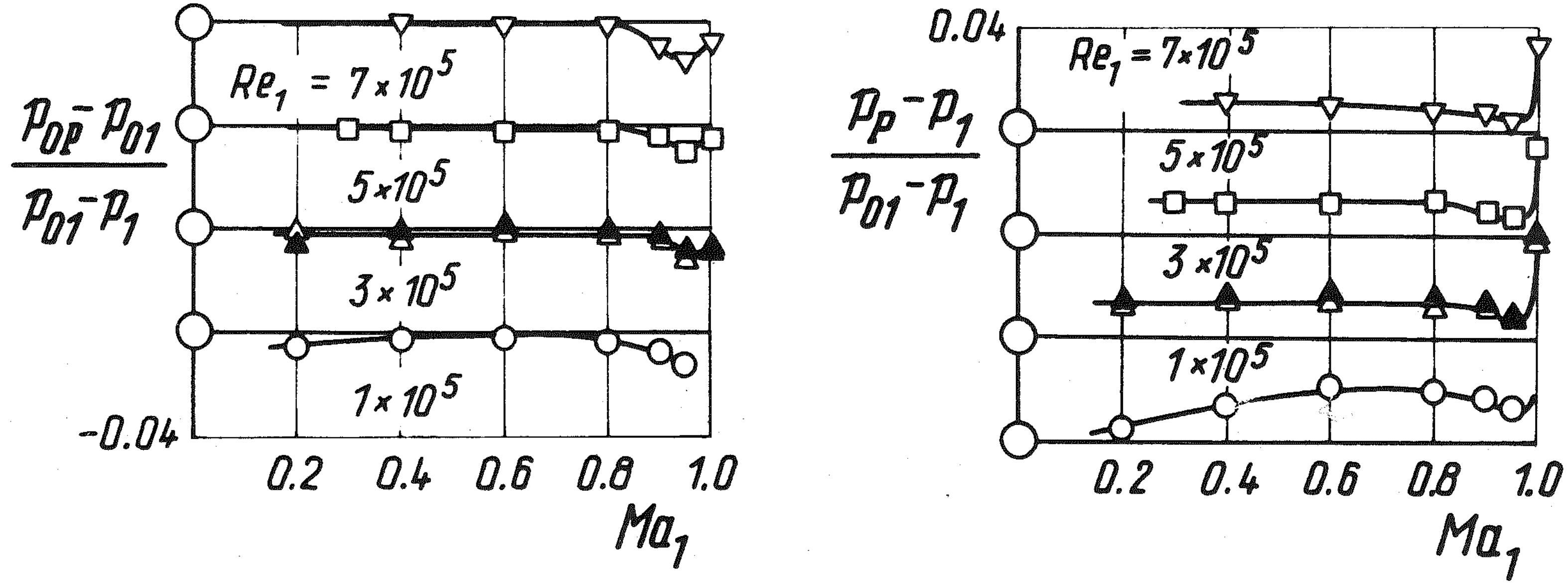

Fig. 5: Total pressure and static pressure as functions of Ma_1 and Re_1

