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EXPERIMENTAL INVESTIGATION OF PERFORMANCE OF LINEAR NOZZLES CASCADE AT SUPERSONIC EXIT MACH NUMBERS

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Abstract

Experimental investigation of a linear supersonic nozzles cascade has been carried out at different isentropic exit Mach numbers, by means of 2D-aerodynamic traversing probes. The aim of the experimental tests, which are here described, is to analyse the reliability of the measurements carried out by this probe at different traversing probe conditions. This is of extremaly importance to better evaluate the limit in use of this probe type to measuring traverse parameters (ζ, β_2) at high Mach number range.

Introduction

The modern steam and gas turbine design philosophy essentially aims to decrease the number of stages and to increase the blade load, while manteining high values of the overall efficiency for a sufficiently wide range of operating conditions. Highly loaded turbine blade rows often operate at supersonic flow regimes. In this situation very complicated shock wave structures occur in the trailing edge region.

Furthermore nowaday calculation methods, at a satisfactory standard to predict surface pressure distribution and losses in turbine blade cascades, are available [1].

It is therefore important to analyse experimentally these flows and measure the flow parameters with good reliability such that these may be employed also to comparison with theoretical results.

The measurements here presented deal with the hub section stator blade of the last stage of a large steam turbine. Experimental tests have been carried out at the D.I.ME.CA. for a variety of pressure ratios at zero incidence angle.

Apparatus and Instrumentation

Experimental investigations have been carried out in the high speed wind tunnel at the D.I.ME.CA.; the tunnel description and the employed measurement technique are discussed in [2]. The exit isoentropic Mach number has been varied between 0.83 and 1.77. Two blades of the five-blade cascade were instrumented with 24 pressure tappings on the pressure side and 23 on the suction side surface respectively. A tapping at the center of the trailing edge circle of both blades was used to measure the base pressure. In table 1 are shown the characteristic dimensions of the cascade. Traverses were made by using 2D-combined stagnation-yaw-static probes of type shown in figure 1 [3] [4] and covered three blade pitches.

Results and Discussion.

General flow conditions. The variation of the total pressure in the settling chamber during each test has been held less than ± 0.5 %, while the turbulence level at the inlet of the cascade is, for all tests, less than 1.5 %. Figure 2 shows the relation between the Reynold number (refered to the axial chord) and the exit isentropic Mach number. The inlet Mach number, calculated with the wall static pressure tappings one pitch ahead of the cascade, is shown in figure 3 versus the exit isentropic Mach number. The experimental values move lower than the theoric ones at high Mach numbers. This may be due to leakage losses in the straight channel ahead of the cascade, in fact the inlet duct with $L/H < 5$, may justify a limited growth of the inlet boundary layer [5].

Surface Mach number distribution. The isentropic Mach number distributions on the blade surfaces are plotted in figure 4, for different exit wall isentropic Mach number. All the suction side pressure distributions show a strong recompression due to the incident shock wave produced at the trailing edge of the lower blade and a subsequent reexpansion as far as the trealing edge. The lack of static pressure tappings close to the exit of the blade, does not allow an analysis of the effects of the interaction between shock and boundary layer on the Mach number distribution.

Base pressure measurements. The base pressure measurements are very important for analysis of the shock wave system generated at the exit of the cascade in supersonic flow conditions. Figure 5 shows the base pressure curve; it is in good agreement with that proposed by Sieverding in his correlation [6] for convergent-divergent ducts considering that the A/A^* ratio of the experimented cascade ($A/A^*=1.070$) is lightly higher than the maximum one analised in the correlation.

Wake traverse results. Wake traverses were carried out by means the 2D-combined total-directional, static probe shown in fig: 1. The error on the measured Mach number has been estimated during calibration in 0.01 except in the transonic region where the estimated value is always less than 0.03.

