to provide the necessary back pressure. This is done by feeding the pressure just upstream of the throttle through the chamber to the open slots. With this method we have successfully obtained periodic back pressure conditions even for blade sections having internal contractions (Fig. 5). The experiments showed that the measured exit flow conditions of the cascade are not sensitive to the angular position of the tailboard. The same exit flow could be obtained by using either the throttle or by rotating the tailboard in order to vary the back pressure.

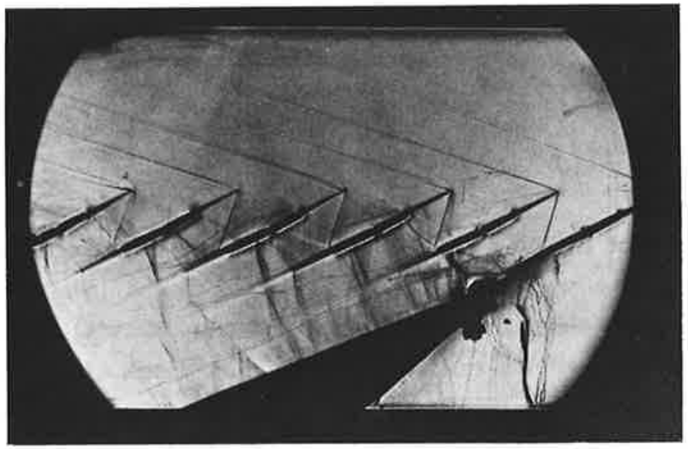


Fig. 5 Schlieren picture of cascade, throttled with porous tailboard

Reference

[1] Lichtfuss, H.J., Starken, H.: Supersonic Exit Flow of Two-Dimensional Cascades. ASME paper 72-GT-49 (1972).

A new configuration of wind tunnel and some experience with an annular cascade for transonic flow conditions

by

A. Bölcs and T. Fransson

Summary:

To investigate experimentally the transonic flow in annular cascades, a new type of wind tunnel was developed. The testrig enables variations of the medium velocities and flowangles in the test section, as well as of the velocity- and flowangle-distributions over the channel height.

Flow-measurements were made in a transonic turbine-cascade with a small aspect ratio (H/S = 0.19). A comparison between the profile Mach numbers measured on the outer wall of the test section and in the middle of the channel shows a fairly good agreement on the pressure side, but a greater deviation is found on the suction side of the blade. This is due to the clearance-flow.

By attaching end-plates on the tip of the blades, the clearance-flow was reduced. In this case, the difference between the measured profile Mach numbers in the middle of the channel and on the outer wall was also reduced. The flow-velocity in the cascade with end-plates, compared to the case without end-plates, increases in the case of identical up-stream-conditions.

1. INTRODUCTION

To investigate transonic flow in annular cascades a new type of an annular wind-tunnel was developed ([1]). The objectives for this tunnel were set as follows:

- Generator of a disturbancefree and axisymetric flow
- Variable Mach number and flowangle in the testsection
- Variations of the Machnumber- and flowangle-distributions in the radial direction should be possible.

2. THE TEST FACILITY

2.1 The wind tunnel

The developed wind tunnel is shown schematically in Figure 1. The flow is guided into the nozzle radially and is turned and accelerated in the channel.

The inlet is divided into two independent channels by a wall. In each of these channels there is a guide-vane, with which we can vary the flow to any desired Mach number and angle. The velocity- and flowangle-distributions and gradients in the testsection are established by mixing the two inlet flows. The velocity distribution can also be adjusted by applying a suction through the channel walls.

The testcascade is placed in the axial part of the wind tunnel. The flow is measured up- und down-stream with the probes Nr. 1 and 2, and the backpressure is adjusted with a throttle.

Our compressor restricted us to limited dimensions of the test wind tunnel. The mean channel-diameter was chosen to be 160 mm, and the height of the channel to 8 mm.

