Cascade test methods in wind tunnel at ONERA

by
J. Leynaert

1. PRELIMINARY

Cascade test methods have been developed at ONERA by using the main chamber of a supersonic wind tunnel converted for cascade tests.

Thanks to the high wind tunnel pressure ratio, 5:1, it is possible to choke mass flows of the cascade test rig by independent sonic throats, and to bleed controlled quantities of sidewall boundary layer. These possibilities are most useful and convenient.

Various aspects of the cascade tests will be presented: flow boundaries definition, sidewall boundary layer bleed device, converging sidewall definition, flow measurement.

2. FLOW BOUNDARIES DEFINITION

At the limits of the cascade, the flow has to be as it would be for an infinite cascade, which leads to appropriate devices in the following cases:

2.1 Subsonic stator blade of compressors

In that case (fig. 1), the main difficulty of adjusting the flow arises at the upstream "corner" of the cascade, because of the high slope of the flow on the front grid. To solve the problem, the part of the cascade actually tested is limited to the center, and includes only six channels. The upstream flow is delivered by a subsonic nozzle with perforated walls, as usual for transonic wind tunnels. The pressure of the plenum

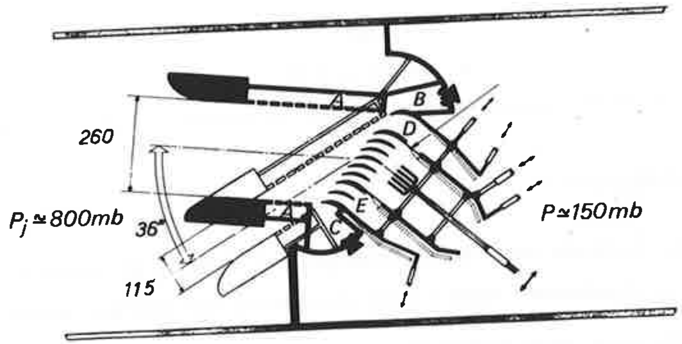

Fig. 1 Test rig for subsonic stator cascade at the S5Ch wind tunnel

chambers behind the perforated walls is controlled by a leakage mass flow. The incidence of the nozzle is adjustable. At a short distance upstream of the cascade, the nozzle flow becomes a free jet, which is adjusted by the pressure of the plenums B and C. These pressures are imposed by controlled mass flows.

Moreover, two channels E and D, at each extremity of the tested cascade, have independent mass flows, controlled by sonic throats.

For a given downstream throttled condition of the main flow, the periodicity of the flow in the channels under study is tentatively achieved by adjusting the pressures B and C, and the mass flows D and E.

At both ends, the limiting blades are continued downstream by flexible walls and by two straight flaps, adjustable in incidence.

For compressor stator blades, the subsonic exit flow is usually almost normal to the front grid, with a negligible curvature, so adjustable straight walls are sufficient to avoid a downstream pressure gradient along the cascade, and to achieve a good periodicity.

The main flow is throttled by an adjustable sonic throat. The various devices are electrically operated; the operator is in front of a display of all the pressures measured to qualify the flow. Periodicity is obtained by an iterative process between upstream and downstream flow adjustments.

For a new cascade, half an hour of attempts may be necessary to achieve the periodicity. Results are very satisfactory [1]. An example is given on figure 2 for an usual test condition, $M_o = 0.85$, deviation 55^o.

2.2 Supersonic compressor blades

The test rig is described in detail in [2]. As previously, only the central part of the rig is the tested cascade, which includes five channels, in the typical arrangement shown figure 3.

The upstream Mach number is established by a supersonic nozzle. A small divergence can be given to the nozzle walls, to compensate the effects of the wall boundary layers.

The incidence of the cascade is adjusted on the "unique incidence" condition; this avoids any secondary effects that are observed when the "unique incidence" is let to be imposed by itself by the first blade of the cascade.

