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Technical Note 174

AERO-THERMAL INVESTIGATION OF A HIGHLY LOADED TRANSONIC LINEAR TURBINE GUIDE VANE CASCADE

A test case for inviscid and viscous flow computations

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Abstract

This contribution deals with an experimental aero-thermal investigation of a highly loaded transonic turbine nozzle guide vane mounted in a linear cascade arrangement. The measurements were performed in the von Karman Institute short duration Isentropic Light Piston Compression Tube facility, allowing a correct simulation of Mach and Reynolds numbers as well as of the gas to wall temperature ratio compared to the values currently observed in modern aero engines. The experimental programme consisted of flow periodicity checks by means of wall static pressure measurements and Schlieren flow visualizations, blade velocity distribution measurements by means of static pressure tappings, blade convective heat transfer measurements by means of platinum thin films, downstream loss coefficient and exit flow angle determinations by using a new fast traversing mechanism and freestream turbulence intensity and spectrum measurements. These different measurements were performed for several combinations of the freestream flow parameters looking at the relative effects on the aerodynamic blade performance and blade convective heat transfer of Mach number, Reynolds number and freestream turbulence intensity.

Keywords :

-Heat transfer
-Aerodynamics
-Transonic turbines
-Euler/Navier Stokes codes

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List of symbols

c	: chord
g	: pitch
h	: heat transfer coefficient
k	: isentropic exponent (= 1.4)
M	: Mach number
o	: throat
p	: pressure
$\dot{q}_w$	: wall heat flux
r_{LE}	: leading edge radius
r_{TE}	: trailing edge radius
Re	: Reynolds number
s	: coordinate along blade surface
T	: temperature
Tu	: freestream turbulence
u	: velocity
u'	: fluctuating component of velocity
V	: velocity
x	: coordinate along axial chord
γ	: stagger angle
ρ	: density

Subscripts

0	: total condition
1	: upstream condition
2	: downstream condition
ax	: along the axial chord
is	: isentropic condition
w	: condition at the wall
∞	: freestream condition

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1.Introduction

The description of the present test case is a follow up of similar events which were presented at the occasion of Lecture Series held at the von Karman Institute for Fluid Dynamics in May 1973 on "*Transonic Flow in Turbomachinery*" [1] and in April 1982 on "*Numerical Methods for Flows in Turbomachinery Bladings*" [2]. At these occasions, several two and three dimensional cascade configurations were designed and their aerodynamic performances were experimentally determined as completely and accurately as possible. These measurements mostly served for comparisons with results obtained from inviscid flow calculation methods and presented by different Lecture Series participants. Ever since many other researchers have used the VKI subsonic and transonic turbine cascade test cases to evaluate the accuracy of their two and three dimensional Euler codes.

A general review on "*Test cases for Computation of Internal Flows in Aero-Engine Components*" by AGARD Working Group 18, headed by Prof. Fottner, led to the conclusions that further cascade test cases should provide more information on boundary layer characteristics including heat transfer and turbulence data [3] for comparison with the numerous Navier-Stokes numerical codes developed over the last years.

Based on these recommendations, the guidelines for the present experiment were established as follows :

- the experimental data should be as reliable as possible and lend itself to as little criticism as possible. The choice was therefore limited to axial turbine bladings ;
- the experimental data should be used for validation of both inviscid and viscous calculation methods. They should provide information on blade velocity distributions, blade convective heat transfer distributions and downstream loss and flow angle evolutions.

The present experimental programme consists of flow periodicity checks by means of wall static pressure measurements and Schlieren flow visualizations, blade velocity distribution measurements by means of static pressure tappings, blade convective heat transfer measurements by means of platinum thin films, downstream loss coefficient and exit flow angle determinations by using a new fast traversing mechanism and freestream turbulence intensity and spectrum measurements. These different measurements have been performed for different combinations of the freestream flow parameters looking at the relative effects of Mach number, Reynolds number and freestream turbulence intensity on the aerodynamic blade performance and blade convective heat transfer.

A preliminary set of results was presented during the Lecture Series on "*Numerical Methods for Flows in Turbomachinery*" [4] held at the VKI in May 1989, and compared to the numerical predictions provided by a number of participants. The complete experimental results were then published during the 1990 International Gas Turbine Conference held in Brussels [5]. The present report describes the complete, detailed and tabulated set of measurements.

2. Experimental apparatus

2.1 Description of the facility

The present experimental investigation was carried out in the von Karman Institute Isentropic Light Piston Compression Tube facility CT-2 (Fig. 1). The operating principles of this type of wind tunnel were developed by Schultz and Jones [6, 7] about 15 years ago. The VKI CT-2 facility, constructed in 1978 is basically made of three main parts : a 5 meter long and 1 meter diameter cylinder, the test section and a 15 m^3 downstream dump tank. The cylinder contains a light weight piston driven by the air of a high pressure reservoir (... 150... 250 bar). The cylinder is isolated from the test section by a fast opening "shutter" or slide valve. As the piston is pushed forward, the gas located in front of it is nearly isentropically compressed until it reaches the requested pressure, and hence temperature, levels. The fast opening valve is then actuated by means of a pneumatic system and a detonator, allowing the pressurized and heated gas to flow through the test section without any additional compression or expansion, providing constant freestream conditions, i.e. total temperature, pressure and mass flow until the piston completes its stroke.

The maximum test section dimensions are 250 x 100 mm^2. The freestream gas conditions can be varied between 300 and 600 K and 0.5 and 7 bar respectively. The downstream dump tank allows exit static pressure adjustments between 0.15 and 3 bar. This provides an independent selection of both Mach and Reynolds numbers. The typical test duration is about ... 400... ms. Air is used as working fluid. Further details about the VKI CT-2 facility have been described by Consigny and Richards [8,9].

2.2 Description of the model

The different measurements described in the present contribution were carried out on a high pressure turbine nozzle guide vane profile especially designed for this purpose at the von Karman Institute. The blade shape was optimized for a downstream isentropic Mach number equal to 0.9 by means of an inverse method [10], developed at the VKI. The blade profile is plotted in figure 2 whereas the manufacturing coordinates are listed in table 1. The blade was mounted in a linear cascade, made of 5 profiles, i.e. 4 passages. The central blade was instrumented either for static pressure measurements (blade velocity distributions) or for heat flux measurements (blade convective heat transfer distributions). The inlet flow angle to the cascade is 0 deg. The most important geometrical characteristics of the cascade are summarized as follows :

c	: 67.647 mm
g/c	: 0.850
γ	: 55.0 deg (from axial direction)
o/c	: 0.2207
r_{LE}/c	: 0.061 (evaluated around stagnation point)
r_{TE}/c	: 0.0105

2.3 Measurement techniques

Freestream total pressure and temperature, static pressure and turbulence intensity were measured 55 mm (x/c_{ax} = -1.487) upstream of the leading edge plane, respectively by means of a Pitot probe connected to a variable reluctance Valydine differential pressure transducer, a small type K thermocouple probe, wall static pressure tappings connected to National Semi Conductor differential pressure transducers and a constant temperature hot wire probe. Wall static pressure tappings were also installed downstream of the cascade, in a plane parallel to the trailing edge plane and located 16.0 mm (x/c_{ax} = 1.433) (measured along the axial chord direction) downstream of the latter. They covered a distance of 130 mm, i.e. a little more than 2 pitches to verify the downstream periodicity of the flow and to determine the exit Mach number to the cascade. Blade velocity distributions were obtained from 27 static pressure measurements performed along the central blade profile and referred to the upstream total pressure. The downstream loss coefficient evolution as well as the exit flow angle were obtained by means of a fast traversing mechanism, transporting a Pitot probe over 2 pitches.

Local wall convective heat fluxes were obtained from the corresponding time dependent surface temperature evolutions, provided by platinum thin film gauges painted onto the central blade, made of machinable glass ceramic. The wall temperature/wall heat flux conversion was obtained from an electrical analogy, simulating a one dimensional semi-infinite body configuration. A detailed description of this transient measurement technique is presented in [11]. The convective heat transfer coefficient h used in this contribution is defined as the ratio of the measured wall heat flux and the difference between the total freestream and the local wall temperatures :

$$h = \frac{\dot{q}_w}{T_{01} - T_w}$$

It is also worth to mention that the heat transfer measurements discussed in the present paper describe a spanwise averaged behaviour as the different thin films were about 20 mm long, but nevertheless situated only in the clean flow region.

2.4 Freestream turbulence generation

One of the important parameters considered in this investigation is the freestream turbulence. The complete definition of this parameter not only involves its intensity but also its spectrum. These measurements were rather difficult to perform in the CT-2 facility because of the nature of the flow, i.e. an abrupt establishment of a high speed hot stream, leading to some difficulties in the calibration procedure of the hot wire probe. The freestream turbulence was generated by a grid of spanwise oriented parallel bars ($d = 3$ mm ; $s/d = 4$). The turbulence intensity was varied by displacing the grid upstream of the model : a maximum of 6 % could be obtained. The natural turbulence of the facility is about 1 %. The turbulence intensity quoted in this contribution is defined as :

$$Tu_{\infty} = \frac{\sqrt{\overline{u'^2}}}{\overline{u}}$$

and was measured using a VKI manufactured constant temperature hot wire probe. The frequency response of this part of the measurement chain was observed to be of the order of 10 kHz.

In order to obtain the freestream turbulence spectrum, the raw signal of the hot wire probe was processed by means of a Fast Fourier analysis. A typical example is shown in figure 3. This result is representative of a 4 % turbulence intensity. Discrete peaks are observed at 5.5 and 11 kHz. In order to investigate the nature of this phenomenon and to determine if it could have any influence on the boundary layer development, a microphone was mounted inside of the test section. The fluctuating component of the output signal was also processed by a Fast Fourier Transform (Fig. 4). This analysis revealed the existence of similar peaks, therefore obviously of acoustic nature. The information accumulated on this subject up to now seems to indicate that no effect on the boundary layer development is expected from those frequencies. Further investigations on this subject are currently underway at the VKI for high speed as well as low speed flows.

2.5 Data acquisition system

All pressure, temperature and heat flux measurements were directly acquired by a VAX 3500 computer by means of a VKI manufactured 48 channel data acquisition system through a direct memory access principle. The analog (±5.0 V) signals were digitized using 12 bit words. For the present measurements, the sampling rate was selected to be 1 kHz for pressure, temperature and heat flux measurements and 25 or 50 kHz for turbulence intensity and spectrum measurements.

2.6 Measurement uncertainty

The uncertainty on the various measured quantities was carefully evaluated and led to the following error bars, based on a 20:1 confidence interval. The uncertainty on pressure measurements was of the order of ± 0.5 %, on temperature measurements of the order of ± 1.5 K, on the heat transfer coefficient of the order of ± 5 %, on the integrated loss coefficient of the order of ± 0.2 points and on the exit flow angle of the order of ± 0.5 deg.

3. Test conditions

The test programme was built up by varying the freestream conditions according to the following limits :

T_{01}	: 420 K
$M_{2,is}$	: 0.70 ... 1.10
$Re_{2,is}$	: 0.5 10^5 ... 2.0 10^6
Tu_∞	: 1.0 ... 6.0 %

The different flow conditions were defined by all possible combinations of these parameters. All the tests were conducted at least twice to verify the repeatability of the results.

4. Periodicity of the flow

In order to correctly model the flow in a cascade, one must ensure periodic inlet and outlet conditions. The higher the number of blades, the easier it is to establish periodic flow conditions, but for aerodynamic measurements one generally considers 8 to 10 blades to be a minimum. In the present experiment, however, the scale of the blade has been chosen as large as possible to allow a dense instrumentation of the model, required by the particular goal of this investigation. As a result, only 5 profiles, i.e. 4 passages, were used. A careful verification of the flow periodicity was therefore absolutely necessary.

In order to verify the flow periodicity, distributions of the downstream wall static pressure were measured and Schlieren flow visualizations were performed for different exit Mach and Reynolds number values. The effect of turbulence intensity was not considered ; the measurements were conducted without turbulence grid ($Tu_\infty = 1\%$) .

The downstream static pressure measurements were performed in a plane parallel to the trailing edge plane, located at $x/c_{ax} = 1.433$. The different pressure tappings were located 5 mm from each other and covered 130 mm, i.e. a little more than 2 pitches. Each tapping was connected to a National Semi Conductor differential pressure transducer; the low pressure port of the latter was connected to a vacuum pump to allow a continuous calibration of the system. In order to correctly calculate the downstream flow Mach and Reynolds numbers, the upstream total pressure and temperature were also measured, respectively by means of a small Pitot probe connected to a variable reluctance Valydine differential pressure transducer and a type K thermocouple probe. The frequency response of the pressure instrumentation was of the order of 150 Hz; the sampling rate was set at 1kHz. All tests were performed for an upstream total temperature of about 415 ... 420 K. The useful testing time was of the order of 450 ms.

The results are presented as isentropic downstream Mach number distributions versus a coordinate measured along the pitch, towards the lowest profile of the cascade and basically capturing the wakes of blades 3 (the central profile of the cascade) and 4. These plots allowed to calculate the averaged exit isentropic Mach number of the cascade. Based on these measurements, the flow proved to be reasonably periodic for $M_{2,is}$ up to 1.15, as can be seen e.g. from figure 5 . Similar measurements were repeated for different downstream Reynolds numbers ranging from $5.0\ 10^5$ to $2.0\ 10^6$; they provided the same conclusions.

Flow visualizations were obtained in the transonic regime from a single pass Schlieren system. Figures 6 and 7 present typical results obtained for $M_{2,is} = 1.03$ and $Re_{2,is} = 10^6$ and $2.0\ 10^6$ respectively. Profiles 3 (the central profile of the cascade) and

4 are shown on these pictures. The spark was initiated about 150 ms after the shutter opening, i.e. after the beginning of the test, to be sure that the flow was correctly established in the cascade. A normal shock is observed along the rear part of the suction side, as well as the trailing edge shock; no definite separated flow regions can clearly be identified for any value of the Reynolds number. These measurements confirm the conclusions drawn from the wall static pressure measurements. For values of $M_{2,is}$ in excess of 1.2, however, the flow periodicity deteriorates very quickly. Additional measurements are presently underway to overcome this difficulty by modifying the downstream tailboard arrangement.

5. Blade velocity distributions

Blade isentropic Mach number distributions were obtained for different loadings from local static pressure measurements, referred to the upstream total pressure. The central blade of the cascade was therefore replaced by a similar profile equipped with 27 static pressure tappings, each of them connected to a National Semi Conductor differential pressure transducer ; the low pressure ports were again connected to a vacuum pump to allow a regular verification of the calibration characteristics. The position of the pressure tappings is shown in figure 8 and is tabulated in table 2.

The uncertainty on the measurements, the frequency response of the measurement chain and the sampling rate have been quoted in the preceding section. The repeatability of the results was verified and proved to remain within 0.5 %. The influence of freestream turbulence intensity and Reynolds number on the blade velocity distributions were not considered at this stage. All tests were performed for an upstream total temperature of about 415 ... 420 K. The useful testing time was of the order of 450 ms.

Typical measurement results are presented in figure 9 . They are plotted as an isentropic Mach number evolution in function of a reduced coordinate (s/c) measured along the profile surface, starting from the theoretical stagnation point ($x/c_{ax} = 0.$). Starting from tap 1, the flow steeply accelerates along the suction side up to tap 6 (s/c = 0.3). A small plateau (s/c $\approx$ 0.35 ... 0.40, taps 7,8) is followed by a reacceleration. For the lowest exit Mach number ($M_{2,is} = 0.875$), the velocity distribution is then rather flat with a weak adverse pressure gradient starting from tap 13 (s/c $\approx$ 0.75). Let us remember that the blade was initially designed and optimized for about this value of the exit Mach number. For the higher exit Mach number ($M_{2,is} = 1.02$), the flow accelerates up to taps 15 ... 16 (s/c $\approx$ 0.85 ... 0.95). A shock is then observed (s/c $\approx$ 1.05, taps 17, 18) ; this position is consistent with the one deduced from the Schlieren pictures. The velocity distribution along the pressure side varies smoothly, with no existence of a velocity peak downstream of the leading edge.

These measurements were compared to the results obtained from a two dimensional inviscid prediction code [12], based on a time marching integration technique and a finite volume discretization method. For a subsonic exit Mach number, the calculated results nearly match the measured data (Fig. 9). For transonic exit Mach numbers, only small differences are observed. It appears from a recent investigation that using a finer mesh along the rear part of the blade might improve the comparison, but to the detriment of CPU costs. A complete tabulation of the measured blade velocity distributions is provided in Appendix 1.

6. Blade heat transfer distributions

Blade convective heat transfer distributions were obtained for different Mach and Reynolds numbers and freestream turbulence intensities by means of 45 platinum thin films. The latter were painted on a machinable glass ceramic blade replacing the central profile of the cascade. The position of the thin films is shown in figure 10 and tabulated in table 3.

The frequency response of the measurement chain associated with the thin films (gauges, analogs, amplifiers) is far above 1 kHz. The sampling rate was selected to be 1 kHz, and the signals were filtered at 800 Hz. The useful testing time was of the order of 300 ms. The repeatability of the results was verified and proven to remain within 1 %. All tests were performed for an upstream total temperature of about 415... 420 K.

The different results are presented on figures 11 to 26 under the form of a heat transfer coefficient distribution ($W/m^2/K$, see section 2.3) versus a length (mm) measured along the suction and pressure sides of the blade, starting from the theoretical stagnation point ($x/c_{ax} = 0$). A complete tabulation of the measured blade heat transfer distributions is provided in Appendix 2.

6.1 Influence of freestream turbulence

The influence of freestream turbulence is presented on figures 11 to 17 for 3 different Mach and Reynolds numbers. The turbulence intensity was varied between 1.0 and 6.0 %. At low Reynolds numbers (Fig. 11, 12), Tu_∞ mainly affects the laminar part of the boundary layer. After having reached relatively high values in the region of the leading edge, the heat transfer falls quite rapidly on either side of the blades : this behaviour corresponds to the development of a laminar boundary layer. The level of heating is slightly but distinctly increased by increasing Tu_∞; this effect is however less important than at the stagnation point. Similar results were obtained for constant pressure and accelerating laminar boundary layers developing on a flat plate [13]. For the lowest Mach number ($M_{2,is} = 0.92$, Fig. 11) the position of the transition onset on the suction side ($s = 62\ldots\ 68$ mm) does not seem to be significantly affected by Tu_∞. For the highest Mach number ($M_{2,is} = 1.12$, Fig. 13), the boundary layer transition starts at the shock position ($s = 71.0$ mm). These measurements confirm the shock location observed from the Schlieren pictures and the velocity distribution. Along the pressure side, the boundary layer is most probably in a laminar state.

Similar conclusions are drawn for the intermediate Reynolds number value (Fig. 13, 14, 15), and for the 2 lowest values of Tu_∞ ($Tu_\infty = 1\%, 4\%$). For the highest value ($Tu_\infty = 6\%$) however, the onset of transition is observed earlier along the suction side. This position corresponds to the small plateau observed on figure 9 along the suction side (s = 24.0 mm; s/c= 0.36). This phenomenon is not marked for the highest exit Mach number where the acceleration rate is high enough to prevent the onset of transition. The behaviour along the pressure side is rather similar to what has been observed for $Re_{2,is} = 5.0\ 10^5$.

The behaviour of the boundary layer seems to be quite different for the highest value of the Reynolds number (Fig. 16, 17). Along the suction side, it appears that the transition onset is very much influenced by the the velocity distributions (Fig. 9). In the present case, the transition is triggered by the first important decrease in velocity gradient (s = 20.3 mm; s/c = 0.3). Along the pressure side the boundary layer is much more sensitive to freestream turbulence. It appears that a fully turbulent state is obtained for the highest value of Tu_∞.

6.2 Influence of freestream Reynolds number

The influence of freestream Reynolds number is presented on figures 18 to 23 for 2 different Mach numbers and 3 different turbulence intensities. The Reynolds number was varied between $5.0\ 10^5$ and $2.0\ 10^6$. The first effect of Reynolds number is, as expected, to increase the overall level of heat flux. This seems to be the only significative effect at low turbulence intensity (Tu_∞ = 1 %, Fig. 18, 19). For $M_{2,is}$ = 0.92 the suction side boundary layer transition onset seems to depend only on the velocity distribution, whereas for $M_{2,is}$ = 1.10, the onset of transition moves towards the leading edge for the highest value of the Reynolds number. The boundary layer is more sensitive to the acceleration changes along this surface. Along the pressure side the boundary layer remains in a laminar state.

For the intermediate turbulence intensity (Tu_∞ = 4 %, Fig. 20, 21), similar conclusions can be drawn along the suction side. Along the pressure side however, the increase in heat transfer is much more important for the highest value of $Re_{2,is}$. For the highest value of turbulence intensity (Tu_∞ = 6 %, Fig. 22, 23), the transition of the suction side boundary layer moves gradually upstream with increasing Reynolds number for the two values of the Mach number. For $M_{2,is}$ = 1.1 and $Re_{2,is} = 2.0\ 10^6$, the stabilizing effect of the favourable pressure gradient is clearly observed between s = 25 mm (onset of transition) and s = 40 mm.

6.3 Influence of freestream Mach number

The influence of freestream Mach number is presented on figures 24 to 26 for 3 different Mach numbers and 1 Reynolds number. Along the pressure side, the velocity distributions are almost similar. As a result, no significative differences appear in the heat transfer coefficient distributions. The behaviour of the suction side boundary layer is basically a fonction of the different acceleration rates observed in figure 9 . This is most clearly demonstrated in figure 26.

6.4 Numerical predictions

An attempt was made to predict numerically these heat transfer measurements. A two-dimensional boundary layer code "TEXSTAN" [14] was used for this purpose. This program is based on the classical Spalding-Patankar approach [15] to compute boundary layer or pipe flows. It uses a finite difference technique to solve, through a streamwise space marching procedure, the simplified two dimensional boundary layer equations as applied to flows developing along, e.g. a flat wall or in an axisymmetric tube. In the present paper, the modelling of the turbulent quantities was provided through a Prandtl mixing length approach. The initial velocity and enthalpy profiles were determined 0.5 mm downstream of the theoretical stagnation point by means of the analytical solution of laminar flow around a cylinder [16]. The predictions (full line) are compared with the measurements (open symbols) on figures 11 to 17. This boundary layer code performs rather well as far as laminar boundary layers are concerned, both on the suction side and on the pressure side. The weak point remains the prediction of the suction side transition onset. Attempts were made to use more sophisticated two-equation turbulence models provided into the programme [17]. This led to rather disappointing comparisons. More work should be performed in this area from a transition modelling point of view.

7. Downstream loss coefficient and angle distributions

Although the VKI CT-2 facility was originally designed for convective heat transfer measurements only, it is evident that it would also be extremely attractive for aerodynamic performance measurements, if the problems related to the short running time ... 400 ... ms and the relatively high air temperature of 400 ... 500 K could be overcome.

The first problem was solved by designing a fast traversing mechanism, transporting a Pitot probe at a maximum speed of 800 mm/s over at least 2 pitches in a plane parallel to the trailing edge plane. The probe carriage is driven by a pneumatic piston. The traversing speed is controlled by the air supply pressure and choked air bleeds. The position of the probe is measured by a linear variable differential transducer. The frequency response of the complete system was evaluated to be 150 Hz. The second problem was solved by locating the transducer outside of the wind tunnel, taking advantage of the conduction effect in the pneumatic pipe between the head of the probe and the transducer. The probe used with this carriage is a classical total, left/right pressure probe except for the absence of the cone head for the static pressure, which was taken instead from the side wall pressure tappings. The performance and accuracy of the complete system were demonstrated in an earlier paper [18].

Rigorously constant downstream conditions, imperatively needed for this type of measurements, were ensured downstream of the cascade (even with a closed dump tank) by means of a second sonic throat. The total pressure heads of the upstream and downstream Pitot probes were connected respectively to the high and low pressure ports of a National Semi Conductor differential pressure transducer, providing a direct measurement of Δp_{01-02}. The left and right heads of the downstream probe were connected to the two ports of a variable reluctance Valydine differential pressure transducer, providing a measure of Δp_{LR}, proportional to the exit flow angle. The downstream probe was inclined in such a way to have its head located in the same axial plane ($x/c_{ax} = 1.433$) as the wall static pressure tappings already described in section 4. The sampling rate was set at 4 kHz to have a sufficient number of points to resolve the wake. The influence of freestream turbulence has not been considered up to now. All tests were performed for an upstream total temperature of about 415 K . The useful testing time was of the order of 250 ... 300 ms.

Typical examples of measured wakes are shown in figures 27 ($M_{2,is} = 0.85, 1.0$). They correspond from left to right to the wakes of blades 2 and 3 (central blade). The resolution of the deepest point of the wake was confirmed by running different tests with the probe blocked at different positions in this wake, i.e. without being influenced by the frequency response of the system. The loss coefficient was defined as follows :

$$\zeta_2 = 1 - \frac{V_2^2}{V_{2,is}^2}$$

$$\zeta_2 = 1 - \frac{1 - \left(\frac{p_2}{p_{02}}\right)^{\frac{k-1}{k}}}{1 - \left(\frac{p_2}{p_{01}}\right)^{\frac{k-1}{k}}}$$

The downstream integrated loss coefficient distribution (area averaged) of figure 28 was finally obtained as a function of the isentropic exit Mach number. The measurements were performed for three different Reynolds numbers (5.0 10^5, 10^6 and 2.0 10^6). The uncertainty on this loss coefficient was estimated to be 0.2 points. The general level of the losses, measured for 1 % freestream turbulence, is quite low in the subsonic regime. This is explained by the late transition observed for all configurations below $M_{2,is} = 1.0$. Some more confidence in these results was found when comparing them with a classical boundary layer calculation performed by Happel and Ramm [19] at MTU, Germany for $M_{2,is}$ =1.0. This boundary layer program, based on an integral method, predicted boundary layer losses of the order of 1 % . To this number, one should add trailing edge losses, evaluated at 0.75 %, base pressure losses, almost zero in this particular situation and shock losses, estimated at 0.5 %. This reasonnable overall estimation is consistent with the measured value. In the transonic regime,the losses are increasing as expected. No numerical comparison is available in that regime.

Figure 29 presents the exit flow angle distribution as a function of exit Mach number. The measurements were performed for two Reynolds numbers (5.0 10^5 and 10^6). They are compared with the calculated values obtained from the two dimensional inviscid predictions mentioned previously. All these results are tabulated in Appendix 3.

8. Summary - Conclusion

Detailed aerodynamic and convective heat transfer measurements have been obtained on a high pressure turbine nozzle guide vane, looking at the effect of freestream Mach and Reynolds numbers as well as turbulence intensity. The measurements were taken using the VKI short duration compression tube facility and were compared to some extent to the results obtained from in-house available two dimensional inviscid and boundary layer programs.

The aim of this investigation is to provide detailed information about the flowfield in this cascade for operating conditions similar to those observed in real engines in order to allow the evaluation of both advanced inviscid and viscous turbomachinery calculation methods.