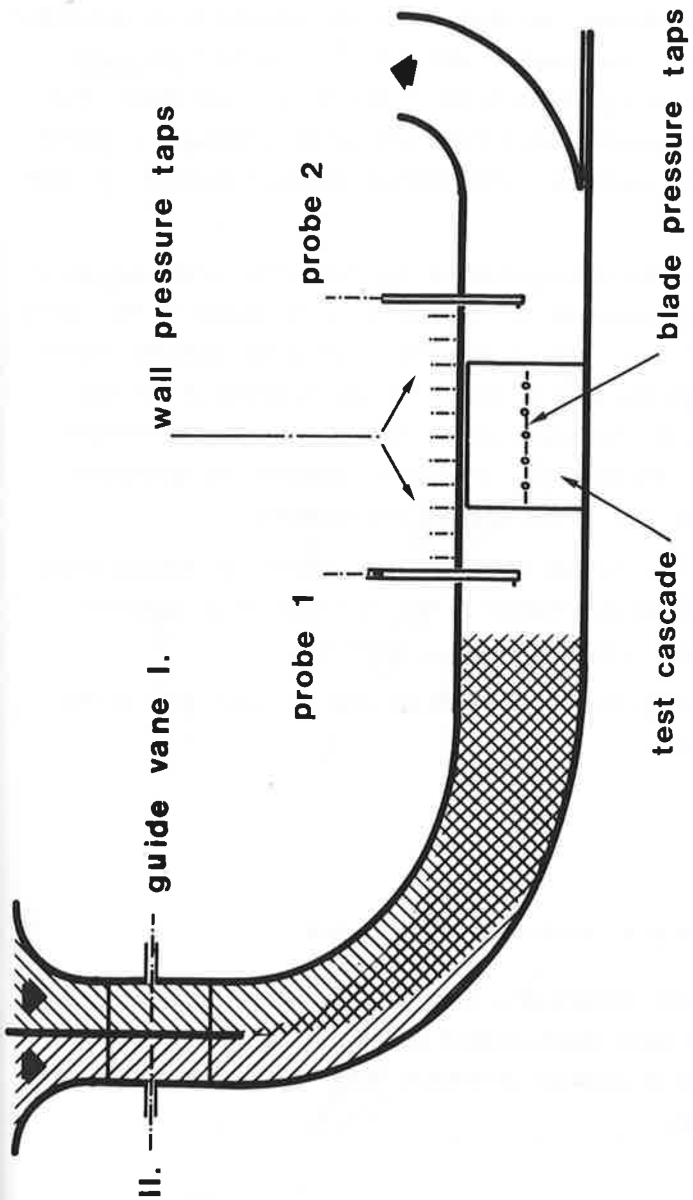


Fig. 1 Annular wind tunnel

2.2 The testcascade and measuring points

After testing the windtunnel, we made a few measurements in an annular cascade. From these experiments, with the small aspect ratio used (H/S = 0.19), it is only possible to draw qualitative conclusions. The objective of the experiments were therefore not to investigate a specific cascade, but to gain experience with cascade measurements in the windtunnel.

The testcascade and the arrangement of the measuring points are shown on Figure 2. Static pressures are measured on the blades in the middle of the channel and in one row on the outer wall of the annulus. These latter pressure-taps are used to determine the flowfield on the outer wall. This is done by displacing the cascade step by step in circumferential direction. Thereby it is possible to measure the pressure-field - on the outer wall - with any desired netwidth.

This displacing of the cascade makes it also possible to determine the velocity- and flowangle-distribution in the circumferential direction (and over the channel height) up- and downstream.

The clearance between the tip of the blade and the outer wall of the annulus is 0.05 mm.

3. RESULTS

3.1 Measurements without end-plates

In Figure 3, we have presented a case with an inlet Mach number of 0.7 and a medium outlet Mach number of 1.2. The Figure 3b shows the measured lines of constant isentropic Mach numbers on the outer wall of the annulus.