Downstream, several parameters are used to adjust the flow. This adjustment is not easy owing to the large slope of the exit flow.

The initial pressure of the exit flow is controlled by adjusting the mass flows of each limiting channel, and by acting on the slope of the external wall of these channels.

The main direction and the curvature of the exit flow are obtained by adjusting the slopes of the limiting walls, the wall near the "corner" of the exit flow being articulated into two flaps.

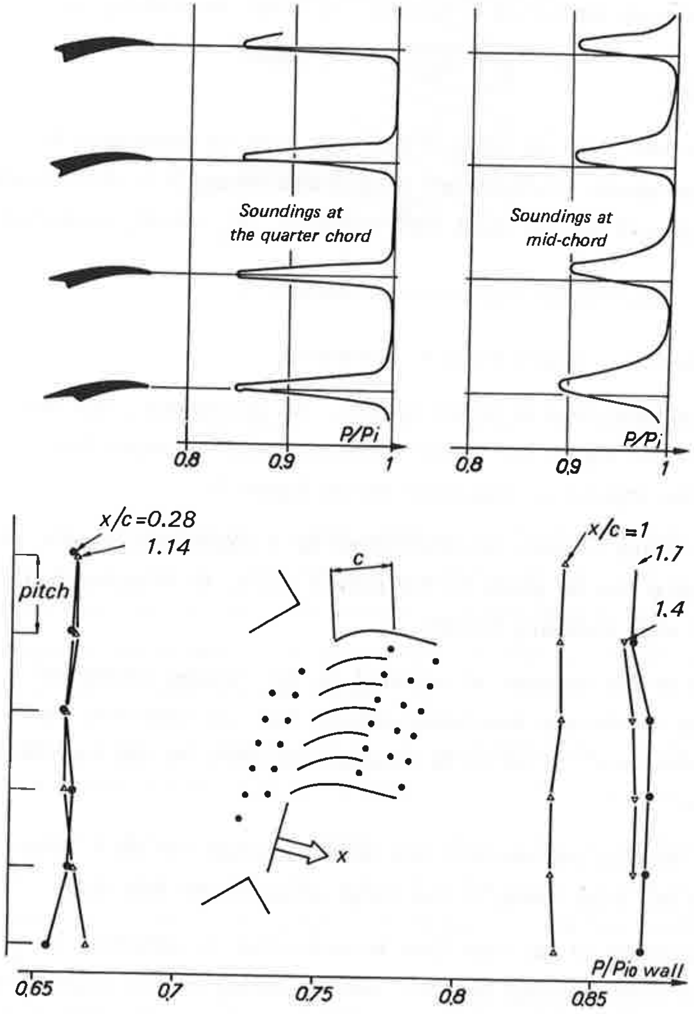

Fig. 2 Test results - Subsonic stator cascade

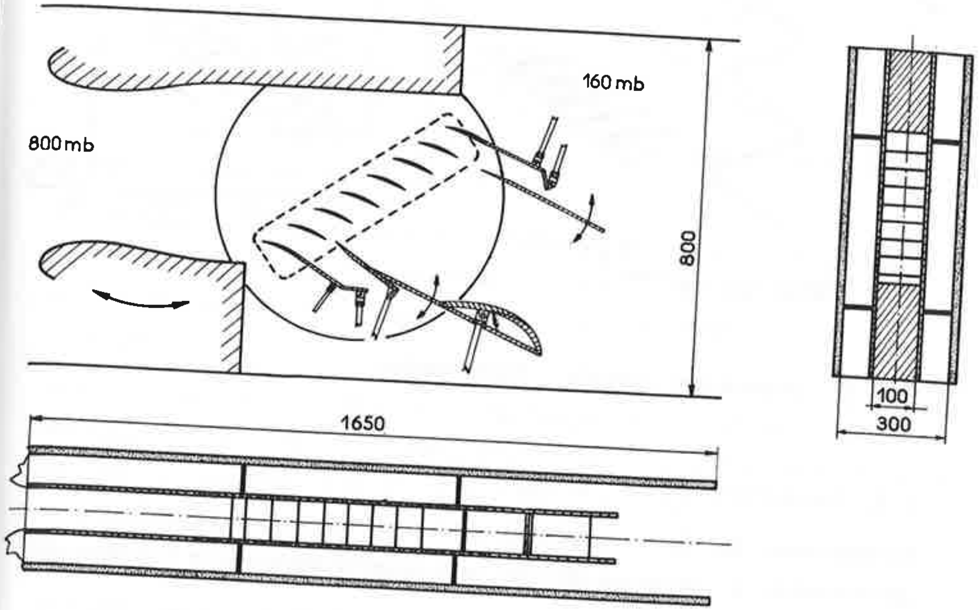

Fig. 3 Test rig for supersonic mobile row section

The mean flow throttling is imposed by a controlled sonic throat. An example of the results is given in figure 4, at $M_o = 1.5$, for a subsonic exit flow.