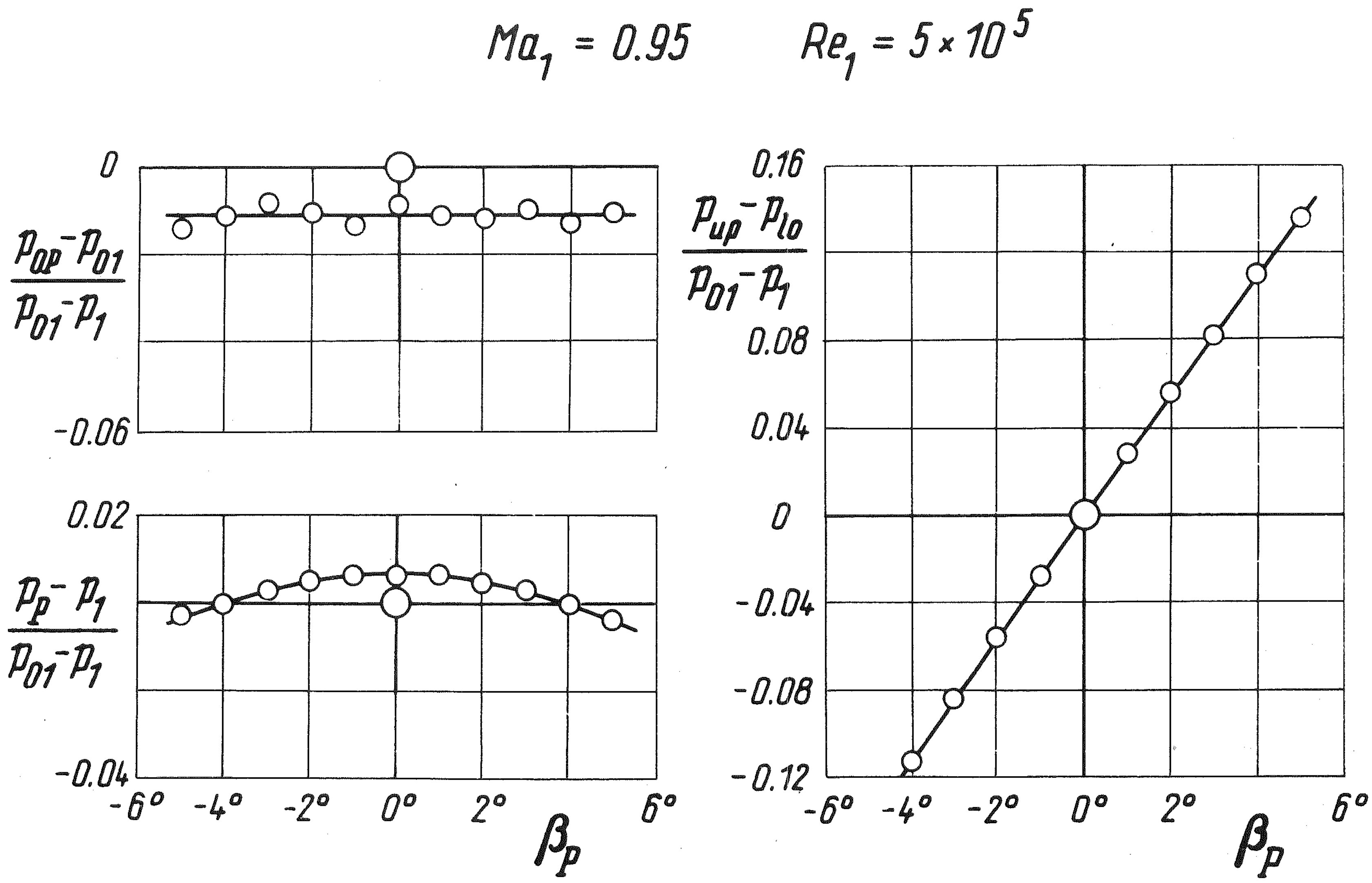

Fig. 6: Readings at probe inclination

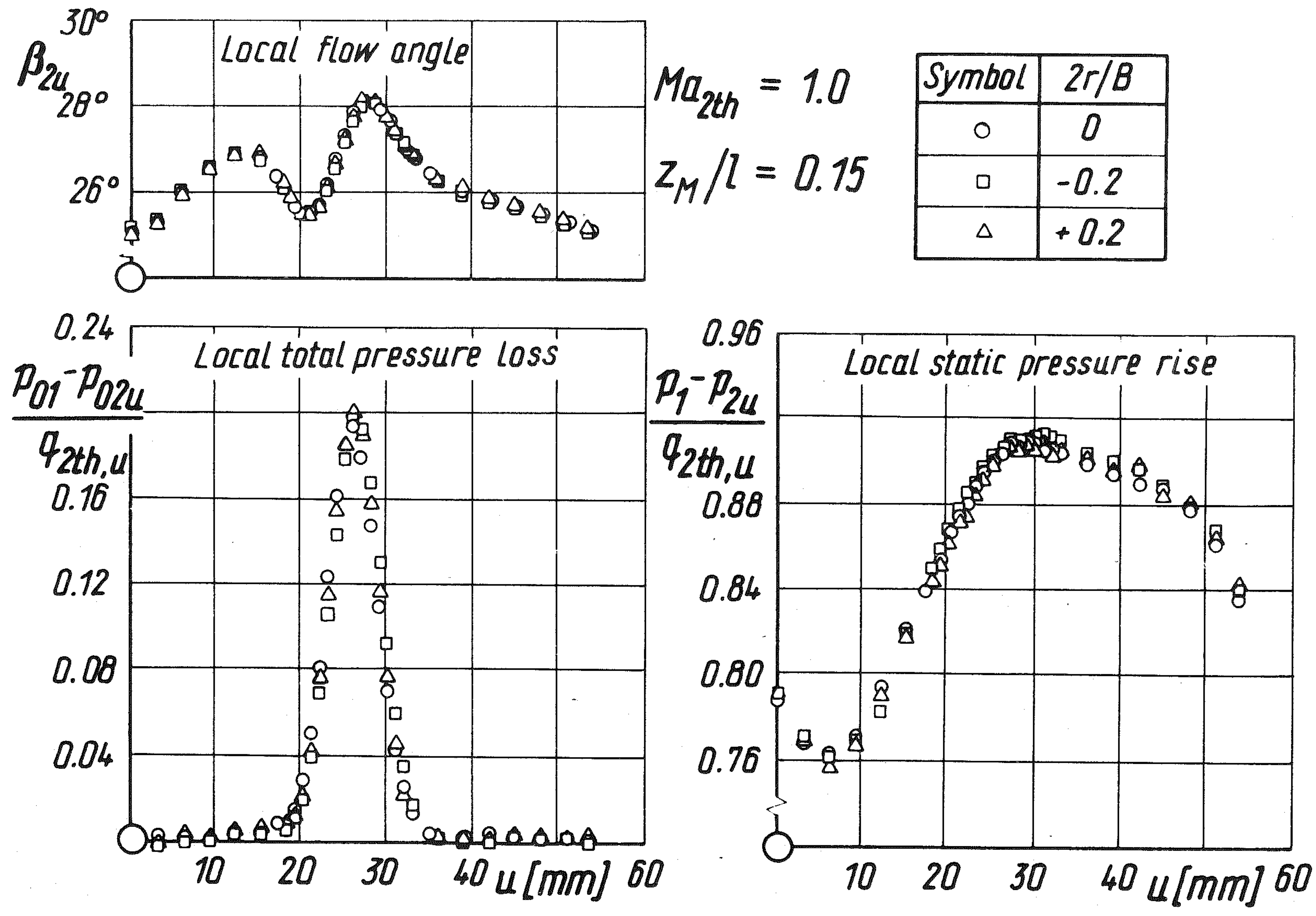

