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Abstract

Fully developed turbulent air flow in a heated 37-rod bundle with a pitch to diameter ratio of 1.12 has been investigated. The first measurements were performed with a hot-wire probe with x-wires and a temperature wire. Besides the distributions of the mean velocity and temperature and of the wall shear stress and wall temperature, the turbulent quantities such as the turbulent kinetic energy, the Reynolds-stresses and the turbulent heat fluxes were measured and compared with data from isothermal flow and heated flow in pipes.

Messungen der turbulenten Geschwindigkeit und Temperatur in einem Zentralkanal eines beheizten Stabbündels

Zusammenfassung

Voll ausgebildete turbulente Strömung durch ein beheiztes 37-Stabbündel mit einem P/D-Verhältnis von 1.12 wurde untersucht. Die ersten Messungen wurden mit einer Hitzdrahtsonde mit x-Drähten und einem Temperaturdraht durchgeführt. Außer den Verteilungen der mittleren Geschwindigkeit und Temperatur und der Wandschubspannung und Wandtemperatur wurden die turbulenten Größen, wie die kinetische Energie, die Reynoldschen Schubspannungen und die turbulenten Energieflüsse gemessen und mit den Daten bei isothermer Strömung und der beheizten Strömung in Rohren verglichen.

INTRODUCTION

The optimal design of rod bundles in a nuclear reactor requires an accurate prediction of the pressure drop and heat transfer of the coolant and of the rod temperatures associated with it. The thermal-hydraulic analysis is performed by solution of the conservation equation for mass, momentum and energy. Recently developed codes applying a distributed parameter analysis [1] need empirical information on turbulent transport properties of both momentum and energy transport.

A number of experiments has been performed in various rod bundle geometries with isothermal flow (for a review see [2]). It has been found that the structure of turbulent flow through rod bundles is different from turbulent flow through circular tubes. The eddy viscosities parallel to walls are considerably higher than those normal to walls and depend strongly on the pitch to diameter ratio of the rod bundle. To model the heated flow correctly a knowledge of turbulent temperature fluctuations such as the eddy diffusivity of heat in all directions is necessary. Since no such data were available for flow through rod bundles, it is the aim of our ongoing research program to measure the turbulent quantities in heated flow through triangular array rod bundles.

EXPERIMENTAL APPARATUS AND PROCEDURE

A rod bundle of 37 parallel rods (O.D. D = 140 mm) arranged in triangular array in a hexagonal symmetric channel was built (Fig.1). The position of the channel is horizontal. The total length of the working section is L = 11.50 m with an unheated entrance length of $L_{iso} = 4.60\,m$ and a heated length of $L_{heat} = 6.90\,m$. The pitch to diameter ratio of the rods is P/D = 1.12, but it can be varied in the range $1.06 \leq P/D \leq 1.25$. With this P/D-ratio the length to hydraulic diameter ratio for the heated part is $L_{heat} / D_h = 128$. The rods are made of epoxy reinforced with fiberglas, sheathed with a 50 μm foil of monel metal, which serves as resistance heating element. It is heated by low voltage, high direct current to temperatures in the range of 60° to 100°C. Since the metal foil has a very accurate thickness the heat flux is uniform around the perimeter of the rods. The heat conduction is very small due to the small thickness of the metal foil and the low conductivity of the rod material. Thus, any circumferential temperature variations due to different heat transfer will not be smoothed by conduction. The wall heat flux was determined from the measurements of the current and the voltage drop along the rods with an estimated error of ± 1.5%. The heat flux in the present experiment was $1.37\,W/m^2$.

The channel walls are made of aluminum covered with a thick insulation at the outside to minimize the heat losses. The whole bundle is made up from five sections, each 2.30 m long. The rod gap spacers were made of 4 mm thick and 15 mm wide (in axial direction) steel with rounded edges. Due to extremely small manufacturing tolerances the deviations from the nominal bundle geometry are less than 0.2 mm, including the bending of the rods.

The fluid is air at atmospheric pressure and room temperature at the entrance. The air is driven by a centrifugal blower. Before entering the working section it passes through a filter to remove particles greater than 1 μm and an entrance section of 5 m lenght with a honeycomb grid and a number of fine grid screens.

The measurements are performed at a position 20 mm upstream of the outlet. The time-mean values of the axial velocity and the wall shear stresses are measured by Pitot and Preston tubes (O.D. d=0.6 mm), respectively, the mean temperatures are measured by sheathed thermocouples (O.D. d=0.25 mm).

The turbulent quantities are measured by hot wire anemometry using a three-wire probe. This probe consists of an x-wire probe with an additional cold wire perpendicular to the x-wire plane for simultaneous measurement of two components of instantaneous velocity and temperature. The x-wires have a length of 1.2 mm, a diameter of 5 μm and a spacing of 0.35 mm. The cold wire has a diameter of 2 μm, a length of 0.9 mm and is positioned 0.1 mm upstream of the x-wire prong tips. The measuring volume is approximately 1 mm^3. Since the cold wire is run in the CCA-mode the frequency response is not as good as that of the x-wires, which are run in the CTA-mode. Therefore in future measurements a cold wire of 1 μm diameter will be strived for to improve the frequency response. The probe was fabricated in our laboratory using the DANTEC probe 55P61. The calibration and evaluation method uses look-up tables as described by Lueptow et al. [14], extended by the temperature dimension. The performance of the method was evaluated by measurements in heated turbulent pipe flow. Due to the poor frequency response of a 2 μm cold wire the attenuation and phase shift of the temperature signal leads to errors in all correlations of u, v and t. A rough estimate gives the following maximum errors; $\overline{t^2}$ 5 %, $\overline{ut}$ 13 % and $\overline{vt}$ 23 % too low, and $\overline{u^2}$ 14 % , $\overline{uv}$ 18 % and $\overline{v^2}$ 3 % too high [3].

The wall temperatures are measured by the liquid crystal technique using digitized video signals for precision readings of local temperatures.

The performance of the measurements is fully automated; the mass flow rate, the heating power and the traversing of the measuring probe are controlled by a microcomputer HP-RS25C. The triple wire probe is run by two CTA- and one CCA-bridge from the Dantec 55M system. A TSI-IFA-100 with three channels was used for signal conditioning, with filter, offset and amplification. The signals were digitized at sample rates of 2 kHz per channel by a DT2828-card, which provided sample and hold digitisation with 12-bit resolution and a maximum input signal of 5 Volts. The total number of samples taken in a continous stream were 96000 per channel, with a measuring time of 48 seconds. The raw data were loaded into extended memory of the computer by DMA. The evaluation of all correlations takes approximately 1 minute. At each measuring point the probe is turned into two positions to measure the velocity components normal and parallel to the nearest wall.

Measurements were taken in a central channel next to the central rod under isothermal and non-isothermal conditions. In each subchannel measurements at 87 points (Fig. 2) were taken, which took approximately eight hours. The data of the heated experiment were: Reynolds number $Re = 6.60 \times 10^4$ with a bulk velocity in the central channel $u_b = 22.7m/s$ and a bulk temperature $T_b = 52.8^\circ C$. The wall heat flux was $q = 1.37kW/m^2$.

RESULTS

Flow characteristics across the whole bundle cross section

Mean velocity and temperature was measured in all 54 central channels and 18 wall channels, each at the position of maximum velocity in the channel. The velocity varies sligthly across the bundle. The maximum velocity is in the center channels around the 7 center rods (24 channels). Here the variation or scatter is 1.2 % for isothermal and 1.7 % for heated flow. The scatter in the six channels around the center rod is only 0.5 %. In the channels around the 19 center rods the velocity is on the average 1 % lower. The velocity in the central wall channels is 2.1 % lower, and in the wall channels next to the corner it is 4.0 % lower in isothermal flow and 4.6 % lower in heated flow.

In heated flow the temperature is uniform for all central channels with a variation of $\pm 0.2°C$, except for the two channels next to the bottom corner rod. Here the temperature was 1.4° lower. The temperature in the wall channels is lower by $7.4 \pm 0.8°C$ except for the four bottom wall channels, where it was lower by $9.6 \pm 0.5°C$.

The choice of a W/D = 1.06 seems to be a good compromise to have a small velocity gradient across the bundle cross section together with a low overcooling of the wall channels. The effect of thermal convection is only detectable in the bottom part of the bundle in two central channels and four wall channels. The Grashof number with $GrPr = 10^5$ is small enough together with a Reynolds number of 6.60×10^4 for the heated case to avoid any distortion of the velocity or temperature profiles.