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X mm	Y mm	S mm	S/SSS -	S/C -	X mm	Y mm	S mm	S/SPS -	S/C -
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.185	1.554	1.565	0.018	0.023	0.185	-0.913	0.932	0.014	0.014
0.371	2.349	2.381	0.028	0.035	0.371	-1.513	1.560	0.024	0.023
0.556	2.850	2.916	0.034	0.043	0.556	-1.858	1.951	0.030	0.029
0.742	3.298	3.401	0.039	0.050	0.742	-2.086	2.245	0.034	0.033
0.927	3.662	3.809	0.044	0.056	0.927	-2.278	2.512	0.038	0.037
1.113	3.982	4.179	0.048	0.062	1.113	-2.467	2.777	0.042	0.041
1.298	4.267	4.519	0.052	0.067	1.298	-2.649	3.037	0.046	0.045
1.484	4.548	4.856	0.056	0.072	1.484	-2.810	3.283	0.050	0.049
1.669	4.825	5.189	0.060	0.077	1.669	-2.963	3.523	0.054	0.052
1.855	5.099	5.520	0.064	0.082	1.855	-3.112	3.761	0.058	0.056
2.040	5.366	5.845	0.068	0.086	2.040	-3.260	3.998	0.061	0.059
2.226	5.618	6.158	0.071	0.091	2.226	-3.407	4.235	0.065	0.063
2.411	5.859	6.462	0.075	0.096	2.411	-3.554	4.471	0.068	0.066
2.597	6.095	6.762	0.078	0.100	2.597	-3.703	4.710	0.072	0.070
2.782	6.326	7.058	0.082	0.104	2.782	-3.852	4.947	0.076	0.073
2.968	6.549	7.349	0.085	0.109	2.968	-4.001	5.186	0.079	0.077
3.153	6.765	7.633	0.088	0.113	3.153	-4.150	5.423	0.083	0.080
3.339	6.971	7.911	0.091	0.117	3.339	-4.299	5.661	0.087	0.084
3.524	7.166	8.179	0.095	0.121	3.524	-4.448	5.899	0.090	0.087
3.710	7.351	8.442	0.098	0.125	3.710	-4.596	6.137	0.094	0.091
3.895	7.524	8.695	0.101	0.129	3.895	-4.746	6.375	0.098	0.094
4.081	7.688	8.943	0.103	0.132	4.081	-4.895	6.613	0.101	0.098
4.266	7.843	9.184	0.106	0.136	4.266	-5.044	6.851	0.105	0.101
4.452	7.987	9.420	0.109	0.139	4.452	-5.194	7.090	0.108	0.105
4.637	8.122	9.649	0.112	0.143	4.637	-5.343	7.327	0.112	0.108
4.822	8.251	9.874	0.114	0.146	4.822	-5.493	7.565	0.116	0.112
5.008	8.372	10.096	0.117	0.149	5.008	-5.643	7.804	0.119	0.115
5.193	8.486	10.313	0.119	0.152	5.193	-5.793	8.043	0.123	0.119
5.379	8.594	10.528	0.122	0.156	5.379	-5.944	8.282	0.127	0.122
5.564	8.698	10.741	0.124	0.159	5.564	-6.094	8.520	0.130	0.126
5.750	8.798	10.952	0.127	0.162	5.750	-6.245	8.760	0.134	0.129
5.935	8.895	11.161	0.129	0.165	5.935	-6.396	8.999	0.138	0.133
6.121	8.987	11.368	0.131	0.168	6.121	-6.547	9.238	0.141	0.137
6.306	9.077	11.574	0.134	0.171	6.306	-6.699	9.478	0.145	0.140
6.492	9.164	11.779	0.136	0.174	6.492	-6.851	9.718	0.149	0.144
6.677	9.248	11.983	0.139	0.177	6.677	-7.003	9.957	0.152	0.147
6.863	9.326	12.184	0.141	0.180	6.863	-7.156	10.198	0.156	0.151
7.048	9.400	12.383	0.143	0.183	7.048	-7.309	10.438	0.160	0.154
7.234	9.469	12.582	0.146	0.186	7.234	-7.463	10.680	0.163	0.158
7.419	9.533	12.778	0.148	0.189	7.419	-7.616	10.920	0.167	0.161
7.605	9.591	12.972	0.150	0.192	7.605	-7.771	11.162	0.171	0.165
7.790	9.644	13.165	0.152	0.195	7.790	-7.926	11.403	0.174	0.169
7.976	9.691	13.357	0.154	0.197	7.976	-8.081	11.645	0.178	0.172
8.161	9.732	13.546	0.157	0.200	8.161	-8.237	11.887	0.182	0.176

Table 1

X	Y	S	S/SSS	S/C	X	Y	S	S/SPS	S/C
mm	mm	mm	-	-	mm	mm	mm	-	-
8.347	9.770	13.736	0.159	0.203	8.347	-8.393	12.130	0.186	0.179
8.532	9.804	13.924	0.161	0.206	8.532	-8.550	12.373	0.189	0.183
8.718	9.833	14.112	0.163	0.209	8.718	-8.707	12.616	0.193	0.186
8.903	9.859	14.299	0.165	0.211	8.903	-8.865	12.859	0.197	0.190
9.089	9.880	14.486	0.168	0.214	9.089	-9.023	13.103	0.201	0.194
9.274	9.898	14.672	0.170	0.217	9.274	-9.182	13.347	0.204	0.197
9.460	9.912	14.859	0.172	0.220	9.460	-9.342	13.593	0.208	0.201
9.645	9.923	15.044	0.174	0.222	9.645	-9.502	13.837	0.212	0.205
9.830	9.931	15.229	0.176	0.225	9.830	-9.663	14.083	0.216	0.208
10.016	9.936	15.415	0.178	0.228	10.016	-9.824	14.329	0.219	0.212
10.201	9.938	15.600	0.180	0.231	10.201	-9.987	14.575	0.223	0.215
10.387	9.936	15.786	0.183	0.233	10.387	-10.149	14.822	0.227	0.219
10.572	9.932	15.971	0.185	0.236	10.572	-10.313	15.069	0.231	0.223
10.758	9.923	16.158	0.187	0.239	10.758	-10.476	15.316	0.234	0.226
10.943	9.910	16.343	0.189	0.242	10.943	-10.642	15.565	0.238	0.230
11.129	9.893	16.530	0.191	0.244	11.129	-10.809	15.815	0.242	0.234
11.314	9.871	16.716	0.193	0.247	11.314	-10.978	16.065	0.246	0.237
11.500	9.846	16.904	0.196	0.250	11.500	-11.148	16.317	0.250	0.241
11.685	9.816	17.091	0.198	0.253	11.685	-11.320	16.570	0.254	0.245
11.871	9.783	17.280	0.200	0.255	11.871	-11.491	16.823	0.257	0.249
12.056	9.744	17.469	0.202	0.258	12.056	-11.664	17.076	0.261	0.252
12.242	9.701	17.660	0.204	0.261	12.242	-11.837	17.330	0.265	0.256
12.427	9.652	17.852	0.206	0.264	12.427	-12.010	17.583	0.269	0.260
12.613	9.598	18.045	0.209	0.267	12.613	-12.184	17.838	0.273	0.264
12.799	9.538	18.241	0.211	0.270	12.799	-12.358	18.093	0.277	0.267
12.984	9.473	18.437	0.213	0.273	12.984	-12.534	18.348	0.281	0.271
13.169	9.403	18.635	0.216	0.275	13.169	-12.709	18.603	0.285	0.275
13.355	9.331	18.834	0.218	0.278	13.355	-12.885	18.859	0.289	0.279
13.540	9.253	19.035	0.220	0.281	13.540	-13.062	19.115	0.293	0.283
13.726	9.170	19.238	0.223	0.284	13.726	-13.240	19.372	0.296	0.286
13.911	9.082	19.443	0.225	0.287	13.911	-13.418	19.629	0.300	0.290
14.097	8.987	19.652	0.227	0.291	14.097	-13.597	19.887	0.304	0.294
14.282	8.884	19.864	0.230	0.294	14.282	-13.776	20.145	0.308	0.298
14.467	8.774	20.079	0.232	0.297	14.467	-13.956	20.403	0.312	0.302
14.653	8.660	20.297	0.235	0.300	14.653	-14.137	20.662	0.316	0.305
14.838	8.541	20.517	0.237	0.303	14.838	-14.318	20.921	0.320	0.309
15.024	8.417	20.741	0.240	0.307	15.024	-14.501	21.182	0.324	0.313
15.209	8.289	20.966	0.242	0.310	15.209	-14.686	21.444	0.328	0.317
15.395	8.154	21.196	0.245	0.313	15.395	-14.872	21.707	0.332	0.321
15.580	8.013	21.428	0.248	0.317	15.580	-15.058	21.969	0.336	0.325
15.766	7.866	21.665	0.251	0.320	15.766	-15.247	22.234	0.340	0.329
15.951	7.713	21.905	0.253	0.324	15.951	-15.436	22.499	0.344	0.333
16.137	7.554	22.150	0.256	0.327	16.137	-15.627	22.765	0.348	0.337
16.322	7.392	22.396	0.259	0.331	16.322	-15.819	23.032	0.352	0.340
16.508	7.226	22.645	0.262	0.335	16.508	-16.012	23.300	0.357	0.344

Table 1

X	Y	S	S/SSS	S/C	X	Y	S	S/SPS	S/C
mm	mm	mm	-	-	mm	mm	mm	-	-
16.693	7.053	22.899	0.265	0.339	16.693	-16.208	23.569	0.361	0.348
16.879	6.874	23.157	0.268	0.342	16.879	-16.405	23.840	0.365	0.352
17.064	6.686	23.420	0.271	0.346	17.064	-16.603	24.111	0.369	0.356
17.250	6.490	23.691	0.274	0.350	17.250	-16.803	24.384	0.373	0.360
17.436	6.287	23.966	0.277	0.354	17.436	-17.005	24.659	0.377	0.365
17.621	6.078	24.245	0.280	0.358	17.621	-17.208	24.934	0.382	0.369
17.806	5.864	24.528	0.284	0.363	17.806	-17.412	25.209	0.386	0.373
17.992	5.645	24.815	0.287	0.367	17.992	-17.619	25.487	0.390	0.377
18.177	5.422	25.105	0.290	0.371	18.177	-17.828	25.766	0.394	0.381
18.363	5.190	25.402	0.294	0.376	18.363	-18.038	26.047	0.399	0.385
18.548	4.951	25.705	0.297	0.380	18.548	-18.250	26.328	0.403	0.389
18.734	4.705	26.013	0.301	0.385	18.734	-18.465	26.613	0.407	0.393
18.919	4.452	26.326	0.304	0.389	18.919	-18.681	26.897	0.412	0.398
19.105	4.195	26.644	0.308	0.394	19.105	-18.899	27.184	0.416	0.402
19.290	3.933	26.964	0.312	0.399	19.290	-19.120	27.472	0.420	0.406
19.475	3.665	27.290	0.316	0.403	19.475	-19.342	27.761	0.425	0.410
19.661	3.392	27.620	0.319	0.408	19.661	-19.567	28.053	0.429	0.415
19.846	3.112	27.956	0.323	0.413	19.846	-19.794	28.346	0.434	0.419
20.032	2.824	28.299	0.327	0.418	20.032	-20.022	28.640	0.438	0.423
20.217	2.528	28.648	0.331	0.423	20.217	-20.254	28.937	0.443	0.428
20.403	2.226	29.003	0.335	0.429	20.403	-20.488	29.235	0.447	0.432
20.588	1.917	29.363	0.340	0.434	20.588	-20.724	29.535	0.452	0.437
20.774	1.602	29.729	0.344	0.439	20.774	-20.963	29.838	0.457	0.441
20.959	1.282	30.098	0.348	0.445	20.959	-21.204	30.142	0.461	0.446
21.145	0.956	30.474	0.352	0.450	21.145	-21.447	30.448	0.466	0.450
21.330	0.623	30.854	0.357	0.456	21.330	-21.694	30.757	0.471	0.455
21.516	0.284	31.241	0.361	0.462	21.516	-21.943	31.067	0.475	0.459
21.701	-0.062	31.634	0.366	0.468	21.701	-22.195	31.380	0.480	0.464
21.887	-0.415	32.033	0.370	0.474	21.887	-22.449	31.695	0.485	0.469
22.073	-0.772	32.435	0.375	0.479	22.073	-22.707	32.013	0.490	0.473
22.258	-1.135	32.842	0.380	0.485	22.258	-22.966	32.331	0.495	0.478
22.444	-1.503	33.255	0.385	0.492	22.444	-23.229	32.653	0.500	0.483
22.629	-1.880	33.675	0.389	0.498	22.629	-23.496	32.978	0.505	0.488
22.814	-2.266	34.103	0.394	0.504	22.814	-23.764	33.304	0.510	0.492
23.000	-2.663	34.541	0.399	0.511	23.000	-24.036	33.633	0.515	0.497
23.185	-3.068	34.986	0.405	0.517	23.185	-24.312	33.966	0.520	0.502
23.371	-3.480	35.439	0.410	0.524	23.371	-24.591	34.301	0.525	0.507
23.556	-3.896	35.894	0.415	0.531	23.556	-24.872	34.637	0.530	0.512
23.742	-4.314	36.351	0.420	0.537	23.742	-25.157	34.978	0.535	0.517
23.927	-4.735	36.811	0.426	0.544	23.927	-25.445	35.320	0.540	0.522
24.112	-5.163	37.277	0.431	0.551	24.112	-25.737	35.666	0.546	0.527
24.298	-5.598	37.751	0.437	0.558	24.298	-26.032	36.014	0.551	0.532
24.483	-6.043	38.232	0.442	0.565	24.483	-26.331	36.366	0.556	0.538
24.669	-6.501	38.727	0.448	0.572	24.669	-26.634	36.722	0.562	0.543
24.854	-6.971	39.232	0.454	0.580	24.854	-26.941	37.080	0.567	0.548

Table 1

X	Y	S	S/SSS	S/C	X	Y	S	S/SPS	S/C
mm	mm	mm	-	-	mm	mm	mm	-	-
25.040	-7.448	39.744	0.460	0.588	25.040	-27.250	37.441	0.573	0.553
25.225	-7.929	40.259	0.466	0.595	25.225	-27.562	37.803	0.578	0.559
25.411	-8.417	40.781	0.472	0.603	25.411	-27.877	38.169	0.584	0.564
25.596	-8.911	41.309	0.478	0.611	25.596	-28.197	38.539	0.590	0.570
25.782	-9.415	41.846	0.484	0.619	25.782	-28.521	38.912	0.595	0.575
25.967	-9.929	42.392	0.490	0.627	25.967	-28.850	39.290	0.601	0.581
26.153	-10.453	42.949	0.497	0.635	26.153	-29.185	39.673	0.607	0.586
26.338	-10.988	43.515	0.503	0.643	26.338	-29.525	40.060	0.613	0.592
26.524	-11.532	44.090	0.510	0.652	26.524	-29.869	40.451	0.619	0.598
26.710	-12.085	44.673	0.517	0.660	26.710	-30.215	40.844	0.625	0.604
26.895	-12.647	45.265	0.524	0.669	26.895	-30.567	41.242	0.631	0.610
27.081	-13.217	45.864	0.530	0.678	27.081	-30.921	41.642	0.637	0.616
27.266	-13.798	46.474	0.538	0.687	27.266	-31.280	42.045	0.643	0.622
27.451	-14.389	47.093	0.545	0.696	27.451	-31.643	42.453	0.650	0.628
27.637	-14.986	47.719	0.552	0.705	27.637	-32.012	42.866	0.656	0.634
27.822	-15.591	48.351	0.559	0.715	27.822	-32.385	43.282	0.662	0.640
28.008	-16.202	48.990	0.567	0.724	28.008	-32.763	43.704	0.669	0.646
28.193	-16.821	49.636	0.574	0.734	28.193	-33.145	44.128	0.675	0.652
28.379	-17.445	50.287	0.582	0.743	28.379	-33.532	44.557	0.682	0.659
28.564	-18.076	50.945	0.589	0.753	28.564	-33.924	44.991	0.688	0.665
28.750	-18.713	51.608	0.597	0.763	28.750	-34.322	45.430	0.695	0.672
28.935	-19.358	52.279	0.605	0.773	28.935	-34.724	45.873	0.702	0.678
29.120	-20.009	52.956	0.612	0.783	29.120	-35.133	46.322	0.709	0.685
29.306	-20.665	53.638	0.620	0.793	29.306	-35.546	46.775	0.716	0.691
29.491	-21.327	54.325	0.628	0.803	29.491	-35.964	47.232	0.723	0.698
29.677	-21.992	55.016	0.636	0.813	29.677	-36.387	47.694	0.730	0.705
29.862	-22.664	55.713	0.644	0.824	29.862	-36.816	48.161	0.737	0.712
30.048	-23.344	56.418	0.653	0.834	30.048	-37.250	48.633	0.744	0.719
30.233	-24.034	57.132	0.661	0.845	30.233	-37.690	49.111	0.752	0.726
30.419	-24.735	57.857	0.669	0.855	30.419	-38.136	49.594	0.759	0.733
30.604	-25.445	58.591	0.678	0.866	30.604	-38.586	50.080	0.766	0.740
30.790	-26.162	59.332	0.686	0.877	30.790	-39.042	50.573	0.774	0.748
30.975	-26.886	60.079	0.695	0.888	30.975	-39.506	51.072	0.782	0.755
31.161	-27.615	60.831	0.704	0.899	31.161	-39.978	51.580	0.789	0.762
31.347	-28.347	61.587	0.712	0.910	31.347	-40.456	52.093	0.797	0.770
31.532	-29.083	62.346	0.721	0.922	31.532	-40.938	52.609	0.805	0.778
31.718	-29.823	63.109	0.730	0.933	31.718	-41.422	53.127	0.813	0.785
31.903	-30.566	63.874	0.739	0.944	31.903	-41.909	53.648	0.821	0.793
32.089	-31.312	64.643	0.748	0.956	32.089	-42.398	54.171	0.829	0.801
32.274	-32.064	65.418	0.757	0.967	32.274	-42.890	54.697	0.837	0.809
32.459	-32.820	66.196	0.766	0.979	32.459	-43.387	55.227	0.845	0.816
32.645	-33.585	66.983	0.775	0.990	32.645	-43.891	55.765	0.853	0.824
32.830	-34.362	67.782	0.784	1.002	32.830	-44.395	56.301	0.862	0.832
33.016	-35.130	68.572	0.793	1.014	33.016	-44.901	56.841	0.870	0.840
33.201	-35.897	69.361	0.802	1.025	33.201	-45.405	57.377	0.878	0.848

Table 1

X	Y	S	S/SSS	S/C	X	Y	S	S/SPS	S/C
mm	mm	mm	-	-	mm	mm	mm	-	-
33.387	-36.665	70.151	0.811	1.037	33.387	-45.911	57.917	0.886	0.856
33.572	-37.432	70.940	0.820	1.049	33.572	-46.416	58.454	0.895	0.864
33.757	-38.198	71.728	0.830	1.060	33.757	-46.920	58.991	0.903	0.872
33.943	-38.966	72.518	0.839	1.072	33.943	-47.426	59.530	0.911	0.880
34.128	-39.732	73.306	0.848	1.084	34.128	-47.930	60.067	0.919	0.888
34.314	-40.501	74.098	0.857	1.095	34.314	-48.436	60.606	0.927	0.896
34.499	-41.267	74.886	0.866	1.107	34.499	-48.940	61.143	0.936	0.904
34.685	-42.036	75.677	0.875	1.119	34.685	-49.446	61.682	0.944	0.912
34.870	-42.802	76.465	0.884	1.130	34.870	-49.950	62.219	0.952	0.920
35.056	-43.571	77.256	0.894	1.142	35.056	-50.457	62.759	0.960	0.928
35.241	-44.337	78.044	0.903	1.154	35.241	-50.961	63.296	0.969	0.936
35.427	-45.103	78.832	0.912	1.165	35.427	-51.465	63.833	0.977	0.944
35.612	-45.872	79.623	0.921	1.177	35.560	-51.829	64.221	0.983	0.949
35.798	-46.637	80.411	0.930	1.189	35.612	-51.958	64.360	0.985	0.951
35.984	-47.406	81.202	0.939	1.200	35.715	-52.087	64.525	0.987	0.954
36.169	-48.172	81.990	0.948	1.212	35.882	-52.235	64.748	0.991	0.957
36.355	-48.941	82.781	0.957	1.224	36.075	-52.312	64.956	0.994	0.960
36.540	-49.707	83.569	0.967	1.235	36.268	-52.344	65.152	0.997	0.963
36.726	-50.476	84.360	0.976	1.247	36.461	-52.305	65.349	1.000	0.966
36.975	-51.508	85.422	0.988	1.263					
36.985	-51.637	85.551	0.989	1.265					
36.975	-51.765	85.680	0.991	1.267					
36.898	-51.958	85.887	0.993	1.270					
36.814	-52.087	86.041	0.995	1.272					
36.654	-52.228	86.255	0.998	1.275					
36.461	-52.305	86.462	1.000	1.278					

Table 1
Manufacturing coordinates

	X [mm]	Y [mm]	S [mm]	S/C [-]
1	0.	0.	0.	0.
2	0.293	2.078	2.100	0.031
3	1.051	3.880	4.060	0.060
4	5.070	8.411	10.170	0.150
5	11.500	9.846	16.904	0.250
6	14.653	8.660	20.298	0.300
7	17.250	6.490	23.691	0.350
8	19.336	3.867	27.046	0.400
9	22.690	-2.008	33.817	0.500
10	24.854	-6.971	39.232	0.580
11	26.037	-10.124	42.600	0.630
12	27.122	-13.346	46.000	0.680
13	28.509	-17.886	50.747	0.750
14	29.435	-21.127	54.118	0.800
15	30.326	-24.382	57.493	0.850
16	31.996	-30.940	64.260	0.950
17	33.589	-37.501	71.012	1.050
18	35.179	-44.080	77.780	1.150
19	36.355	-48.941	82.781	1.224
20	36.461	-52.305	86.463	1.278/0.966
21	33.757	-46.920	58.991	0.872
22	29.544	-36.083	47.362	0.700
23	23.111	-24.202	33.833	0.500
24	14.375	-13.866	20.274	0.300
25	6.816	-7.118	10.138	0.150
26	2.087	-3.296	4.057	0.060
27	0.603	-1.918	2.027	0.030

Table 2
Position of blade static pressure tappings

	X [mm]	Y [mm]	S [mm]	S/C [-]
1	0.	0.	0.	0.
2	0.177	1.511	1.521	0.022
3	0.787	3.393	3.506	0.052
4	2.132	5.493	6.002	0.089
5	4.444	7.981	9.410	0.139
6	7.450	9.542	12.810	0.189
7	10.820	9.919	16.220	0.239
8	14.078	8.997	19.630	0.290
9	16.796	6.954	23.042	0.341
10	18.986	4.360	26.440	0.391
11	20.835	1.498	29.849	0.445
12	22.446	-1.509	33.261	0.492
13	23.866	-4.596	36.659	0.542
14	25.157	-7.751	40.068	0.592
15	26.326	-10.954	43.478	0.643
16	27.387	-14.185	46.879	0.693
17	28.380	-17.448	50.291	0.743
18	29.323	-20.724	53.699	0.794
19	30.224	-24.001	57.098	0.844
20	31.082	-27.303	60.510	0.894
21	31.914	-30.612	63.921	0.945
22	32.725	-33.923	67.330	0.995
23	33.523	-37.228	70.730	1.046
24	34.324	-40.542	74.140	1.096
25	35.125	-43.855	77.548	1.146
26	35.924	-47.160	80.948	1.197
27	36.726	-50.476	84.360	1.247
28	35.242	-50.963	63.299	0.936
29	33.926	-47.378	59.480	0.879
30	32.609	-43.793	55.661	0.823
31	31.256	-40.221	51.841	0.766
32	29.806	-36.685	48.019	0.710
33	28.224	-33.209	44.200	0.653
34	26.490	-29.806	40.380	0.597
35	24.584	-26.495	36.559	0.540
36	22.494	-23.301	32.741	0.484
37	20.206	-20.240	28.920	0.428
38	17.733	-17.332	25.101	0.371
39	15.093	-14.569	21.279	0.315
40	12.337	-11.926	17.460	0.258
41	9.496	-9.373	13.641	0.202
42	6.571	-6.916	9.821	0.145
43	3.603	-4.511	6.000	0.089
44	1.651	-2.948	3.500	0.052
45	0.353	-1.471	1.515	0.022

Table 3
Position of platinum thin films

APPENDIX 1

Tabulated velocity distributions results

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR43

Free stream conditions :

Total inlet pressure (bar) : 1.435
Isentropic outlet Mach number : 0.84
Outlet Reynolds number : 1E+06

Blade velocity distribution

Suction side			Pressure side		
S	P	Mis	S	P	Mis
mm	bar	-	mm	bar	-
0.000	1.435	0.000	2.027	1.427	0.084
2.100	1.417	0.131	4.057	1.424	0.102
4.060	1.401	0.184	10.138	1.414	0.143
10.170	1.261	0.433	20.274	1.407	0.164
16.904	1.046	0.687	33.833	1.386	0.221
20.298	0.933	0.809	47.362	1.299	0.379
23.691	0.894	0.851	58.991	1.098	0.630
27.046	0.882	0.863			
33.817	0.837	0.912			
39.232	0.811	0.940			
42.600	0.799	0.953			
46.000	0.790	0.964			
50.747	0.807	0.945			
54.118	0.808	0.944			
57.493	0.816	0.935			
64.260	0.845	0.903			
71.012	0.866	0.881			
77.780	0.874	0.872			
82.781	0.857	0.890			
86.463	0.936	0.806			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR44

Free stream conditions :

Total inlet pressure (bar) : 1.433
Isentropic outlet Mach number : 0.840
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side			Pressure side		
S	P	Mis	S	P	Mis
mm	bar	-	mm	bar	-
0.000	1.437	0.000	2.027	1.428	0.074
2.100	1.418	0.123	4.057	1.424	0.097
4.060	1.401	0.180	10.138	1.413	0.141
10.170	1.262	0.430	20.274	1.405	0.170
16.904	1.048	0.684	33.833	1.387	0.218
20.298	0.933	0.808	47.362	1.301	0.375
23.691	0.895	0.849	58.991	1.099	0.628
27.046	0.882	0.863			
33.817	0.837	0.911			
39.232	0.811	0.940			
42.600	0.799	0.953			
46.000	0.789	0.964			
50.747	0.807	0.945			
54.118	0.808	0.944			
57.493	0.816	0.935			
64.260	0.844	0.903			
71.012	0.866	0.880			
77.780	0.874	0.871			
82.781	0.857	0.889			
86.463	0.935	0.805			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR45

Free stream conditions :

Total inlet pressure (bar) : 1.475
Isentropic outlet Mach number : 0.875
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side			Pressure side		
S	P	Mis	S	P	Mis
mm	bar	-	mm	bar	-
0.000	1.487	0.000	2.027	1.479	0.000
2.100	1.469	0.077	4.057	1.474	0.031
4.060	1.451	0.155	10.138	1.467	0.090
10.170	1.302	0.426	20.274	1.457	0.135
16.904	1.074	0.689	33.833	1.436	0.198
20.298	0.947	0.821	47.362	1.344	0.368
23.691	0.908	0.862	58.991	1.124	0.636
27.046	0.898	0.873			
33.817	0.834	0.941			
39.232	0.804	0.973			
42.600	0.782	0.997			
46.000	0.764	1.017			
50.747	0.760	1.022			
54.118	0.777	1.003			
57.493	0.793	0.985			
64.260	0.833	0.942			
71.012	0.858	0.915			
77.780	0.875	0.897			
82.781	0.856	0.917			
86.463	0.949	0.820			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR46