The flow is periodic in at least four of the central channels, although there is a residual pressure gradient downstream of the extreme channels.

Some difficulties however still arise for obtaining the periodicity when the exit flow is transonic.

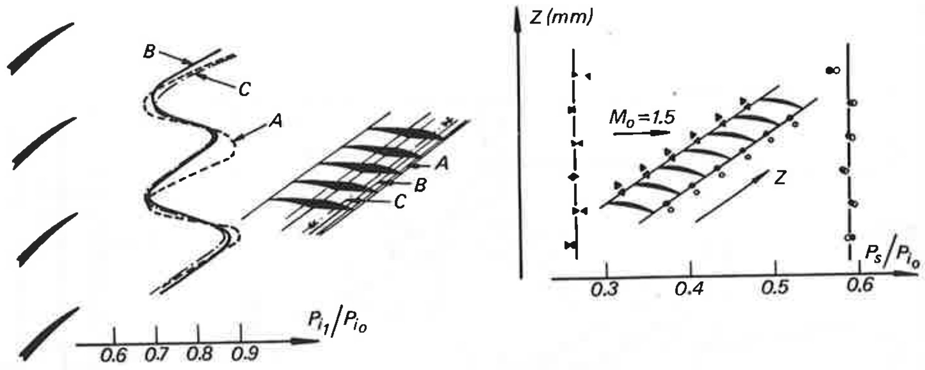

Fig. 4 Supersonic cascade - Test results

2.3 Subsonic rotor blades

In that case, the flow is inclined on the grid upstream as well as downstream, so adjusting devices with several parameters are provided for each side of the flow.

The test rig shown (figure 5) uses the downstream part of the supersonic rig. The upstream part is formed by a subsonic nozzle with a perforated wall (only the one which corresponds to the "corner" of the flow), and

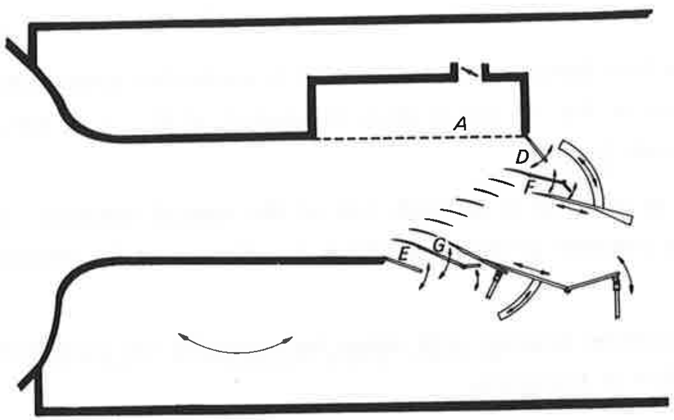

Fig. 5 Test rig for subsonic mobile row section

by two limiting channels, the mass of which are independently controlled.