Wall shear stress distribution

Fig.3 shows the measured wall shear around the perimeter of the channel for both the heated and the unheated case. The shear stress was evaluated by Preston's method. The properties of air were evaluated at the fluid temperature at y = 0.3 mm, which is the radius of the Preston tube.

The average friction factors can be calculated from the measured shear stress by $f = 2\,(u_\tau/U_b)^2$. The data for the heated case are, $u_\tau = 1.163 m/s$, $U_b = 22.73 m/s$ and $f = 0.005236$; for the isothermal case we have $u_\tau = 1.0165 m/s$, $U_b = 20.35 m/s$ and $f = 0.004991$. Compared to the friction factor for circular tubes by the Blasius relation $f = 0.0791/Re^{0.25}$ the friction factor in the central channel of the bundle is 6.3 % larger in the heated flow. If the Reynolds number is evaluated with the properties of air at wall temperature, that is at $70°C$, $Re_w/Re = 0.902$, the Blasius relation gives a friction factor which is 3.8 % smaller. In the unheated case, with $Re = 7.15 \times 10^4$ the difference is 3.5 %.

The shear stress reduced by the mean is shown in Fig.4 together with a calculation by [1] . The data points in that figure are from the heated flow but the curve of the average of all six subchannels is almost identical to the one for isothermal flow. The result that the shear stress distribution does not have a maximum at 30° has been a matter of controversy in the past. Experiments in bundles by other authors, e.g. Carajilescov and Todreas [4], Trupp and Azad [5] and others showed similar behavior while experiments in small bundle simulators in rectangular channels like the experiments by Fakory and Todreas [6], Hooper and Rehme [7] and Seale [8] showed a shear stress distribution with a maximum at the position of maximium channel width. Besides of entrance effects and asymmetries in the experimental flow channel the occurrence of secondary flow and the anisotropy of the eddy viscosity have been attributed to be responsible for this effect. Thus, Rapley and Gosman [9] have predicted secondary flows by calculating measured shear stress distribution without using anisotropic turbulent diffusivities. On the other hand, Bartzis and Todreas [10] demonstrated by their analysis that the anisotropy is much more significant than the secondary flow effect. Trupp and Aly [11] in their analysis come to the conclusion that both effects play an important role and are interdependent on each other. While anisotropic eddy diffusivities have been measured without doubt, it is very difficult to measure secondary flows of the order of 1 % of the axial velocity. Attempts at measuring secondary velocities have been largely unsuccessful although Vonka [13] recently claimes to have measured, by LDA, secondary vortex velocity components in the order of 0.1 % of the mean bulk velocity in a rod bundle simulator with four whole rods and six half rods. Although this short review on this topic could not be comprehensive it is obvious that this question remains open. Further measurements in our rod bundle will be performed at different Reynolds numbers and in the wall channels for comparison with measurements in the rectangular channel of Rehme [12].

Mean velocity and temperature distribution

Similar to the shear stress the temperature distribution at the wall (Fig.5) and the mean axial velocity and temperature distribution in the fluid in azimuthal direction show a level at the position of 30° if plotted at constant wall distances y (Figs. 6 and 7). The reference temperature T_w is the average wall temperature with $70.3°C$. Isoline plots of both, the mean velocity and temperature are shown in Fig.8. Since the scatter of the data between the six subchannels was small the presented data are the averaged data over all subchannels. There was no relevant difference in the velocity data between the isothermal and the heated case.

The logarithmic profiles of the velocity (Fig.9) follow the law of the wall at all azimuthal positions. On the other hand, the temperature profiles in the gap at zero degree show a smaller slope than those in the center. Of course local wall temperatures are used to calculate T^+ . Due to temporary difficulties in the measuring method of the wall temperatures an uncertainty of $1°C$ in the level of the temperatures must be assumed. This would have an effect on the constant in the law of the wall. The slope of the logarithmic profile depends on the wall heat flux. An error of ± 2 % in the heat flux changes the slope by approximately ∓ 0.05.

Turbulent quantities

All measured turbulent quantities are plotted versus the relative wall distance, which is the distance between the measuring position and the wall, y, reduced by the distance between symmetry line and wall, $\hat{y}$ at the respective angular position. If not noted otherwise, scaling was performed by the local friction velocity and local friction temperature. The data displayed in isoline plots were scaled by average values of the friction velocity and temperature. All data are shown for the unheated and for the heated case. The data are averages over all six subchannels, which generally reduced the scatter, compared to data of a single subchannel.

Turbulent intensities and kinetic energy

The turbulent intensities of the axial velocity component $\sqrt{\overline{u^2}}/u_\tau$ are shown in Fig. 10 and 11. The data of the isothermal case are roughly 5 % higher than those of the heated case. This is in contrast to expectation, since in the round pipe flow the data of the heated case were higher [3,16] . It cannot be explained by those measuring errors mentioned before, which would also point into the opposite direction.

The data in the gap at 0° are very similar to those measured in round tubes. In the gap the intensities are lowest and have also their absolute minimum. This coincides with the measurements of Rehme [12,15] in wall channels (at 30°). A striking difference between the heated and unheated case is the intensity at the center of the channel at (30°) which has an absolute maximum in isothermal flow and only a small relative maximum in heated flow. This difference will be further investigated as well as the overall difference between both cases.

The intensities of the radial velocity component $\sqrt{\overline{v^2}}/u_\tau$ shown in Fig.12 and 13 have a 15 % difference between heated and unheated flow, which cannot be explained at present. The data from isothermal flow are similar to those of pipe flow. Compared to the data from measurements in wall channels the variation in azimuthal direction is much smaller, although for those data the uncertainty and scatter was quite high. In the present data we have the smallest intensities in the gap and the highest at about 25° but not at the symmetry line at 30°.

Similar comments can be made about the intensities of the azimuthal velocity component $\sqrt{\overline{w^2}}/u_\tau$ (Fig.14 and 15). Here the variation in azimuthal direction is even less than that of the radial velocity component.

The relative kinetic energy

$$k^+ = \frac{1}{2}(\overline{u^2} + \overline{v^2} + \overline{w^2})/u_\tau^{\,2} \qquad [1]$$

in Fig.16 and 17 shows of course the same characteristics as the individual intensities.

A different distribution was found for the intensity of the temperature fluctuation $\sqrt{\overline{\theta^2}}/T_\tau$ in Fig. 18 and 19. Here the distribution near 30° is similar to that of pipe flow while in the rest of the subchannel the distribution is more uniform or flatter with the highest values at 15° and the smallest in the gap. The intensity along the centerline has a maximum at 10° with identical values at 0° and 30° .

Reynolds shear stress

The scaled turbulent shear stress normal to the wall $-\overline{uv}/u_\tau^2$ (Fig.20) decreases linearly with increasing distance from the wall, as in pipe flow. Especially in the unheated case the data are above the theoretical line for pipe flow. The variation along the perimeter of the rods is small.

The scaled azimuthal shear stress, $\overline{uw}/u_\tau^2$ shown in Fig.21 and 22, is close to zero near the symmetry lines at 0° and 30° and has its maximum values near 10°, with its absolute maximum at the centerline between two subchannels. Compared to the results from measurements in wall channels with P/D = 1.148 and W/D = 1.074 [15] the maximum values found in the subchannels between the rods are similar to the present values. The position of the maximum is however at 25°, due to the neighbouring wall.

Turbulent heat flux

The distribution of the turbulent heat flux in azimuthal direction, $\overline{w\theta}/u_\tau T_\tau$, shown in Fig. 23b and 22, is similar to the distribution of the shear stress.

The scaled turbulent heat flux in axial direction, $\overline{u\theta}/u_\tau T_\tau$ shown in Fig.23a and 24, decreases with increasing distance from the wall. The maximum values are obtained near 30°, however at the centerline the maximum values are near 10°. Compared to results from measurements in round pipes [3,16], the values at 30° are approximately 25 % lower. Other data from measurements in rod bundles are not available.

The scaled heat flux in radial direction $\overline{v\theta}/u_\tau T_\tau$, (Fig.25) has a maximum at a realtive wall distance $y/\hat{y} = 0.25$. At the azimuthal positions of 0° and 30° it is zero at the centerline, while at the other positions it is not. This is due to the choice of the coordinate system, which is not continual at the centerline. The absolute magnitude of the distribution is lower than expected. In the heated pipe [3] the maximum value measured with the same measuring technique was $\overline{v\theta}/u_\tau T_\tau = 0.5$, which is still lower by almost a factor of two compared to measurements by Hishida et al. [17]. From our error analysis the possible maximum error was only 23 %. Measurements with different probes will be performed to resolve this question.