Free stream conditions :

Total inlet pressure (bar) : 1.478
Isentropic outlet Mach number : 0.875
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side			Pressure side		
S	P	Mis	S	P	Mis
mm	bar	-	mm	bar	-
0.000	1.487	0.000	2.027	1.478	0.000
2.100	1.469	0.094	4.057	1.474	0.066
4.060	1.450	0.165	10.138	1.466	0.107
10.170	1.302	0.429	20.274	1.456	0.145
16.904	1.075	0.690	33.833	1.435	0.205
20.298	0.948	0.823	47.362	1.344	0.372
23.691	0.909	0.863	58.991	1.125	0.637
27.046	0.899	0.874			
33.817	0.835	0.941			
39.232	0.804	0.975			
42.600	0.783	0.997			
46.000	0.765	1.018			
50.747	0.755	1.028			
54.118	0.779	1.002			
57.493	0.794	0.985			
64.260	0.832	0.944			
71.012	0.859	0.916			
77.780	0.876	0.897			
82.781	0.858	0.917			
86.463	0.950	0.820			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR47

Free stream conditions :

Total inlet pressure (bar) : 1.596
Isentropic outlet Mach number : 1.020
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side

S	P	Mis
mm	bar	-
0.000	1.604	0.000
2.100	1.587	0.088
4.060	1.565	0.167
10.170	1.398	0.438
16.904	1.146	0.704
20.298	1.001	0.844
23.691	0.951	0.892
27.046	0.937	0.907
33.817	0.837	1.006
39.232	0.799	1.045
42.600	0.779	1.066
46.000	0.743	1.105
50.747	0.710	1.141
54.118	0.672	1.183
57.493	0.644	1.216
64.260	0.655	1.203
71.012	0.774	1.071
77.780	0.882	0.960
82.781	0.844	0.999
86.463	0.969	0.875

Pressure side

S	P	Mis
mm	bar	-
2.027	1.594	0.036
4.057	1.593	0.049
10.138	1.583	0.107
20.274	1.572	0.145
33.833	1.548	0.209
47.362	1.446	0.378
58.991	1.194	0.657

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR48

Free stream conditions :

Total inlet pressure (bar) : 1.605
Isentropic outlet Mach number : 1.020
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side

S	P	Mis
mm	bar	-
0.000	1.613	0.000
2.100	1.596	0.092
4.060	1.573	0.171
10.170	1.404	0.441
16.904	1.151	0.706
20.298	1.007	0.844
23.691	0.956	0.894
27.046	0.941	0.908
33.817	0.837	1.011
39.232	0.795	1.055
42.600	0.779	1.071
46.000	0.742	1.110
50.747	0.708	1.148
54.118	0.669	1.192
57.493	0.639	1.227
64.260	0.642	1.223
71.012	0.715	1.140
77.780	0.887	0.961
82.781	0.850	0.998
86.463	0.973	0.877

Pressure side

S	P	Mis
mm	bar	-
2.027	1.602	0.059
4.057	1.601	0.058
10.138	1.591	0.116
20.274	1.580	0.151
33.833	1.556	0.212
47.362	1.453	0.380
58.991	1.200	0.658

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR49

Free stream conditions :

Total inlet pressure (bar) : 1.608
Isentropic outlet Mach number : 1.020
Outlet Reynolds number : 1.E+06

Blade velocity distribution

Suction side			Pressure side		
S	P	Mis	S	P	Mis
mm	bar	-	mm	bar	-
0.000	1.612	0.000	2.027	1.603	0.067
2.100	1.592	0.120	4.057	1.600	0.082
4.060	1.570	0.185	10.138	1.589	0.130
10.170	1.403	0.446	20.274	1.581	0.157
16.904	1.147	0.711	33.833	1.556	0.217
20.298	1.004	0.849	47.362	1.451	0.386
23.691	0.954	0.897	58.991	1.199	0.661
27.046	0.937	0.913			
33.817	0.837	1.013			
39.232	0.799	1.051			
42.600	0.780	1.071			
46.000	0.745	1.109			
50.747	0.712	1.144			
54.118	0.671	1.191			
57.493	0.642	1.225			
64.260	0.648	1.218			
71.012	0.806	1.045			
77.780	0.886	0.963			
82.781	0.847	1.002			
86.463	0.970	0.881			

APPENDIX 2

Tabulated heat transfer results

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR241

Measured parameters :

Total temperature (K) :	416.40
Total inlet pressure (bar) :	3.257
Static inlet pressure (bar) :	3.207
Static outlet pressure (bar) :	1.547
Wall temperature (K) :	299.75
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	416.40	
Total pressure (bar) :	3.257	
Mach number (-) :	0.150	1.089
Reynolds number (-) :	4.6740E+05	2.1139E+06
Temperature (K) :	414.53	336.57
Pressure (bar) :	3.207	1.547
Density (Kg/m**3) :	2.694	1.600
Velocity (m/s) :	61.23	400.54
Dynamic viscosity (kg/m.s) :	2.3876E-05	2.0515E-05
Kinematic viscosity (m2/s) :	8.8616E-06	1.2818E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR241

Wall heat flux distribution

Suction side			Pressure side		
S mm	Q W/cm2	H W/m2K	S mm	Q W/cm2	H W/m2K
0.000	11.896	1019.8			
1.521	10.621	910.5	1.515	11.506	986.4
3.506	9.839	843.5	3.500	7.848	672.8
6.002	9.009	772.3	6.000	6.575	563.7
9.410	8.927	765.3	9.821	5.902	506.0
12.810	8.426	722.3	13.641	5.703	488.9
16.220	7.452	638.8	17.460	5.791	496.4
19.630	6.526	559.5	21.279	5.935	508.8
23.042	5.272	452.0	25.101	0.000	0.0
26.440	4.820	413.2	28.920	6.700	574.4
29.849	5.075	435.1	32.741	7.086	607.5
33.261	5.278	452.5	36.559	7.501	643.0
36.659	5.176	443.7	40.380	8.060	691.0
40.068	4.703	403.2	44.200	8.648	741.4
43.478	6.100	522.9	48.019	9.437	809.0
46.879	7.323	627.8	51.841	0.000	0.0
50.291	8.095	694.0	55.661	11.095	951.1
53.699	8.585	736.0	59.480	11.687	1001.9
57.098	8.703	746.1	63.299	10.487	899.0
60.510	8.712	746.8			
63.921	8.655	742.0			
67.330	8.490	727.8			
70.730	8.435	723.1			
74.140	8.330	714.1			
77.548	8.505	729.1			
80.948	9.872	846.3			
84.360	9.084	778.7			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR239

Measured parameters :

Total temperature (K) :	411.90
Total inlet pressure (bar) :	3.387
Static inlet pressure (bar) :	3.335
Static outlet pressure (bar) :	1.955
Wall temperature (K) :	301.15
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	411.90	
Total pressure (bar) :	3.387	
Mach number (-) :	0.150	0.922
Reynolds number (-) :	4.9250E+05	2.1397E+06
Temperature (K) :	410.05	352.05
Pressure (bar) :	3.335	1.955
Density (Kg/m**3) :	2.832	1.934
Velocity (m/s) :	60.90	346.83
Dynamic viscosity (kg/m.s) :	2.3692E-05	2.1211E-05
Kinematic viscosity (m2/s) :	8.3645E-06	1.0965E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR239

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	11.675	1054.2
1.521	10.424	941.2
3.506	9.635	870.0
6.002	8.817	796.1
9.410	8.747	789.8
12.810	8.271	746.8
16.220	7.333	662.1
19.630	6.442	581.7
23.042	5.220	471.3
26.440	4.802	433.6
29.849	5.132	463.4
33.261	5.493	496.0
36.659	5.915	534.1
40.068	6.914	624.3
43.478	7.955	718.3
46.879	8.636	779.8
50.291	9.222	832.7
53.699	9.884	892.5
57.098	10.435	942.2
60.510	11.280	1018.5
63.921	12.259	1106.9
67.330	12.301	1110.7
70.730	12.144	1096.5
74.140	12.057	1088.7
77.548	11.910	1075.4
80.948	11.819	1067.2
84.360	11.412	1030.4

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	11.372	1026.8
3.500	7.766	701.2
6.000	6.509	587.7
9.821	5.845	527.8
13.641	5.658	510.9
17.460	5.762	520.3
21.279	5.913	533.9
25.101	0.000	0.0
28.920	6.681	603.3
32.741	7.068	638.2
36.559	7.485	675.8
40.380	8.048	726.7
44.200	8.676	783.4
48.019	9.515	859.1
51.841	0.000	0.0
55.661	11.249	1015.7
59.480	11.893	1073.9
63.299	10.943	988.1

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR245

Measured parameters :

Total temperature (K) :	412.60
Total inlet pressure (bar) :	3.384
Static inlet pressure (bar) :	3.331
Static outlet pressure (bar) :	1.949
Wall temperature (K) :	300.75
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	412.60	
Total pressure (bar) :	3.384	
Mach number (-) :	0.150	0.924
Reynolds number (-) :	4.9092E+05	2.1343E+06
Temperature (K) :	410.75	352.42
Pressure (bar) :	3.331	1.949
Density (Kg/m**3) :	2.824	1.926
Velocity (m/s) :	60.95	347.76
Dynamic viscosity (kg/m.s) :	2.3721E-05	2.1228E-05
Kinematic viscosity (m2/s) :	8.3985E-06	1.1022E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR245

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	10.598	947.5
1.521	9.595	857.8
3.506	8.953	800.4
6.002	8.175	730.9
9.410	8.116	725.6
12.810	7.648	683.8
16.220	6.797	607.7
19.630	5.977	534.4
23.042	4.806	429.7
26.440	4.305	384.9
29.849	4.323	386.5
33.261	4.286	383.2
36.659	4.003	357.9
40.068	4.014	358.9
43.478	4.249	379.9
46.879	4.406	393.9
50.291	4.402	393.6
53.699	4.604	411.6
57.098	4.751	424.8
60.510	6.250	558.8
63.921	10.949	978.9
67.330	13.591	1215.1
70.730	13.590	1215.0
74.140	13.114	1172.5
77.548	12.708	1136.2
80.948	12.456	1113.6
84.360	11.918	1065.5

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	10.304	921.2
3.500	6.856	613.0
6.000	5.593	500.0
9.821	4.812	430.2
13.641	4.485	401.0
17.460	4.437	396.7
21.279	4.483	400.8
25.101	0.000	0.0
28.920	5.289	472.9
32.741	5.827	521.0
36.559	6.351	567.8
40.380	7.008	626.6
44.200	7.690	687.5
48.019	8.550	764.4
51.841	0.000	0.0
55.661	10.331	923.6
59.480	11.021	985.3
63.299	10.282	919.3

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR243

Measured parameters :

Total temperature (K) :	414.70
Total inlet pressure (bar) :	3.260
Static inlet pressure (bar) :	3.210
Static outlet pressure (bar) :	1.531
Wall temperature (K) :	301.45
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	414.70	
Total pressure (bar) :	3.260	
Mach number (-) :	0.150	1.098
Reynolds number (-) :	4.7016E+05	2.1289E+06
Temperature (K) :	412.84	334.13
Pressure (bar) :	3.210	1.531
Density (Kg/m**3) :	2.708	1.596
Velocity (m/s) :	61.10	402.39
Dynamic viscosity (kg/m.s) :	2.3807E-05	2.0403E-05
Kinematic viscosity (m2/s) :	8.7917E-06	1.2786E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR243

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	10.661	941.4
1.521	9.666	853.5
3.506	9.012	795.8
6.002	8.224	726.2
9.410	8.186	722.8
12.810	7.729	682.5
16.220	6.863	606.0
19.630	6.024	531.9
23.042	4.830	426.5
26.440	4.310	380.6
29.849	4.306	380.2
33.261	4.254	375.6
36.659	3.901	344.5
40.068	3.107	274.3
43.478	3.359	296.6
46.879	3.867	341.5
50.291	4.021	355.1
53.699	4.332	382.5
57.098	4.491	396.6
60.510	4.537	400.6
63.921	4.563	402.9
67.330	4.725	417.2
70.730	4.872	430.2
74.140	4.923	434.7
77.548	5.530	488.3
80.948	9.485	837.5
84.360	10.895	962.0

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	10.344	913.4
3.500	6.869	606.5
6.000	5.617	496.0
9.821	4.831	426.6
13.641	4.496	397.0
17.460	4.445	392.5
21.279	4.487	396.2
25.101	0.000	0.0
28.920	5.275	465.8
32.741	5.825	514.3
36.559	6.332	559.1
40.380	6.991	617.3
44.200	7.642	674.8
48.019	8.474	748.3
51.841	0.000	0.0
55.661	10.189	899.7
59.480	10.823	955.7
63.299	9.764	862.2

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR116

Measured parameters :

Total temperature (K) :	418.90
Total inlet pressure (bar) :	3.269
Static inlet pressure (bar) :	3.213
Static outlet pressure (bar) :	1.550
Wall temperature (K) :	297.55
Free stream turbulence (%) :	0.8
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	418.90	
Total pressure (bar) :	3.269	
Mach number (-) :	0.157	1.090
Reynolds number (-) :	4.8694E+05	2.1059E+06
Temperature (K) :	416.85	338.47
Pressure (bar) :	3.213	1.550
Density (Kg/m**3) :	2.685	1.595
Velocity (m/s) :	64.26	402.04
Dynamic viscosity (kg/m.s) :	2.3970E-05	2.0601E-05
Kinematic viscosity (m2/s) :	8.9278E-06	1.2915E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR116

Wall heat flux distribution

Suction side			Pressure side		
S mm	Q W/cm2	H W/m2K	S mm	Q W/cm2	H W/m2K
0.000	0.000	0.0			
1.521	8.404	692.5	1.515	9.142	753.4
3.506	7.829	645.2	3.500	5.803	478.2
6.002	7.171	590.9	6.000	4.565	376.2
9.410	7.274	599.4	9.821	3.721	306.6
12.810	7.038	580.0	13.641	3.400	280.2
16.220	6.413	528.5	17.460	3.218	265.2
19.630	5.712	470.7	21.279	3.076	253.5
23.042	4.609	379.8	25.101	2.989	246.3
26.440	4.247	350.0	28.920	3.031	249.8
29.849	4.427	364.8	32.741	3.147	259.3
33.261	4.391	361.8	36.559	3.275	269.9
36.659	4.167	343.4	40.380	3.537	291.5
40.068	3.548	292.4	44.200	3.773	310.9
43.478	3.671	302.5	48.019	4.063	334.8
46.879	4.048	333.6	51.841	4.278	352.5
50.291	4.197	345.9	55.661	4.379	360.9
53.699	4.295	353.9	59.480	4.225	348.2
57.098	4.488	369.8	63.299	4.079	336.1
60.510	4.563	376.0			
63.921	4.848	399.5			
67.330	4.994	411.5			
70.730	5.404	445.3			
74.140	5.590	460.7			
77.548	5.885	485.0			
80.948	10.292	848.1			
84.360	11.137	917.8			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR247

Measured parameters :

Total temperature (K) :	416.20
Total inlet pressure (bar) :	3.395
Static inlet pressure (bar) :	3.342
Static outlet pressure (bar) :	1.960
Wall temperature (K) :	302.15
Free stream turbulence (%) :	1.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	416.20	
Total pressure (bar) :	3.395	
Mach number (-) :	0.150	0.922
Reynolds number (-) :	4.8743E+05	2.1171E+06
Temperature (K) :	414.34	355.72
Pressure (bar) :	3.342	1.960
Density (Kg/m**3) :	2.810	1.919
Velocity (m/s) :	61.21	348.63
Dynamic viscosity (kg/m.s) :	2.3868E-05	2.1374E-05
Kinematic viscosity (m2/s) :	8.4954E-06	1.1140E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR247

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	9.120	799.6
1.521	8.159	715.4
3.506	7.617	667.9
6.002	6.984	612.4
9.410	7.089	621.6
12.810	6.861	601.6
16.220	6.278	550.5
19.630	5.616	492.4
23.042	4.582	401.8
26.440	4.111	360.5
29.849	4.089	358.5
33.261	4.019	352.4
36.659	3.643	319.4
40.068	3.510	307.8
43.478	3.630	318.3
46.879	3.678	322.5
50.291	3.458	303.2
53.699	3.442	301.8
57.098	3.114	273.0
60.510	3.282	287.8
63.921	6.872	602.5
67.330	14.866	1303.5
70.730	15.401	1350.4
74.140	14.105	1236.7
77.548	13.214	1158.6
80.948	13.204	1157.7
84.360	12.694	1113.0

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	8.922	782.3
3.500	5.686	498.6
6.000	4.489	393.6
9.821	3.710	325.3
13.641	3.332	292.2
17.460	3.146	275.8
21.279	3.000	263.0
25.101	0.000	0.0
28.920	2.991	262.3
32.741	3.119	273.5
36.559	3.267	286.5
40.380	3.523	308.9
44.200	3.764	330.0
48.019	4.015	352.0
51.841	0.000	0.0
55.661	4.381	384.1
59.480	4.367	382.9
63.299	4.300	377.0

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR232

Measured parameters :

Total temperature (K) :	413.20
Total inlet pressure (bar) :	1.673
Static inlet pressure (bar) :	1.646
Static outlet pressure (bar) :	0.822
Wall temperature (K) :	298.45
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	413.20	
Total pressure (bar) :	1.673	
Mach number (-) :	0.150	1.061
Reynolds number (-) :	2.4224E+05	1.0915E+06
Temperature (K) :	411.35	337.27
Pressure (bar) :	1.646	0.822
Density (Kg/m**3) :	1.394	0.849
Velocity (m/s) :	60.99	390.65
Dynamic viscosity (kg/m.s) :	2.3745E-05	2.0546E-05
Kinematic viscosity (m2/s) :	1.7033E-05	2.4212E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR232

Wall heat flux distribution

Suction side			Pressure side		
S mm	Q W/cm2	H W/m2K	S mm	Q W/cm2	H W/m2K
0.000	8.711	759.1			
1.521	7.822	681.7	1.515	8.473	738.4
3.506	7.249	631.7	3.500	5.659	493.2
6.002	6.610	576.0	6.000	4.648	405.1
9.410	6.576	573.1	9.821	4.036	351.7
12.810	6.195	539.9	13.641	3.764	328.0
16.220	5.476	477.2	17.460	3.672	320.0
19.630	4.803	418.6	21.279	3.608	314.4
23.042	3.767	328.3	25.101	0.000	0.0
26.440	3.298	287.4	28.920	3.826	333.4
29.849	3.241	282.4	32.741	3.996	348.2
33.261	3.060	266.7	36.559	4.110	358.2
36.659	2.698	235.1	40.380	4.332	377.5
40.068	2.195	191.3	44.200	4.456	388.3
43.478	2.373	206.8	48.019	4.563	397.6
46.879	2.383	207.7	51.841	0.000	0.0
50.291	2.316	201.8	55.661	4.617	402.4
53.699	2.287	199.3	59.480	4.416	384.8
57.098	2.237	194.9	63.299	4.141	360.9
60.510	2.228	194.2			
63.921	2.260	196.9			
67.330	2.336	203.6			
70.730	2.553	222.5			
74.140	3.012	262.5			
77.548	6.002	523.0			
80.948	9.359	815.6			
84.360	9.817	855.5			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR235

Measured parameters :

Total temperature (K) :	413.30
Total inlet pressure (bar) :	1.828
Static inlet pressure (bar) :	1.800
Static outlet pressure (bar) :	1.049
Wall temperature (K) :	301.15
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	413.30	
Total pressure (bar) :	1.828	
Mach number (-) :	0.150	0.927
Reynolds number (-) :	2.6471E+05	1.1521E+06
Temperature (K) :	411.45	352.69
Pressure (bar) :	1.800	1.049
Density (Kg/m**3) :	1.524	1.036
Velocity (m/s) :	61.00	349.02
Dynamic viscosity (kg/m.s) :	2.3750E-05	2.1240E-05
Kinematic viscosity (m2/s) :	1.5589E-05	2.0494E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR235

Wall heat flux distribution

Suction side			Pressure side		
S mm	Q W/cm2	H W/m2K	S mm	Q W/cm2	H W/m2K
0.000	8.666	772.7			
1.521	7.762	692.1	1.515	8.467	755.0
3.506	7.198	641.8	3.500	5.668	505.4
6.002	6.550	584.0	6.000	4.670	416.4
9.410	6.536	582.8	9.821	4.065	362.5
12.810	6.156	548.9	13.641	3.794	338.3
16.220	5.445	485.5	17.460	3.711	330.9
19.630	4.751	423.6	21.279	3.664	326.7
23.042	3.793	338.2	25.101	0.000	0.0
26.440	3.371	300.6	28.920	3.897	347.5
29.849	3.426	305.5	32.741	4.100	365.6
33.261	3.327	296.7	36.559	4.283	381.9
36.659	3.150	280.9	40.380	4.479	399.4
40.068	3.290	293.4	44.200	4.627	412.6
43.478	3.439	306.6	48.019	4.759	424.3
46.879	3.487	310.9	51.841	0.000	0.0
50.291	3.660	326.3	55.661	4.873	434.5
53.699	3.822	340.8	59.480	4.738	422.5
57.098	4.103	365.8	63.299	4.316	384.8
60.510	5.001	445.9			
63.921	7.220	643.8			
67.330	9.354	834.1			
70.730	9.006	803.0			
74.140	8.671	773.2			
77.548	8.390	748.1			
80.948	8.220	732.9			
84.360	7.756	691.6			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR237

Measured parameters :

Total temperature (K) :	417.30
Total inlet pressure (bar) :	1.753
Static inlet pressure (bar) :	1.726
Static outlet pressure (bar) :	1.179
Wall temperature (K) :	299.85
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	417.30	
Total pressure (bar) :	1.753	
Mach number (-) :	0.150	0.775
Reynolds number (-) :	2.5092E+05	1.0112E+06
Temperature (K) :	415.43	372.55
Pressure (bar) :	1.726	1.179
Density (Kg/m**3) :	1.447	1.102
Velocity (m/s) :	61.29	299.90
Dynamic viscosity (kg/m.s) :	2.3913E-05	2.2111E-05
Kinematic viscosity (m2/s) :	1.6525E-05	2.0063E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR237

Wall heat flux distribution

Suction side			Pressure side		
S	Q	H	S	Q	H
mm	W/cm2	W/m2K	mm	W/cm2	W/m2K
0.000	8.680	739.0			
1.521	7.775	662.0	1.515	8.457	720.1
3.506	7.199	612.9	3.500	5.637	479.9
6.002	6.551	557.8	6.000	4.637	394.8
9.410	6.542	557.0	9.821	4.015	341.8
12.810	6.197	527.6	13.641	3.740	318.4
16.220	5.510	469.1	17.460	3.634	309.4
19.630	4.853	413.2	21.279	3.578	304.6
23.042	3.876	330.0	25.101	0.000	0.0
26.440	3.438	292.7	28.920	3.790	322.7
29.849	3.484	296.6	32.741	3.972	338.2
33.261	3.436	292.6	36.559	4.133	351.9
36.659	3.446	293.4	40.380	4.328	368.5
40.068	3.613	307.6	44.200	4.471	380.7
43.478	3.845	327.4	48.019	4.595	391.2
46.879	4.101	349.2	51.841	0.000	0.0
50.291	4.752	404.6	55.661	4.673	397.9
53.699	5.477	466.3	59.480	4.553	387.7
57.098	6.170	525.3	63.299	4.381	373.0
60.510	6.932	590.2			
63.921	7.599	647.0			
67.330	8.051	685.5			
70.730	8.263	703.5			
74.140	8.317	708.1			
77.548	8.174	696.0			
80.948	8.075	687.5			
84.360	7.747	659.6			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR213

Measured parameters :

Total temperature (K) :	413.10
Total inlet pressure (bar) :	1.669
Static inlet pressure (bar) :	1.643
Static outlet pressure (bar) :	0.813
Wall temperature (K) :	298.25
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	413.10	
Total pressure (bar) :	1.669	
Mach number (-) :	0.150	1.068
Reynolds number (-) :	2.4174E+05	1.0904E+06
Temperature (K) :	411.25	336.37
Pressure (bar) :	1.643	0.813
Density (Kg/m**3) :	1.391	0.842
Velocity (m/s) :	60.99	392.70
Dynamic viscosity (kg/m.s) :	2.3741E-05	2.0505E-05
Kinematic viscosity (m2/s) :	1.7065E-05	2.4362E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR213

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	7.844	683.0
1.521	7.076	616.1
3.506	6.562	571.4
6.002	5.997	522.2
9.410	5.995	522.0
12.810	5.684	494.9
16.220	5.091	443.3
19.630	4.427	385.5
23.042	3.493	304.1
26.440	3.053	265.8
29.849	2.994	260.7
33.261	2.810	244.7
36.659	2.421	210.8
40.068	1.868	162.6
43.478	2.001	174.2
46.879	2.000	174.1
50.291	1.876	163.3
53.699	1.778	154.8
57.098	1.636	142.4
60.510	1.564	136.2
63.921	1.453	126.5
67.330	1.219	106.1
70.730	0.693	60.3
74.140	0.780	67.9
77.548	4.000	348.3
80.948	9.328	812.2
84.360	10.622	924.9

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	7.658	666.8
3.500	4.962	432.0
6.000	4.022	350.2
9.821	3.422	298.0
13.641	3.138	273.2
17.460	3.021	263.0
21.279	2.938	255.8
25.101	0.000	0.0
28.920	3.079	268.1
32.741	3.203	278.9
36.559	3.302	287.5
40.380	3.578	311.5
44.200	3.732	324.9
48.019	3.846	334.9
51.841	0.000	0.0
55.661	3.917	341.1
59.480	3.729	324.7
63.299	3.486	303.5

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR217

Measured parameters :

Total temperature (K) :	412.70
Total inlet pressure (bar) :	1.835
Static inlet pressure (bar) :	1.806
Static outlet pressure (bar) :	1.045
Wall temperature (K) :	300.15
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	412.70	
Total pressure (bar) :	1.835	
Mach number (-) :	0.150	0.934
Reynolds number (-) :	2.6618E+05	1.1614E+06
Temperature (K) :	410.85	351.39
Pressure (bar) :	1.806	1.045
Density (Kg/m**3) :	1.532	1.036
Velocity (m/s) :	60.96	351.01
Dynamic viscosity (kg/m.s) :	2.3725E-05	2.1182E-05
Kinematic viscosity (m2/s) :	1.5491E-05	2.0445E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR217

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	8.052	715.4
1.521	7.245	643.7
3.506	6.740	598.8
6.002	6.144	545.9
9.410	6.150	546.4
12.810	5.810	516.2
16.220	5.168	459.2
19.630	4.554	404.6
23.042	3.590	319.0
26.440	3.144	279.3
29.849	3.067	272.5
33.261	2.872	255.2
36.659	2.495	221.7
40.068	2.406	213.8
43.478	2.338	207.7
46.879	2.242	199.2
50.291	2.098	186.4
53.699	1.898	168.6
57.098	1.677	149.0
60.510	1.000	88.8
63.921	2.133	189.5
67.330	6.437	571.9
70.730	7.103	631.1
74.140	7.646	679.3
77.548	9.402	835.4
80.948	8.924	792.9
84.360	8.404	746.7

