Session 5 - Optical Measurements

LASER-2-FOCUS MEASUREMENTS AT A HIGH SPEED CASCADE WIND TUNNEL

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ABSTRACT

The Laser–2–Focus (L2F)–technique is a non intrusive, optical velocity measurement technique using tracer particles.
In turbomachinery it has often been used for investigations of the flow field in rotating blade rows.
In the Laboratorium für Strömungsmaschinen a L2F–Velocimeter was used to perform measurements at a high speed cascade wind tunnel .
The present paper describes the experiences with the L2F–measurement system when measuring the flow behind a linear transsonic turbine cascade.It also gives a short description of the L2F–measurement technique.
The paper deals with the problem of particle size estimation and particle lag as well as with the problem of measurements inside the blade row.
Some measurement results are presented to illustrate the attained accuracy and resolution with regard to flow angles and shocks.They are also used to show how to check the reliability of the measurement results

1. INTRODUCTION

The Laser–2–Focus (L2F)–technique is a non intrusive, optical velocity measurement technique using tracer particles.
In turbomachinery it has often been used for investigations of the flow field in rotating blade rows.
In the Laboratorium für Strömungsmaschinen a L2F–Velocimeter was used to perform measurements at a high speed cascade wind tunnel (Fig. 1).
The present paper describes the experiences with the L2F–measurement system when measuring the flow behind a linear transsonic turbine cascade.

2. FACILITY DESCRIPTION

To get the velocity vectors behind the cascade a Laser–2–Focus velocimeter was used. Relevant data for this system are shown in Tab.1 (Fig. 2).

Beam Diameter at focus point	:	10 μm
Beam Distance at focus point	:	165 μm
Detecting range along optical axis	:	300 μm
Wave length	:	514,5 nm

Tab. 1: Laser–2–Focus system data

Similar to the Laser doppler velocimetry technique the L2F velocimeter measures the velocity of light scattering particles with a diameter of about 0.1 – 0.5 μm. These particles will follow the gas flow despite their density of about 1000 times as high as the one of the gas. L2F produces two light beams which work as a light gate with high light concentration which results in a high signal–to–noise ratio.
The details within the L2F measurement volume are shown in Fig. 3. As a result of focusing, both beams have a converging–diverging cross section. With the optical data given in Tab.1 it is obvious, that the L2F–system has a very small measurement volume, which is smaller than the one that could be obtained with pressure probes.

A particle passing both light beams inside the measurement volume produces two successive pulses of scattered light. Knowing the distance between the two laser beams, the time between two pulses gives the velocity of the flow perpendicular to the optical axis. More details about this measurement technique and the statistical data processing are described by Schodl (1977).
The Laser could be moved by step–motors in all directions.Particle seeding was done by a Polytec A 1000 seeding generator which produces particles with a mean diameter of 0.1 μm. After having tested several mixtures to produce these particles, a mixture of 15% shell carnea oil (ρ =904 kg/m^3, η =0.15 Ns/m^2 at 293 K) and 85% trichlorethane was used to produce the tracer particles. After the injection of particles into the settling chamber of the wind tunnel proved to be unsuccessful (there was a very poor particle rate mainly in the wake behind the blades) , the particles were brought into the flow by a particle probe some 600mm upstream of the cascade. This method has the disadvantage, that the velocity profile of the flow upstream of the cascade becomes nonuniform. To make this disturbance only two–dimensional a probe that passes all through the channel was used instead of a claw probe (Fig. 4).
The nonuniformity of the flow upstream of the cascade has no considerable influence on the measurements in the midspan section of the blade. The influence of the nonuniformity of the flow upstream of the cascade was checked by flow visualisation and comparative measurements with a wedge probe. It was found, that no considerable influence on the measurements in the midspan section of the blades occurs if one works with the true total pressure in front of the midspan section. The true total pressure p_{t0} is the tank total pressure p_k minus the total pressure loss caused by the particle probe:

$$p_{t0} = p_0/(1 - (1- \zeta_{vl})(1 - (p_0/p_k)^{(\kappa-1)/\kappa}))^{\kappa/(\kappa-1)}$$

where

$$\zeta_{vl} = 1 - \frac{1 - (p_0/p_{t0})^{(\kappa-1)/\kappa}}{1 - (p_0/p_k)^{(\kappa-1)/\kappa}}$$

