Experimental Tests of Transonic Nozzles in Linear Cascades Carried out by Traversing Probe

S. Cabitza, N. Mandas
Universita di Cagliari, Italy

Absract

The purpose of this paper is to present the experimental technique developed at D.I.ME.CA. (Department of Mechanical Engineering of Cagliari) for aerodynamic studies in high speed linear cascades. Because of the limited running time of the wind tunnel (blow-down type) the experiments have been done with a limited number of blades and minimizing the aquisition time of the various measurements consistently with the time relative to the traversing probe. The measurements obtained have shown a good accuracy and the results can be considered more than satisfactory in characterizing blade performance.

Nomenclature.

$\xi 2$ = loss coefficient = $1 - w^2{}_2/w^2{}_{2,is}$

THL2 = total head loss =

$= (1-(P02/P01)^{(k-1)/k})/(1-(Ps2/P01)^{(k-1)/k})$

P0 = total pressure

Ps = static pressure

Subscripts.

1 = plane upstream

2 = traversing plane downstream.

1.Introduction

It is well understood that the availability of experimental data is of fundamental importance to the improvement of the performance of turbomachines.

It permits us to compare different solutions adopted and therefore allows us to continually refine technical design and validate test data with mathematical models.

Today, the accuracy required for experimental analysis is continually increasing and this represents a particular difficulty for the researcher, especially if the research is on cascades working in transonic and supersonic conditions.

Even if many fluid dynamic laborartories are directing their attention towards rotating annular cascade test rigs, experimental studies in linear cascades remains valid particularly in high speed turbine blades, where they will continue to make a noteable contribution.

On the other hand, contemporary progress in measuring instrumentation allows us to experiment cascade flows in reduced time, making it possible to achieve good results whilst employing small wind tunnels and therefore reducing costs.

2.Test Rig.

Starting from this consideration, within D.I.ME.CA., the high speed wind tunnel, which for some time has been utilized for aerodynamic probe research [1], [2], [4], [5], [6], has been modified to allow experimental research on linear cascades

[5], [6], has been modified to allow experimental research on linear cascades operating in transonic and supersonic conditions.

The wind tunnel is a blow-down type, which exhausts to atmosphere, incorporating a rectangular test section with a variable height from 70 to 210mm and with a width of 70mm.

The storage volume is $25m^3$ at a pressure of 1.6Mpa, with an installed power of 100kw.

At time, it is possible to run continuously for periods from 40 to 120 seconds, with a variable number of blades. (from 6 to 4), depending on the dimensions and the type.

Because of the limited running time, it has been necessary to develop a measuring system with relative reduced response time to allow the aquisition of all measurements required to evaluate the cascade performance.

The aquisition system is composed of an HP 9000 Model 360 controller, interfaced by an IEEE 488, to an HP 6942 Multiprogrammer.

The wall static pressures, upstream and downstream, and the blade pressures are measured by means of two X 48 channel scanivalves each with a pressure transducer incorporated, while the aerodynamic probe pressures are measured with separate transducers.

All of the transducers used are of the same type (Scanco PDCR 24) with a response time less than 20ms with a maximum tube length, between probe head and transducer, of 70cm.

For the measurement of the probe position, during test running, an high accuracy linear potentiometer is used (Leane HPL 190).

All of the measurements are taken 8 times, to improve accuracy, with a frequency of 25kHz.

In this way the total measurement time depends on the scanning time of the scanivalves (more than 50ms), but, above all, on the time traversing probe.

The probe travels at a constant speed but the reading of pressure is limited to 100 step positions with a step distance (Ds) equal to or greater than 1mm, and a forward velocity (Vp) variable from 1 to 2.5mm/s, chosen in such a way that the displacement of the probe can be considered negligible in comparison to the step distance ($Ds < 0.005mm$ for $Vp=2.5mm/s$).

Flow control downstream of the cascade is achieved by means of a suitably perforated tailboard.