3 SIDEWALL BOUNDARY LAYER CONTROL

A control of the sidewall boundary layers is necessary to avoid large secondary threedimensional effects.

Three types of solutions have been tested on the subsonic stator blade test rig: tangential jet flow blown by a thin slot just upstream of the front grid, suction through porous walls, and bleed by flush lateral windows.

Good results had been obtained by the tangential jet [1] which permits the suppression of the large separation of the flow in the corner between the sidewall and the blade. However, the contraction ratio of the flow in the plane of symmetry of the cascade was still slightly lower than 1. Morever, the slot manufacturing is very critical.

Boundary layer suction through porous wall was not satisfactory, because the suction was applied on a rather large area and not only where it was strictly necessary, so too much mass flow had to be sucked to suppress the separation of the corner boundary layer.

Reducing the suction area, and increasing locally the permeability, leads to the bleed solution made by a simple window open in the sidewall.

This solution is used in all the cascade rigs. The window is cut along an isopressure strip, in a region of high pressure gradient, to minimize the bleed mass flow.

Moreover, by controlling the bleed mass flow it is possible to finely adjust the contraction ratio of the flow in the plane of symmetry of the grid.

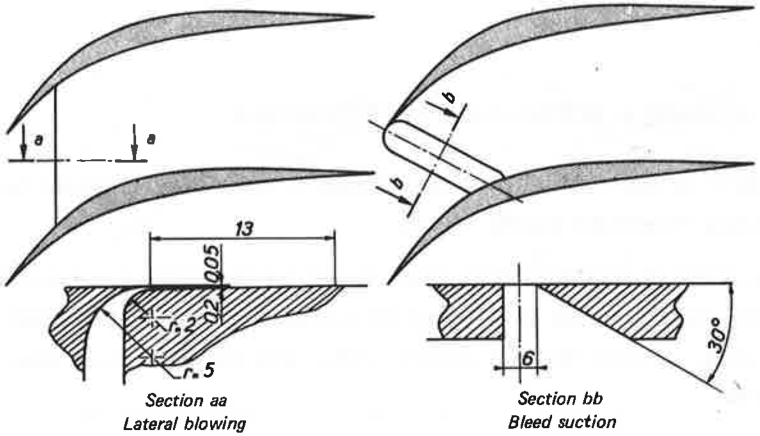

Fig. 6 Control of lateral boundary layers

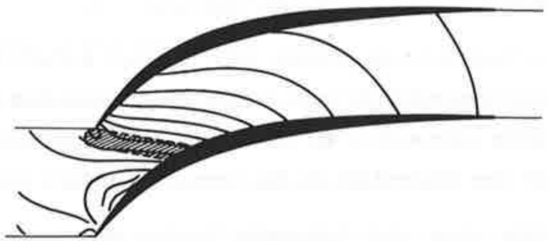

Fig. 7 Stator blades. Lateral suction

Bleed windows for a single cascade and for a double cascade are shown figures 7 and 8. A bleed window for a supersonic cascade is shown in figure 9.

The results given in [1 and 2] indicate that the flow is twodimensional on the whole span of the blades.

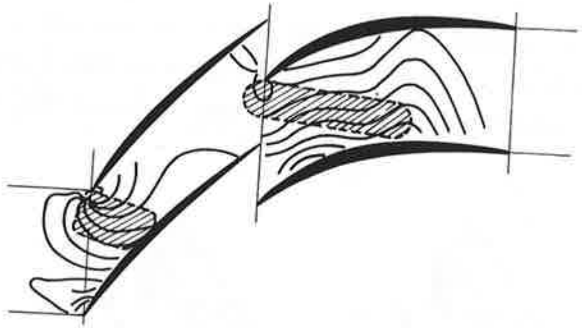

Fig. 8 Stator blades. Double cascade. Lateral suctions.