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	7.830	695.7
3.500	5.099	453.0
6.000	4.145	368.3
9.821	3.536	314.2
13.641	3.246	288.4
17.460	3.136	278.6
21.279	3.048	270.8
25.101	0.000	0.0
28.920	3.186	283.1
32.741	3.363	298.8
36.559	3.545	315.0
40.380	3.755	333.6
44.200	3.916	347.9
48.019	4.057	360.5
51.841	0.000	0.0
55.661	4.150	368.7
59.480	3.966	352.4
63.299	3.757	333.8

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR218

Measured parameters :

Total temperature (K) :	413.50
Total inlet pressure (bar) :	1.744
Static inlet pressure (bar) :	1.717
Static outlet pressure (bar) :	1.190
Wall temperature (K) :	300.25
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	413.50	
Total pressure (bar) :	1.744	
Mach number (-) :	0.150	0.760
Reynolds number (-) :	2.5243E+05	1.0071E+06
Temperature (K) :	411.65	370.68
Pressure (bar) :	1.717	1.190
Density (Kg/m**3) :	1.453	1.118
Velocity (m/s) :	61.01	293.35
Dynamic viscosity (kg/m.s) :	2.3758E-05	2.2030E-05
Kinematic viscosity (m2/s) :	1.6351E-05	1.9704E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR218

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	7.781	687.1
1.521	6.995	617.7
3.506	6.512	575.0
6.002	5.939	524.4
9.410	5.965	526.7
12.810	5.653	499.2
16.220	5.056	446.4
19.630	4.494	396.8
23.042	3.528	311.5
26.440	3.074	271.4
29.849	2.986	263.7
33.261	2.796	246.9
36.659	2.560	226.0
40.068	2.449	216.2
43.478	2.321	204.9
46.879	2.145	189.4
50.291	2.030	179.2
53.699	2.017	178.1
57.098	1.980	174.8
60.510	1.950	172.2
63.921	2.038	180.0
67.330	2.425	214.1
70.730	3.339	294.8
74.140	4.939	436.1
77.548	6.503	574.2
80.948	7.615	672.4
84.360	7.632	673.9

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	7.555	667.1
3.500	4.910	433.6
6.000	3.992	352.5
9.821	3.403	300.5
13.641	3.119	275.4
17.460	3.010	265.8
21.279	2.921	257.9
25.101	0.000	0.0
28.920	3.046	269.0
32.741	3.220	284.3
36.559	3.381	298.5
40.380	3.589	316.9
44.200	3.743	330.5
48.019	3.873	342.0
51.841	0.000	0.0
55.661	3.953	349.1
59.480	3.797	335.3
63.299	3.648	322.1

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR210

Measured parameters :

Total temperature (K) :	414.60
Total inlet pressure (bar) :	1.689
Static inlet pressure (bar) :	1.663
Static outlet pressure (bar) :	0.815
Wall temperature (K) :	297.35
Free stream turbulence (%) :	1.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	414.60	
Total pressure (bar) :	1.689	
Mach number (-) :	0.150	1.076
Reynolds number (-) :	2.4363E+05	1.1001E+06
Temperature (K) :	412.74	336.65
Pressure (bar) :	1.663	0.815
Density (Kg/m**3) :	1.403	0.843
Velocity (m/s) :	61.10	395.80
Dynamic viscosity (kg/m.s) :	2.3803E-05	2.0518E-05
Kinematic viscosity (m2/s) :	1.6964E-05	2.4339E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR210

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	7.160	610.7
1.521	6.378	544.0
3.506	5.917	504.6
6.002	5.393	460.0
9.410	5.474	466.9
12.810	5.292	451.3
16.220	4.838	412.6
19.630	4.278	364.9
23.042	3.421	291.8
26.440	3.023	257.8
29.849	2.961	252.5
33.261	2.802	239.0
36.659	2.460	209.8
40.068	1.880	160.3
43.478	1.964	167.5
46.879	1.976	168.5
50.291	1.848	157.6
53.699	1.808	154.2
57.098	1.706	145.5
60.510	1.675	142.9
63.921	1.690	144.1
67.330	1.181	100.7
70.730	1.221	104.1
74.140	1.945	165.9
77.548	3.829	326.6
80.948	9.854	840.4
84.360	10.828	923.5

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	6.970	594.5
3.500	4.381	373.6
6.000	3.449	294.2
9.821	2.860	243.9
13.641	2.574	219.5
17.460	2.435	207.7
21.279	2.318	197.7
25.101	0.000	0.0
28.920	2.306	196.7
32.741	2.380	203.0
36.559	2.484	211.9
40.380	2.637	224.9
44.200	2.770	236.2
48.019	2.903	247.6
51.841	0.000	0.0
55.661	3.026	258.1
59.480	2.940	250.7
63.299	2.778	236.9

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR129

Measured parameters :

Total temperature (K) :	409.20
Total inlet pressure (bar) :	1.849
Static inlet pressure (bar) :	1.820
Static outlet pressure (bar) :	1.165
Wall temperature (K) :	297.75
Free stream turbulence (%) :	0.8
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	409.20	
Total pressure (bar) :	1.849	
Mach number (-) :	0.150	0.840
Reynolds number (-) :	2.7098E+05	1.1352E+06
Temperature (K) :	407.37	358.60
Pressure (bar) :	1.820	1.165
Density (Kg/m**3) :	1.556	1.131
Velocity (m/s) :	60.70	318.91
Dynamic viscosity (kg/m.s) :	2.3581E-05	2.1501E-05
Kinematic viscosity (m2/s) :	1.5152E-05	1.9003E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR129

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	0.000	0.0
1.521	6.423	576.3
3.506	5.959	534.7
6.002	5.452	489.2
9.410	5.554	498.3
12.810	5.364	481.3
16.220	4.854	435.5
19.630	4.310	386.7
23.042	3.435	308.2
26.440	3.030	271.9
29.849	2.947	264.4
33.261	2.759	247.6
36.659	2.479	222.4
40.068	2.384	213.9
43.478	2.268	203.5
46.879	2.074	186.1
50.291	1.891	169.7
53.699	1.818	163.1
57.098	1.688	151.5
60.510	1.521	136.5
63.921	1.377	123.6
67.330	1.306	117.2
70.730	1.322	118.6
74.140	1.540	138.2
77.548	3.070	275.5
80.948	6.470	580.5
84.360	8.019	719.5

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	6.999	628.0
3.500	4.415	396.1
6.000	3.475	311.8
9.821	2.886	259.0
13.641	2.596	232.9
17.460	2.440	218.9
21.279	2.325	208.6
25.101	2.269	203.6
28.920	2.310	207.3
32.741	2.397	215.1
36.559	2.494	223.8
40.380	2.676	240.1
44.200	2.811	252.2
48.019	2.958	265.4
51.841	3.051	273.8
55.661	3.084	276.7
59.480	3.007	269.8
63.299	2.914	261.5

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR132

Measured parameters :

Total temperature (K) :	408.50
Total inlet pressure (bar) :	1.757
Static inlet pressure (bar) :	1.736
Static outlet pressure (bar) :	1.289
Wall temperature (K) :	299.75
Free stream turbulence (%) :	0.8
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	408.50	
Total pressure (bar) :	1.757	
Mach number (-) :	0.130	0.680
Reynolds number (-) :	2.2420E+05	9.6600E+05
Temperature (K) :	407.12	373.92
Pressure (bar) :	1.736	1.289
Density (Kg/m**3) :	1.486	1.201
Velocity (m/s) :	52.59	263.62
Dynamic viscosity (kg/m.s) :	2.3571E-05	2.2170E-05
Kinematic viscosity (m2/s) :	1.5867E-05	1.8461E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR132

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	0.000	0.0
1.521	5.942	546.4
3.506	5.516	507.2
6.002	5.049	464.3
9.410	5.153	473.8
12.810	5.012	460.9
16.220	4.573	420.5
19.630	4.114	378.3
23.042	3.264	300.1
26.440	2.828	260.0
29.849	2.733	251.3
33.261	2.568	236.1
36.659	2.649	243.6
40.068	2.246	206.5
43.478	2.113	194.3
46.879	1.957	180.0
50.291	1.834	168.6
53.699	1.784	164.0
57.098	1.691	155.5
60.510	1.567	144.1
63.921	1.453	133.6
67.330	1.383	127.2
70.730	1.370	126.0
74.140	1.441	132.5
77.548	1.606	147.7
80.948	2.748	252.7
84.360	3.958	364.0

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	6.470	594.9
3.500	4.069	374.2
6.000	3.205	294.7
9.821	2.656	244.2
13.641	2.385	219.3
17.460	2.245	206.4
21.279	2.142	197.0
25.101	2.085	191.7
28.920	2.123	195.2
32.741	2.197	202.0
36.559	2.289	210.5
40.380	2.462	226.4
44.200	2.588	238.0
48.019	2.720	250.1
51.841	2.817	259.0
55.661	2.865	263.4
59.480	2.822	259.5
63.299	2.798	257.3

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR222

Measured parameters :

Total temperature (K) :	409.20
Total inlet pressure (bar) :	0.822
Static inlet pressure (bar) :	0.809
Static outlet pressure (bar) :	0.369
Wall temperature (K) :	301.95
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	409.20	
Total pressure (bar) :	0.822	
Mach number (-) :	0.150	1.135
Reynolds number (-) :	1.2048E+05	5.4770E+05
Temperature (K) :	407.37	325.37
Pressure (bar) :	0.809	0.369
Density (Kg/m**3) :	0.692	0.395
Velocity (m/s) :	60.70	410.45
Dynamic viscosity (kg/m.s) :	2.3581E-05	2.0000E-05
Kinematic viscosity (m2/s) :	3.4079E-05	5.0696E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR222

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	5.734	534.6
1.521	5.180	483.0
3.506	4.860	453.1
6.002	4.440	414.0
9.410	4.463	416.1
12.810	4.202	391.8
16.220	3.710	345.9
19.630	3.227	300.9
23.042	2.528	235.7
26.440	2.217	206.7
29.849	2.157	201.1
33.261	2.026	188.9
36.659	1.757	163.8
40.068	1.379	128.6
43.478	1.352	126.1
46.879	1.345	125.4
50.291	1.278	119.2
53.699	1.202	112.1
57.098	1.122	104.6
60.510	1.030	96.0
63.921	0.987	92.0
67.330	0.794	74.0
70.730	0.346	32.3
74.140	0.350	32.6
77.548	1.397	130.3
80.948	4.435	413.5
84.360	5.286	492.9

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	5.570	519.3
3.500	3.662	341.4
6.000	3.002	279.9
9.821	2.571	239.7
13.641	2.381	222.0
17.460	2.298	214.3
21.279	2.224	207.4
25.101	0.000	0.0
28.920	2.262	210.9
32.741	2.358	219.9
36.559	2.459	229.3
40.380	2.566	239.3
44.200	2.652	247.3
48.019	2.713	253.0
51.841	0.000	0.0
55.661	2.727	254.3
59.480	2.592	241.7
63.299	2.401	223.9

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR224

Measured parameters :

Total temperature (K) :	402.60
Total inlet pressure (bar) :	0.909
Static inlet pressure (bar) :	0.895
Static outlet pressure (bar) :	0.522
Wall temperature (K) :	302.05
Free stream turbulence (%) :	6.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	402.60	
Total pressure (bar) :	0.909	
Mach number (-) :	0.150	0.927
Reynolds number (-) :	1.3591E+05	5.9191E+05
Temperature (K) :	400.80	343.55
Pressure (bar) :	0.895	0.522
Density (Kg/m**3) :	0.778	0.529
Velocity (m/s) :	60.21	344.48
Dynamic viscosity (kg/m.s) :	2.3309E-05	2.0831E-05
Kinematic viscosity (m2/s) :	2.9967E-05	3.9369E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR224

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	5.625	559.4
1.521	5.021	499.4
3.506	4.733	470.7
6.002	4.343	431.9
9.410	4.355	433.1
12.810	4.118	409.5
16.220	3.621	360.1
19.630	3.155	313.8
23.042	2.473	245.9
26.440	2.163	215.1
29.849	2.100	208.9
33.261	1.951	194.0
36.659	1.671	166.2
40.068	1.612	160.3
43.478	1.558	154.9
46.879	1.458	145.0
50.291	1.320	131.3
53.699	1.167	116.1
57.098	0.899	89.4
60.510	0.812	80.8
63.921	1.004	99.9
67.330	2.021	201.0
70.730	2.813	279.8
74.140	3.409	339.0
77.548	5.196	516.8
80.948	4.970	494.3
84.360	4.597	457.2

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	5.442	541.2
3.500	3.617	359.7
6.000	2.966	295.0
9.821	2.546	253.2
13.641	2.349	233.6
17.460	2.257	224.5
21.279	2.207	219.5
25.101	0.000	0.0
28.920	2.265	225.3
32.741	2.357	234.4
36.559	2.406	239.3
40.380	2.554	254.0
44.200	2.617	260.3
48.019	2.694	267.9
51.841	0.000	0.0
55.661	2.704	268.9
59.480	2.574	256.0
63.299	2.315	230.2

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR221

Measured parameters :

Total temperature (K) :	405.30
Total inlet pressure (bar) :	0.818
Static inlet pressure (bar) :	0.805
Static outlet pressure (bar) :	0.367
Wall temperature (K) :	301.55
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	405.30	
Total pressure (bar) :	0.818	
Mach number (-) :	0.150	1.134
Reynolds number (-) :	1.2131E+05	5.5165E+05
Temperature (K) :	403.48	322.39
Pressure (bar) :	0.805	0.367
Density (Kg/m**3) :	0.695	0.397
Velocity (m/s) :	60.41	408.21
Dynamic viscosity (kg/m.s) :	2.3421E-05	1.9862E-05
Kinematic viscosity (m2/s) :	3.3684E-05	5.0058E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR221

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	5.025	484.3
1.521	4.482	432.0
3.506	4.176	402.5
6.002	3.812	367.4
9.410	3.847	370.8
12.810	3.662	353.0
16.220	3.265	314.7
19.630	2.858	275.5
23.042	2.262	218.0
26.440	1.995	192.3
29.849	1.947	187.7
33.261	1.825	175.9
36.659	1.611	155.3
40.068	1.204	116.0
43.478	1.188	114.5
46.879	1.205	116.1
50.291	1.142	110.1
53.699	1.076	103.7
57.098	0.997	96.1
60.510	0.948	91.4
63.921	0.737	71.0
67.330	0.352	33.9
70.730	0.257	24.8
74.140	0.465	44.8
77.548	1.521	146.6
80.948	3.654	352.2
84.360	5.404	520.9

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	4.869	469.3
3.500	3.101	298.9
6.000	2.500	241.0
9.821	2.128	205.1
13.641	1.944	187.4
17.460	1.862	179.5
21.279	1.803	173.8
25.101	0.000	0.0
28.920	1.848	178.1
32.741	1.940	187.0
36.559	2.012	193.9
40.380	2.156	207.8
44.200	2.247	216.6
48.019	2.326	224.2
51.841	0.000	0.0
55.661	2.375	228.9
59.480	2.262	218.0
63.299	2.131	205.4

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR226

Measured parameters :

Total temperature (K) :	404.10
Total inlet pressure (bar) :	0.904
Static inlet pressure (bar) :	0.890
Static outlet pressure (bar) :	0.523
Wall temperature (K) :	301.65
Free stream turbulence (%) :	4.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	404.10	
Total pressure (bar) :	0.904	
Mach number (-) :	0.150	0.920
Reynolds number (-) :	1.3458E+05	5.8455E+05
Temperature (K) :	402.29	345.60
Pressure (bar) :	0.890	0.523
Density (Kg/m**3) :	0.771	0.527
Velocity (m/s) :	60.32	342.89
Dynamic viscosity (kg/m.s) :	2.3371E-05	2.0923E-05
Kinematic viscosity (m2/s) :	3.0319E-05	3.9681E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR226

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	5.360	523.2
1.521	4.783	466.9
3.506	4.451	434.5
6.002	4.055	395.8
9.410	4.094	399.6
12.810	3.898	380.5
16.220	3.472	338.9
19.630	3.051	297.8
23.042	2.412	235.4
26.440	2.119	206.8
29.849	2.067	201.8
33.261	1.916	187.0
36.659	1.691	165.1
40.068	1.597	155.9
43.478	1.538	150.1
46.879	1.430	139.6
50.291	1.263	123.3
53.699	1.061	103.6
57.098	0.811	79.2
60.510	0.713	69.6
63.921	0.679	66.3
67.330	0.766	74.8
70.730	1.457	142.2
74.140	2.340	228.4
77.548	4.097	399.9
80.948	4.915	479.7
84.360	4.937	481.9

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	5.185	506.1
3.500	3.321	324.2
6.000	2.680	261.6
9.821	2.282	222.7
13.641	2.095	204.5
17.460	1.999	195.1
21.279	1.934	188.8
25.101	0.000	0.0
28.920	1.975	192.8
32.741	2.075	202.5
36.559	2.164	211.2
40.380	2.305	225.0
44.200	2.402	234.5
48.019	2.483	242.4
51.841	0.000	0.0
55.661	2.533	247.2
59.480	2.425	236.7
63.299	2.303	224.8

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR230

Measured parameters :

Total temperature (K) :	402.30
Total inlet pressure (bar) :	0.824
Static inlet pressure (bar) :	0.811
Static outlet pressure (bar) :	0.377
Wall temperature (K) :	303.95
Free stream turbulence (%) :	1.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	402.30	
Total pressure (bar) :	0.824	
Mach number (-) :	0.150	1.118
Reynolds number (-) :	1.2331E+05	5.6017E+05
Temperature (K) :	400.50	321.84
Pressure (bar) :	0.811	0.377
Density (Kg/m**3) :	0.706	0.408
Velocity (m/s) :	60.18	402.11
Dynamic viscosity (kg/m.s) :	2.3297E-05	1.9837E-05
Kinematic viscosity (m2/s) :	3.3016E-05	4.8560E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR230

Wall heat flux distribution

Suction side			Pressure side		
S	Q	H	S	Q	H
mm	W/cm2	W/m2K	mm	W/cm2	W/m2K
0.000	4.627	470.5			
1.521	4.100	416.9	1.515	4.492	456.7
3.506	3.801	386.5	3.500	2.791	283.8
6.002	3.454	351.2	6.000	2.196	223.3
9.410	3.513	357.2	9.821	1.818	184.9
12.810	3.376	343.3	13.641	1.635	166.2
16.220	3.036	308.7	17.460	1.539	156.5
19.630	2.682	272.7	21.279	1.473	149.8
23.042	2.137	217.3	25.101	0.000	0.0
26.440	1.890	192.2	28.920	1.458	148.2
29.849	1.845	187.6	32.741	1.512	153.7
33.261	1.730	175.9	36.559	1.570	159.6
36.659	1.533	155.9	40.380	1.666	169.4
40.068	1.131	115.0	44.200	1.749	177.8
43.478	1.125	114.4	48.019	1.823	185.4
46.879	1.140	115.9	51.841	0.000	0.0
50.291	1.081	109.9	55.661	1.898	193.0
53.699	1.013	103.0	59.480	1.838	186.9
57.098	0.936	95.2	63.299	1.719	174.8
60.510	0.904	91.9			
63.921	0.664	67.5			
67.330	0.324	32.9			
70.730	0.326	33.1			
74.140	0.510	51.9			
77.548	1.227	124.8			
80.948	3.750	381.3			
84.360	4.719	479.8			

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR228

Measured parameters :

Total temperature (K) :	403.30
Total inlet pressure (bar) :	0.915
Static inlet pressure (bar) :	0.901
Static outlet pressure (bar) :	0.522
Wall temperature (K) :	302.85
Free stream turbulence (%) :	1.0
Incidence angle (degr.) :	0.0

Free stream conditions

	Inlet conditions	Outlet conditions
Total temperature (K) :	403.30	
Total pressure (bar) :	0.915	
Mach number (-) :	0.150	0.932
Reynolds number (-) :	1.3650E+05	5.9554E+05
Temperature (K) :	401.49	343.61
Pressure (bar) :	0.901	0.522
Density (Kg/m**3) :	0.782	0.530
Velocity (m/s) :	60.26	346.36
Dynamic viscosity (kg/m.s) :	2.3338E-05	2.0833E-05
Kinematic viscosity (m2/s) :	2.9863E-05	3.9343E-05

LS1989 NOZZLE BLADE TEST RESULTS

Test number : MUR228

Wall heat flux distribution

Suction side

S mm	Q W/cm2	H W/m2K
0.000	4.888	486.6
1.521	4.331	431.2
3.506	4.015	399.7
6.002	3.653	363.7
9.410	3.706	368.9
12.810	3.571	355.5
16.220	3.221	320.7
19.630	2.855	284.2
23.042	2.274	226.4
26.440	2.008	199.9
29.849	1.960	195.1
33.261	1.816	180.8
36.659	1.575	156.8
40.068	1.513	150.6
43.478	1.452	144.5
46.879	1.361	135.5
50.291	1.212	120.7
53.699	0.970	96.6
57.098	0.821	81.7
60.510	0.776	77.3
63.921	0.692	68.9
67.330	0.506	50.4
70.730	0.660	65.7
74.140	1.756	174.8
77.548	2.000	199.1
80.948	2.450	243.9
84.360	2.800	278.7

Pressure side

S mm	Q W/cm2	H W/m2K
1.515	4.743	472.2
3.500	2.954	294.1
6.000	2.322	231.2
9.821	1.922	191.3
13.641	1.734	172.6
17.460	1.630	162.3
21.279	1.559	155.2
25.101	0.000	0.0
28.920	1.540	153.3
32.741	1.596	158.9
36.559	1.667	166.0
40.380	1.767	175.9
44.200	1.854	184.6
48.019	1.941	193.2
51.841	0.000	0.0
55.661	2.015	200.6
59.480	1.962	195.3
63.299	1.879	187.1

Test	$M_{2,is}$	$Re_{2,is}$	Tu [%]	T_{01} [K]	P_{01} [bar]	ζ_2 [%]	β_2 [deg]
MUR286	0.801	5.0 10^5	1.0	413.	0.903	1.67	74.79
MUR283	0.884	5.0 10^5	1.0	411.	0.889	1.77	74.46
MUR284	0.875	5.0 10^5	1.0	409.	0.897	1.76	74.42
MUR285	0.868	5.0 10^5	1.0	413.	0.889	1.74	74.46
MUR264	0.970	5.0 10^5	1.0	414.	0.910	2.00	74.62
MUR265	0.970	5.0 10^5	1.0	412.	0.906	2.02	74.64
MUR266	0.970	5.0 10^5	1.0	410.	0.899	2.00	74.40
MUR281	1.085	5.0 10^5	1.0	412.	0.884	4.42	73.48
MUR282	1.090	5.0 10^5	1.0	407.	0.882	3.82	73.72
MUR269	1.175	5.0 10^5	1.0	407.	0.921	5.17	73.82
MUR270	1.176	5.0 10^5	1.0	414.	0.924	5.15	73.54
MUR271	1.168	5.0 10^5	1.0	408.	0.936	5.66	73.87
MUR151	0.710	10^6	1.0	415.	1.779	2.46	
MUR152	0.704	10^6	1.0	413.	1.758	2.42	
MUR153	0.701	10^6	1.0	408.	1.759	2.36	
MUR288	0.769	10^6	1.0	412.	1.817	2.55	74.27
MUR289	0.765	10^6	1.0	406.	1.826	2.49	74.37
MUR250	0.880	10^6	1.0	415.	1.785	2.90	73.80
MUR251	0.890	10^6	1.0	410.	1.827	2.81	73.82
MUR252	0.880	10^6	1.0	418.	1.841	2.93	73.77
MUR279	1.046	10^6	1.0	407.	1.900	3.68	73.95
MUR280	1.049	10^6	1.0	405.	1.864	3.57	74.10
MUR272	1.095	10^6	1.0	409.	1.895	5.00	73.19
MUR273	1.104	10^6	1.0	417.	1.900	5.18	73.18
MUR290	0.760	2.0 10^6	1.0	415.	3.171	2.71	
MUR291	0.757	2.0 10^6	1.0	416.	3.167	2.77	
MUR253	0.880	2.0 10^6	1.0	414.	3.157	2.97	
MUR254	0.890	2.0 10^6	1.0	413.	3.169	3.07	
MUR258	0.880	2.0 10^6	1.0	415.	3.184	2.60	
MUR259	0.880	2.0 10^6	1.0	417.	3.218	2.82	
MUR260	0.890	2.0 10^6	1.0	412.	3.165	2.68	
MUR261	0.890	2.0 10^6	1.0	411.	3.133	2.67	
MUR277	1.009	2.0 10^6	1.0	416.	3.293	4.12	
MUR278	1.008	2.0 10^6	1.0	418.	3.283	4.02	
MUR274	1.079	2.0 10^6	1.0	411.	3.213	6.09	
MUR275	1.075	2.0 10^6	1.0	415.	3.264	6.37	