For the present investigations it was of minor relevance that the particle probe produced a high turbulence rate of $Tu_0 = 8\%$. But if very low rates of turbulence are desired, the introduction of particles into the settling chamber would have to be taken into consideration, although it is quite troublesome to get enough particles in the measurement volume. If 3–D–Measurements shall be performed, the influence of the particle probe may also produce unwelcome effects.
For the calculation of the profile losses at the cascade an additional information about the pressure is needed. At first it was tried to get the total pressure behind the cascade from static wall pressure measurements and the L2F measured velocity. But the measurement errors, which were accumulated by the independent measurements of velocity and pressure, the nonuniform flow upstream of the cascade and the secondary flow lead to unacceptable errors in the loss calculation. Therefore the total pressure was measured by an independent procedure with a Kiel probe. As the Kiel probe was only used to determine the total pressure and it was not introduced into the flow during the L2F measurements, the distortion of the flow field could only affect the the loss rates. But the errors resulting from this remain small.

3. PARTICLE LAG

One of the problems with L2F–technique is, that one must be sure that the tracer particles are following the gas flow with a sufficient accuracy .
There are several publications that deal with particle lag in accelerating, decelerating and oscillating flows and flows with a strong streamline curvature (Dring, 1982, Schodl, 1977, Binder, 1985). They recommend particle sizes that are required to achieve measurements of a certain accuracy. In turbomachinery particle sizes of 0.1 – 0.5 μm are recommended. Normally one is unable to measure the particle size that actually occurs in the measurement volume. When using a commercial seeding generator one can use the manufacturers data (Fig. 5). Otherwise one has to measure the particle size using whisker nets (Oertel,1989). But there is normally a rather long distance between the seeding generator and the measurement volume. Particle size may increase due to coagulation or diminish by evaporation.

To make statements about the reliability of the measurements, it is therefore useful to interpret the measurement results with regard to the particle lag errors. Good criteria are given by shock resolution or the flow direction close to the blade surface in case of attached flows.

To estimate the particle lag and the measurement errors, the results from Dring(1982) are helpful. He uses a Stokes number

$$St = \frac{\rho_p \, U \, D_p^2}{18 \, \eta_L \, L}$$

as a characteristic value to calculate the difference between the particle and the gas flow motion. The meaning of the time L/U depends on the application .It may be an inverse frequency in the case of oscillating flows or a recovery length divided by the flow velocity in the case of a shock. An example for how to use these correlations is shown in the chapter that deals with the measurement results.

4. MEASUREMENTS INSIDE THE BLADE ROW

The problem with L2F when measuring very close to the blade surface is that the Laser beams are conical. To prevent the Laser beam from getting clipped off partially by the blade one can incline the beam axis untill the lower edge of the beam is parallel to the blade surface (Fig. 6). It is obvious that if one gets too close to the surface there will occur a strong background radiation which can be diminished by using black anodized blades.

Another possibility is to place the optical axis no longer perpendicular to the velocity vector (Fig. 7). In this case one has to consider that the effective beam distance s will change with respect to the angle γ between the direction perpendicular to the velocity vector and the beam axis .

During the present tests we used the latter method to measure the flow vectors closely upstream of the trailing edge (Fig. 8)

5. MEASUREMENT RESULTS

The L2F measurement technique was used to determine the flow downstream of a transsonic turbine cascade. The special feature of the cascade is its small dimensions (t = 19.4mm) which were chosen in order to get measurements at a high Mach number together with a low Reynolds number.