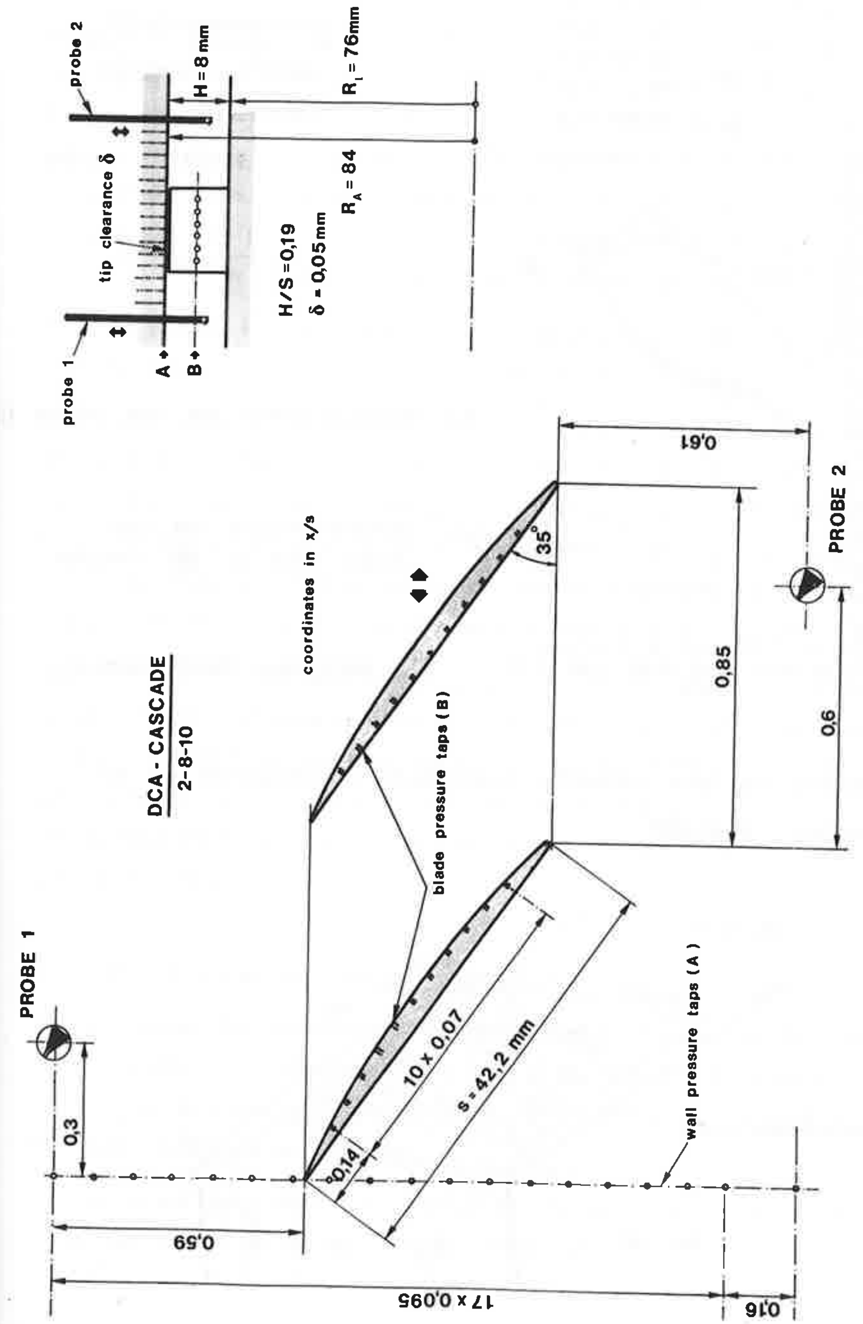
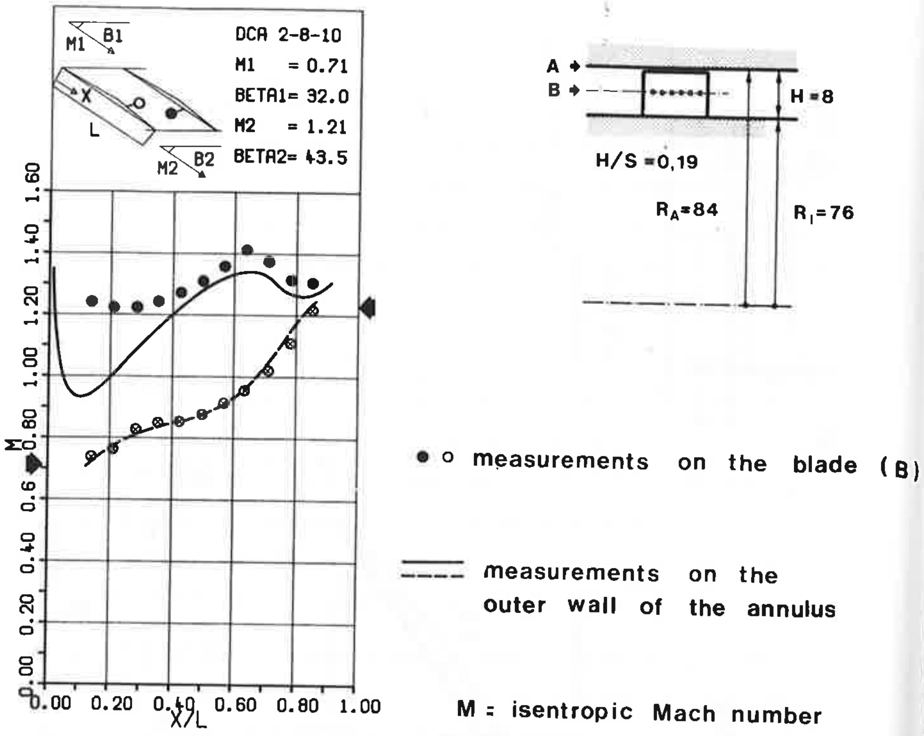
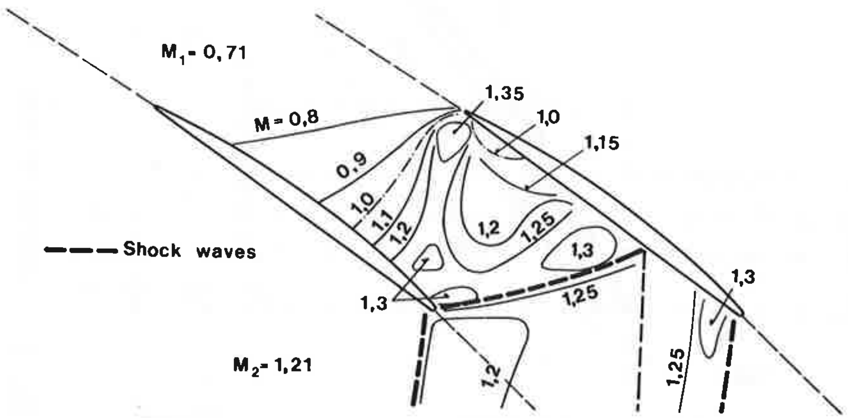