Appendix 3
Tabulated loss coefficient and exit flow angle results

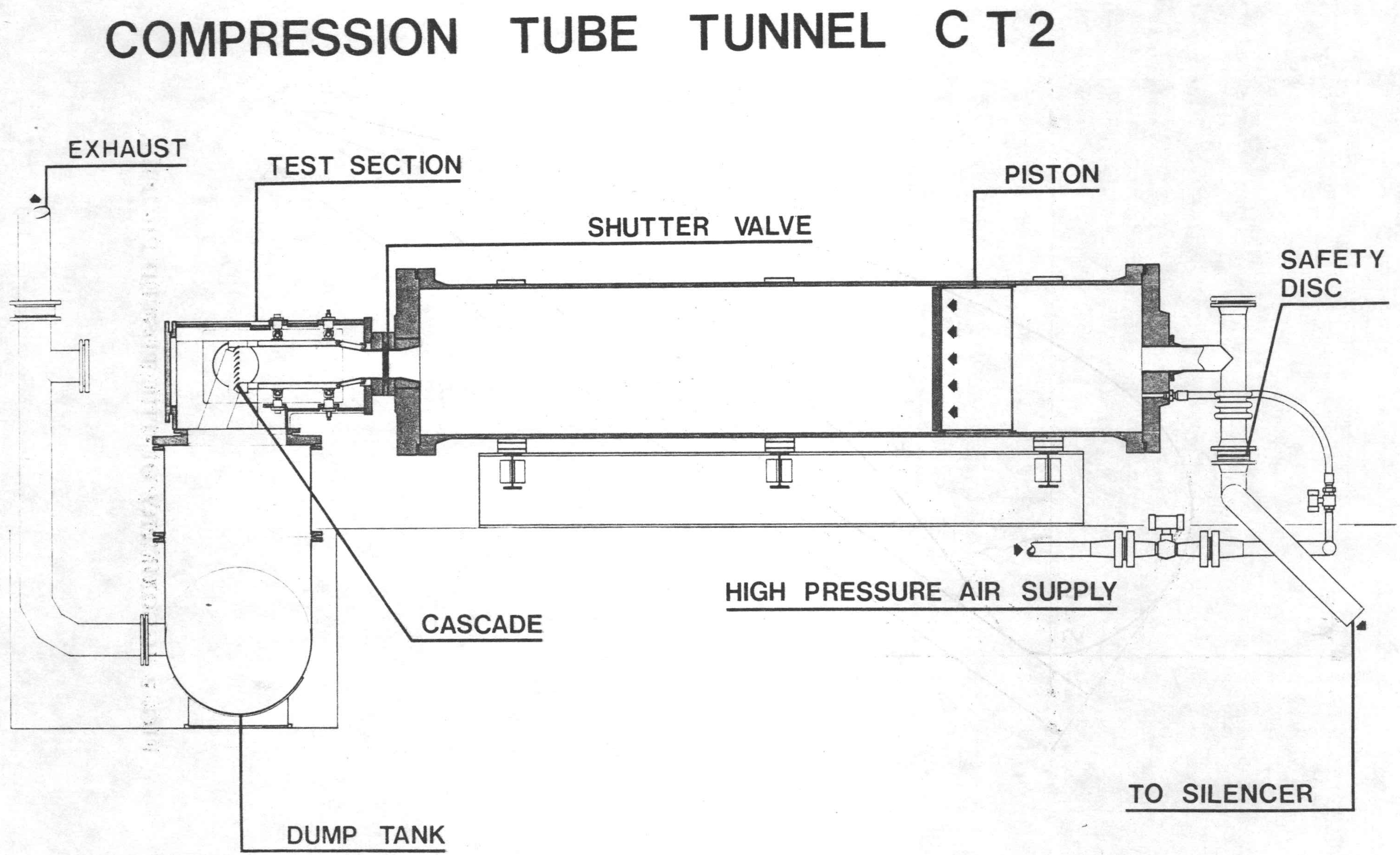

FIG. 1 - THE VKI CT-2 FACILITY

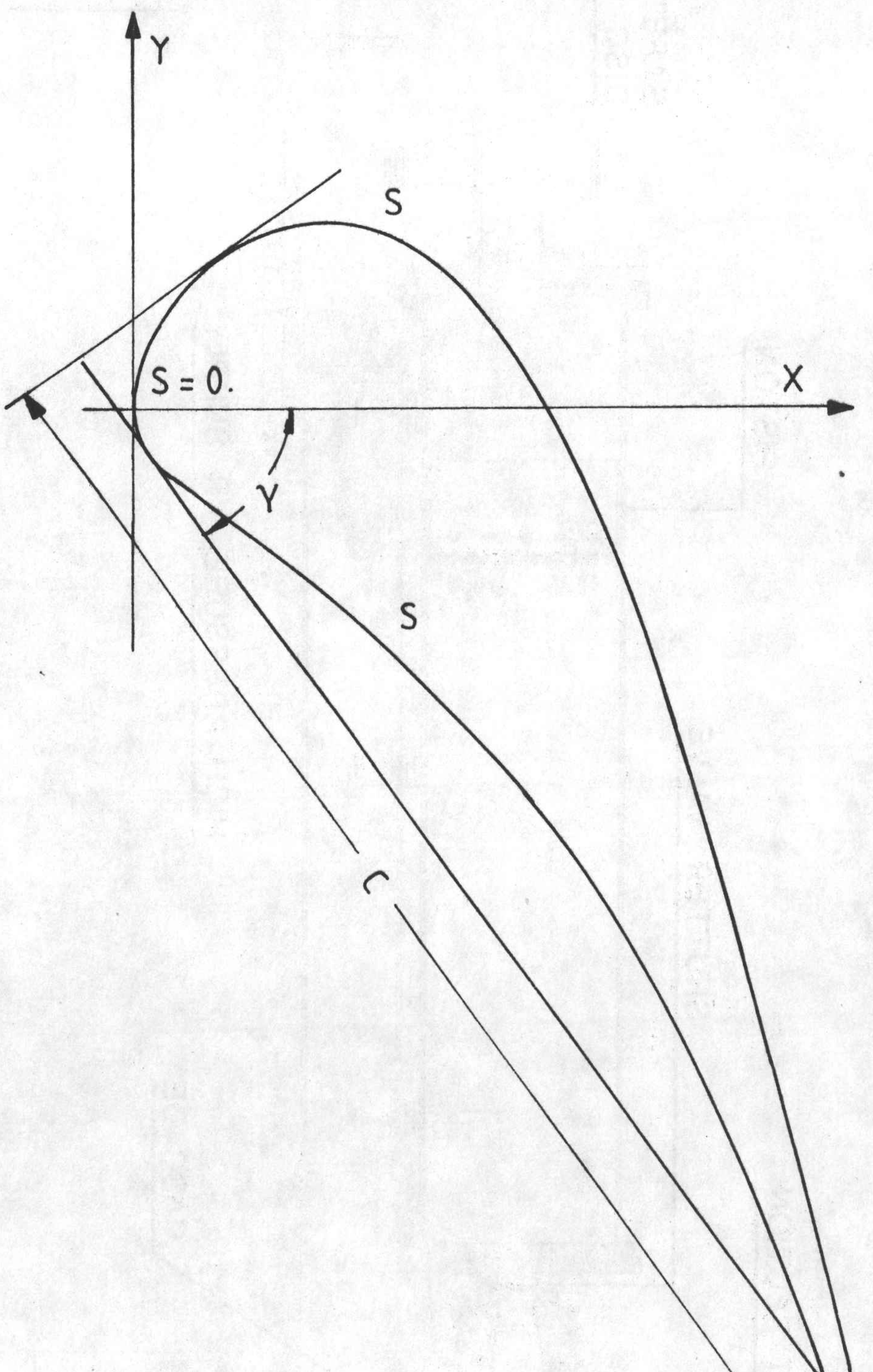

FIG. 2 - GEOMETRY OF THE TESTED PROFILE

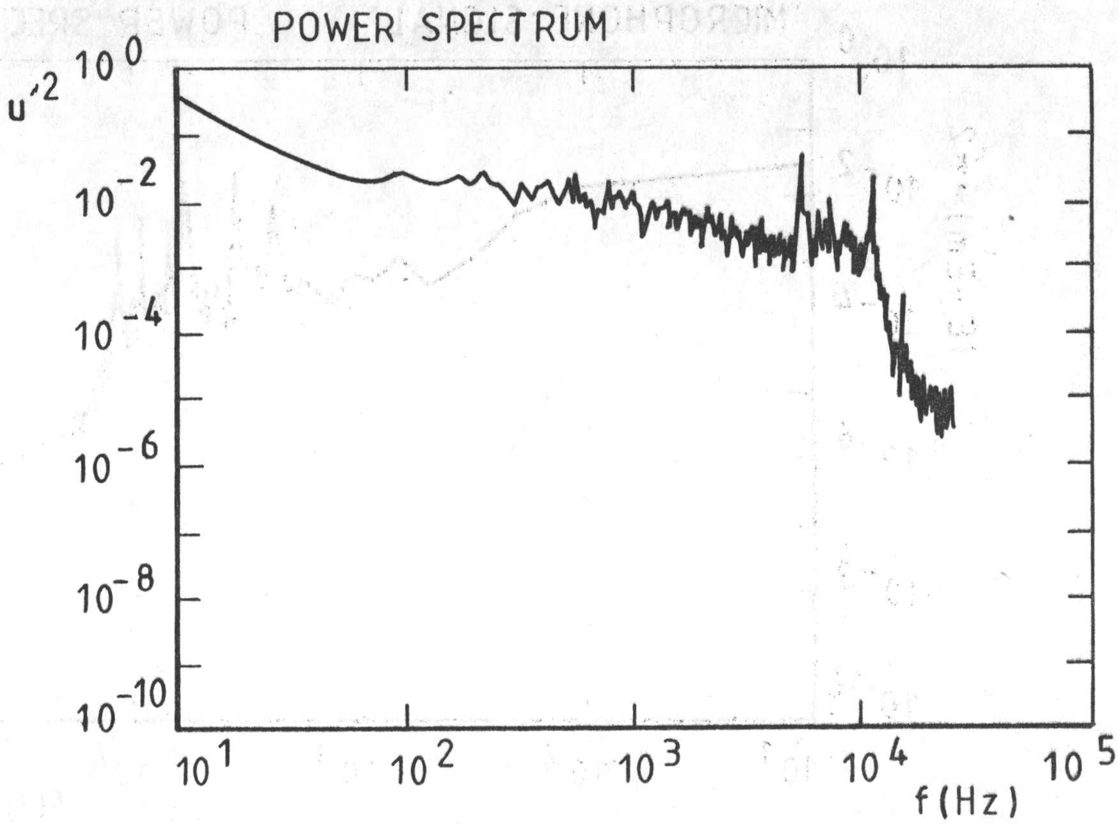

FIG. 3 - FREESTREAM TURBULENCE SPECTRUM ANALYSIS (Tu_∞=4.%)

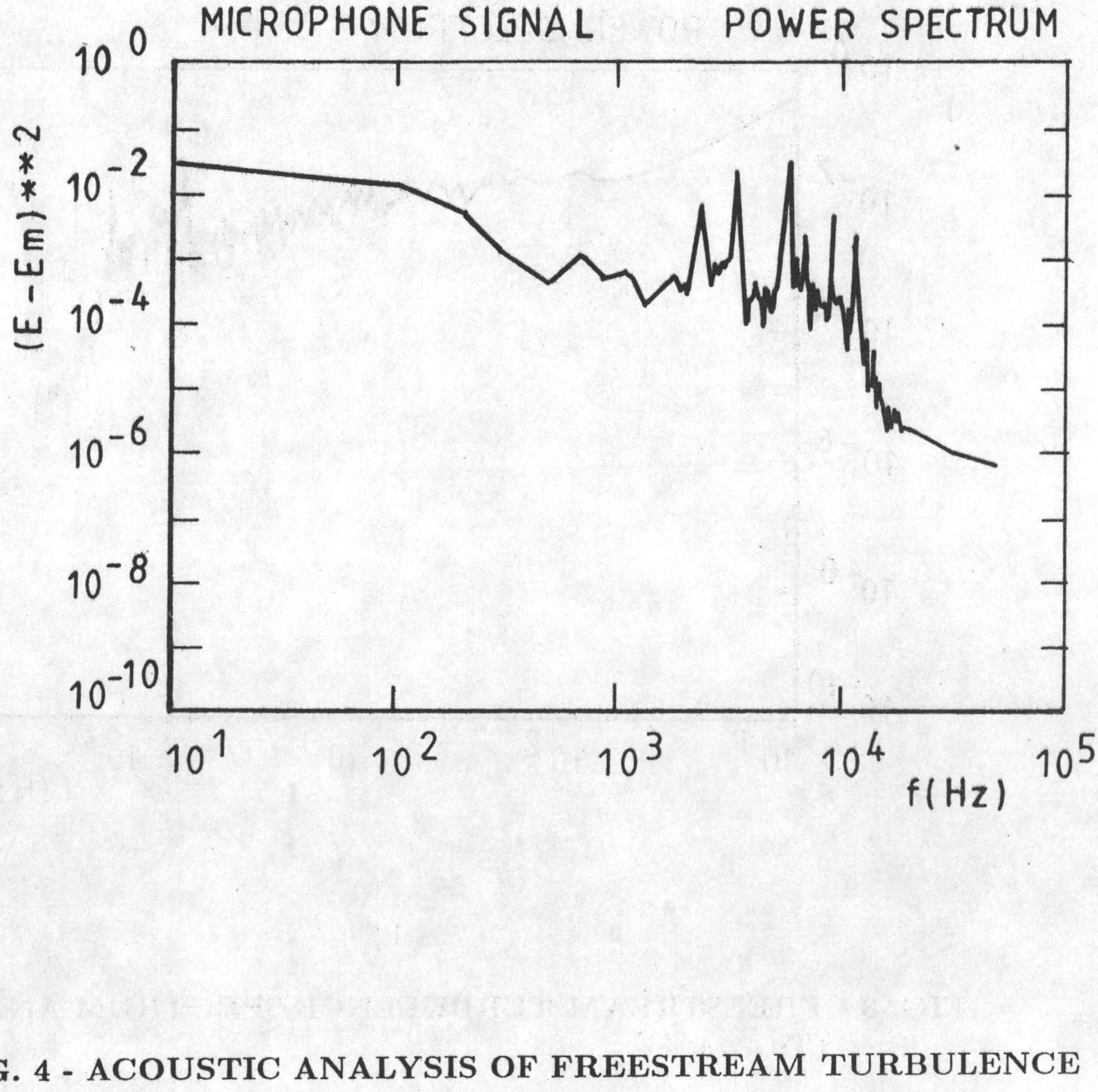

FIG. 4 - ACOUSTIC ANALYSIS OF FREESTREAM TURBULENCE (Tu_{∞}=4.%)