The problems which arise from this configuration are shown in Fig. 9, where the results of a measurement with a calibrated wedge probe (which had a diameter of 6mm) and of a L2F measurement are plotted. As the measurements were taken in an axial distance of only 5mm from the trailing edge , a distinct influence on the flow due to the probe can be seen. In addition, the resolution, especially in the wake, is very poor with the wedge probe. The strong changes in flow angle,which occured in the L2F measurement were not found by the wedge probe. To verify the L2F result, further L2F measurements were taken upstream of the trailing edge. They show that the changes in flow angle are caused by the "metal" angle of the blade. The flow direction corresponds quite good with the direction given by the blade surface (Fig. 8).

Even the resolution of the shocks is good as shown in Fig.10, where the transsonic flow behind a turbine cascade is plotted against the pitchwise distance y/t. The expected trailing edge shock that goes approximately in axial direction, is reproduced sharply by the L2F measurement. The shock region extends from y/t= 0.33 to 0.37 which is equivalent to 0.8mm. Using the correlation of Dring (1982) for strong decelerations and setting St=0.217 and L = 0.8mm we get a particle size of

$$D_p = \sqrt{18*St*\eta_L*L/(\rho_p*U)} = 0.4\mu m \ ,$$

where U is the velocity behind the shock.

With this example ,a method is shown to estimate the the true particle size that occurs in the measurement volume.

6. CONCLUSIONS

In the present paper the use of the L2F measurement technique proved to be a good tool for cascade measurements.Its strong point is the measurement in trans– and supersonic flow especially in low size configurations and blade channels, where every kind of probe would disturb the flow field.

The problems with the systems are on the one hand the particle seeding and on the other hand the long measurement times of about 2 minutes per measurement point or about one hour to traverse the whole pitch which requires a wind tunnel that could maintain a steady state flow for the whole measuring time.

7. NOMENCLATURE

D_p	particle diameter
L	length
M*	Laval number
p	static pressure
p_k	total pressure in the settling chamber
p_t	total pressure
s	true beam distance
s_m	beam distance at focus point
St	Stokes number
t	pitch
Tu	turbulence rate
U	velocity
x	spanwise direction
y	pitchwise direction
α	flow angle
η	dynamic viscosity
ρ	density
ζ_v	loss rate

Subscripts

L	Air
l	seeding probe
p	particle
0	inlet plane
1	outlet plane

8. REFERENCES

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Oertel,H.(1989) Optische Strömungsmeßtechnik,Karlsruhe

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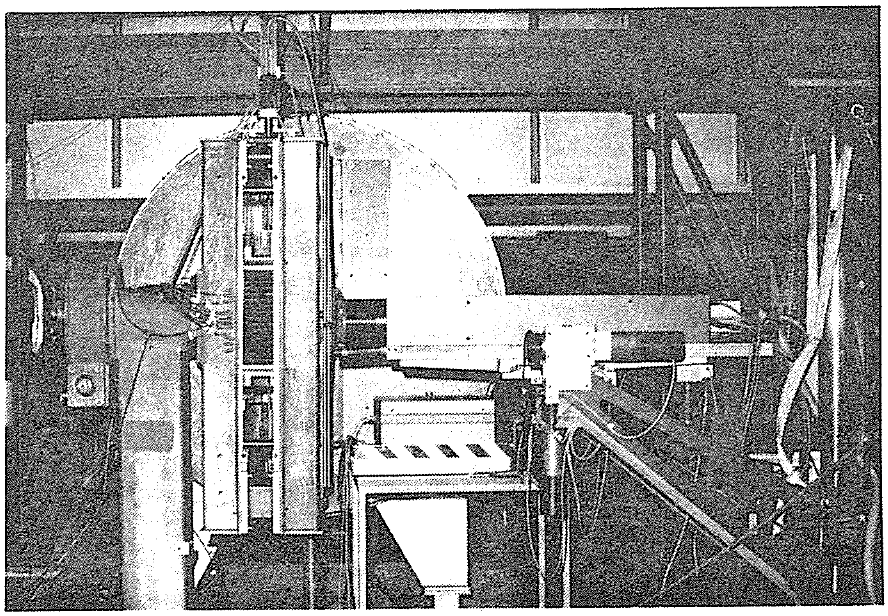
9. FIGURES

a)



b)