The correlation coefficients

The correlation coefficient (Fig.26)

$$R_{uv} = \frac{-\overline{uv}}{\sqrt{\overline{u^2}}\sqrt{\overline{v^2}}} \qquad [2]$$

is independent of the azimuthal position. The radial distribution and absolute magnitude is similar to that in pipe flow. The difference between heated and unheated flow of approximately 12 % is possibly due to measuring errors.

The corresponding correlation coefficient R_{uw} (Fig.27) shows a similar distribution as the turbulent shear stress distribution in azimuthal direction, however with the difference, that close to the wall it is practically zero at all positions.

The distribution of the correlation coefficient $R_{w\theta}$ (Fig.28b) is almost identical to that of $-R_{uw}$.

The correlation of the axial velocity component with the temperature fluctuation $-R_{u\theta}$ is very high near the wall, although some 20 % lower than in pipe flow (Fig.28a). At the centerline $-R_{u\theta}$ does not vanish, it has a relative maximum at 10° – 15° , just as $R_{w\theta}$.

The correlation coefficient $R_{v\theta}$ varies with azimuthal position (Fig.29) unlike $-R_{uv}$, but similar to the radial heat flux. However, the smallest values are found at the azimuthal positon of 10°, which is close to the position of the highest values of the intensitiy of the temperature and of the correlations $\overline{uw}$, $\overline{u\theta}$ and $\overline{w\theta}$. The correlation between v and θ is smaller than between v and u, which was already found for pipe flow [17].

Eddy diffusivities

The eddy diffusivity of momentum or eddy viscosity is defined by

$$\varepsilon_{mr} = \frac{-\overline{uv}}{\partial U/\partial y} . \qquad [3]$$

Shown in Fig.30 is the non-dimensional eddy viscosity

$$\varepsilon_{mr}^{+} = \frac{\varepsilon_{mr}}{\hat{y} u_\tau} , \qquad [4]$$

together with Reichardt's [18] curve for the eddy viscosity in a pipe. As for wall channels [12] the eddy viscosities normal to the wall are higher than the pipe data and only weakly dependent of the azimuthal position.

The non-dimensional eddy viscosity in azimuthal direction is defined by

$$\varepsilon_{ma}^{+} = \frac{-\overline{uw}}{\frac{1}{r}\frac{\partial U}{\partial \phi}\hat{y}_{\max} u_{\tau m}} , \qquad [5]$$

i.e. it is scaled by the average value of the friction velocity and the maximum profile length $\hat{y}_{\max}$ at 30° (Fig.31). Because of only 7 angular measuring stations, a reasonable derivative of the velocity is available at only 4 or 5 positions, and the scatter is quite large. The values of the azimuthal eddy viscosity are higher away from the wall and smaller close to the wall than those of the radial eddy viscosity.

The corresponding eddy diffusivities of heat in radial direction

$$\varepsilon_{hr}^{+} = \frac{\overline{v\theta}}{\partial T/\partial y \; \hat{y} \; u_\tau} , \qquad [6]$$

and in azimuthal direction

$$\varepsilon_{ha}^{+} = \frac{\overline{w\theta}}{\frac{1}{r}\frac{\partial T}{\partial \phi}\hat{y}_{\max} u_{\tau m}} , \qquad [7]$$

are plotted in Fig.32. As for the turbulent shear stress and heat flux the eddy diffusivities of heat are smaller than those of momentum, especially in radial direction. This is not due to different gradients of the velocity and temperature as the almost identical distributions for both radial gradients in Fig.33 show.

Turbulent Prandtl number

The turbulent Prandtl number in radial direction determined by

$$Pr_{tr} = \frac{-\overline{uv}}{\overline{\theta v}} \frac{\partial T/\partial y}{\partial U/\partial y} \qquad [8]$$

and in azimuthal direction

$$Pr_{ta} = \frac{\overline{uw}}{\overline{\theta w}} \frac{\partial T/\partial \phi}{\partial U/\partial \phi} \qquad [9]$$

is shown in Fig.34. Because the diffusivities of heat are small compared to those of momentum, the turbulent Prandtl number is large. In respect to the generally assumed Prandtl numbers for pipe flow it is large by a factor of two. For turbulent Prandtl numbers in azimuthal direction, which are lower than those in radial direction, no data are available in the literature for comparison. As stated before, the measuring technique has to be carefully checked and measurements will be repeated with different probes, before those data can be used with confidence.

Tables

All results are documented in Table I and II. Additional to the presented results in the diagramms the tables contain the correlations of third and fourth order. The skewness defined e.g. for the axial component as $\overline{u^3}/\sigma_u^3$, and the flatness defined as $\overline{u^4}/\sigma_u^4$ with $\sigma_u = \sqrt{\overline{u^2}}$ is given for all velocity components and the temperature. The distribution of the skewness and flatness of the radial velocity component does not show significant differences to pipe flow and the respective values for the azimuthal component are small. The values for the axial component are very large at the center of the channel, which seems to be due to some extremely large fluctuations, which might have been outside of the calibration range of the hot wire probe. Therefore these results have to be checked by a new measurement and all results of higher order correlations will be discussed in a later report.

CONCLUSION

Measurements of turbulence in heated rod bundles were performed for the first time. The results can only be compared to flow in round tubes and in unheated rod bundles, and here most data of turbulent quantities are available from wall channels. The measurements in a central channel indicate that:

1. The wall shear stress distribution is flat at 30°, different from the results in wall channels. The wall temperature distribution has a similar shape.

2. Also the velocity and temperature distribution in azimuthal direction in the flow is similar to the shear stress distribution. The radial distribution obeys the law of the wall for both velocity and temperature.

3. The intensities of the radial and the azimuthal velocity component are less dependent on the angular positon than in comparable wall channels.

4. The intensity of the temperature fluctuation varies less with the distance of the wall than in pipe flow, except at the position of 30°.
5. The shear stress distribution is similar to that found in the subchannels between the rods in wall channels.
6. The turbulent heat flux in radial direction was smaller than in pipe flow.
7. The anisotropy, that is the difference of the eddy diffusivities in radial and in azimuthal direction, is small. It is close to 1 for the diffusivities of momentum and between 2 and 3 for the diffusivities of heat.
8. The turbulent Prandl number lies between 2 and 4 in radial direction and between 1 and 2 in azimuthal direction.

We do have doubts about the accuracy of the correlation $v\theta$ and $w\theta$ which determines the turbulent heat flux, eddy diffusivities of heat and the turbulent Prandtl number. Further measurements with new hot wire probes will be performed for verification. These results are the first of an ongoing investigation where measurements will be taken in different subchannels, such as wall subchannels, and where the pitch to diameter ratio of the rods will be varied.

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NOMENCLATURE

D_h	hydraulic diameter
D	rod diameter
P	rod pitch, distance between rod centers
W	distance between the wall and the rod plus diameter of the rod
L	lenght of rod bundle
f	fanning friction factor
k	kinetic energy of turbulence
Pr_t	turbulent Prantdl number, Eq.8
q_w	wall heat flux, $[Wm^{-2}]$
r	radius, $r = D/2 + y$
R_{uv}	cross correlation coefficient of uv, Eq.2
R_{uw}	cross correlation coefficient of uw
$R_{u\theta}$	cross correlation coefficient of uθ
$R_{v\theta}$	cross correlation coefficient of vθ
$R_{w\theta}$	cross correlation coefficient of wθ
Re	Reynolds number
T	mean fluid temperature
T^+	dimensionless temperature, $(T_w - T)/T_\tau$
T_τ	friction temperature, $q_w/\rho c_p u_\tau$, $[°C]$
U	mean velocity in axial direction
u^+	dimensionless velocity, U/u_τ
u	fluctuating velocity in axial direction
u_τ	local friction velocity, $\sqrt{\tau_w/\rho}$, $[ms^{-1}]$
$u_{\tau m}$	average friction velocity
v	fluctuating velocity normal to the wall
w	fluctuating velocity parallel to the wall
y	distance normal to the wall
$\hat{y}$	distance between wall and centerline
$\hat{y}_{\max}$	$\hat{y}$ at $\phi = 30°$
y^+	dimensionless distance from the wall, yu_τ/ν

ε_m	eddy diffusivity of momentum, Eq.3, $[m^2s^{-1}]$
ε_h	eddy diffusivity of heat, Eq.6, $[m^2s^{-1}]$
ε^+	dimensionless eddy diffusivity, Eq.4
θ	temperature fluctuation
ν	kinematic viscosity, $[m^2s^{-1}]$
ρ	density of fluid (air), $[kgm^{-3}]$
τ_w	wall shear stress, $[Nm^{-2}]$
ϕ	angular coordinate with origin at the gap