The traversing probe distance has been chosen taking in account the results of some authors [7][8] who shown that the influence of secondary flows increases both with the probe traversing distance and Mach number. In the tests here presented, due to probe geometry, it was necessary, for the reliability of the measurements, that the zone non influenced by secondary flow was not less than 25% of the span blade (about 20 mm), centered in the mid span. In fact the test carried out at different spanwise positions for $Ma = 1.4$, have shown the influence of secondary flows even in the mid span region starting from a 15% axial chord traverse position. For this reason all the mass-avereged values ζ and β_2 are relative to measurements carried out at a 10% axial chord traverse distance.

The reference pressure (measured upstream of the cascade) and the pressures measured by the probe, relative to a typical test, are shown in figure 6. In figures 7 the curves relative to total and static pressures, Mach number, exit flow angle and losses, as calculated by probe calibration curves, for the same before typical test, are presented. Wake traverses average values are shown in figures 8 - 9. The exit flow angle falls down while increasing the isentropic exit Mach number. This is typical of the convergent-divergent type of blades where we can have normal or quasi-normal shock with large intensity because of the divergent. The blade losses presents a minimum value in a Mach number range of 1.4 - 1.5.

Conclusions

The flow field in a linear supersonic nozzles cascade has been analysed. Experimental investigation has shown both the isentropic Mach number distribution over the blade surfaces and the complex flow structures downstream of the cascade. Mass-averaged cascade parameters (z and b2) have been determined by 2D-probe traverses. Finally the tests carried out have shown a sensible influence of secondary flow, even in the mid span, for the higher Mach number range. Therefore it would be necessary to analyse the flow exit by 3D-traversing probe to improve the reliability of the results.

Nomenclature

H	width of flow channel	
L	channel lenght ahead of the cascade	
M	Mach number	
Re_{ax}	Reynolds number refered to the axial chord	
Tu	degree of turbulence in mainstream direction	$Tu = 100\sqrt{V'^2 / V}$
V	velocity	
V'	turbolent fluctuating velocity component	
x	chord direction	
y	tangential direction	
β	flow angle relative to cascade axis	
ζ	loss coefficient	$(1 - V_2^2 / V_{2is}^2)$

Subscripts

s	static flow conditions
0	total flow conditions
1	inlet plane
2	far downstream plane

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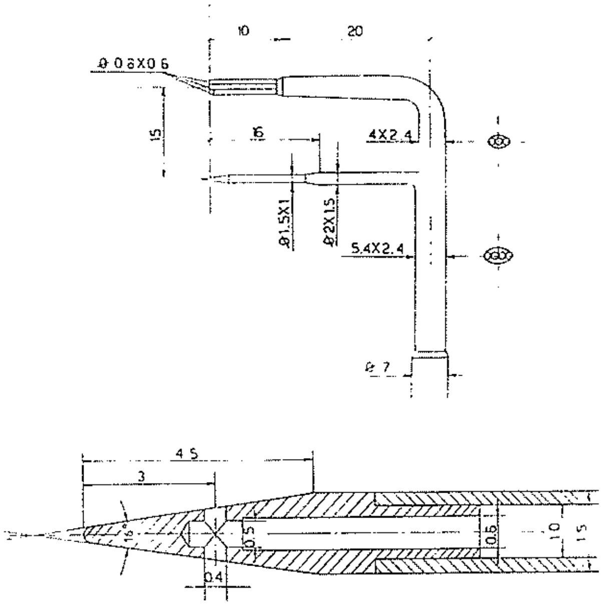

Fig.1 Combined total-yaw, static probe.

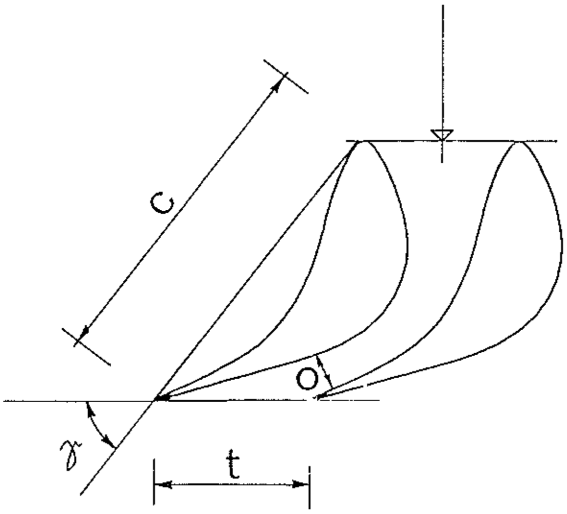

Table 1 - Caascade geometry.