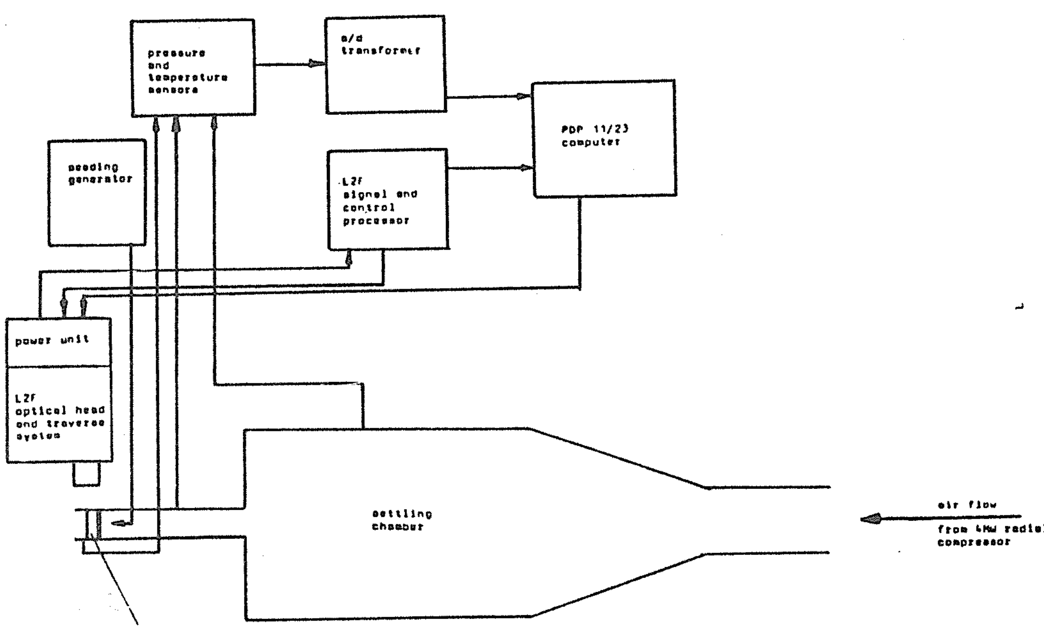


Fig. 1 Testing facility. (a) Overall view of the cascade wind tunnel with built in cascade (center), L2F optical head and traversing system (right),(b)schematic