For the preliminary control of the flow periodicity the Schlieren system is used in conjunction with the wall downstream static pressures and the trailing edge pressures on the instrumented blades.

The aerodynamic probe used in the traverse is a cone-probe type, [4] [16], shown in Fig 1. and during test it is positioned at an axial distance equal to 1/2 of one pitch.

Usually the traverse is equal to 3 pitches which also permits verification of the flow periodicity with the pressure readings.

The results presented in the paper refer to a steam turbine nozzle cascade (shown in Fig 2) where the outlet velocity is supersonic.

3. Measurements Analysis

The individual tests have each been repeated several times, varying the scanivalve scanning time and the speed traversing probe, to verify the measurements accuracy. The observed differences show variations of the order of .003 for the loss coefficient, $\xi2$, and a difference of .006 for the exit Mach number, M2.

Variations could not be detected in the blade pressure readings except on the trailing edge.

All measurements, for a complete test (wall static, blade static and probe pressures distribution), usually are carried out in one run (in about 40-60 seconds) or in two runs with no tangible difference on the results.

The velocity distribution on the blade surfaces has been measured for different outlet flow conditions, from high subsonic to supersonic Mach numbers, less than the limited loading value; in Fig. 3 are shown some of these results, while in Fig: 4 'local' Mach number distribution is compared to 'critical' local Mach number, for a typical test.

Traversing probe measurements are also carried out for different outlet flow conditions but, later on, will be presented results relative to a typical flow condition.

Downstream Pts, Pss, DPlr, traverse pressures and upstream total pressure measurements, over a typical 45 seconds run time, are given in Fig. 5

The equivalent data reduced by probe calibration curves are shown in Fig.6.

The performance of the cascade has been calculated both using mass and area averaged values at the outlet cross section and the flow parameters at infinity down stream.
The results obtained on 2 pitches are shown respectively, in Fig. 7, for the exit Mach number, in Fig. 8, for outlet flow angle, and in Fig. 9, for the loss coefficient.
The difference between the average of the Mach numbers calculated on the two pitches is about 0.02.
This confirms the good periodicity of the exit flow.
The performance parameters calculated with the three methods show no apppreciable difference (Table 1.).

4. Conclusions.

The results of research on a linear cascade of nozzles in a supersonic wind tunnel at D.I.ME.CA. have been presented in this paper.
Under conditions where the scan time of the scanivalves was varied between 50ms and 1s and where the speed traversing probe was varied between 1 - 2.5mm/s, notwithstanding the brief time available for each test, the system of measurement for the analysis of the flow with a downstream aerodynamic probe has been consistently reliable and the results demonstrate a good accuracy.
The test rig and methodology are suitable, therefore, within a contained framework of costs, to undertake fundamental research on aspects of interest in the design of turbomachinery, such as performance under various operating conditions, investigation of trailing edge shock phenomena and the influence of coolant ejection effects.

5. References.

[1] **S. Cabitza, G. Cau, N. Mandas, F. Nurzia.**-Transonic facilities of D.I.ME.CA. for probe calibration and cascades testing.-8th Symposium on measuring techniques for transonic and supersonic flow in cascades and turbomachines- Genova October 24-25, 1985.

[2] **S. Cabitza, N. Mandas** -Metodologia di taratura di sonde aerodinamiche.-Atti del 39° Congresso Nazionale ATI L'Aquila Settembre 1984

[3] **P. Diana, N. Mandas.**-Messa a punto di una procedura di calcolo per la taratura di sonde aerodinamiche.-Atti Facoltà di Ingegneria- Cagliari vol. 24 Maggio 1984

[4] **C. Sieverding.**-Pressure probe measurement in cascades.- AGARDograph n° 207 April 1975.

[5] **S. Cabitza, N. Mandas.**-Problems involved in subsonic and supersonic probes calibration in open tunnels.- 9th Symposium on measuring techniques for transonic and supersonic flow in cascades and turbomachines- Oxford 21-22, March 1988.