Chord	c=85.74 mm
Aspect ratio	h/c=0.816
Pitch/Chord	t/c=0.467
Throat	o=9.49 mm
Stagger angle	γ=51.95°

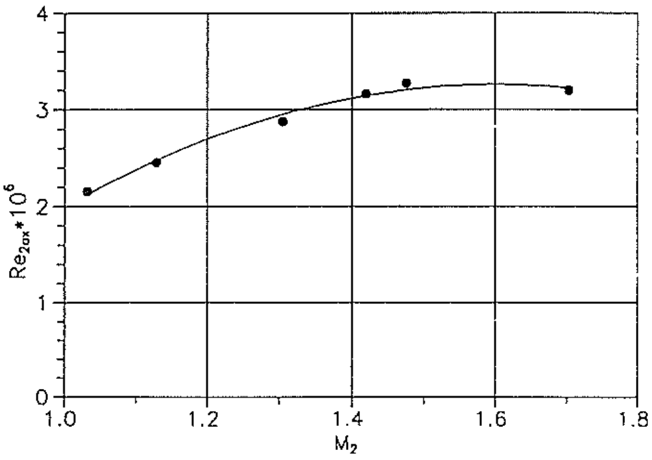

Fig.2 Exit Reynolds number.

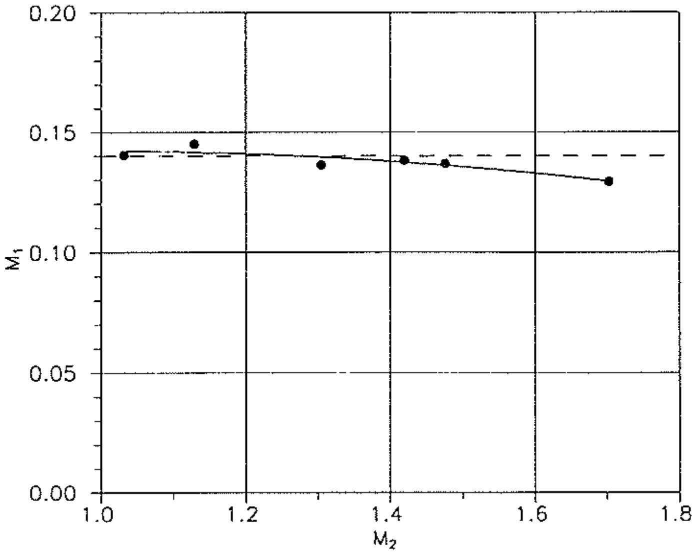

Fig.3 Inlet Mach number.