Fig. 2 Scheme of measuring points



Blade surface velocity distribution measured in an annular cascade.



Mach number distribution on the outer wall of the annulus (A)

Fig. 3

The distribution along the blade of the isentropic Mach numbers is given in Figure 3a. We have presented - with the circles - the measured Mach numbers in the middle of the channel and - with the lines - the Mach numbers on the outer wall of the annulus. These latter values are taken from Figure 3b. The agreement between these two measured values is good on the pressure side of the profile. On the suction side we find a considerable deviation in the forward part of the profile. The reason for his deviation is the tip-clearance-flow.

Also in Figure 3b we find an evidence of this tip-clearance-flow, namely the small subsonic region in the supersonic field.

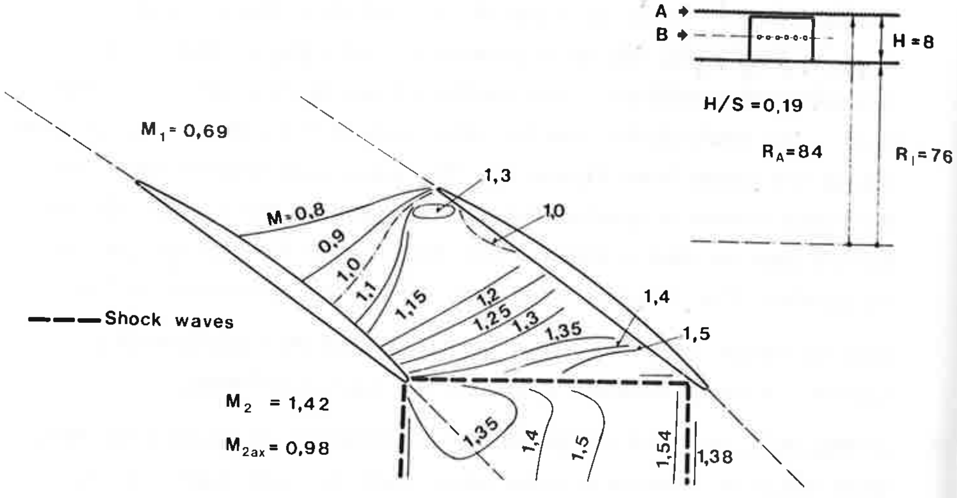
In Figure 4, we have compared the distributions of constant isentropic Mach numbers, measured on the outer wall, for two cases with the same inlet flow conditions but different backpressures. The upper figure shows the field at an axial Mach number close to one, and the lower the field at a higher backpressure. In both these two cases, we find, as in Figure 3, the local subsonic region in the supersonic field.

The velocity-distributions on the profile for these two values of back-pressure are presented in Figure 5. We find a fairly good agreement between the Mach numbers on the blade - in the middle of the channel, and those on the outer wall of the annulus for the pressure side. On the suction side there is, as before, a greater difference on the forward part of the blade.