Subscripts

a	azimuthal
b	bulk
r	radial
w	wall

Superscript

— time averaged quantities

Nomenclature in Figures and Tables

tauw	τ_w
phi	ϕ
u', v', w'	$\sqrt{\overline{u^2}}, \sqrt{\overline{v^2}}, \sqrt{\overline{w^2}},$
T'	$\sqrt{\overline{\theta^2}}$
u*	u_τ
T*	T_τ
y-max	$\hat{y}$
eps	ε

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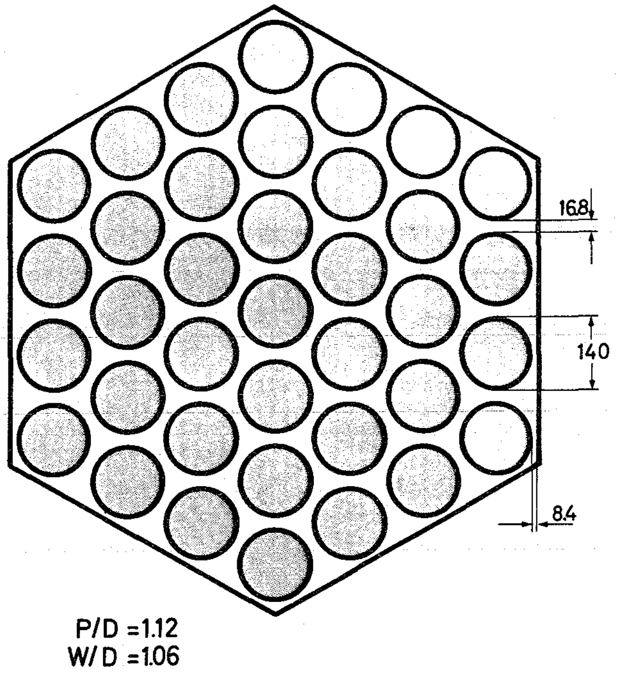


Fig.1 Cross section of 37-rod bundle

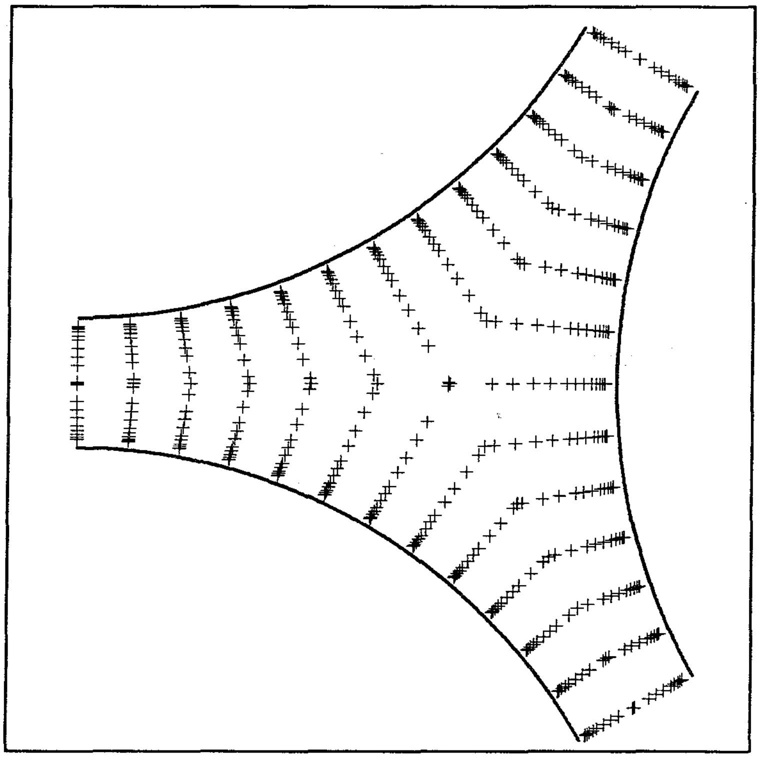


Fig.2 Measuring positions in a central channel

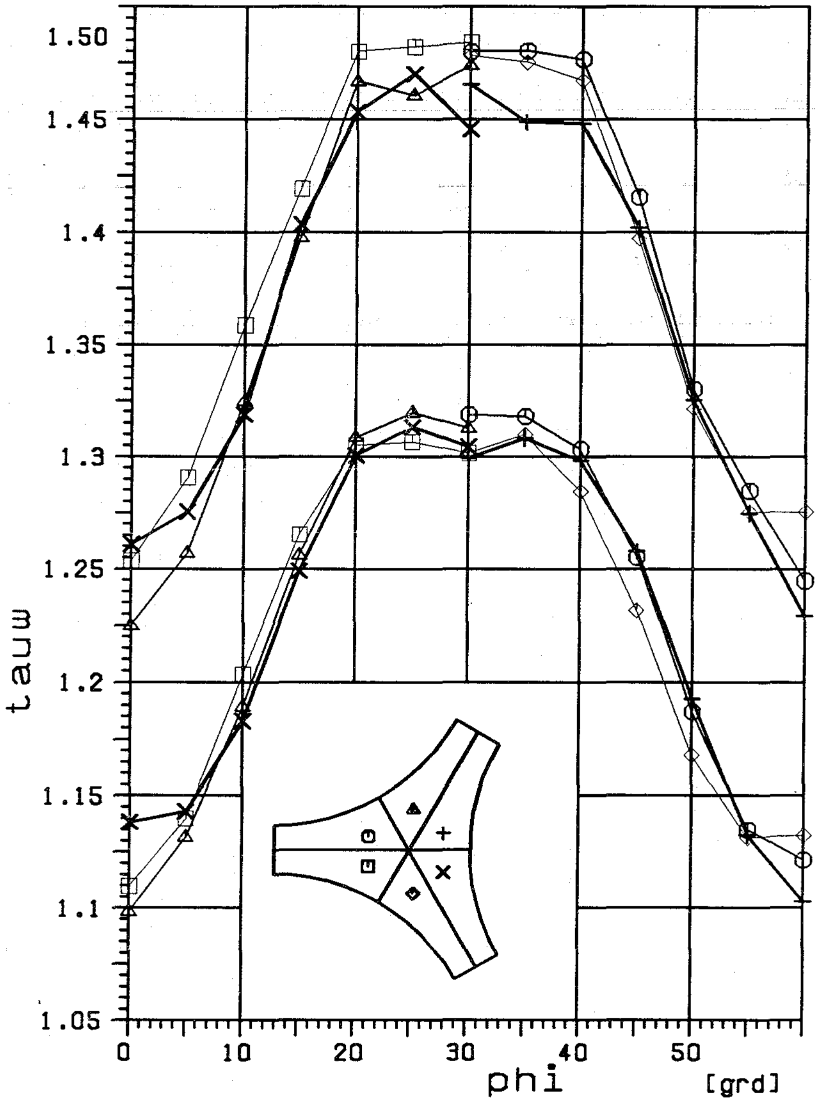


Fig.3 Wall shear stress distribution for heated rods (upper) and unheated rods (lower data)