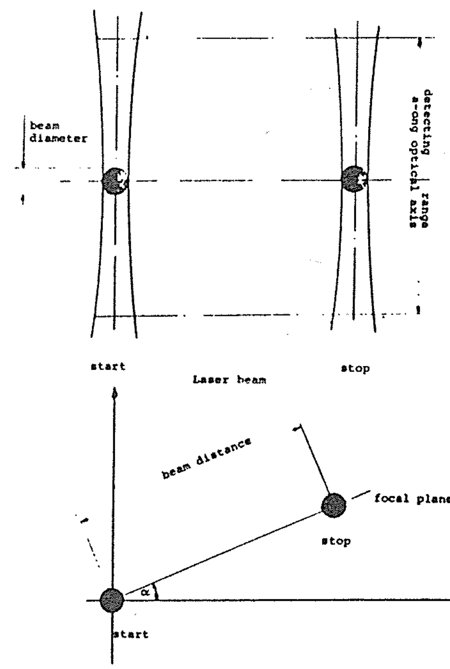


Fig. 2 Relevant dimensions of the L2F measuring volume

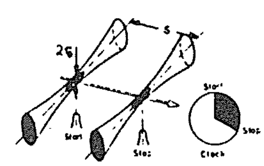
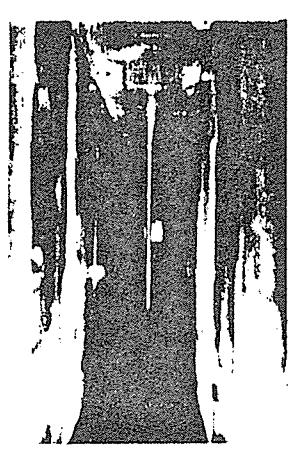


Fig. 3 L2F measuring volume. A linear particle traverse yields two correlated pulses.

a)



b)

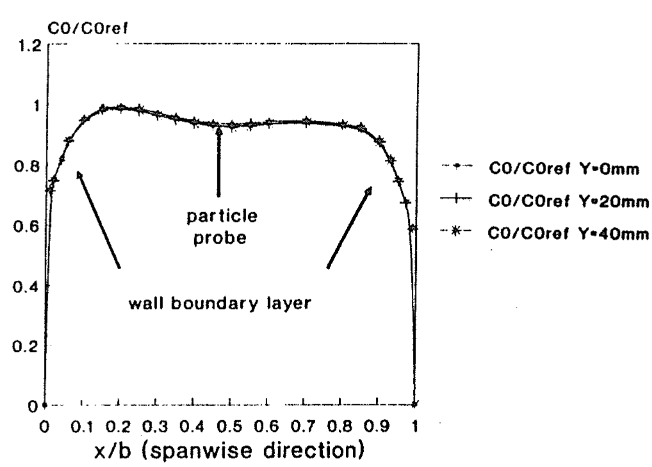


Fig. 4 (a) Particle probe in the tunnel and (b) disturbed velocity profile at the inlet of the cascade due to the particle probe.