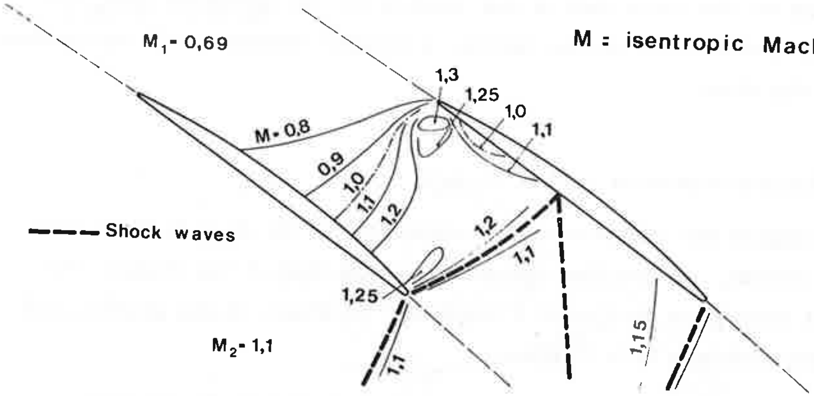
3.2 Measurements with end-plates

To investigate the influence of the clearance on the flow in the middle of the channel, we attached end-plates on the tips of the blades. The width of each plate is almost 3 times the thickness of the profile, and the plate-thickness is 0.15 mm.

The previous tests were then repeated, and in Figure 6, we have compared a case at an inlet Mach number of 0.7.

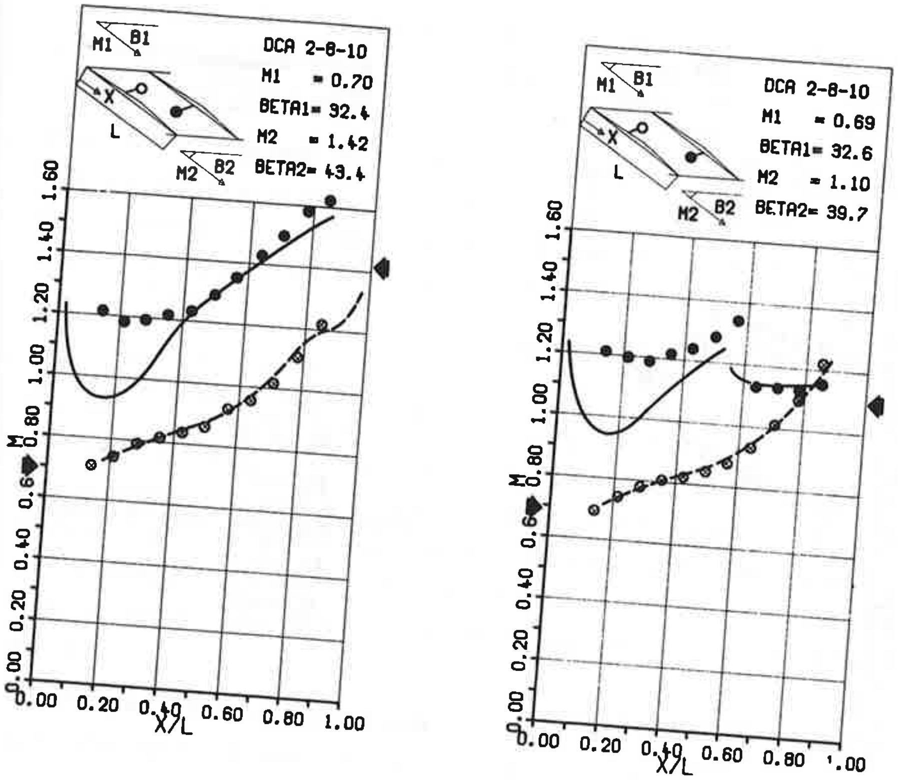


Flow field in the cascade at $M_{2ax} \sim 0{,}98$

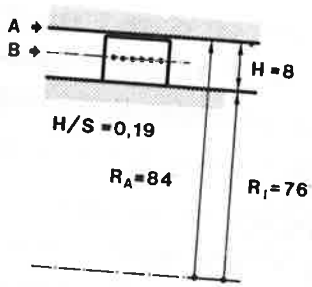


M : isentropic Mach number

Fig. 4 Flow field in the cascade at higher backpressure. Measured Mach number distributions on the annulus outer wall in an annular cascade at different backpressure