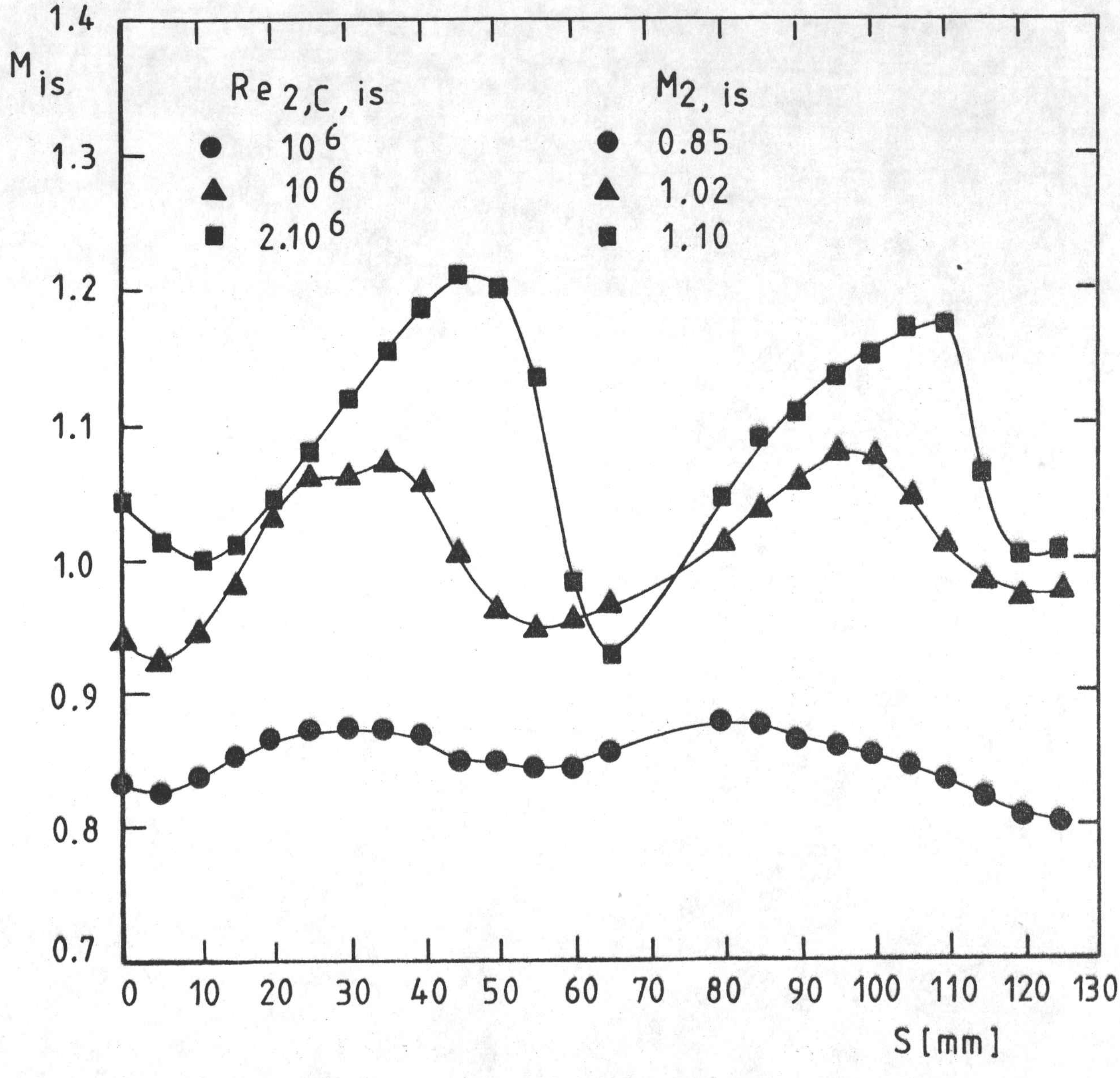

FIG. 5 - DOWNSTREAM STATIC PRESSURE MEASUREMENTS : $M_{2,is}$= 0.85, 1.02, 1.10

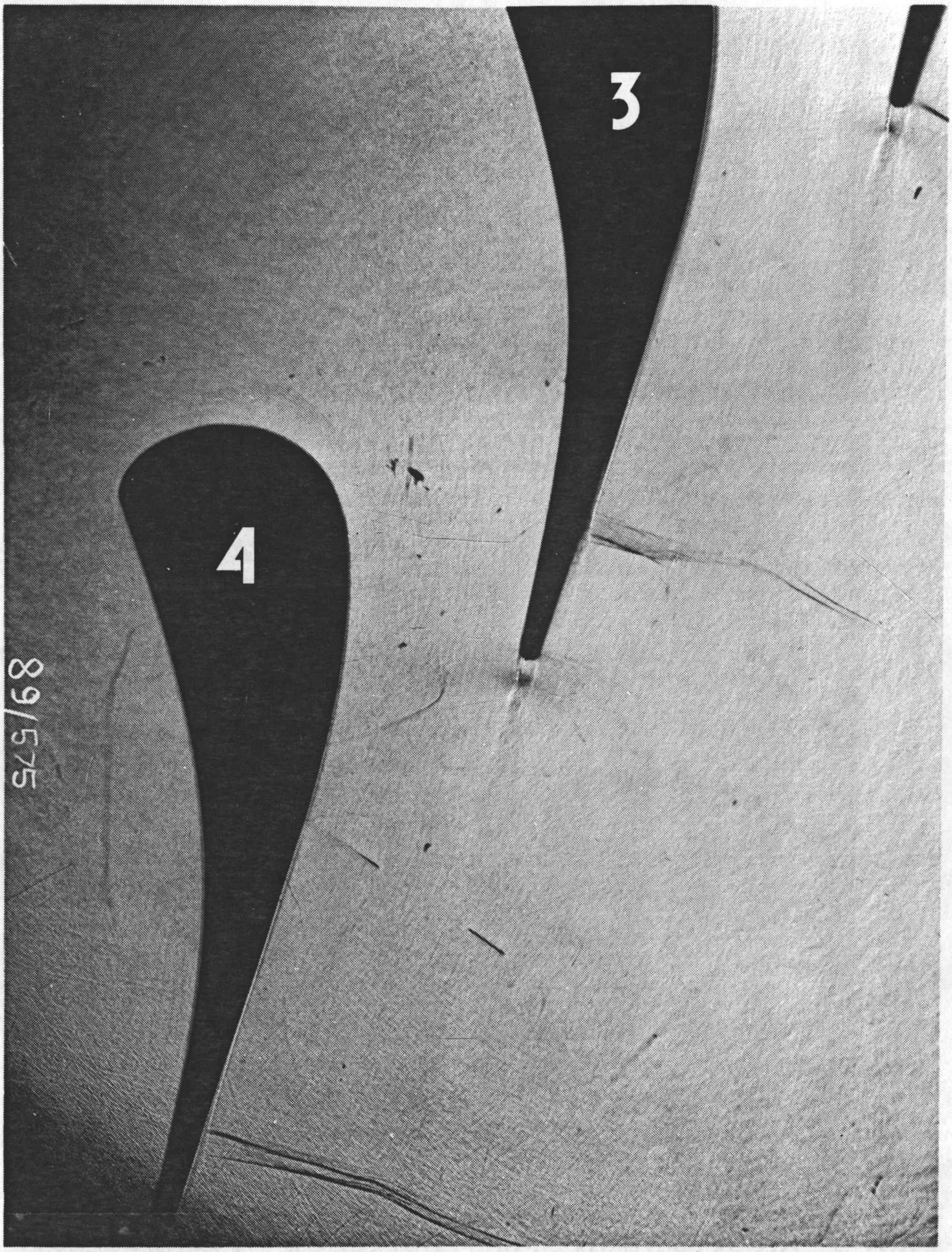

FIG. 6 - SCHLIEREN VISUALIZATION :
$M_{2,is} = 1.03$, $Re_{2,is} = 10^6$

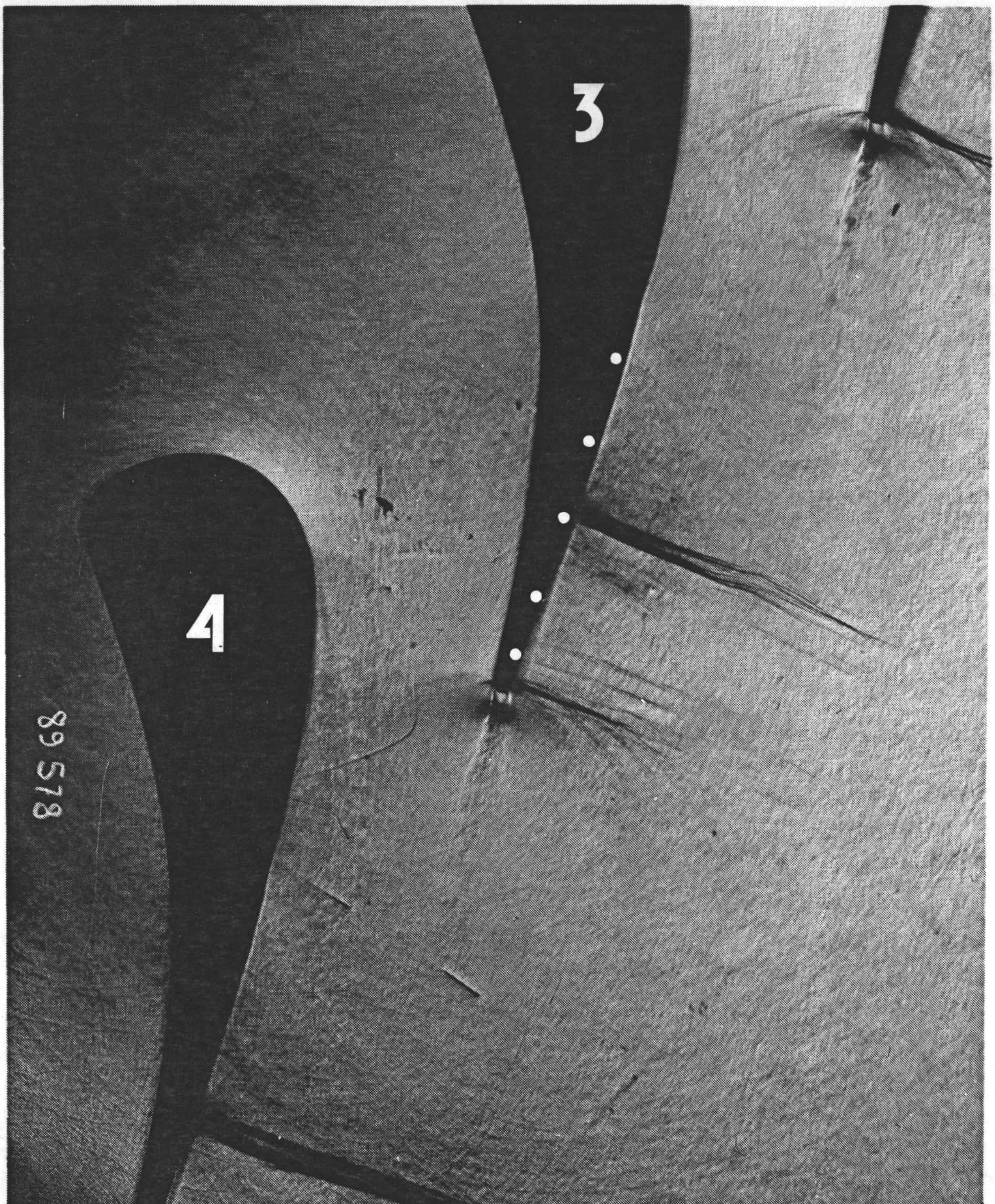

FIG. 7 - SCHLIEREN VISUALIZATION :
$M_{2,is} = 1.03$, $Re_{2,is} = 2.0\ 10^6$

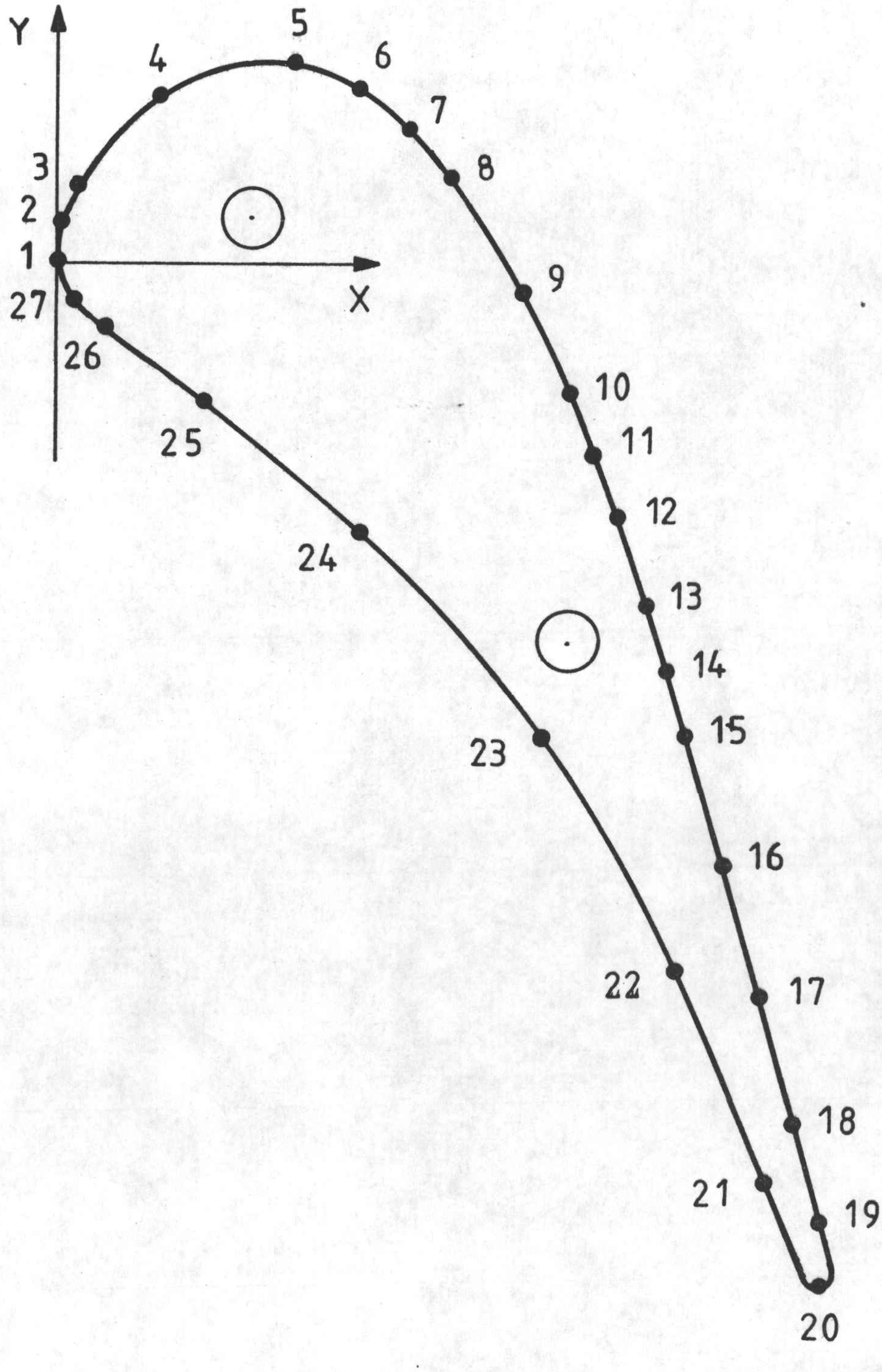

FIG. 8 - STATIC PRESSURE TAPS POSITION
FOR BLADE VELOCITY DISTRIBUTIONS

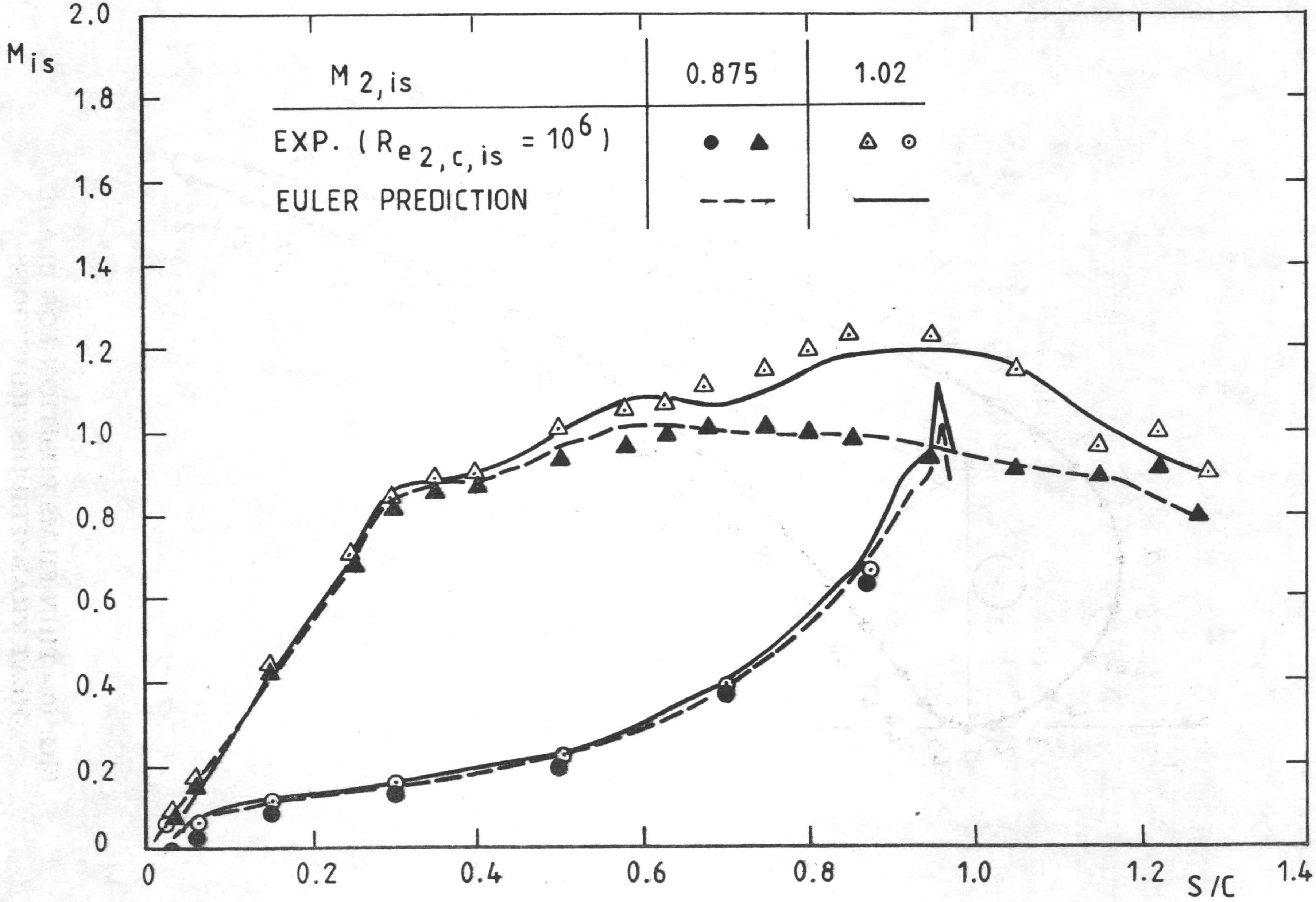

FIG. 9 - BLADE VELOCITY DISTRIBUTIONS : $M_{2,is} = 0.875$, 1.02

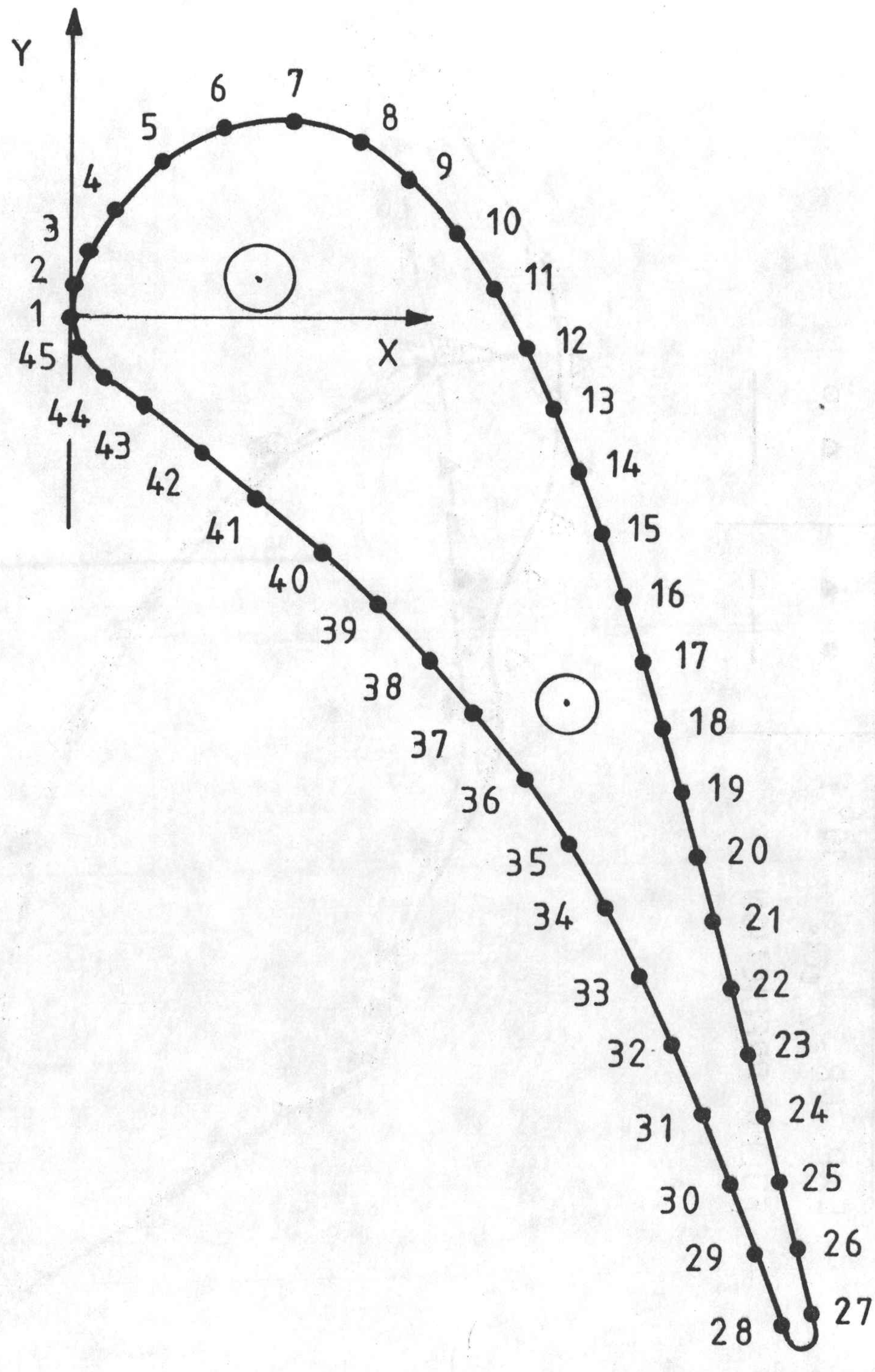

FIG. 10 - THIN FILMS POSITION FOR BLADE HEAT TRANSFER DISTRIBUTIONS

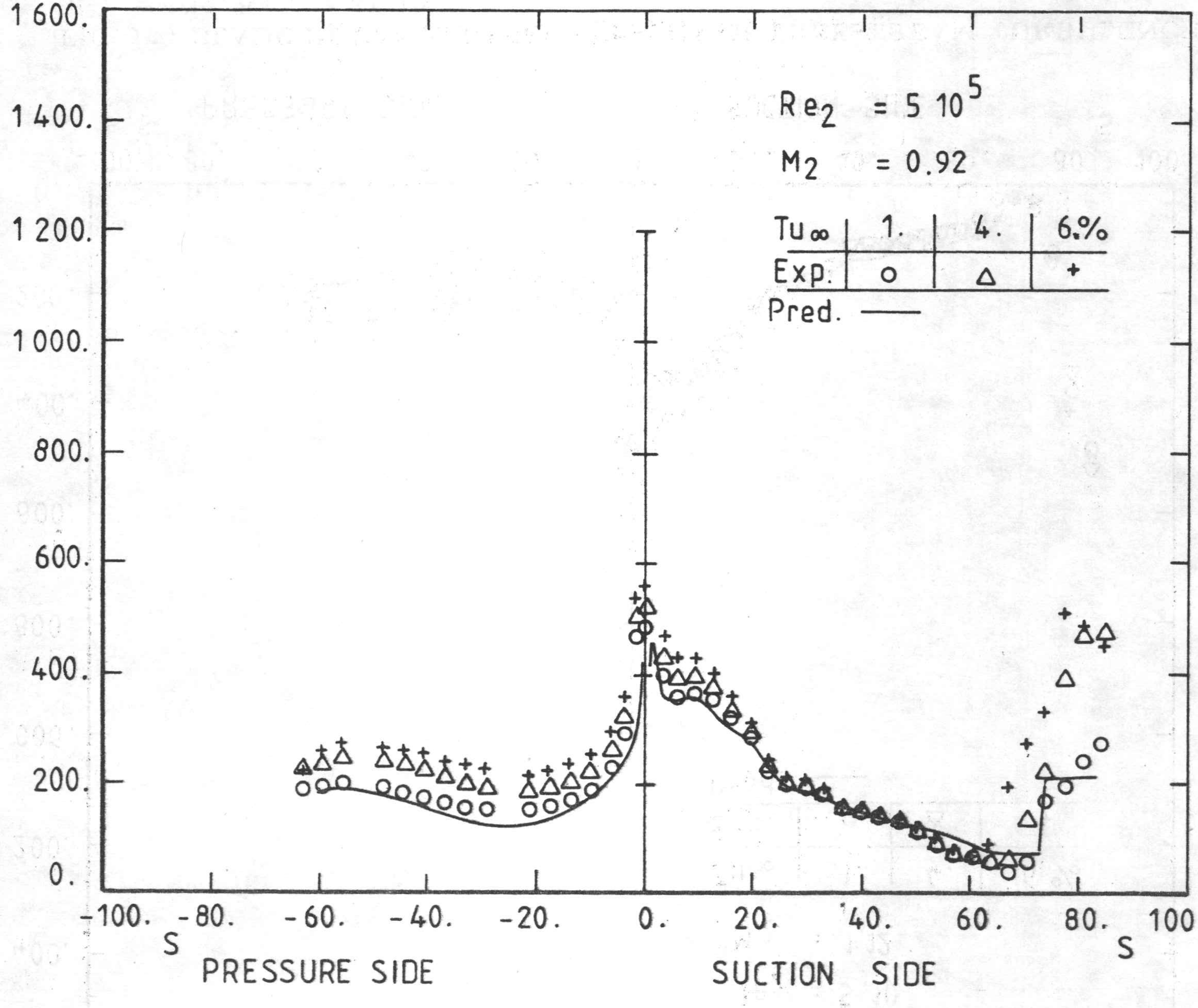

FIG. 11 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE
$M_{2,is} = 0.92$, $Re_{2,is} = 5.0\ 10^5$

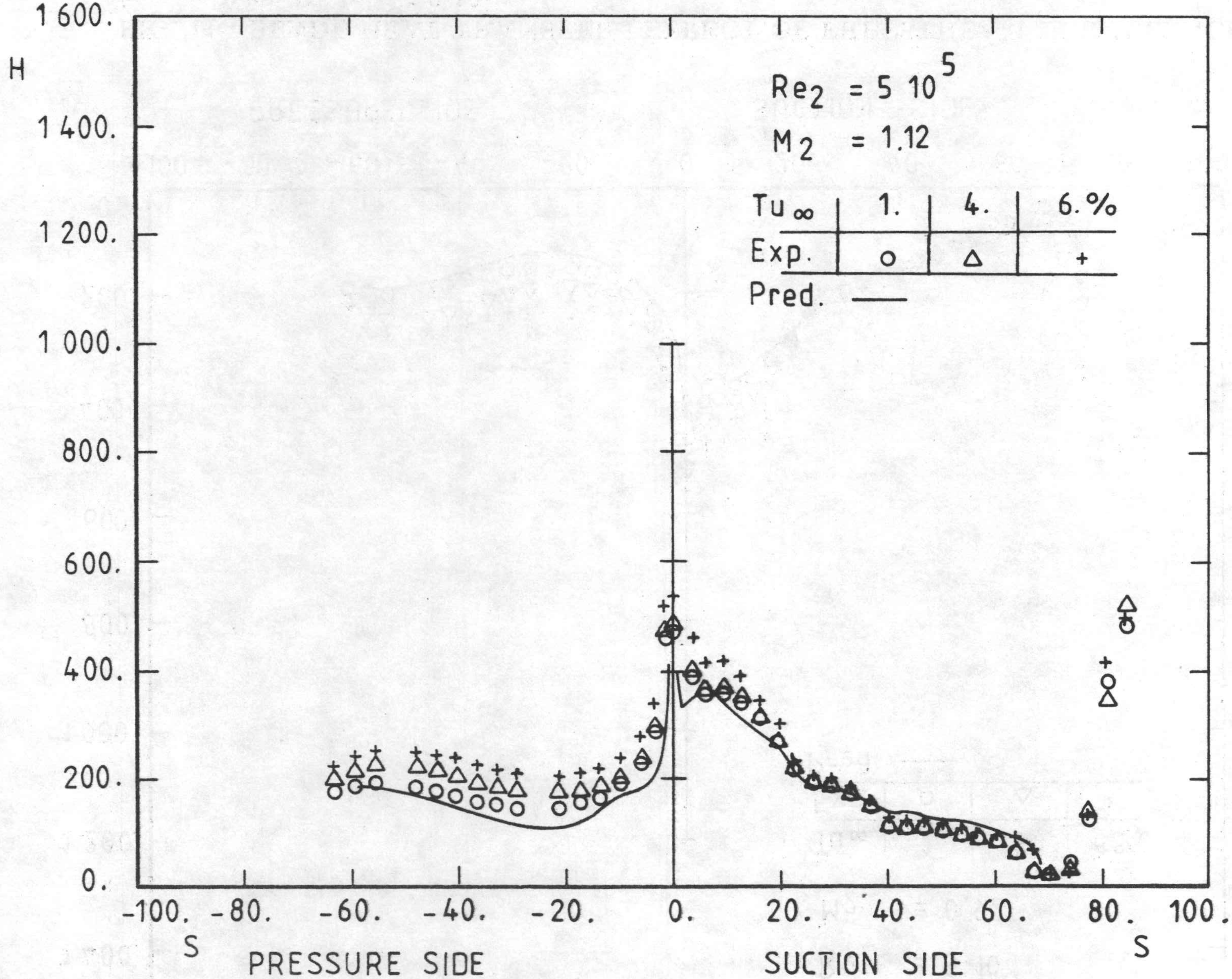

FIG. 12 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE
$M_{2,is} = 1.12$, $Re_{2,is} = 5.0\ 10^5$

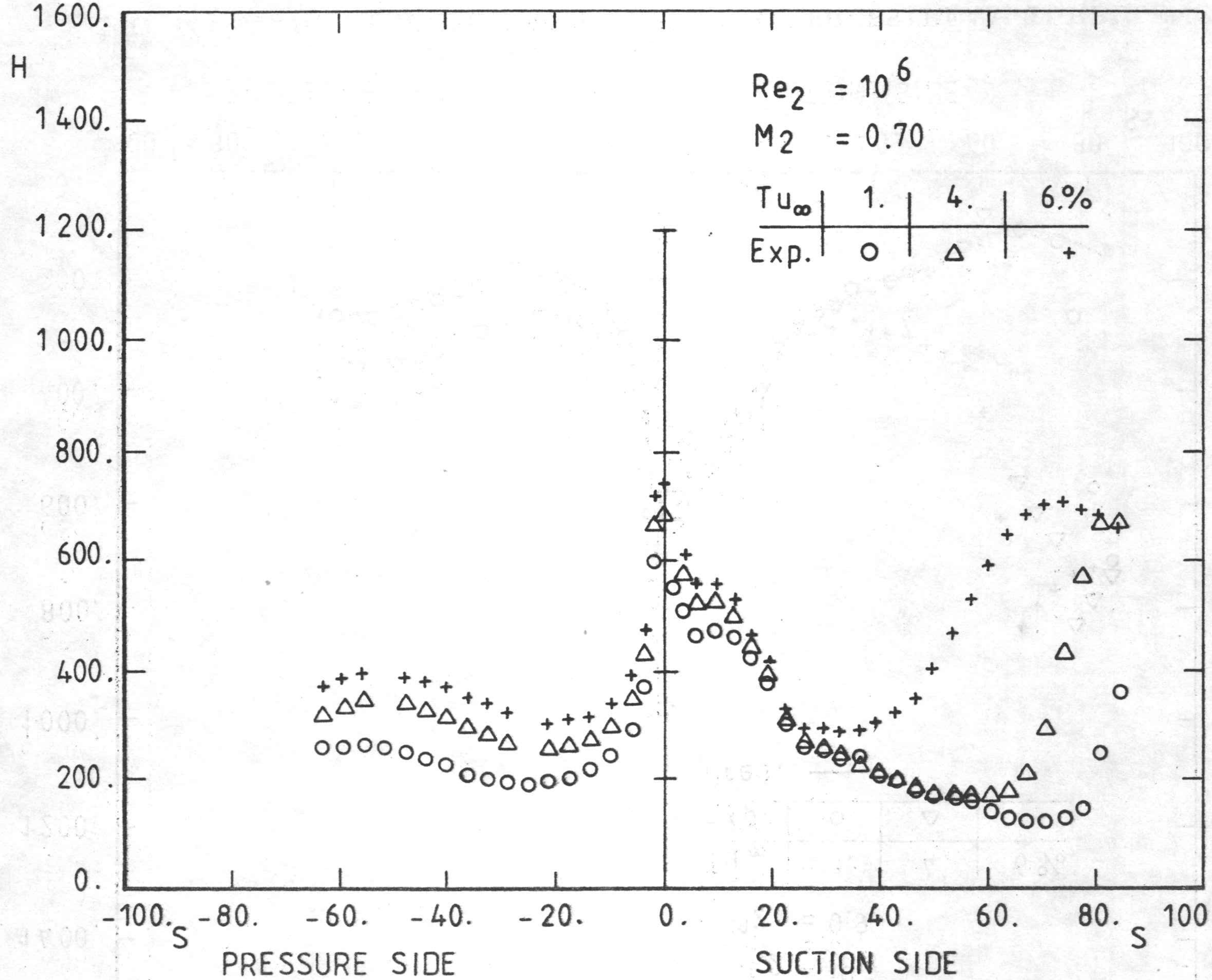

FIG. 13 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE
$M_{2,is} = 0.70$, $Re_{2,is} = 10^6$

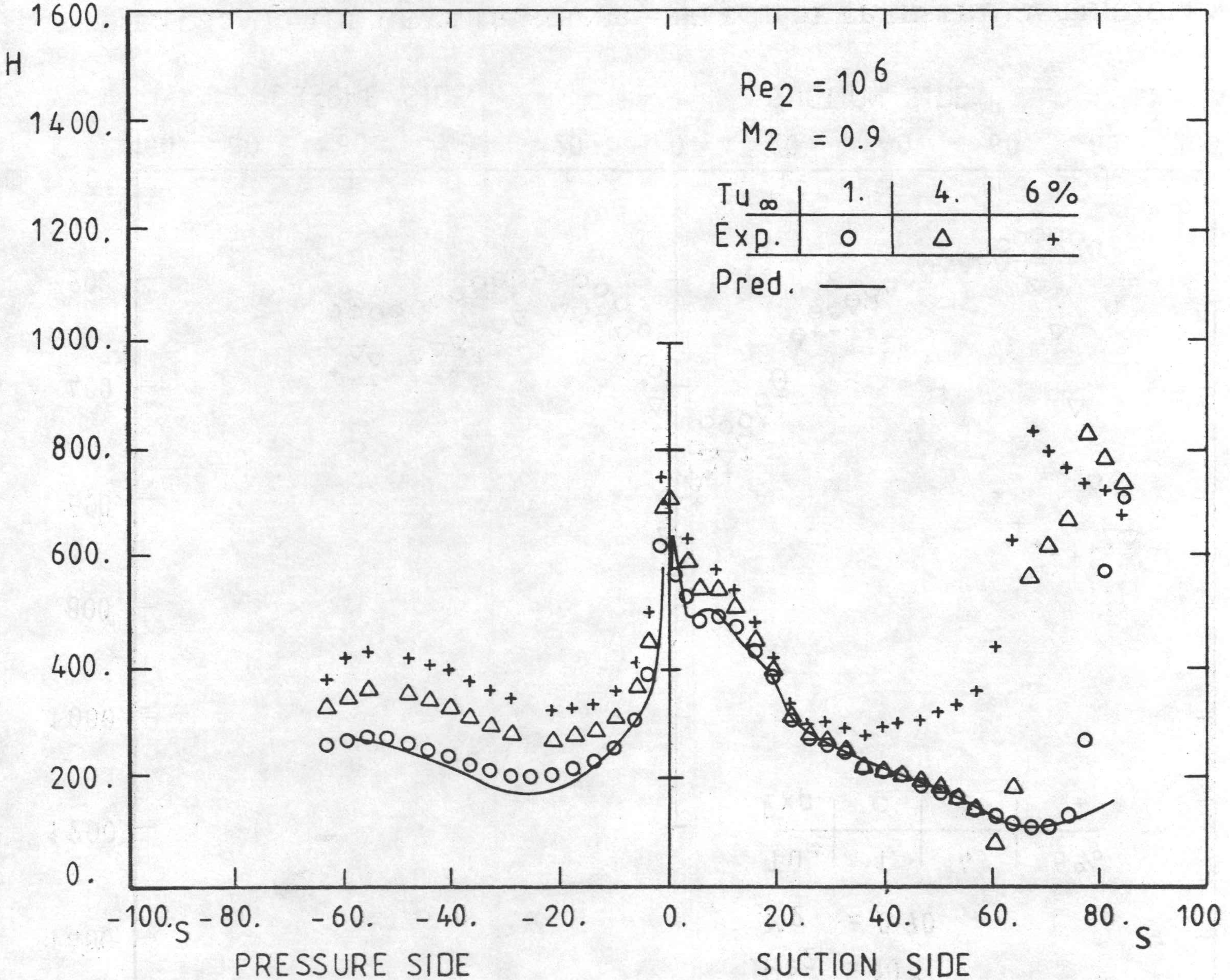

FIG. 14 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE

$M_{2,is} = 0.90$, $Re_{2,is} = 10^6$

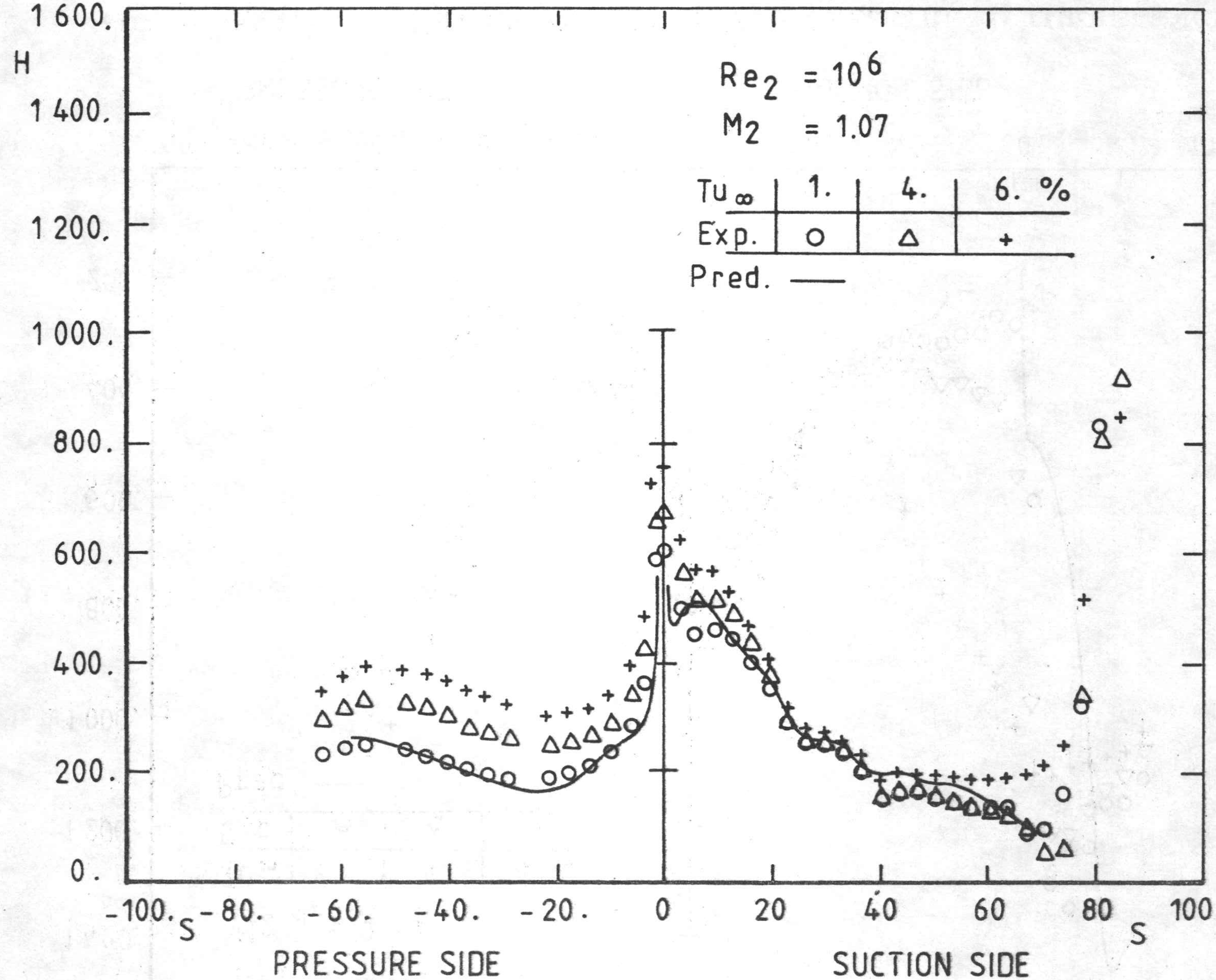

FIG. 15 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE
$M_{2,is} = 1.07$, $Re_{2,is} = 10^6$