[6] **S. Cabitza, N. Mandas.**-An investigation into the influence of the different calibration coefficients upon measurements with aerodynamic pressure probes. Xth Symposium on measuring techniques for transonic and supersonic flows in cascades and turbomachines.- Bruxelles, September 17-18, 1990.

[7] **Warner L. Stewart.**- Investigation of Compressible Flow Mixing Losses Obtained Downstream of a Blade Row. - NACA RM E54120, 1954.

[8] **H. J. A. Cox.** - Analysis of Supersonic Turbine Blade Profiles. - VKI Lecture series 30, January 1971.

[9] **C. H. Sieverding.** - Base Pressure Measurements in Transonic Turbine Cascades. - VKI Lecture series 84, February 2-6, 1976.

[10] **C. H. Sieverding.** - Transonic Flows in Last Stages of Big Steam Turbines. - VKI Course Note 120, March 1984.

[11] **R. Kiock, F. Lehthaus, N. C. Baines, C. H. Sieverding.** - The Transonic Flow Through a Plane Turbine Cascade Measured in Four European Wind Tunnels. - Journal of Engineering for Gas Turbines and Power, Vol. 108, pp. 277-284, 1986.

[12] **C. H. Sieverding, M. Stanislas, J. Snoeck.** - The Base Pressure Problem in

Transonic Turbine Cascades. - Journal of Engineering for Power, Vol. 102, July 1980.

[13] **J. M Henne, H. E. Gallus.** - The Influence of Tailboards with Various Wall Porosity on Transonic Turbine Cascade Flow. - IXth Symposium on Measuring Techniques for Transonic and Supersonic Flow in Cascades and Turbomachines - Oxford 21-22 March 1988.

[14] **L. Xu, J. D. Denton.** - Base Pressure Measurements on a Model of a Turbine Blade Trailing Edge. - C283/87, IMechE 1987.

[15] **M. l: Shelton, B. A. Gregory, R. L. Doughty, T. Kiss, H. L. Moses.** - A Statistical Approach to the Experimental Evaluation of Transonic Turbine Airfoils in a Linear Cascade. - ASME Paper N° 92-GT-5, 1992.

[16] **C. H. Sieverding, S. Sferruzza.** - Standards for Pressure Measurements in Supersonic Non-uniform Flow. An urgent Need.-8th Symposium on measuring techniques for transonic and supersonic flow in cascades and turbomachines- Genova October 24-25, 1985.

[17] **J. P. Costelow.** - Cascade Aerodynamics - Pergamon Press, 1984.

[18] **A. Bolcs, A. Sari.** - A New Base Pressure Correlation for Transonic and Supersonic Flows. - ASME Paper N° 91-GT-324, 1991.

[19] **P.H.Sydenham.** -Handbook of measurements science.-vol. 1 John Wiley & Sons.

	M1 = .1766		β1 = 90°	
	M2	β2	ξ2	THL
Area averaged	1.2164	73.23	.0425	.0550
Mass averaged	1.2148	72.98	.0410	.0530
Infinity downstr.	1.2093	73.22	.0492	.0636