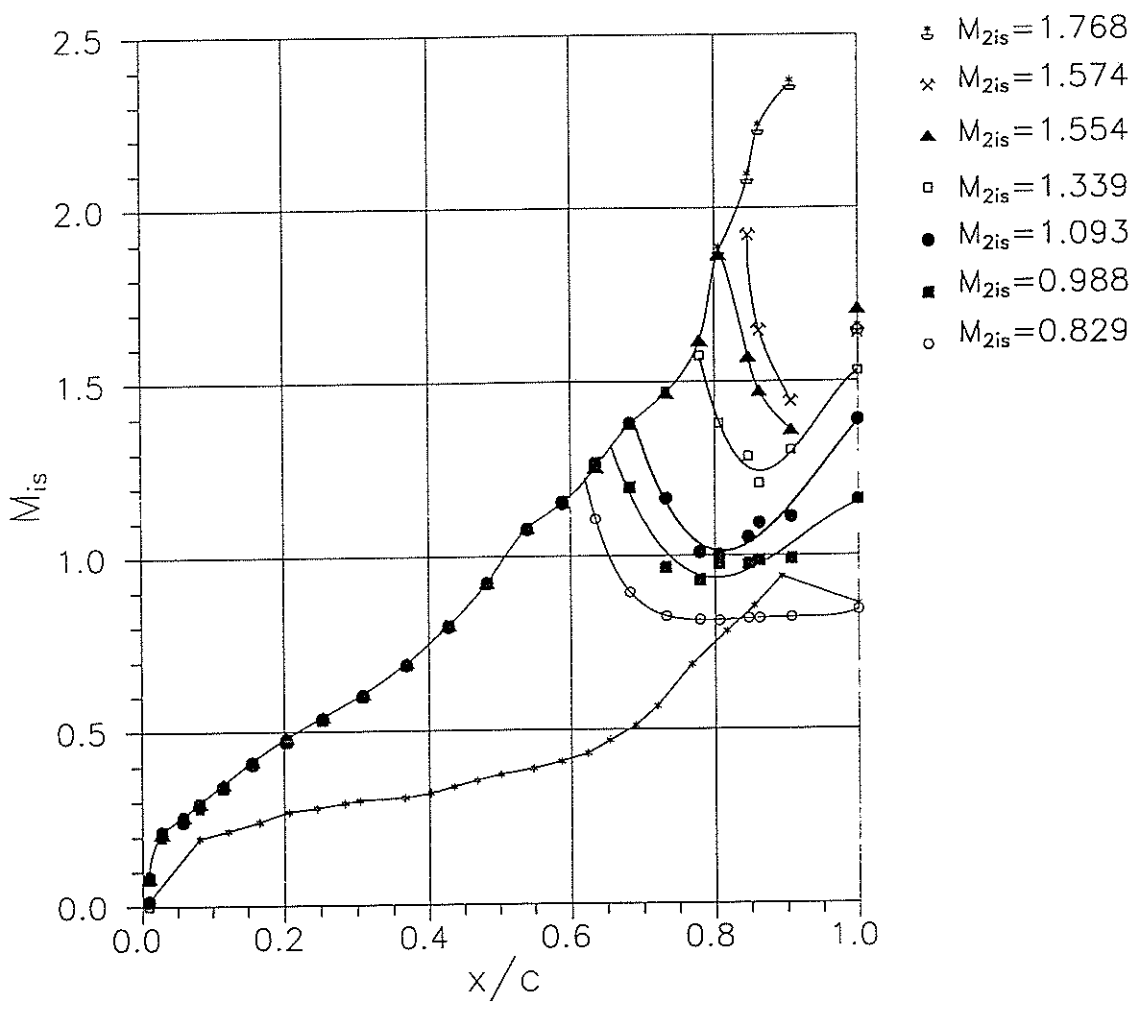

Fig.4 Surface Mach number.

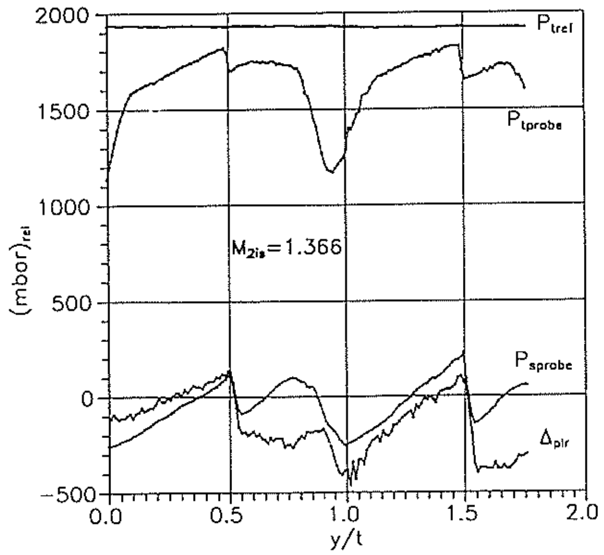

Fig.5 Pressures traversing probe.