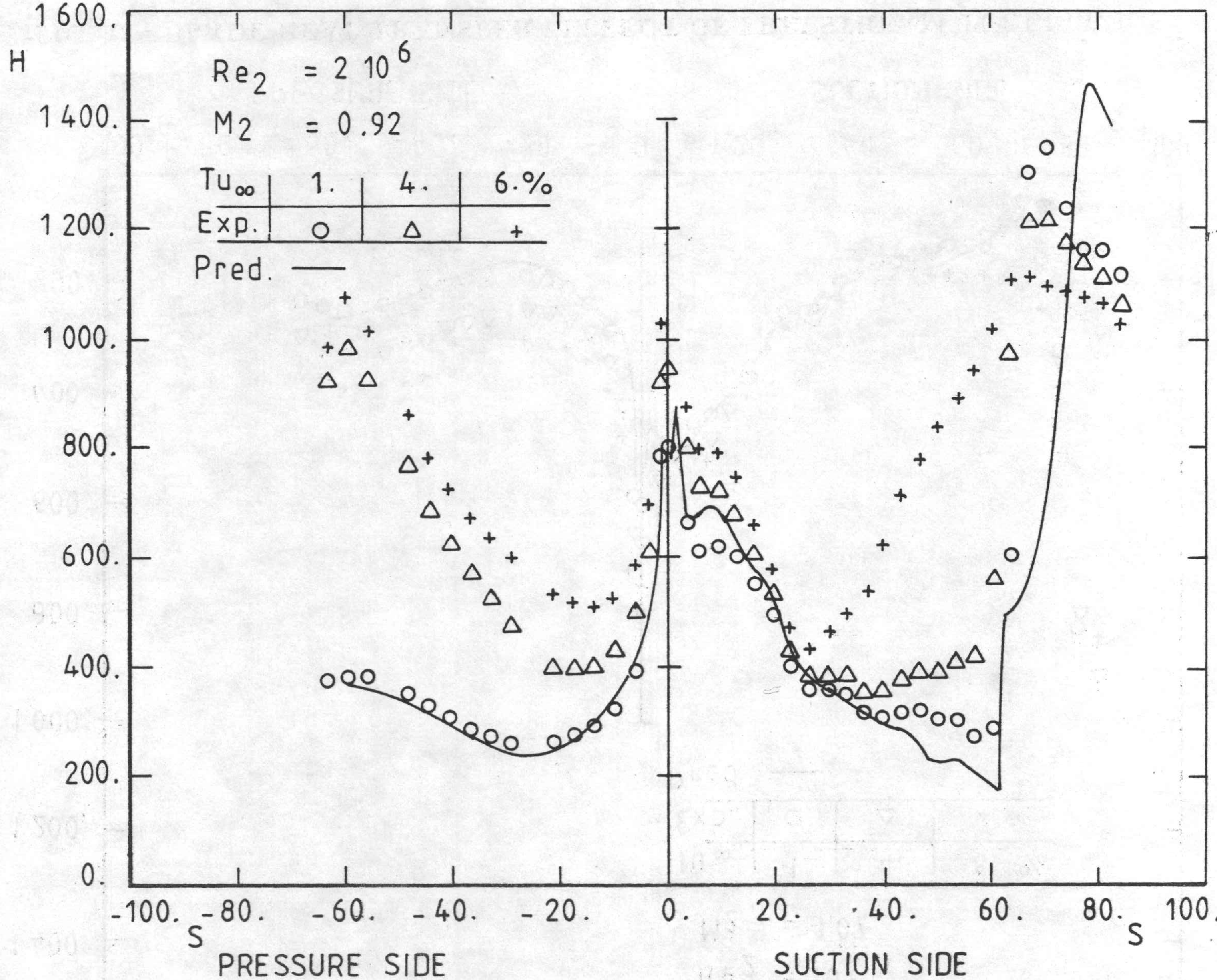

FIG. 16 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE

$M_{2,is} = 0.92$, $Re_{2,is} = 2.0\ 10^6$

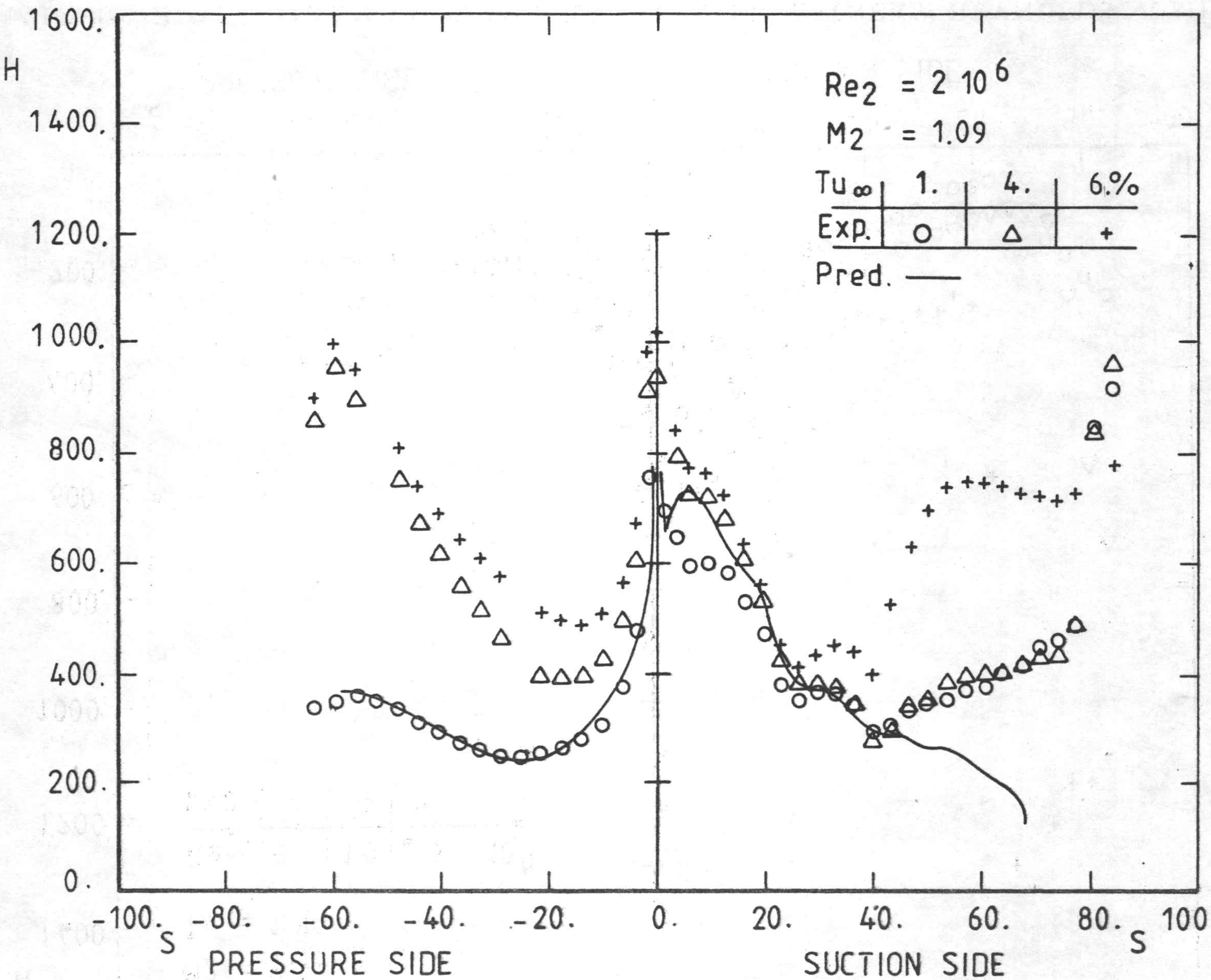

FIG. 17 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM TURBULENCE

$M_{2,is} = 1.09$, $Re_{2,is} = 2.0\ 10^6$

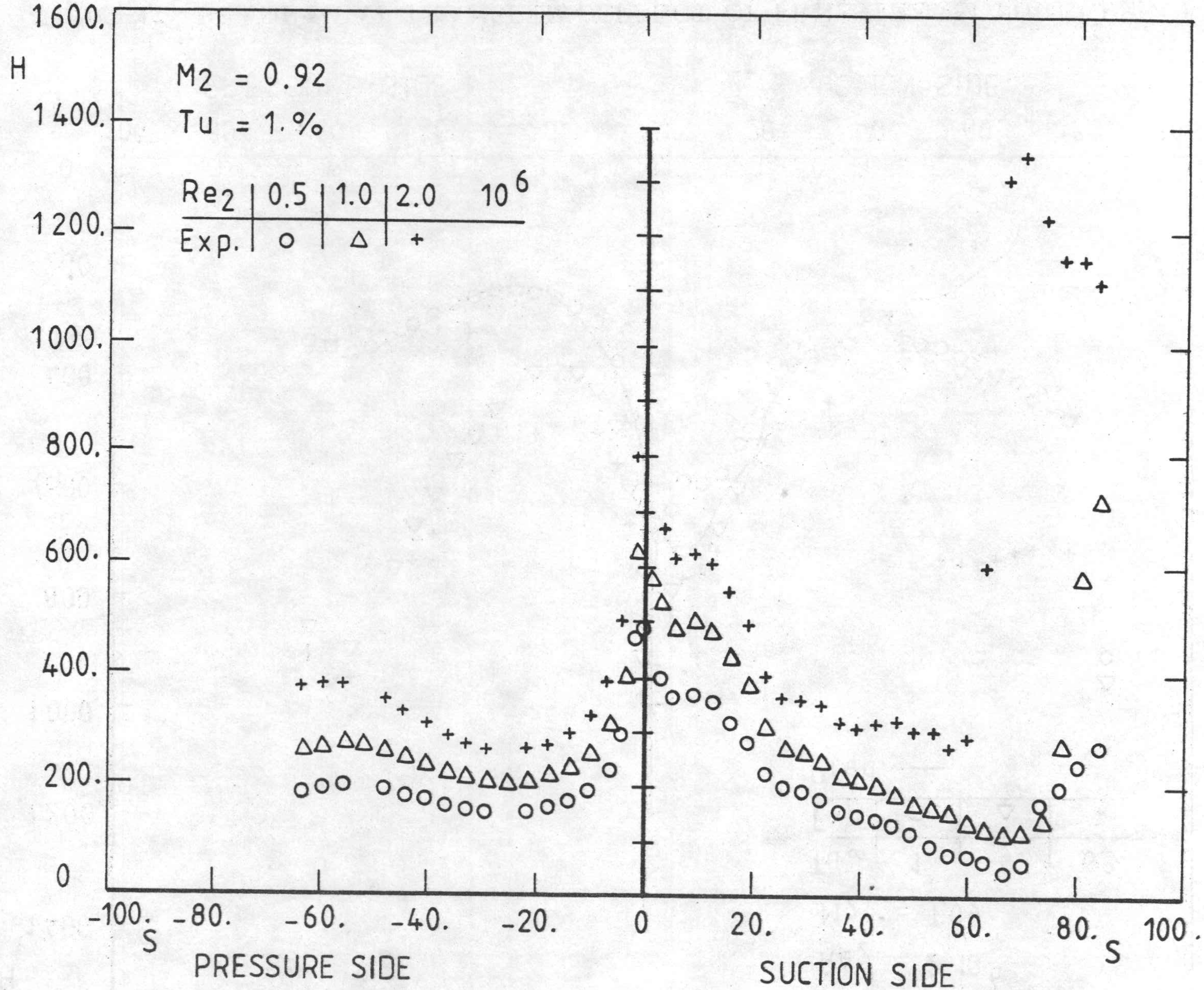

FIG. 18 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER

$M_{2,is} = 0.92$, $Tu_\infty = 1.\%$

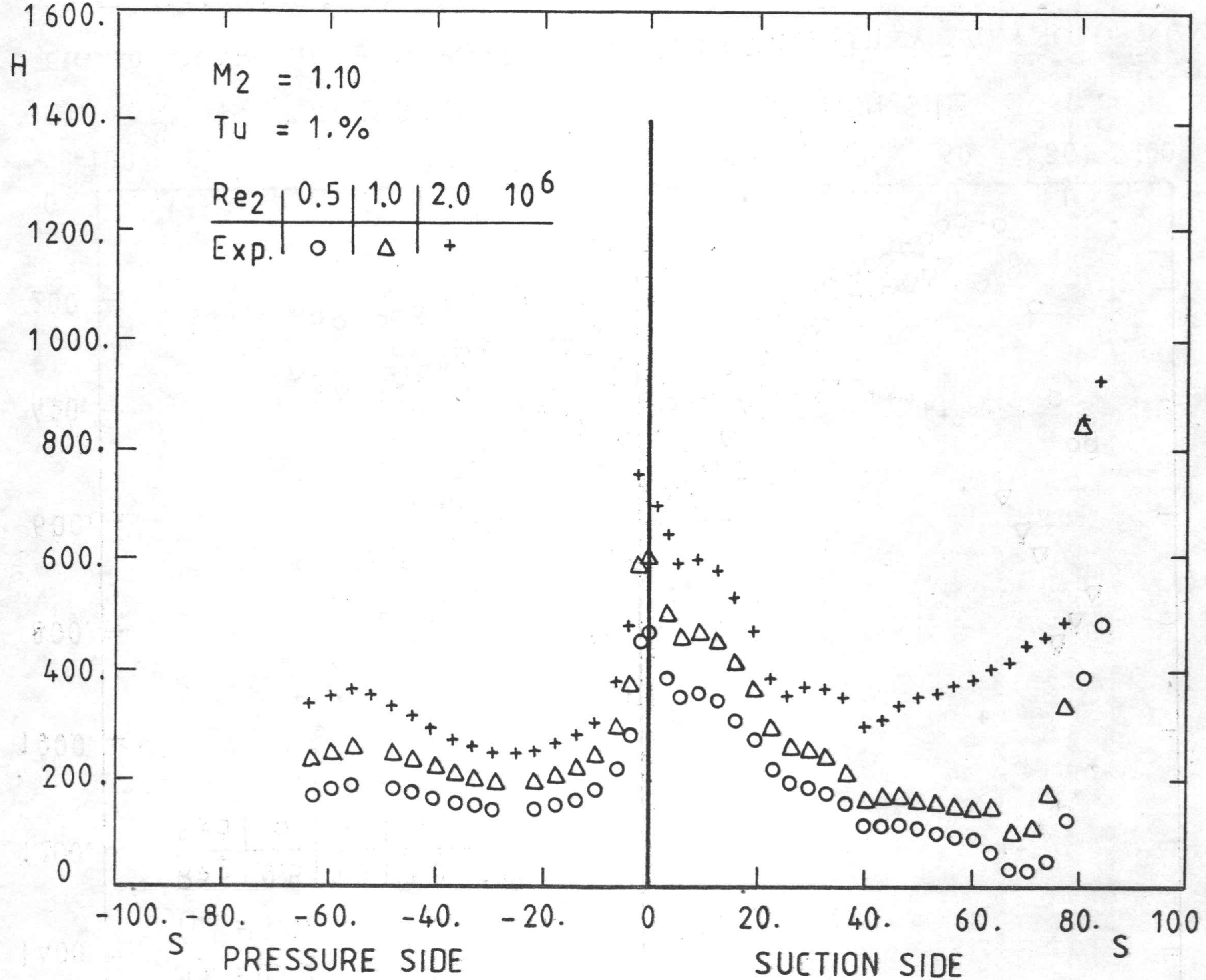

FIG. 19 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER

$M_{2,is}$ = 1.10, Tu_∞ = 1.%

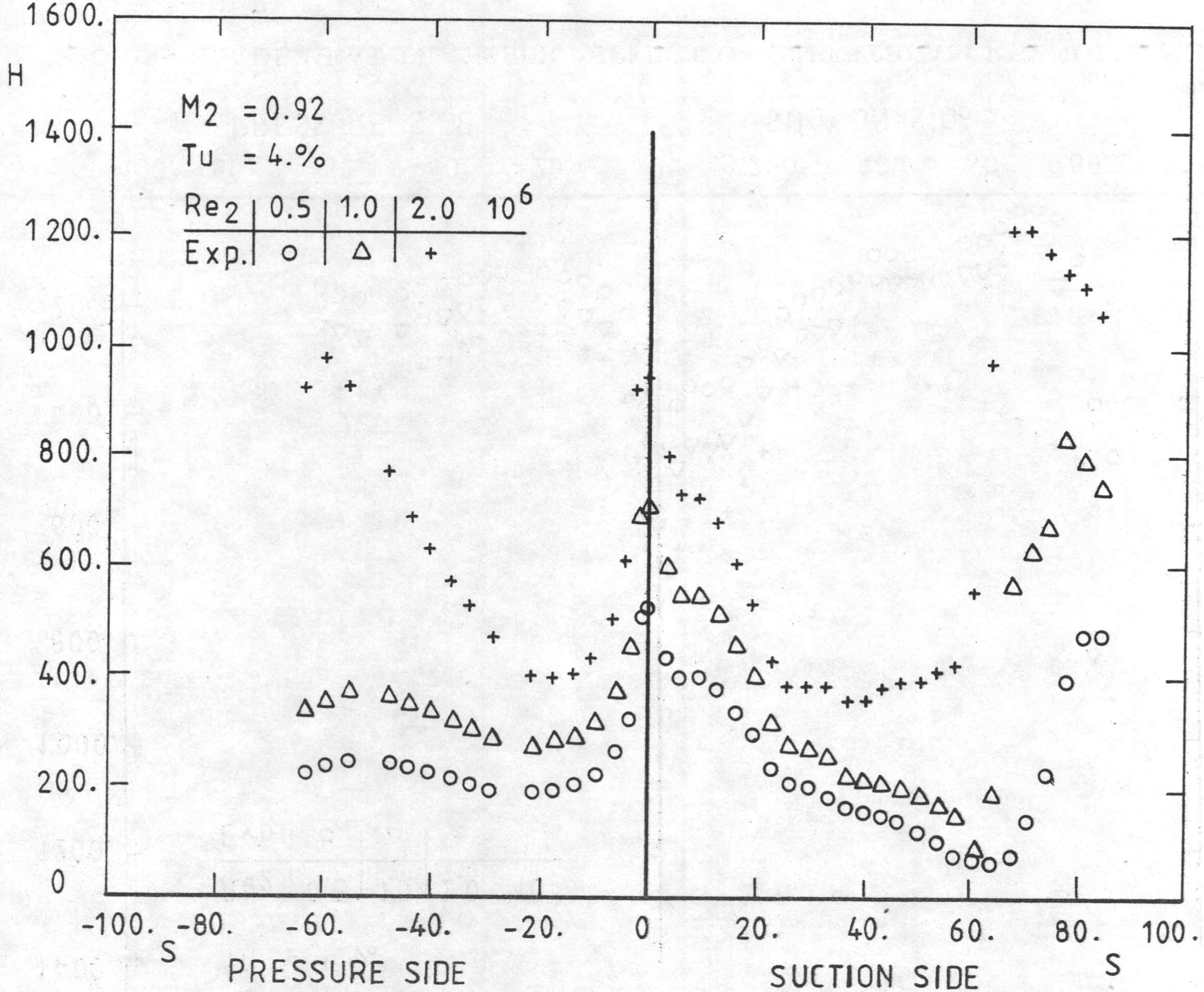

FIG. 20 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER

$M_{2,is} = 0.92$, $Tu_\infty = 4.\%$

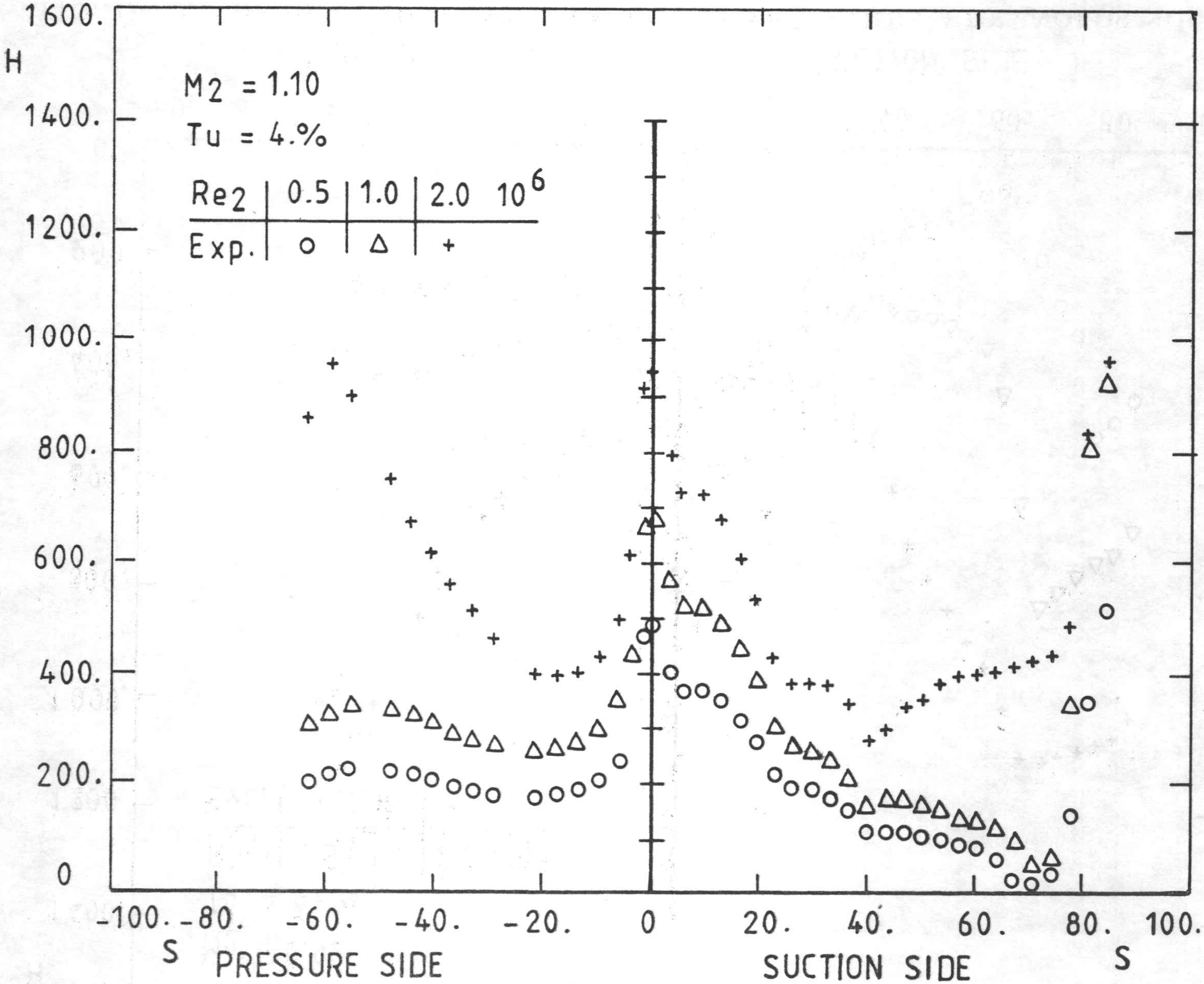

FIG. 21 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER
$M_{2,is} = 1.10$, $Tu_{\infty} = 4.\%$