Table 1

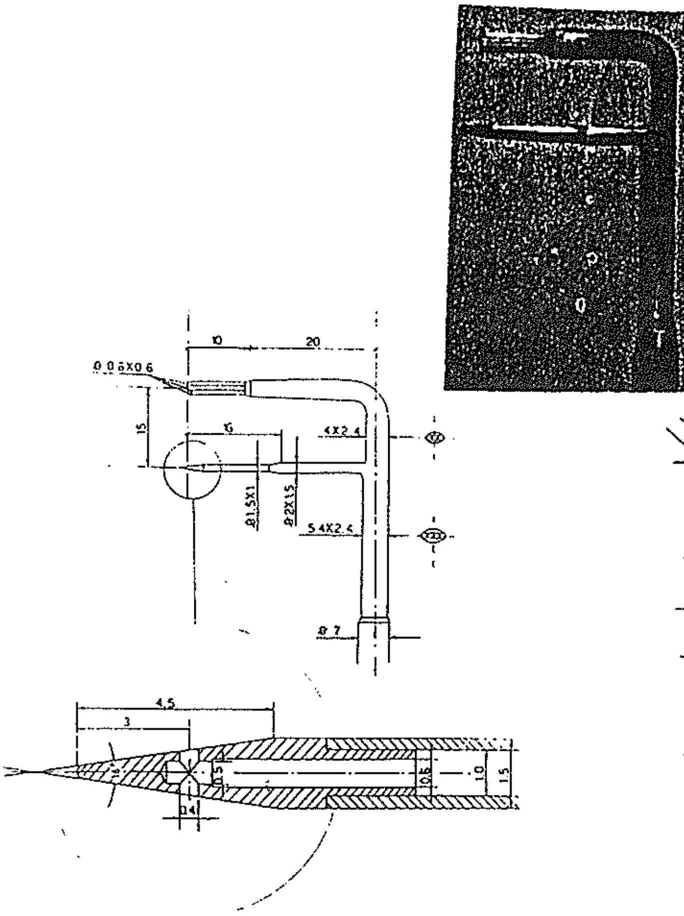
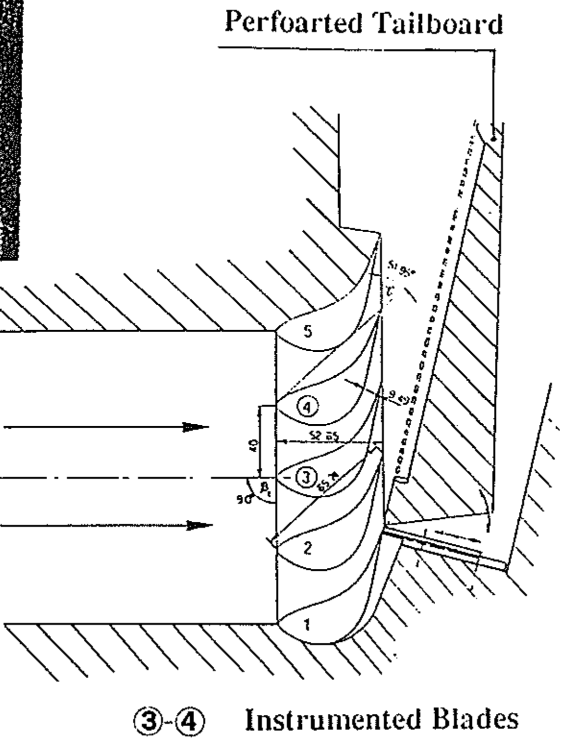