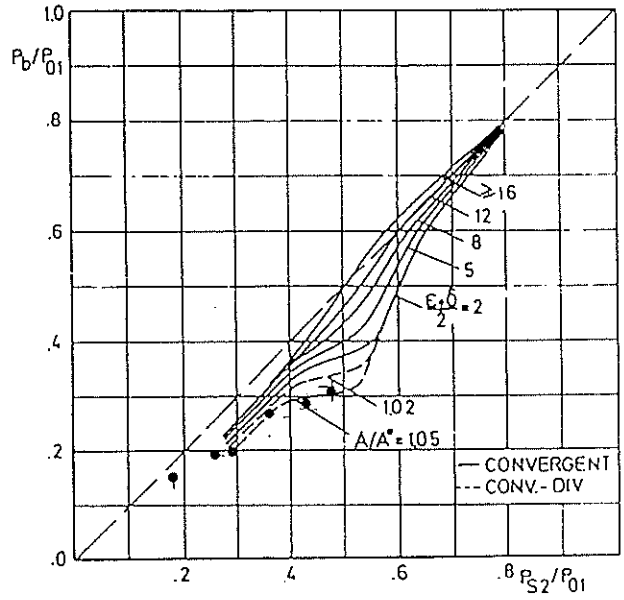

Fig.6 Base pressure (Sieverding correlation).

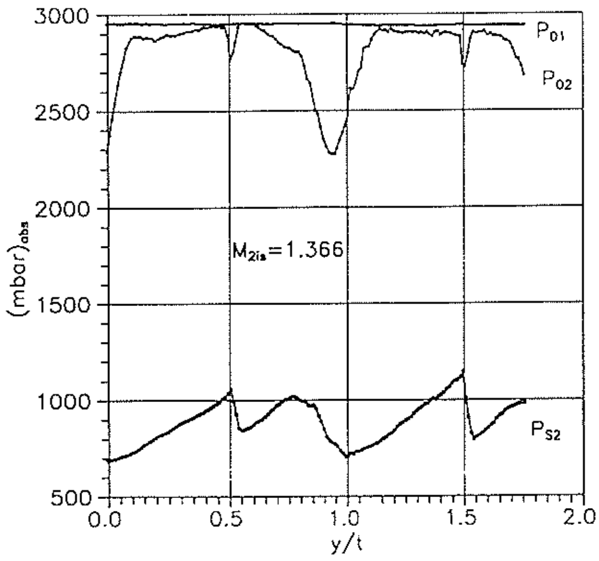

Fig.7a Corrected total and static pressures.

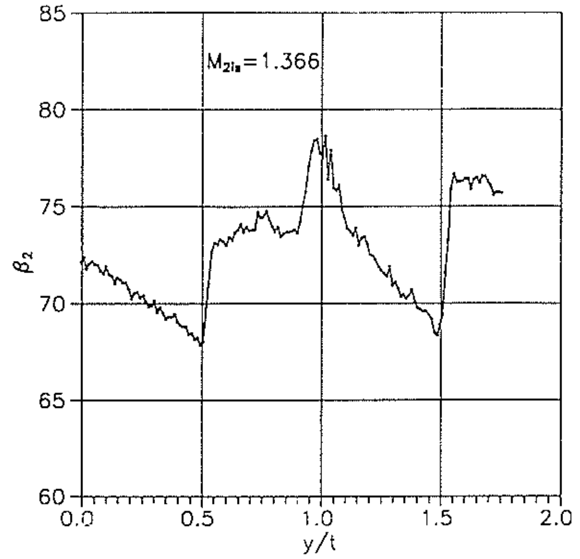

Fig.7b Local exit flow angle.