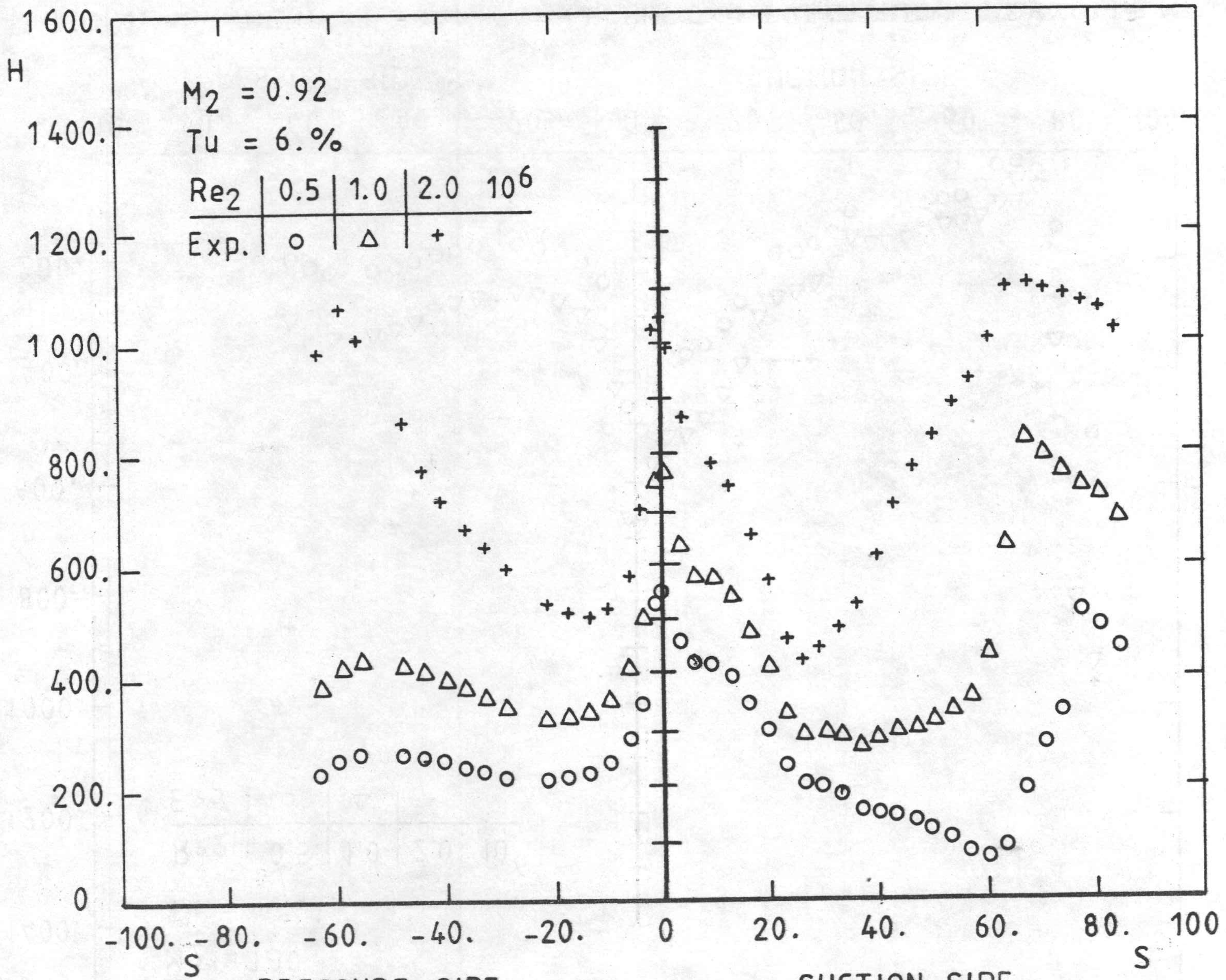

FIG. 22 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER

$M_{2,is} = 0.92$, $Tu_\infty = 6.\%$

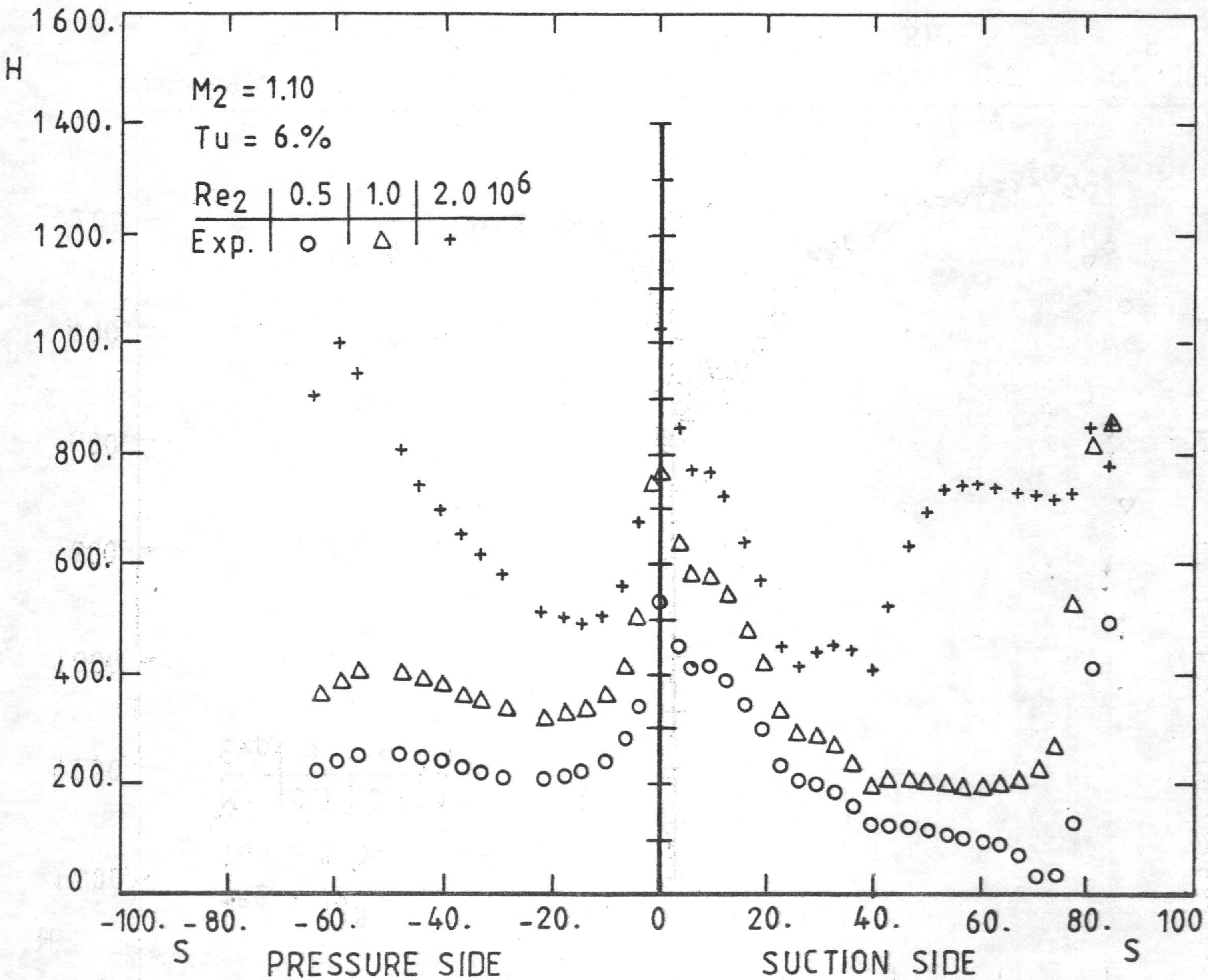

FIG. 23 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM REYNOLDS NUMBER

$M_{2,is} = 1.10$, $Tu_{\infty} = 6.\%$

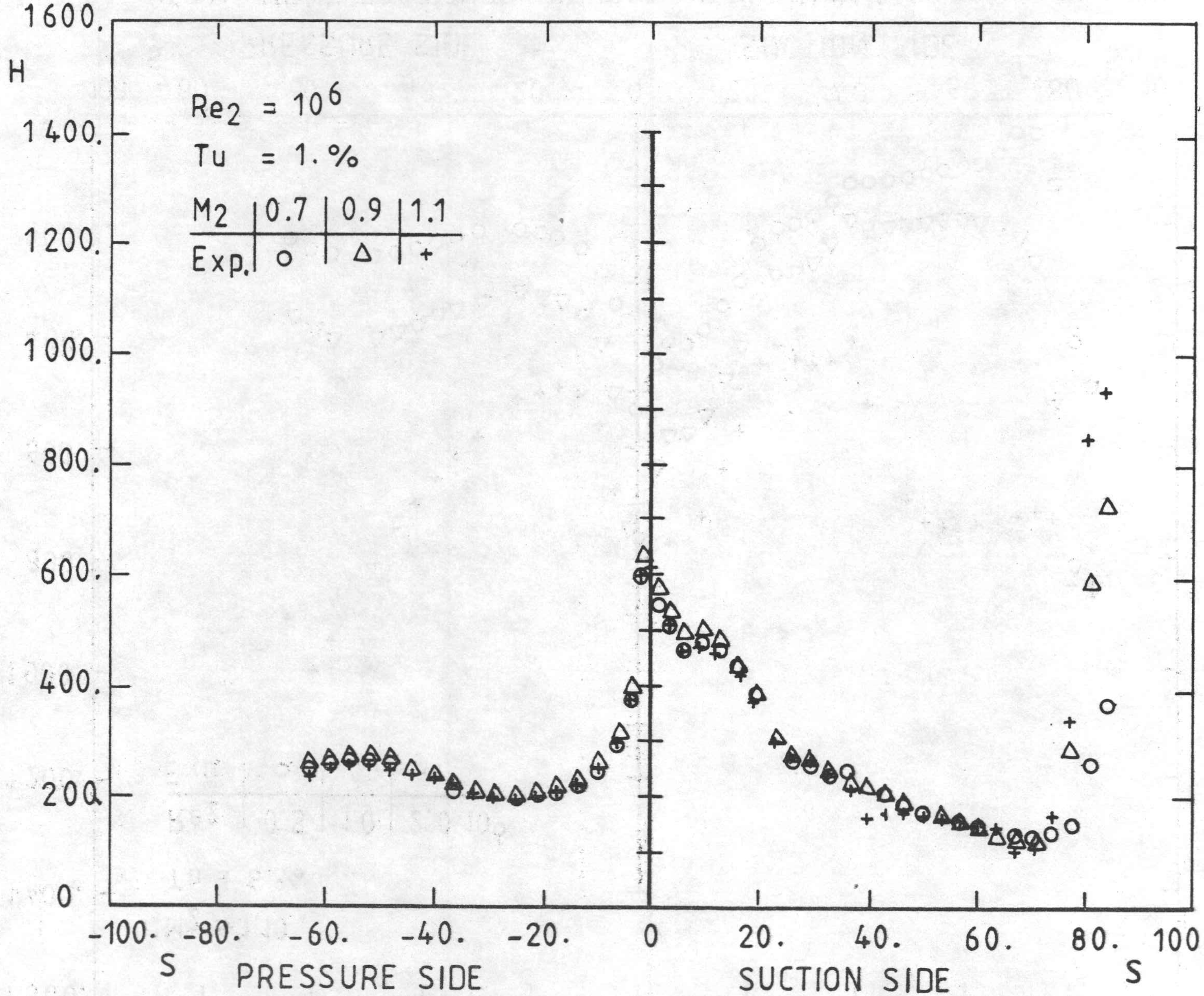

FIG. 24 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM MACH NUMBER

$Re_{2,is} = 10^6$, $Tu_\infty = 1.\%$

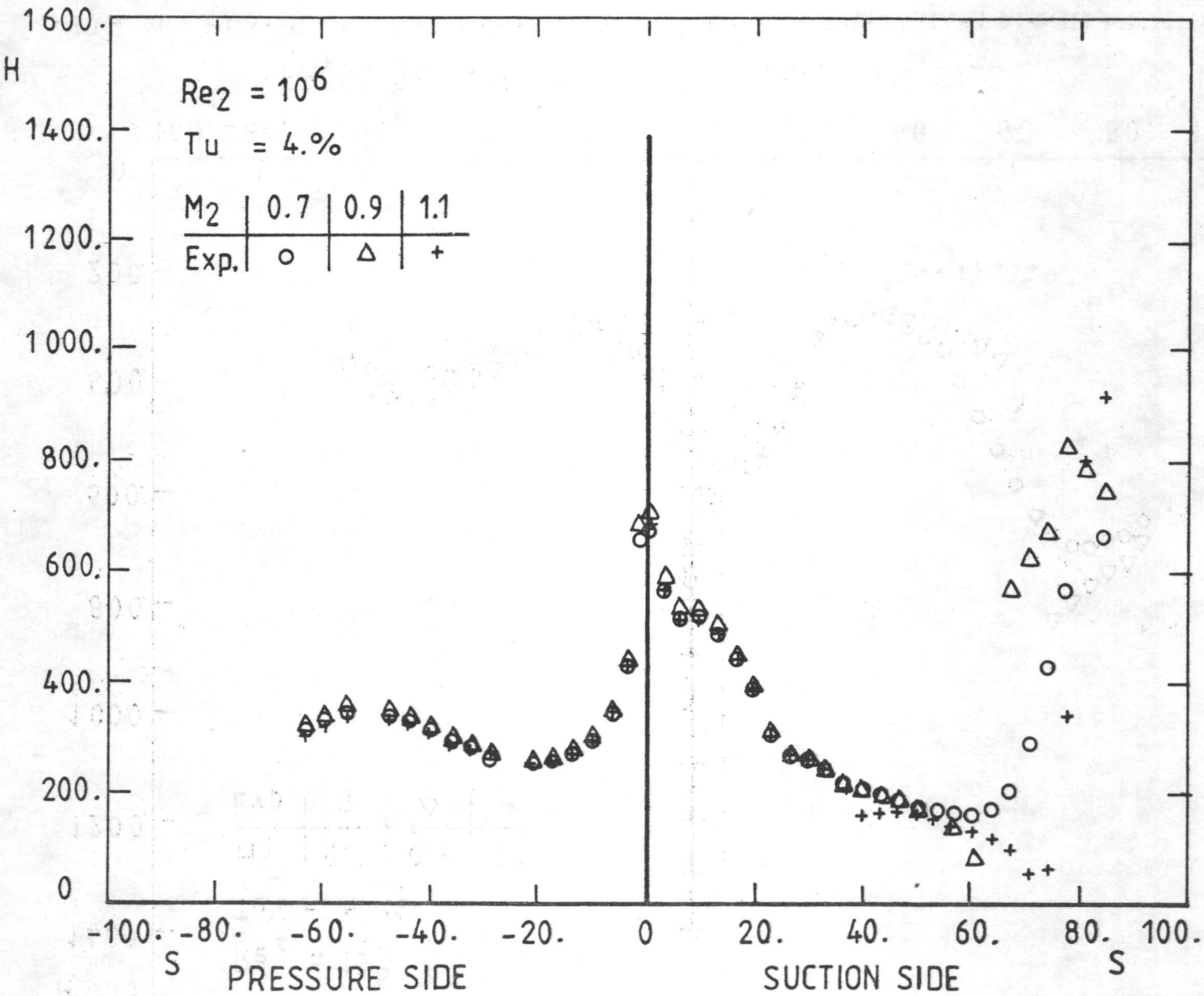

FIG. 25 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM MACH NUMBER $Re_{2,is} = 10^6$, $Tu_\infty = 4.\%$

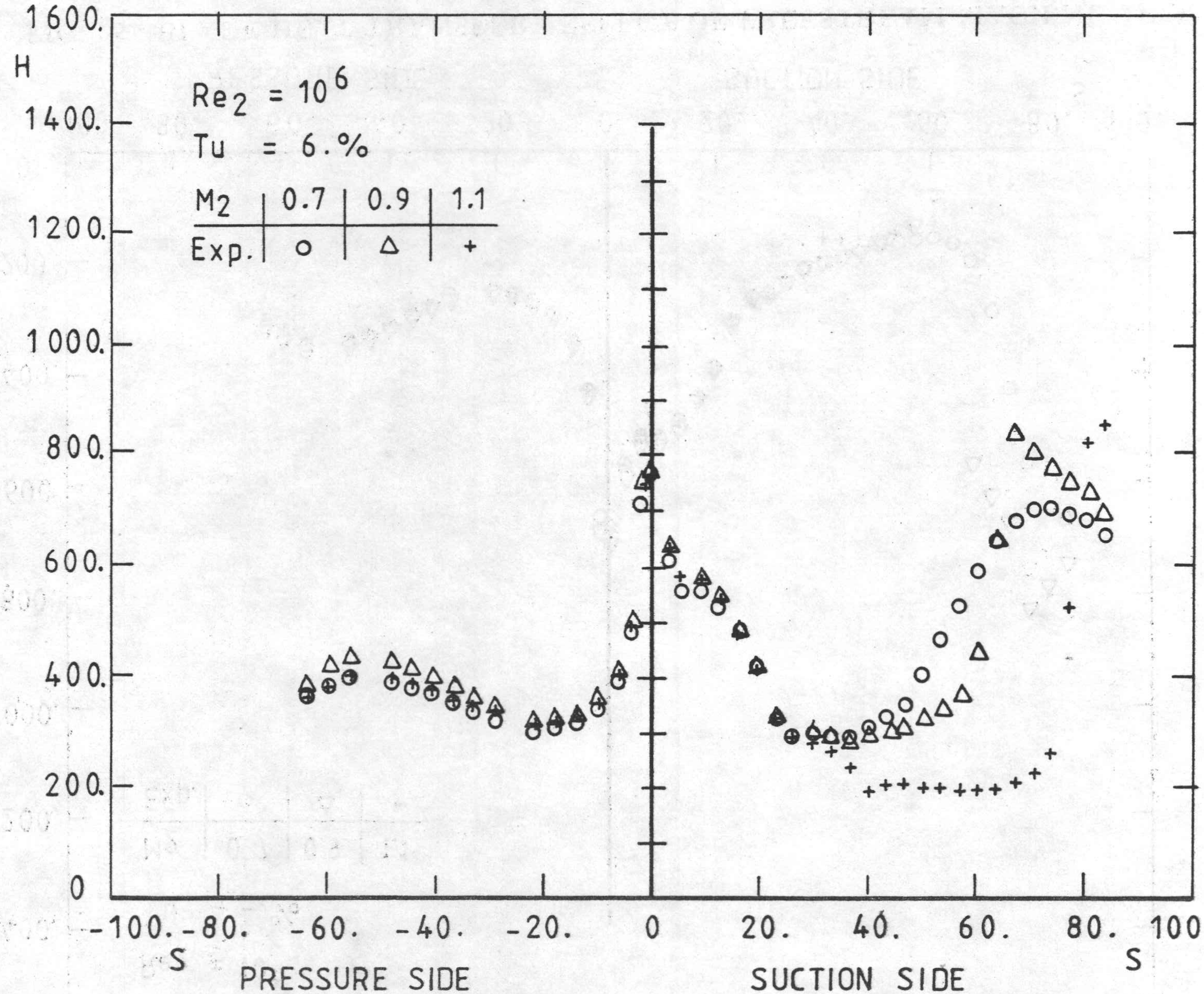

FIG. 26 - BLADE HEAT TRANSFER : EFFECT OF FREESTREAM MACH NUMBER

$Re_{2,is} = 10^6$, $Tu_\infty = 6.\%$

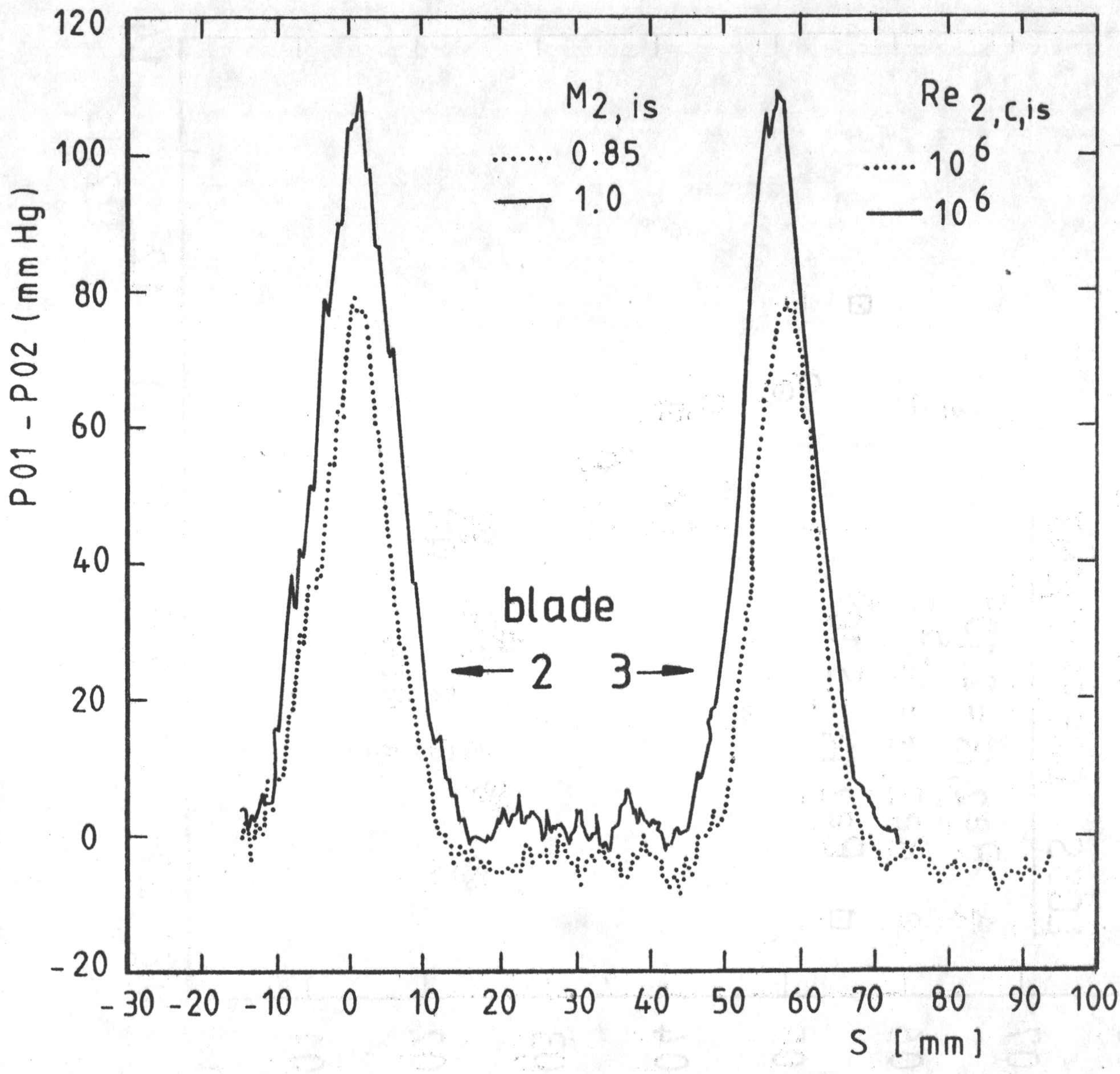

FIG. 27 - MEASURED DOWNSTREAM WAKES :
$M_{2,is} = 0.85, 1.0$; $Re_{2,is} = 10^6$

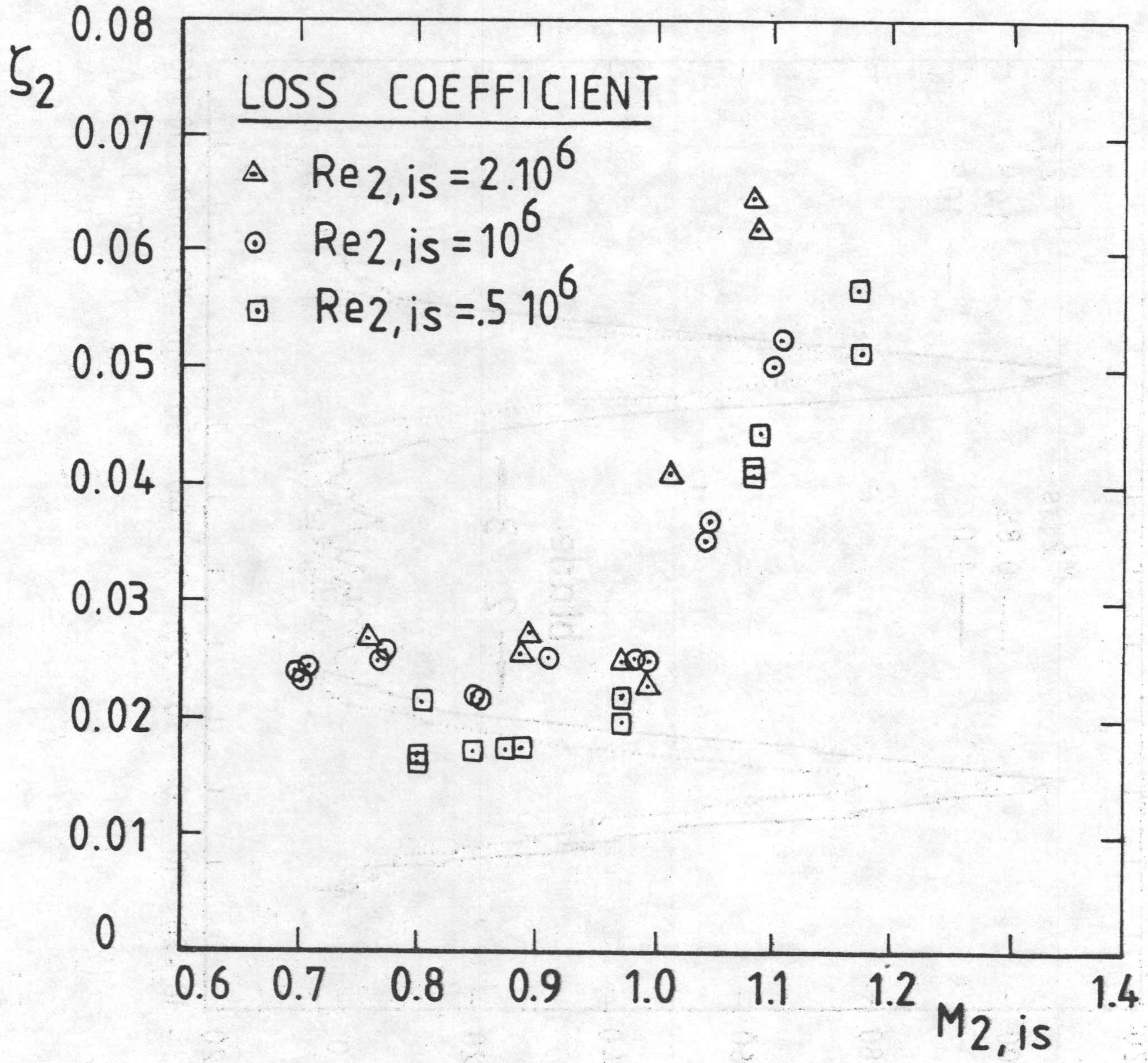

FIG. 28 - DOWNSTREAM LOSS COEFFICIENT EVOLUTION

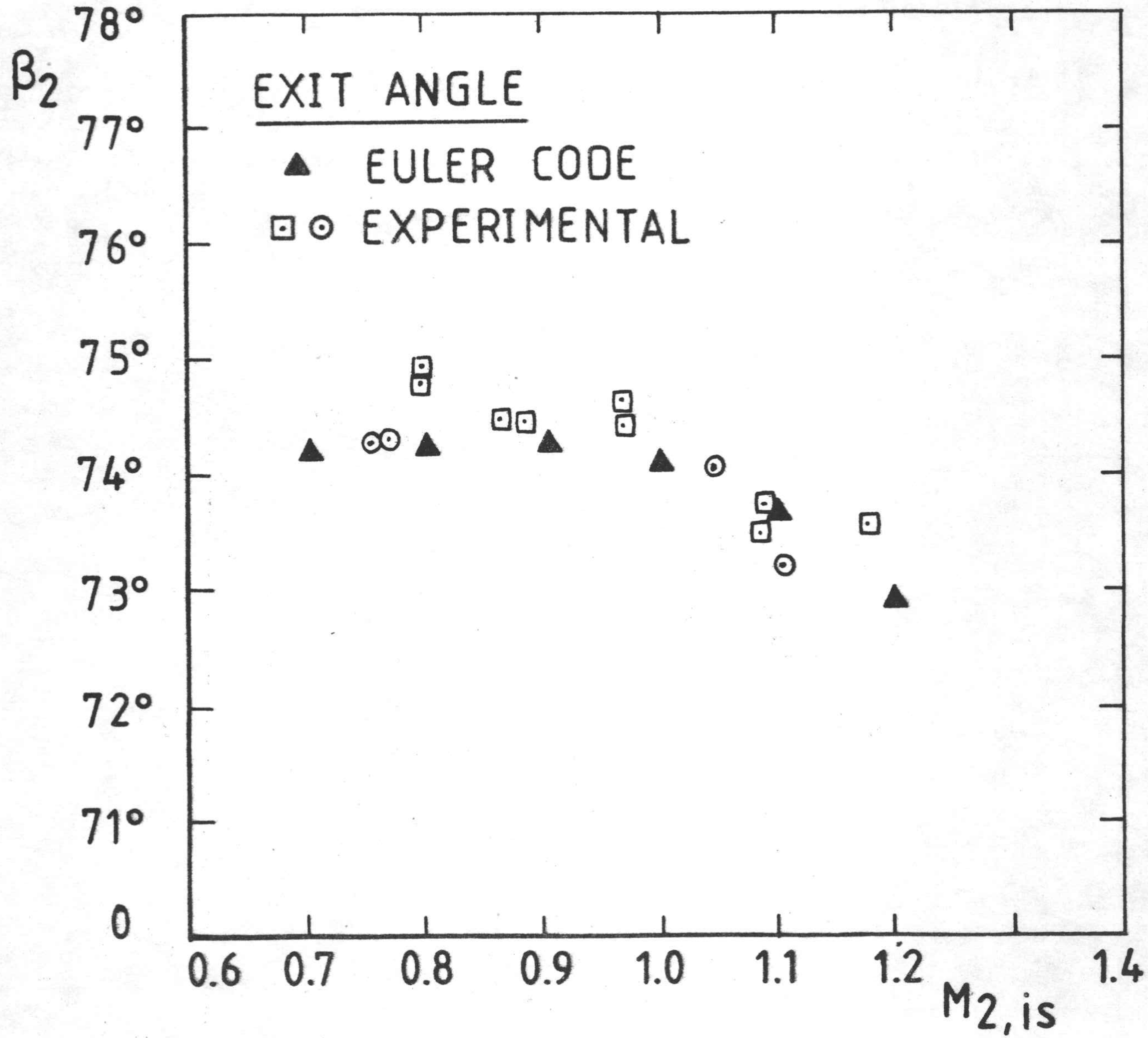

FIG. 29 - EXIT FLOW ANGLE EVOLUTION (MEASUREMENTS AND CALCULATIONS)