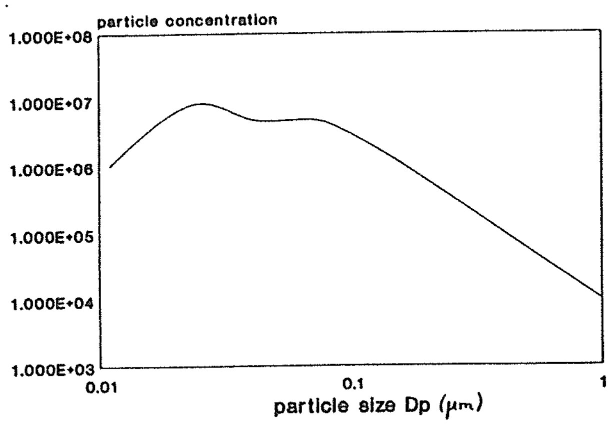


Fig. 5 Particle size distribution of the used seeding generator

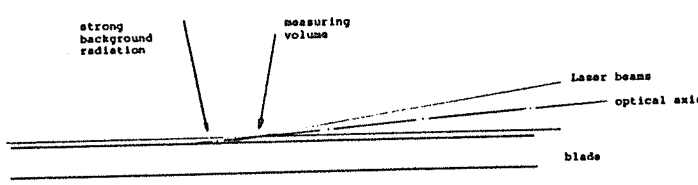


Fig. 6 L2F measurement close to the blade surface

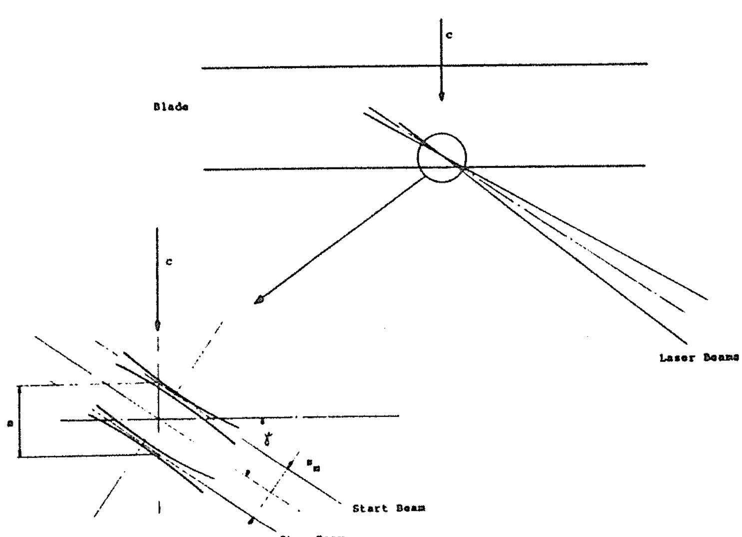


Fig. 7 Non orthogonal positioning of the Laser beams

$s = s_m / \cos\gamma$.

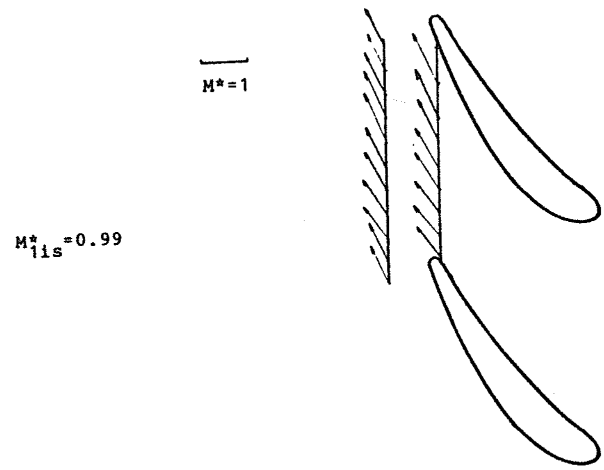


Fig. 8 Velocity vectors near the trailing edge of a turbine cascade (M^*_{1is} = 0.99)

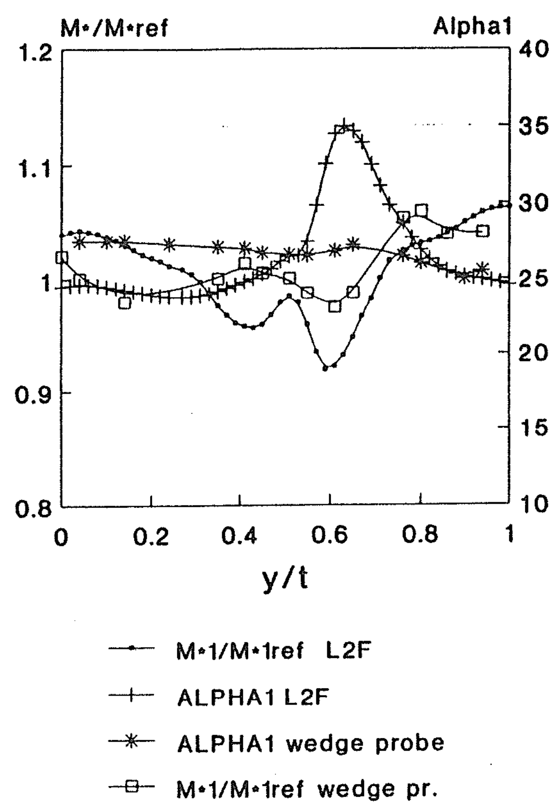


Fig. 9 Comparison between L2F and wedge probe measurements 5mm behind a turbine cascade at M^*_{1is}=0.75.