Fig. 1



③-④ Instrumented Blades

Fig. 2

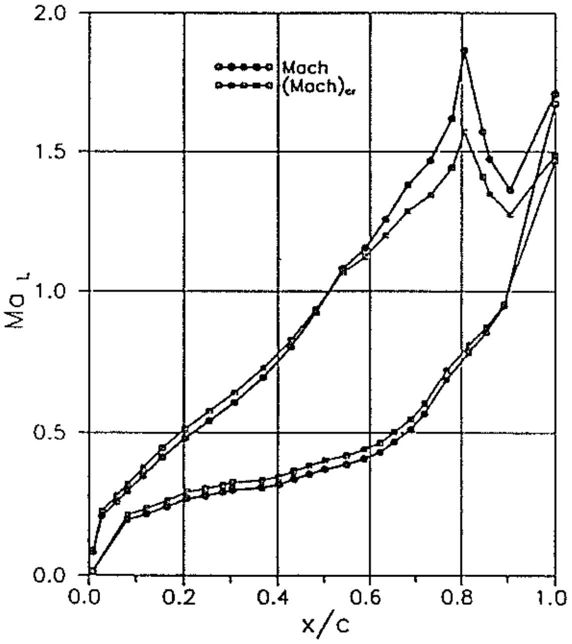


Fig. 4

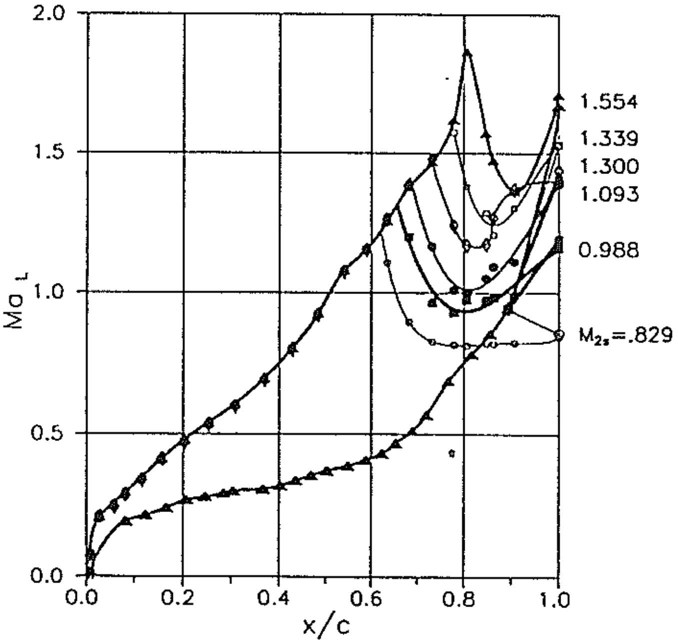


Fig. 3

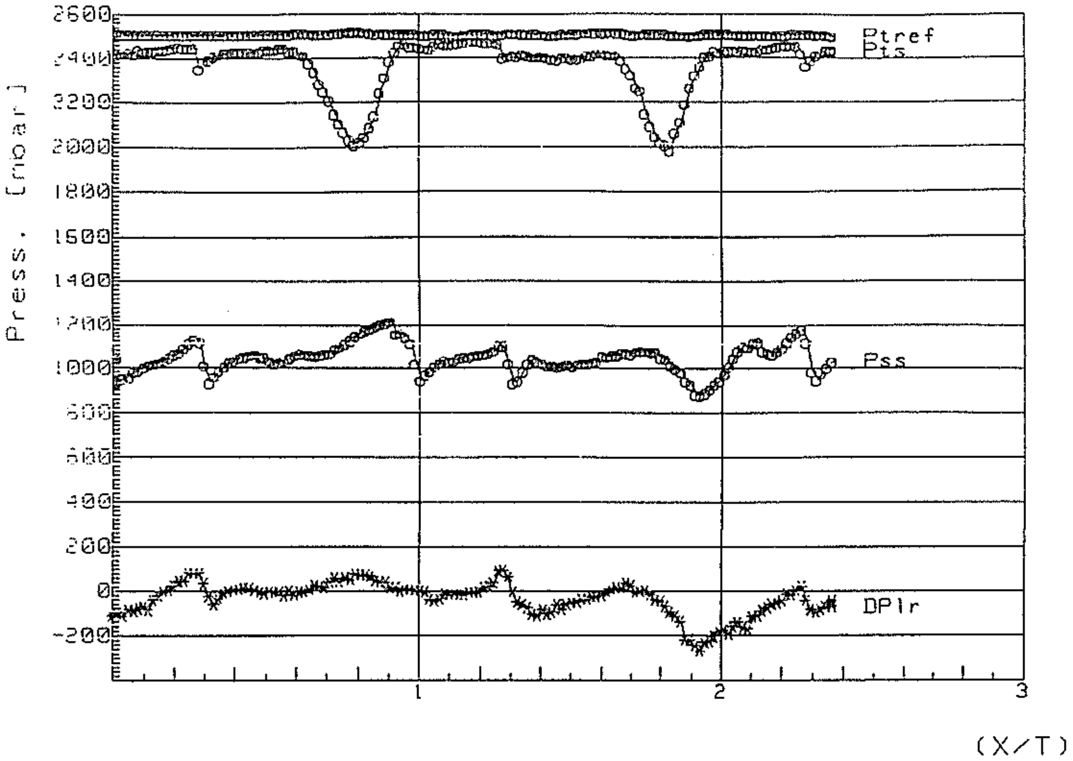

Press. [mbar]
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
1
2
3
(X/T)
Ptref
Pts
Pss
DPlr

Fig. 5.