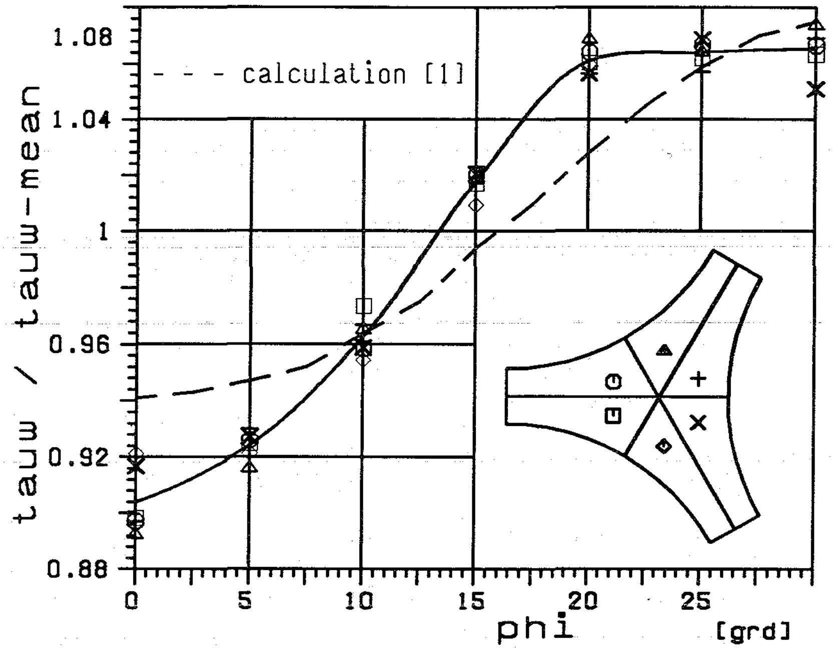


Fig.4 Distribution of relative shear stress for heated flow

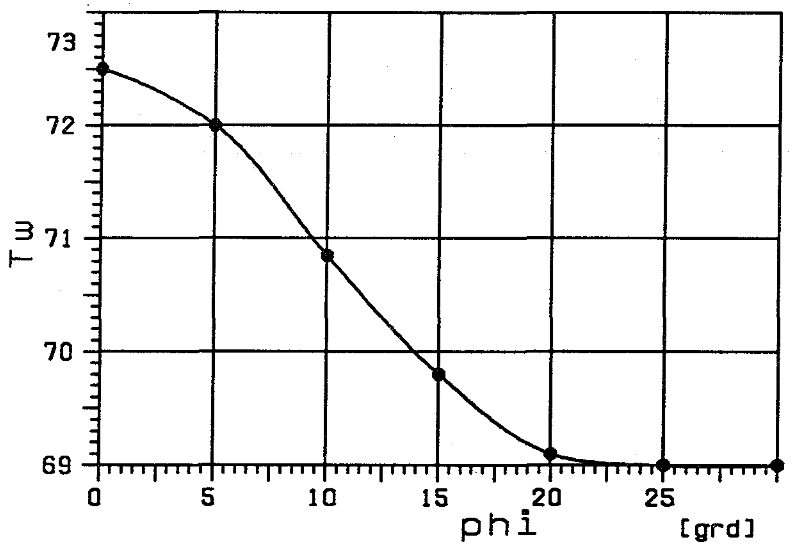


Fig.5 Distribution of wall temperature