Fig. 7: Local readings in the wake of a turbine blade

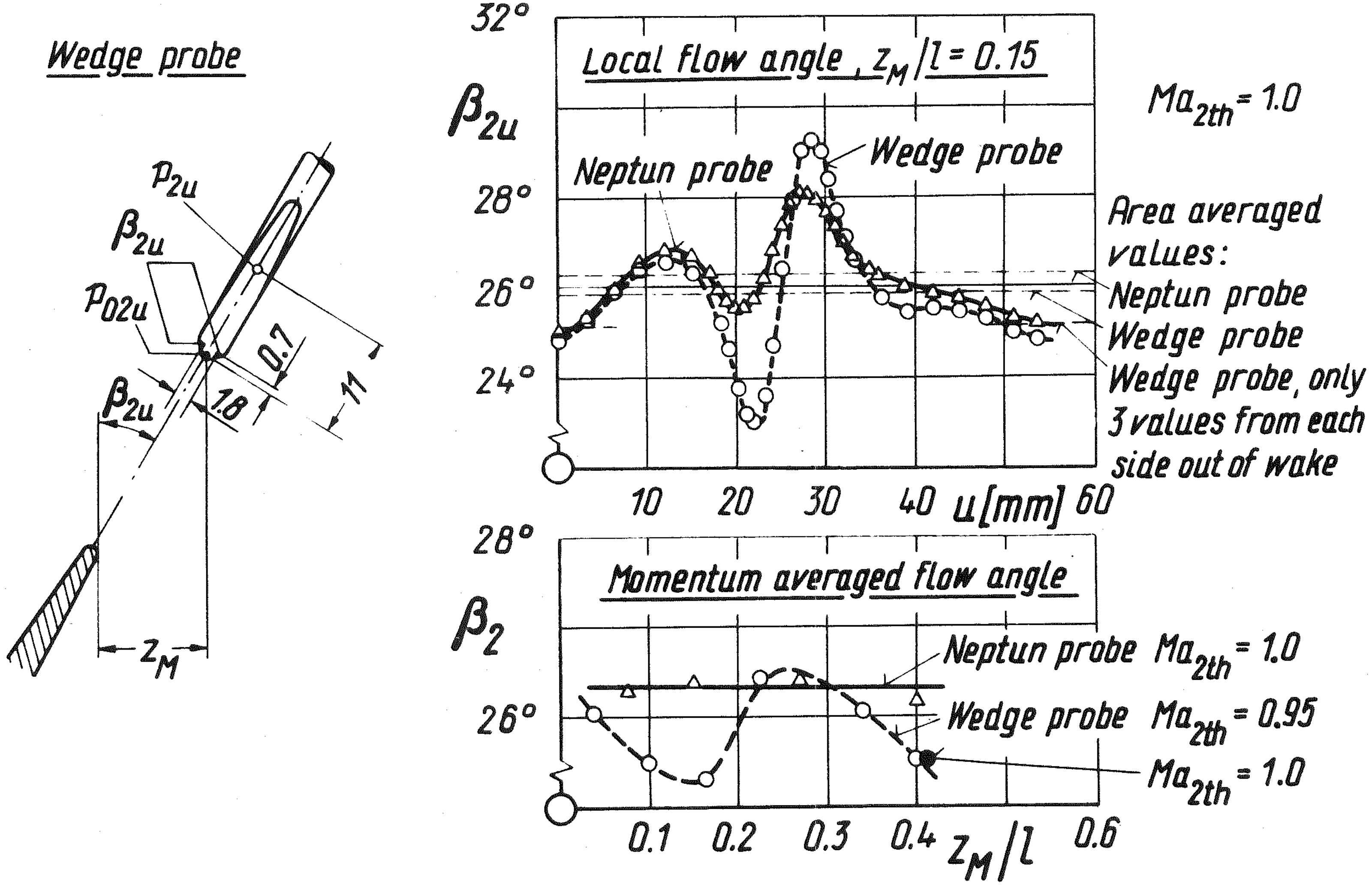

Fig. 8: Flow angle measured by different probes