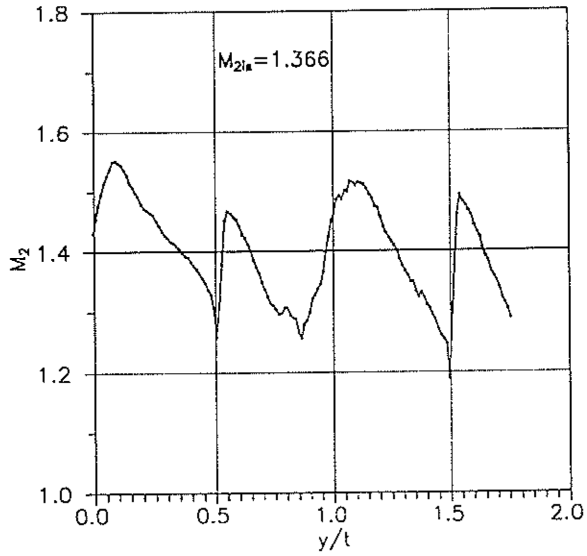

Fig.7c Local exit Mach number.

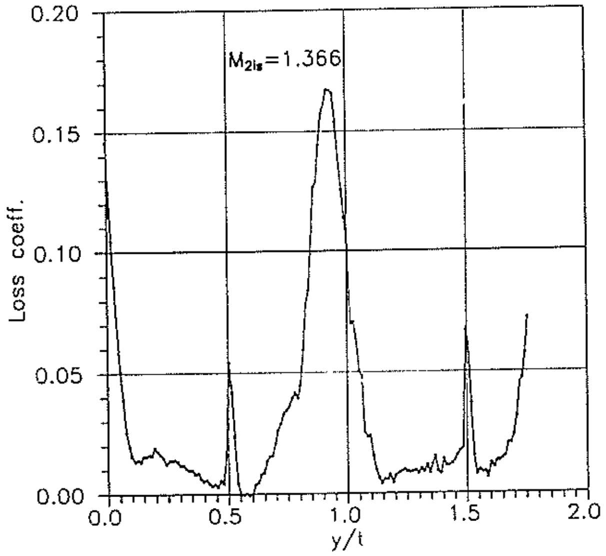

Fig.7d Local loss coefficient.

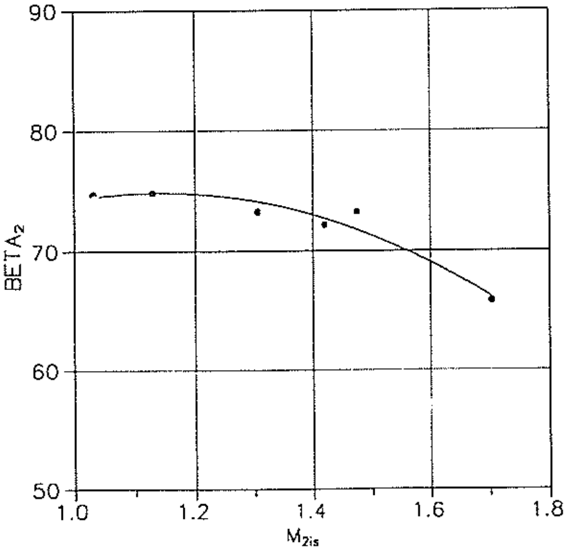

Fig.8 Exit flow angle.

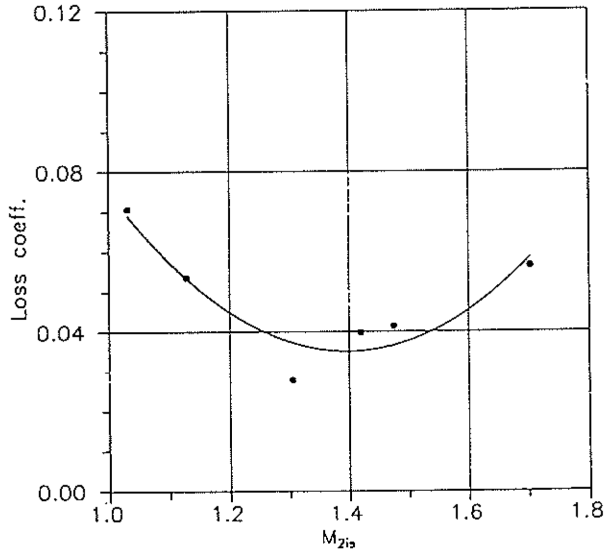

Fig.9 Loss coefficient.