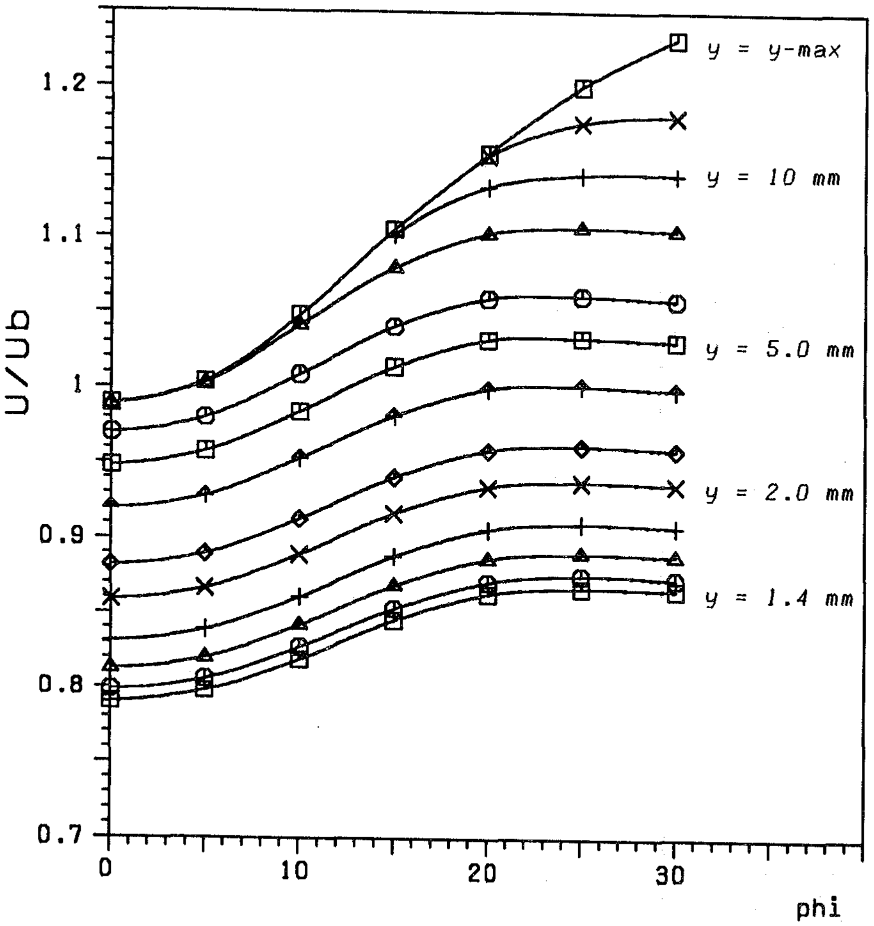


Fig.6 Azimuthal distribution of mean velocity

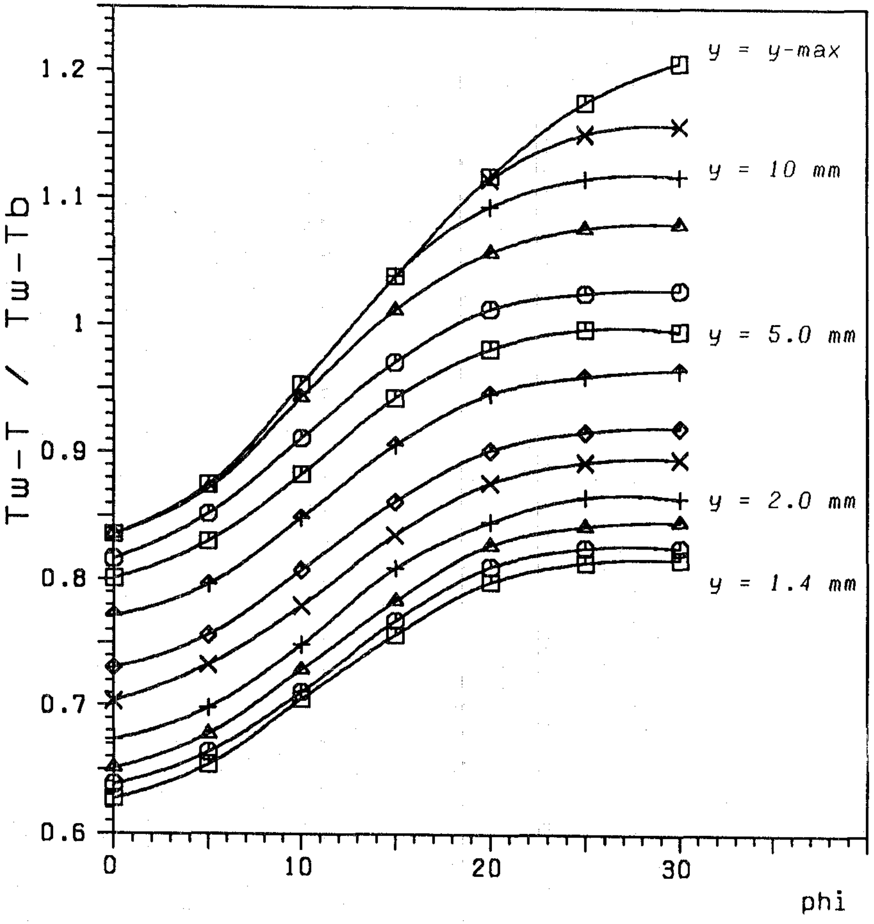
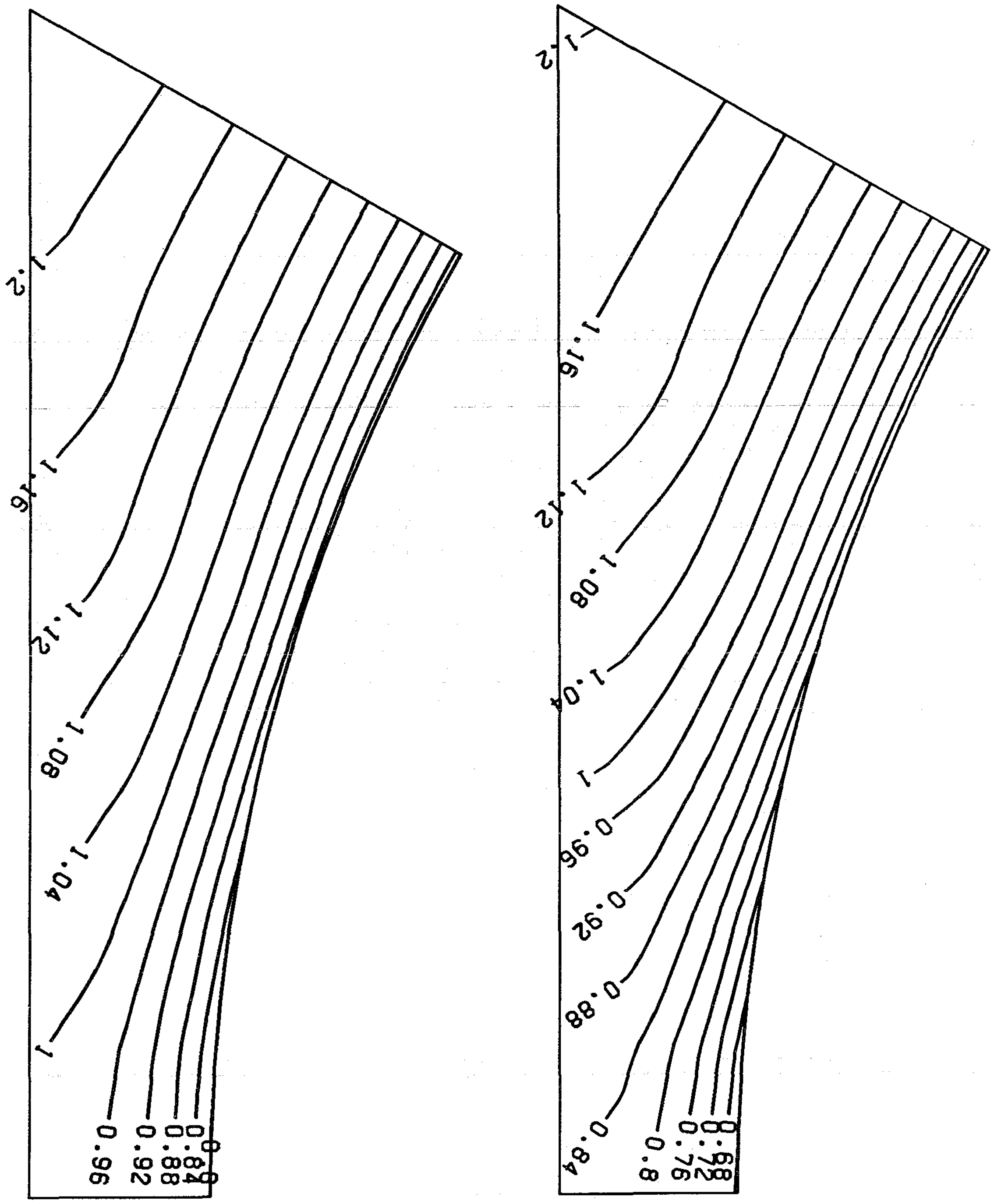