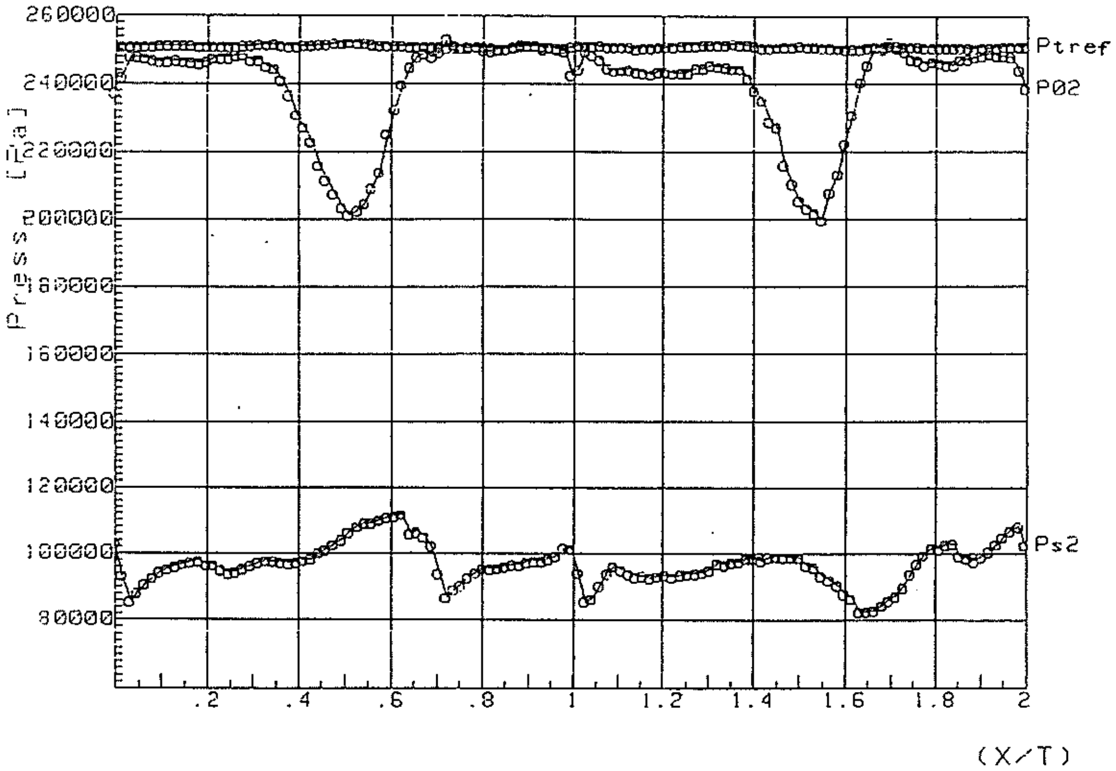

Press. [Pa]
260000
240000
220000
200000
180000
160000
140000
120000
100000
80000
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
(X/T)
Ptref
P02
Ps2