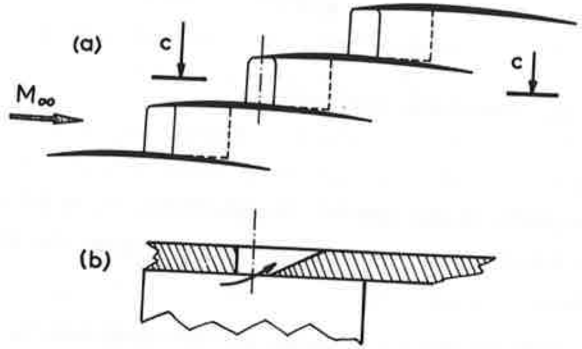

Fig. 9 Supersonic mobile row section. Lateral suction.

4. CONVERGING SIDEWALLS

In a compressor, stream sheets limited by concentric streamsurfaces decrease in thickness along the axis. To reproduce this feature on cascade tests, converging sidewalls have been designed (fig. 10).

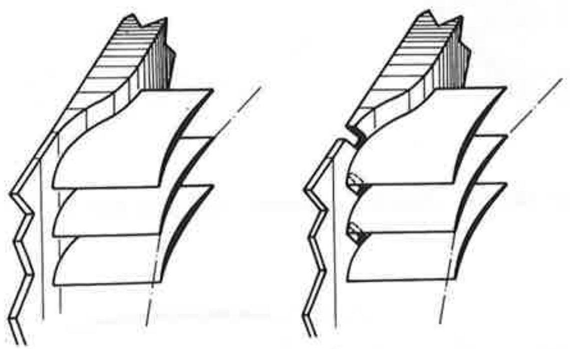

Fig. 10 Test rig, converging test section

However, as the width of the cascade is not small, it is not possible to consider that the convergence rate is the same near the wall as towards the centre.

As threedimensional calculation methods are not available, a simplified method is used to define a lateral sidewall profile giving the desired contraction law in the plane of symmetry, where measurements are made, and where the cascade performance is evaluated.

A first designing method had been tried by calculating a converging sidewall for the mean channel flow between two blades, by means of a pseudo twodimensional flow, neglecting the curvature of the channel, and taking account only of its mean thickness. However this method gives a design of the sidewall normally to the mean channel flow,

and the conversion of the results in a sidewall with generating lines parallel to the front grid is not satisfying.

Better results have been obtained, assuming that the profiles of the flow slices from one side wall to the other are determined only by the sidewall shapes. It is then sufficient to consider the upstream flow component normal to the front grid, and to calculate this two-dimensional flow normal to the front grid between the sidewalls neglecting, in fact, the blades.

At the leading edge of the grid, by composing the calculated normal flow with the component of the upstream flow parallel to the front grid, the method gives a good evaluation of the flow slopes and Mach numbers along the span of the leading edge, which is most necessary to understand the actual flow on the grid.

The converging sidewall technique, associated with sidewall boundary layer bleed, has been applied very successfully to subsonic stator cascades, with contraction ratio up to 30 %.

The same technique applied to supersonic cascade has been less successfull: the difference of steepness of the law of that contraction ratio near the sidewall, and that in the plane of symmetry near the leading edge, leads to a flow without separation near the sidewall and with separation at the centre of the grid. Such a large threedimensional effect is unacceptable to qualify the blade profile.

To avoid that difficulty, it is projected to test longer blades with the same span, in order to reduce the difference of contraction ratio along the span in the forward part of the grid.

5. FLOW SURVEY

Rows of wall static pressures parallel to the front grid permit one to adjust and to verify the periodicity and the upstream Mach number of the flow.

Wake surveys may also be used to confirm the periodicity. The survey of the downstream flow by static, directional and total pressure probes gives the mass flow, and the contraction ratio in the centre of the grid. This coefficient can be finely adjusted by means of the sidewall bleed mass flow, as already said. Wake surveys are made at various span stations, to qualify the blade, to study the secondary effects, and to verify the twodimensionality of the flow near the plane of symmetry, or along the whole span, in the case of twodimensional tests.