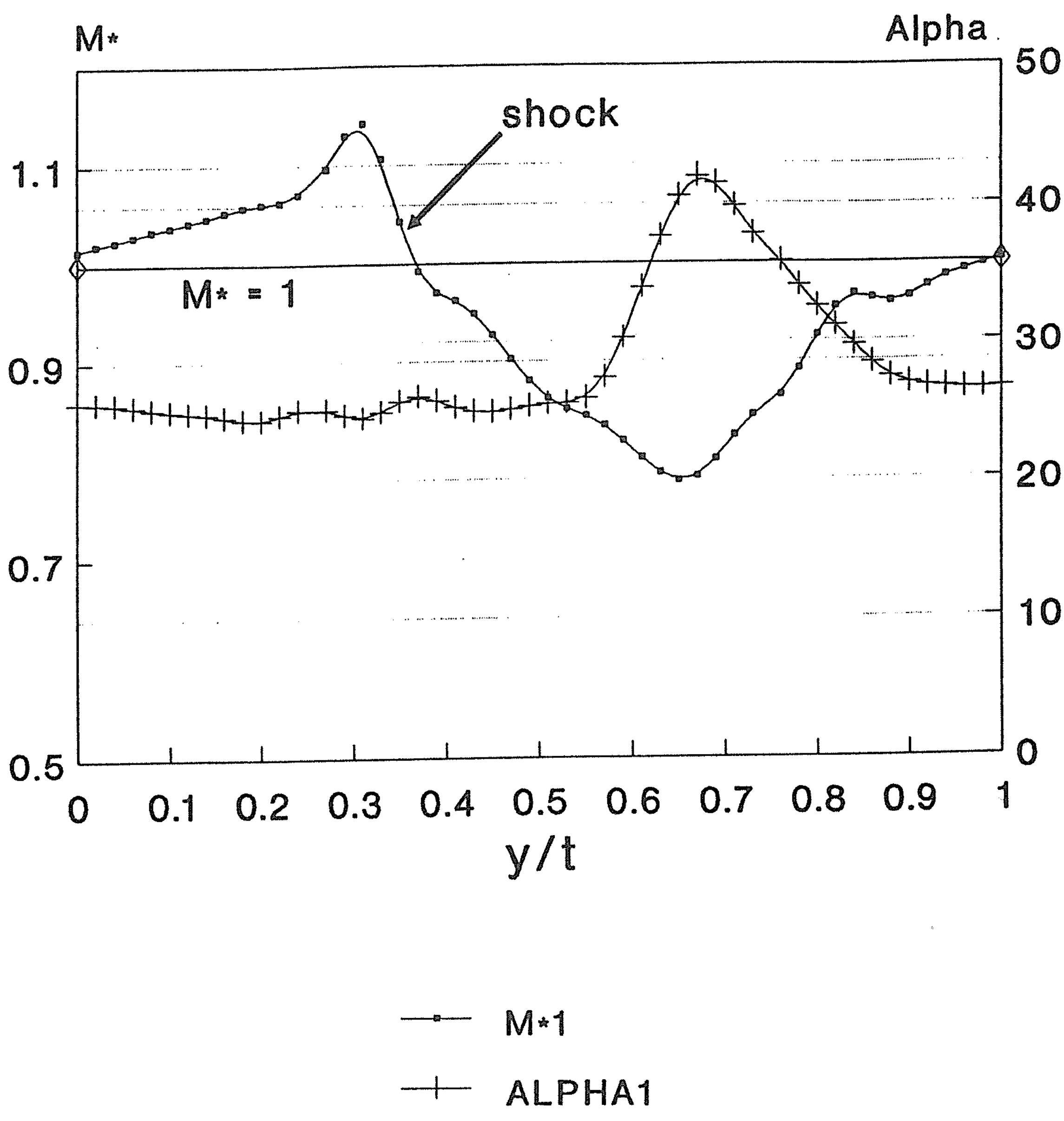


Fig.10 Transsonic flow behind a turbine cascade (L2F measurement) at M^*_{1is}=1.03. The shock region extends from y/t=0.33 to 0.37 which is equivalent to 0.8mm.