Fig.7 Azimuthal distribution of mean temperature



U / Ub

Tw-T / Tw-Tb

Fig.8 Contour plots of mean velocity and temperature

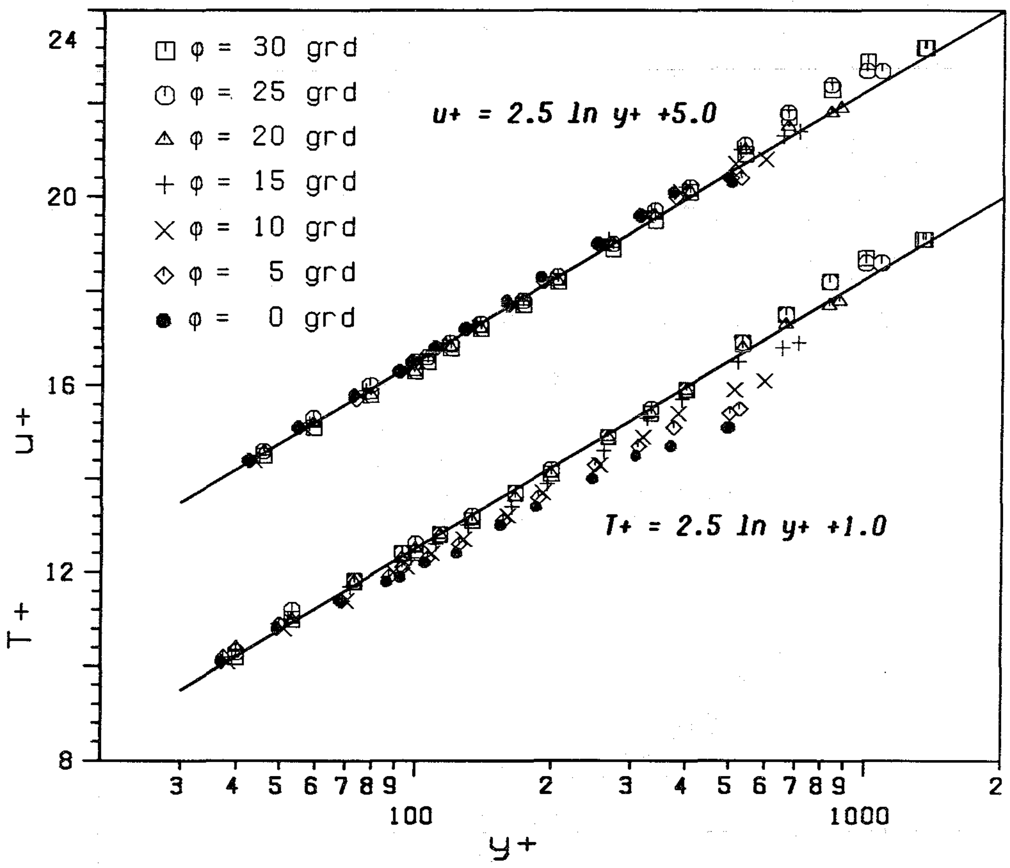


Fig.9 Logarithmic profiles of the dimensionless velocity and temperature

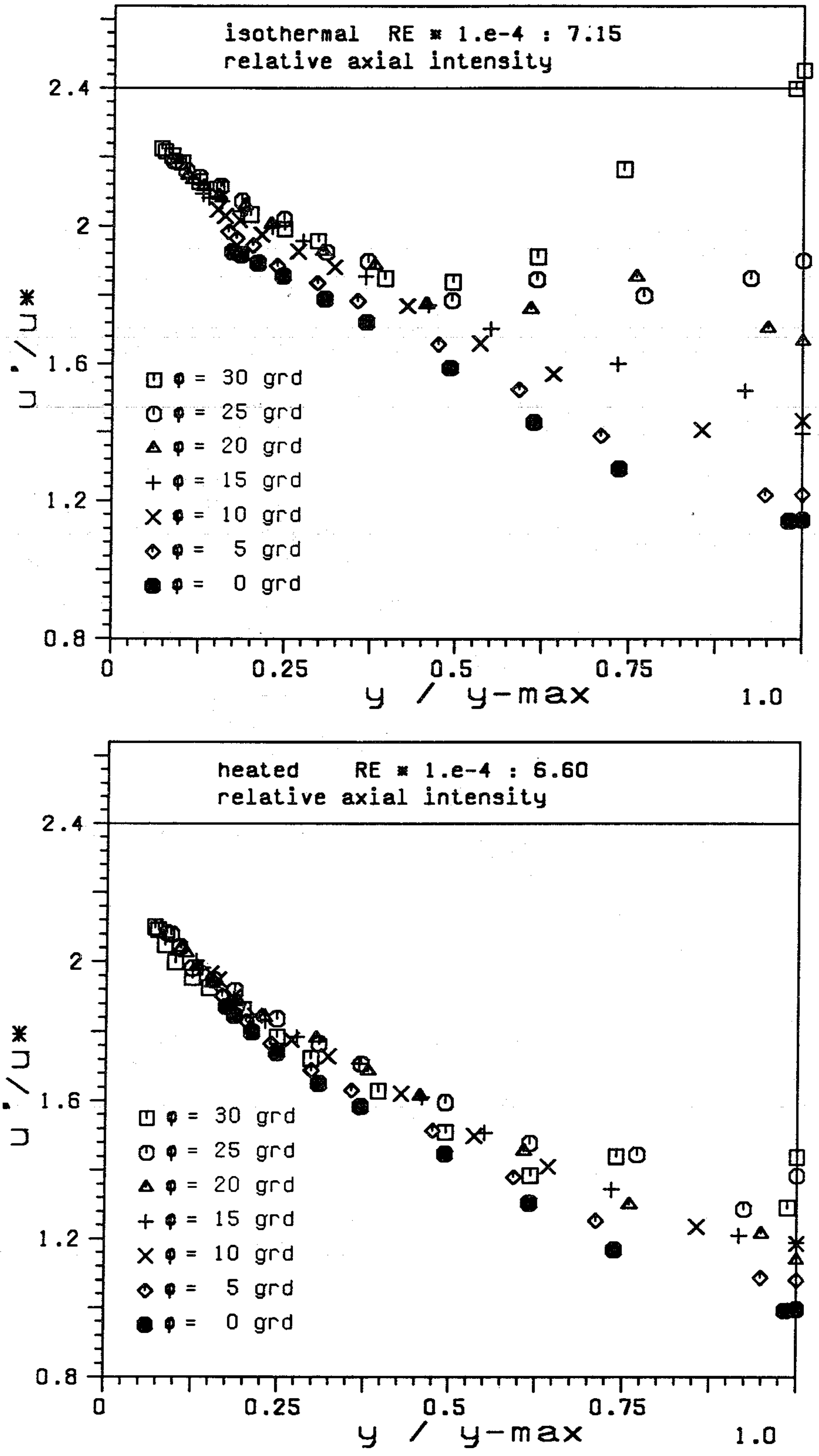
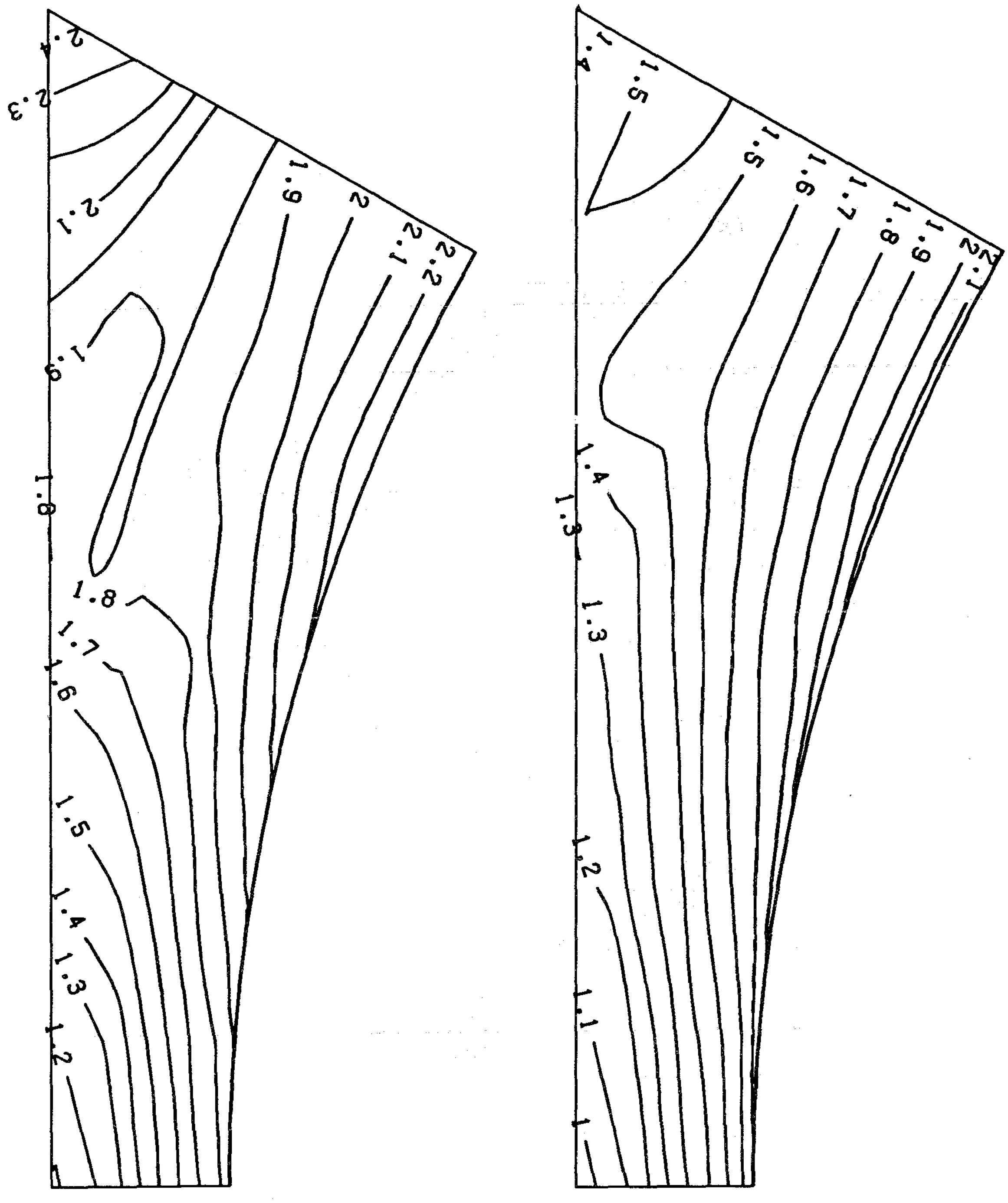