Fig. 6

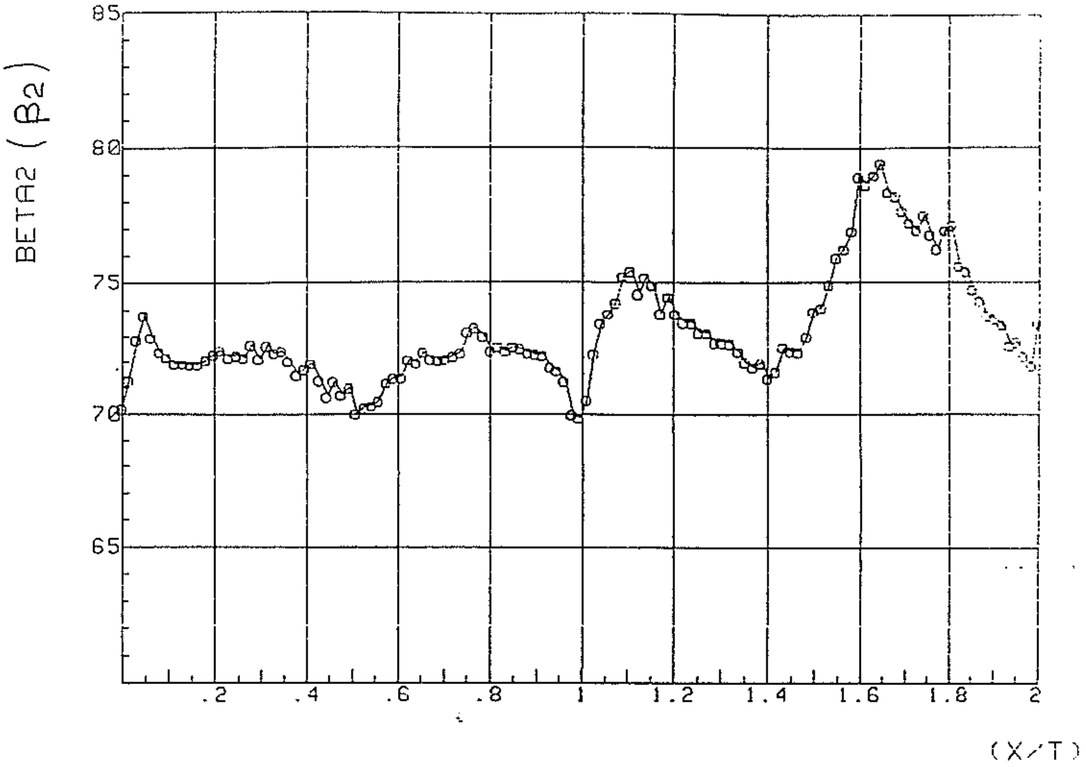

BETA2 (β2)
85
80
75
70
65
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
(X/T)