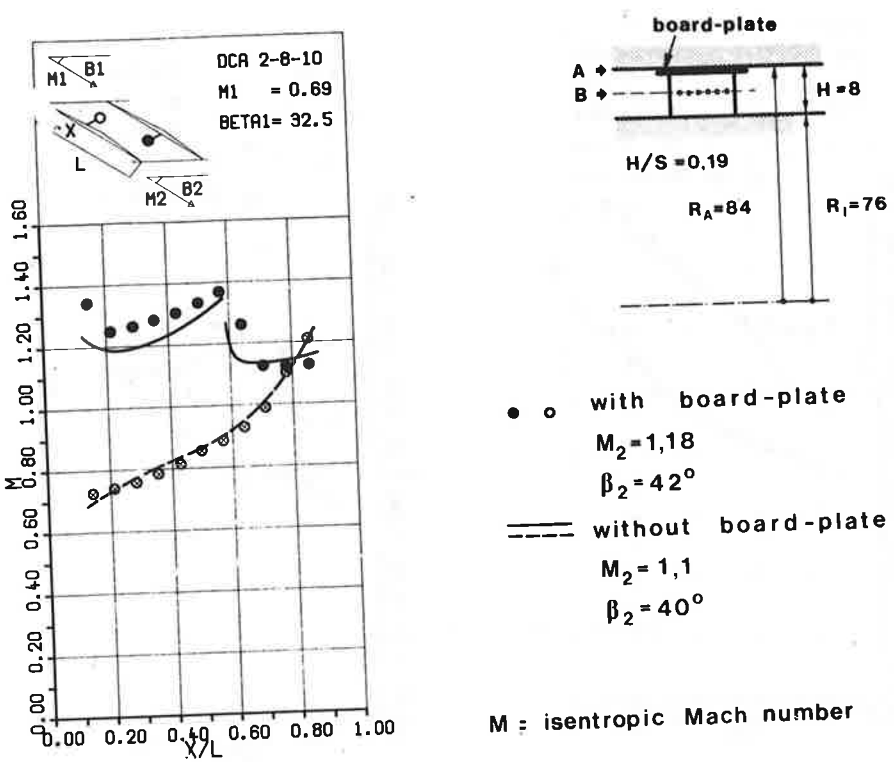
M : isentropic Mach number



● ○ measurements on the blade (B)

—— - - - measurements on the outer wall of the annulus (A)

Fig. 5 Comparison of the Mach number distributions on the profile in the middle of an annular cascade at different backpressure



Blade surface velocity distribution with and without board-plates on the profiles measured in an annular cascade.

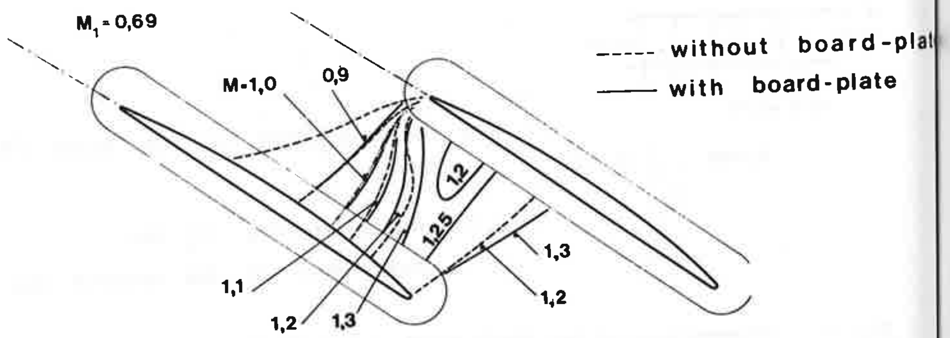


Fig. 6 Mach number distribution on the outer wall of an annular cascade with and without board-plates on the profiles

In the case with the end-plates, we see from the upper figure that the flow-velocity in the middle of the channel is slightly smaller on the pressure side and higer on the suction side.

From the Mach number distribution on the outer wall of the annulus we find that the flow in the cascade is faster accelerated in the case with the end-plates. At the end of the cascade, we reach a Mach number of 1.3 with end-plates but only 1.2 without the end-plates.

The medium downstream Mach number and flowangle is slightly higher in the case with the end-plates.

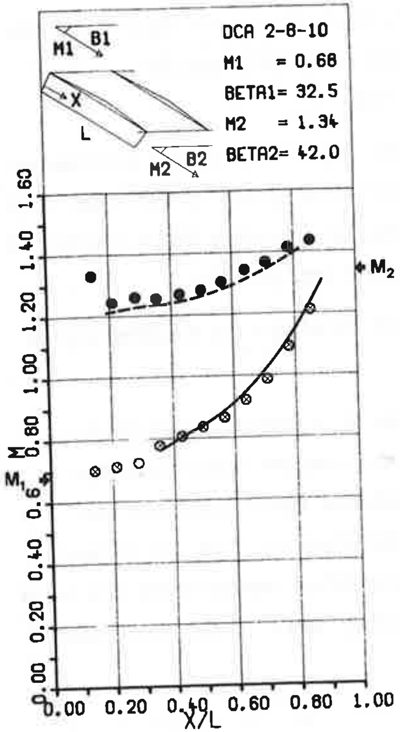
Figure 7 presents the flow in the cascade at a higher outlet Mach-number. The lines of constant Mach numbers on the outer wall are extrapolated to the profile. These extrapolated Mach numbers are presented as lines in the upper figure. We conclude that the values in the middle of the channel and the extrapolated values from the outer wall are much closer to each other than they were in the case without end-plates.