Static and directional probes are presented in figure 11. These probes are calibrated by wind tunnel tests. The calibration coefficient of the static probe is very small, and insensitive to the incidence and Mach number, in subsonic flow.

The directional probe comprises four holes. The direction in a plane is derived from the difference between the two pressure holes in that plane, divided by the local dynamic pressure. The dimension of the probe is taken into account by measuring the pressure on each hole in the same space location of the holes, after displacement of the probe. This is necessary to obtain acceptable flow direction measurements in a wake.

Visualisations of the skin flow are made by an oil film deposit or colored fluid injection on the blades through the pressure holes.

Boundary layer survey on the blades is achieved with a boundary layer probe; its total thickness is as small as 0.1 mm; its span is about 1 mm.

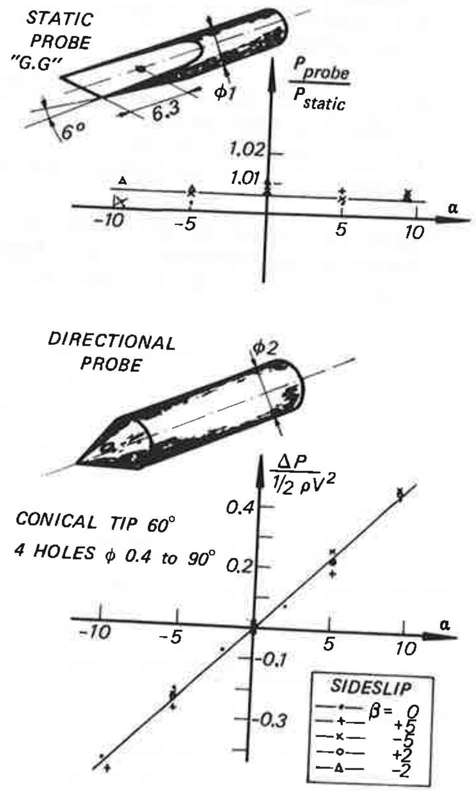

Fig. 11 Static pressure probe and directional probe

References

[1] Meauzé, G., Thibert, J. J.: Méthode d'étude expérimentale de grilles d'aubes transsoniques à forte déviation. Association Technique Maritime et Aéronautique (ATMA). Session 1972.

[2] Meauzé, G.: La soufflerie supersonique de grille plane de l'ONERA à Chalais-Meudon. L'Aéronautique et l'Astronautique No 50 (1975-1). English version available as ONERA TP 1409 (1974).

[3] Meauzé, G.: Méthode d'essai de grille convergence de veine. Paper to be presented at the ASME/CIMAC meeting. Tokyo, 23-27 mai 1977.

Experimental investigation of the flow field downstream of a plane turbine cascade in transonic flow

by

R. Kiock

Summary

The aerodynamic coefficients of a cascade are mostly evaluated from pressures and flow angles, which are measured in a moderate distance downstream of the cascade. But in some cases, the local flow parameters close behind the cascade are of interest: for the consideration of the flow field at inlet of a rotor following a stator or vice versa, from fluid mechanical reasons as well as from the point of view of noise generation. This goal requires a probe, which allows measurements in a flow field of high pressure gradients. For this purpose, a three-finger probe was designed and calibrated. The paper now describes the measurement of total pressure, static pressure and flow angle in several distances close behind a turbine cascade. Average values are evaluated from these local values by means of the laws of conservation. The flow field is discussed on the basis of these wake flow quantities and of schlieren picture, too. Investigations were carried through in the High Speed Cascade Wind Tunnel at an isentropic Mach number of $Ma_{2th} = 1.00$ and at a Reynolds number of $Re_2 = 5 \cdot 10^5$.

Notation

e_M, u	coordinates of wake traverse
l	blade chord
$Ma_{2th} = f(p_K/p_{o1})$	exit Mach number of isentropic cascade flow