Fig. 7

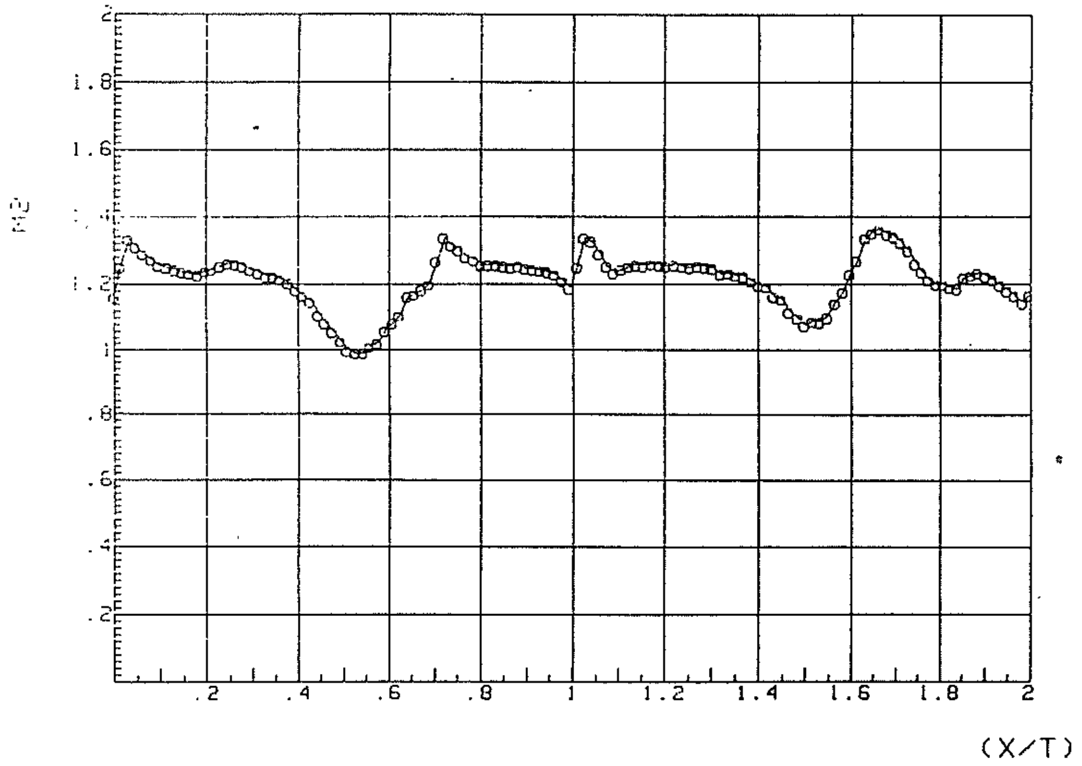

M2
2
1.8
1.6
1.4
1.2
1
.8
.6
.4
.2
.2
.4
.6
.8
1
1.2
1.4
1.6
1.8
2
(X/T)

Fig. 8

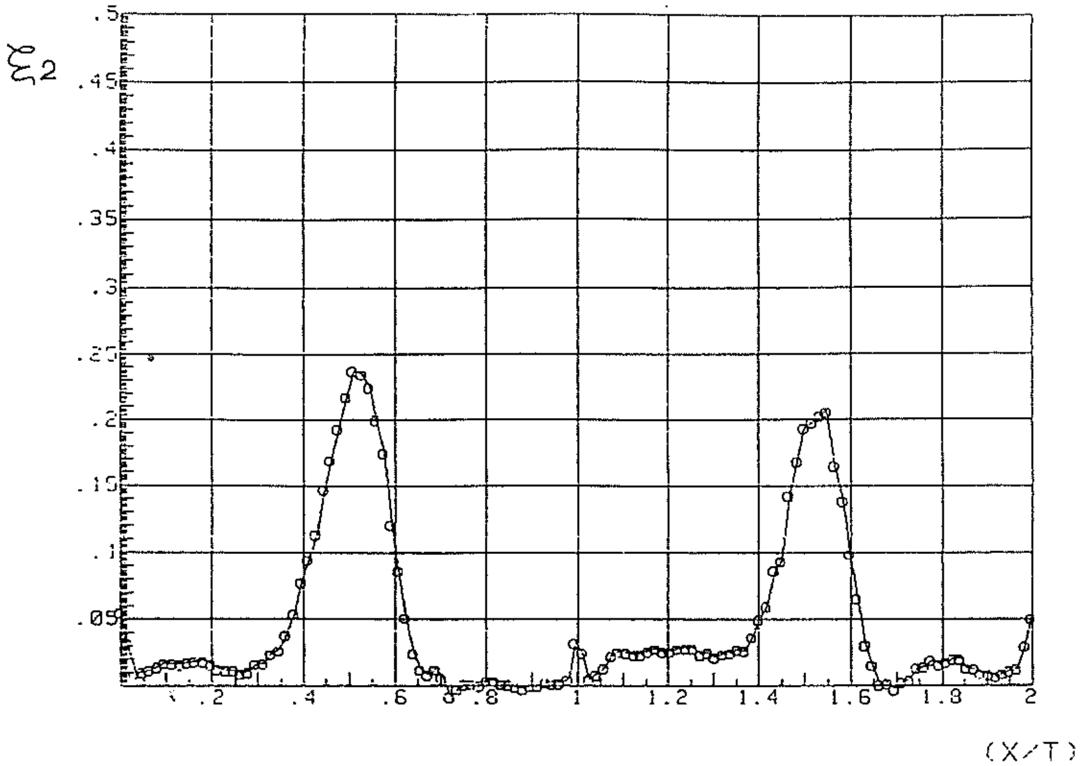


Fig. 9