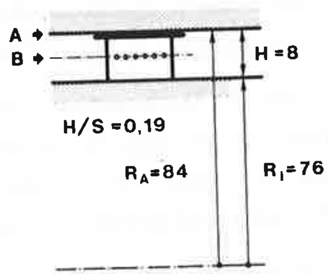
3.3 Flowmeasurements with the probes

To determine the flow up- and downstream, we used wedgeprobes like the one shown in Figure 8. The diameter of the shaft is 3 mm. The probes were calibrated in both subsonic and supersonic regions.

Figure 9 shows the distribution of the Mach numbers and the flow-angles upstream (M_1 = 0.69, β_1 = 32.6) and downstream (M_2 = 1.1, β_2 = 40). We have presented the measured values over the height of the channel (Z/H) at four different pitch-positions.

Upstream, we see that both the Mach numbers and flow-angles are almost constant over the height of the channel and over the pitch. Downstream, the values vary a bit more over the pitch.





● ○ measurements on the blade (B

extrapolated from the Mach number distribution on the outer wall of the annulus

M : isentropic Mach number

Blade surface velocity distribution measured in an annular cascade.

(cascade with board-plates on the profiles)

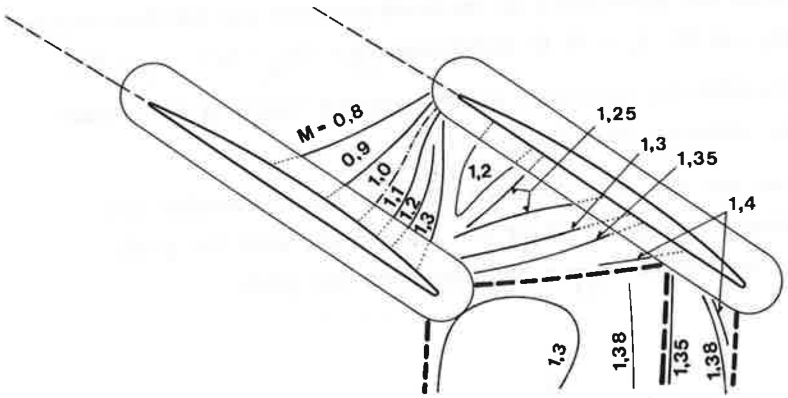
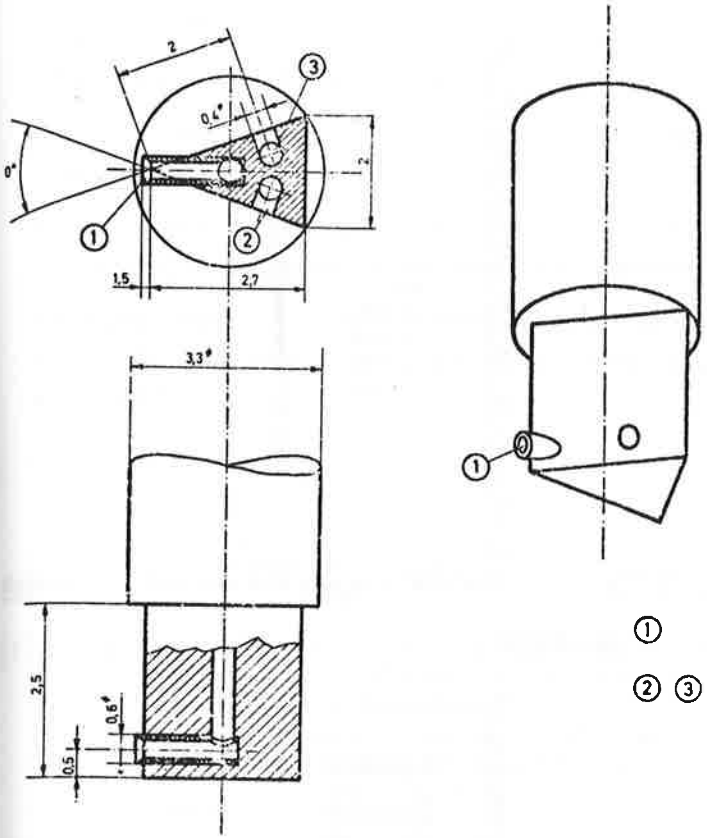


Fig. 7 Mach number distribution on the outer wall of an annular



① Total pressure

② ③ Yaw angle

Fig. 8 Wedge probe

4. CONCLUSION

Our experience with this new wind tunnel can be summarized as follows:

- The rotational symmetry in the test-section is satisfying. (The variation of the Machnumbers around the cascade was smaller than 1%. Changes in the construction can improve the symmetry.)
- Velocity and flowangle in the test-section can be varied by changing the inlet conditions.
  (We have varied the Machnumber between 0.3 and 1.3 and the flow-angle between 20 and 65 degrees in the test-section.)

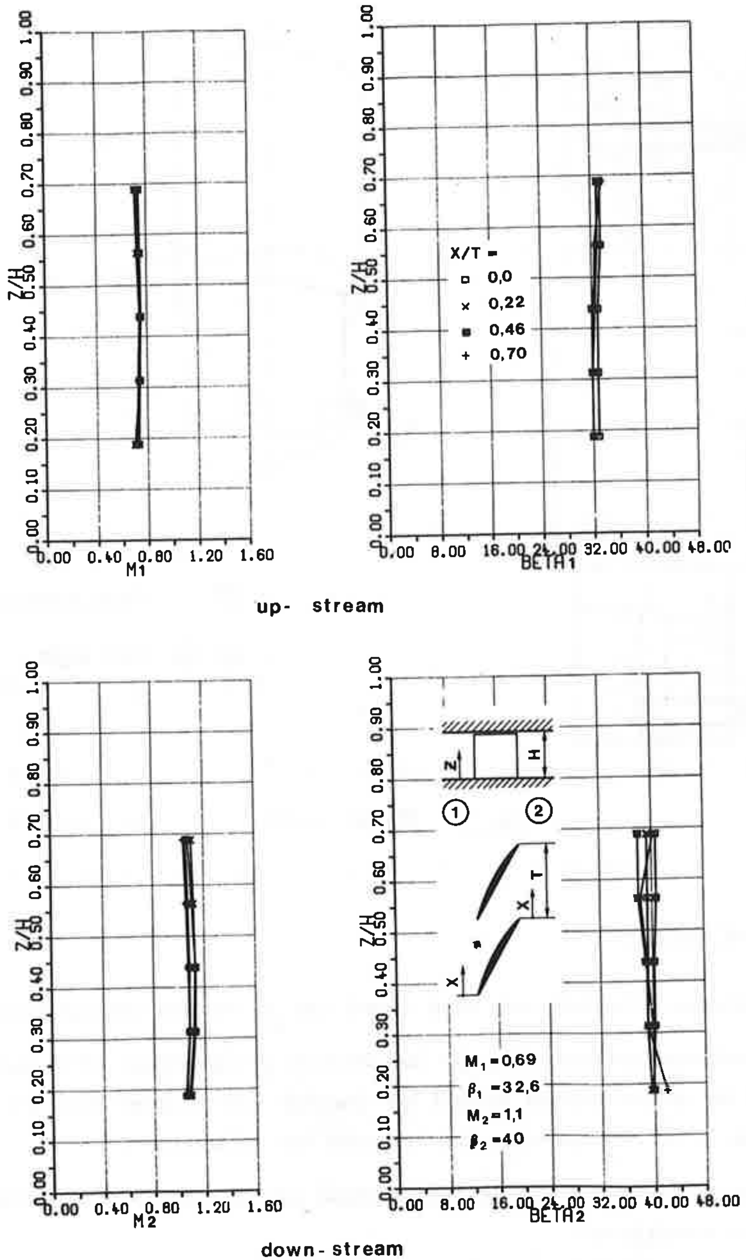


Fig. 9 Velocity- and flowangle distribution in an annular cascade in a plane up- and down-stream

- The periodic downstream-conditions are automatically established by the regulation of the backpressure.
- It has shown that suction of the boundary layer through the canal wall is necessary.
- The clearance-flow must be prevented, if we wish to determine the flow field in the middle of the canal from the field on the walls.

The positiveness of our experiments with this test-wind-tunnel encouraged us to build a bigger one. It is now being constructed and will be operational in 1977.

Reference

[1] Bölcs, A.: Theoretische und experimentelle Untersuchung der drallbehafteten Ueberschallströmung in einer Ringspaltdüse. Communication de l'institut de thermique appliquée EPFL N° 1, 1974.