Fig.10 Turbulent intensity of the axial velocity component



u' / u* isothermal

u' / u* heated

Fig.11 Contour plot of the intensities of the axial velocity component

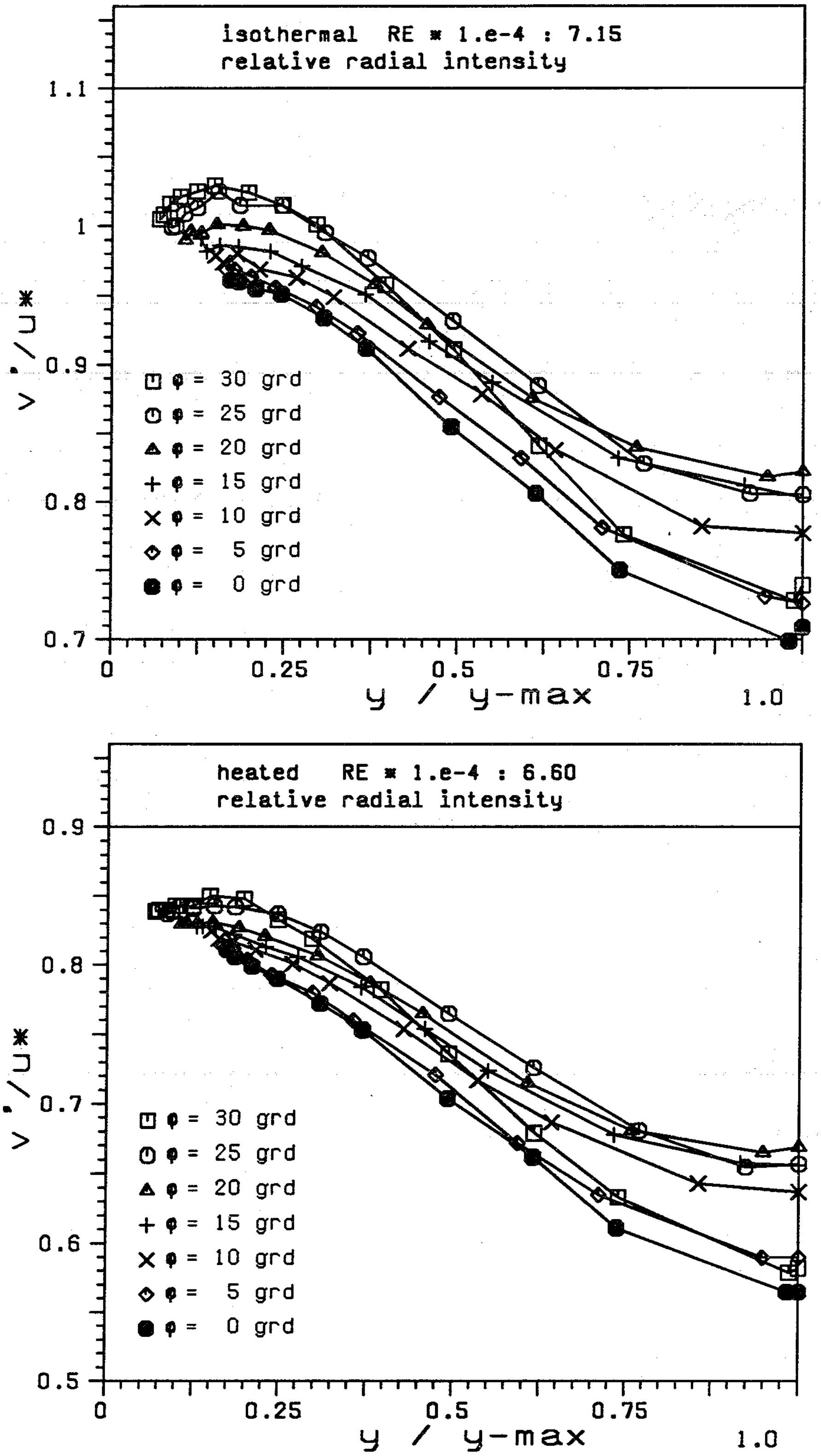
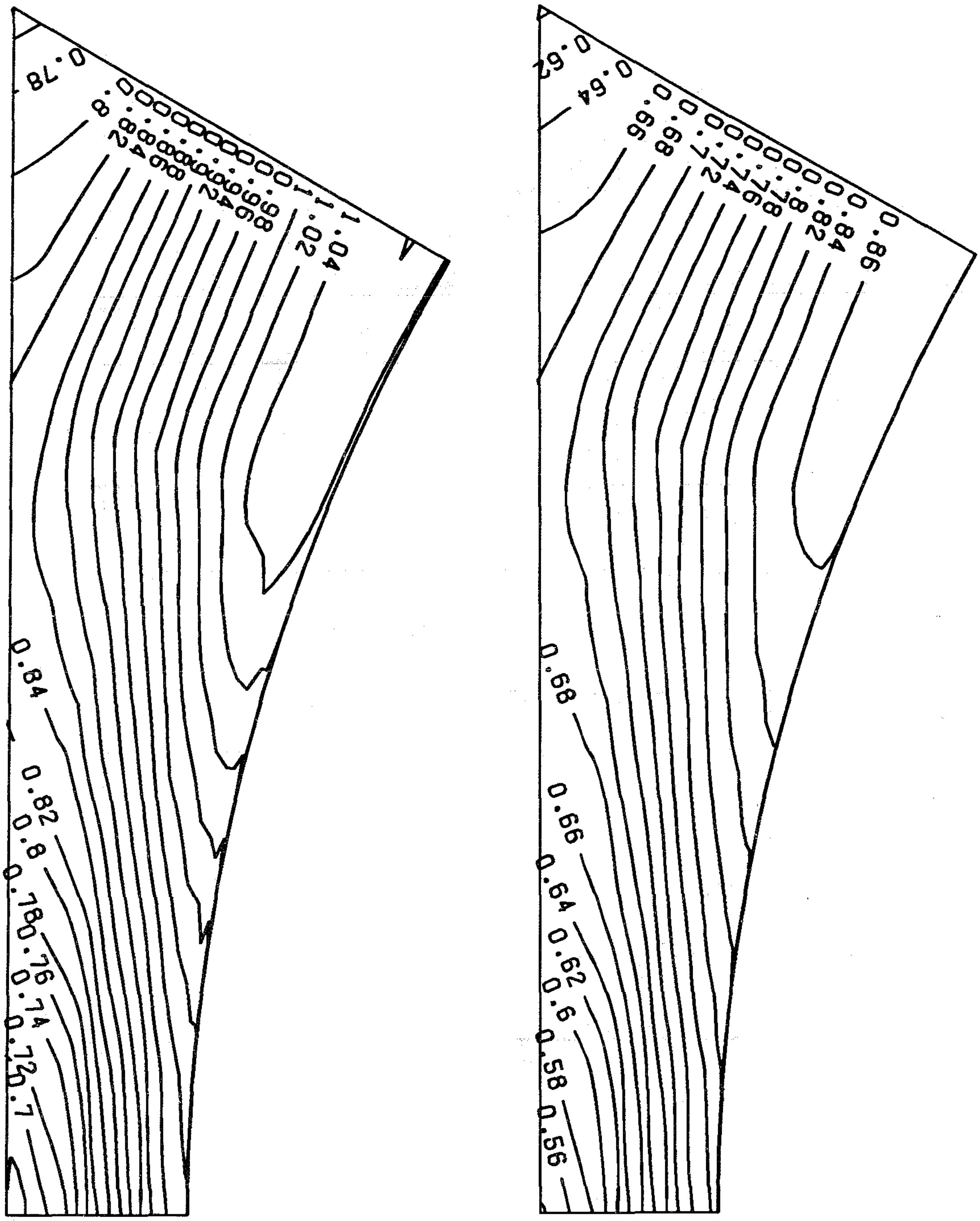


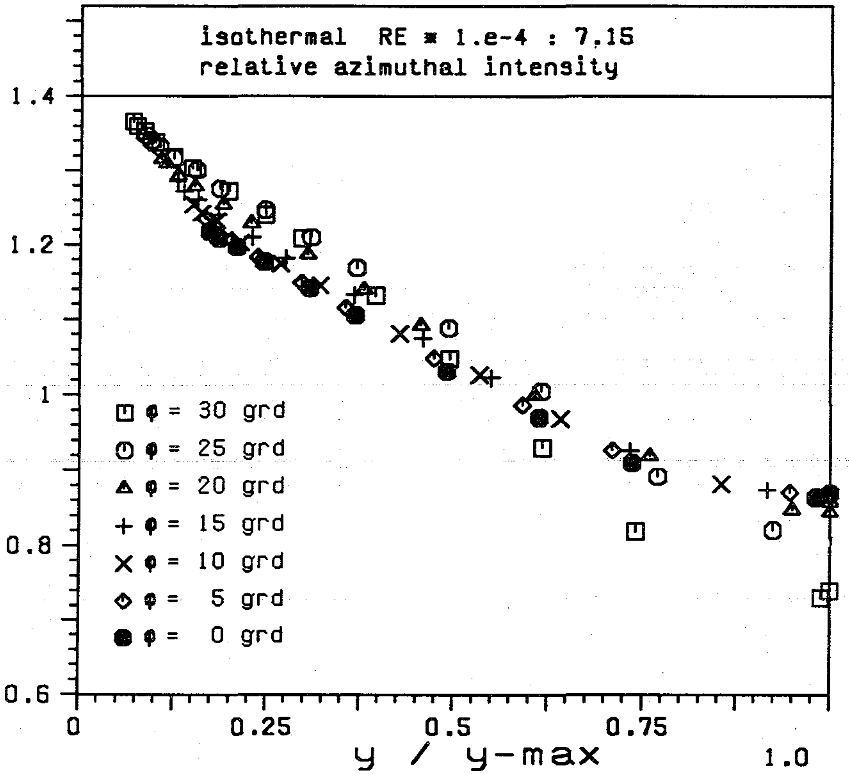
Fig.12 Turbulent intensity of the radial velocity component



v' / v* isothermal

v' / v* heated

Fig.13 Contour plot of the intensities of the radial velocity component



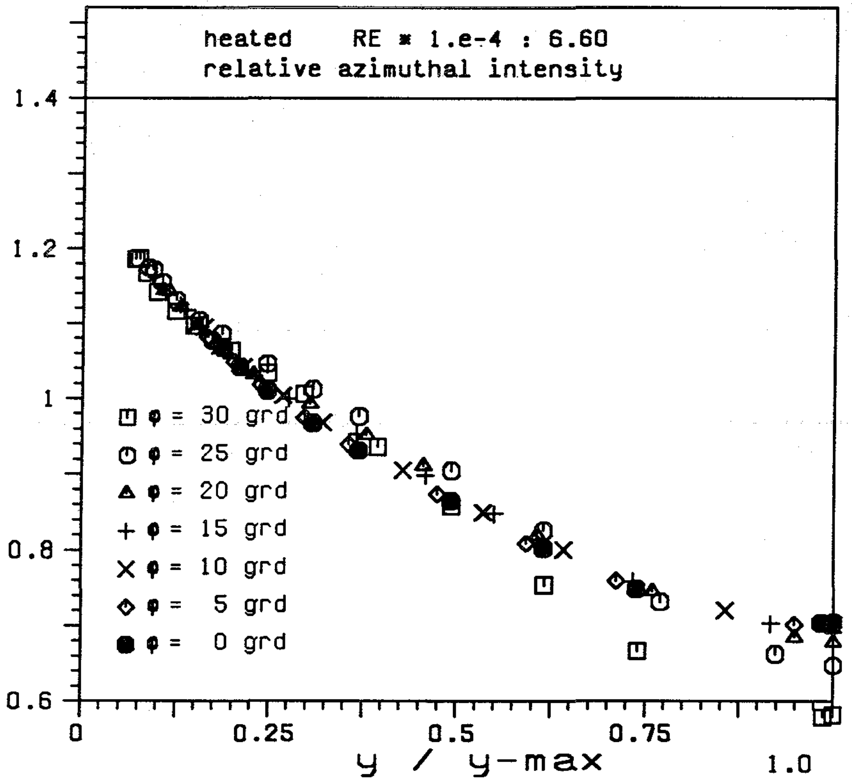
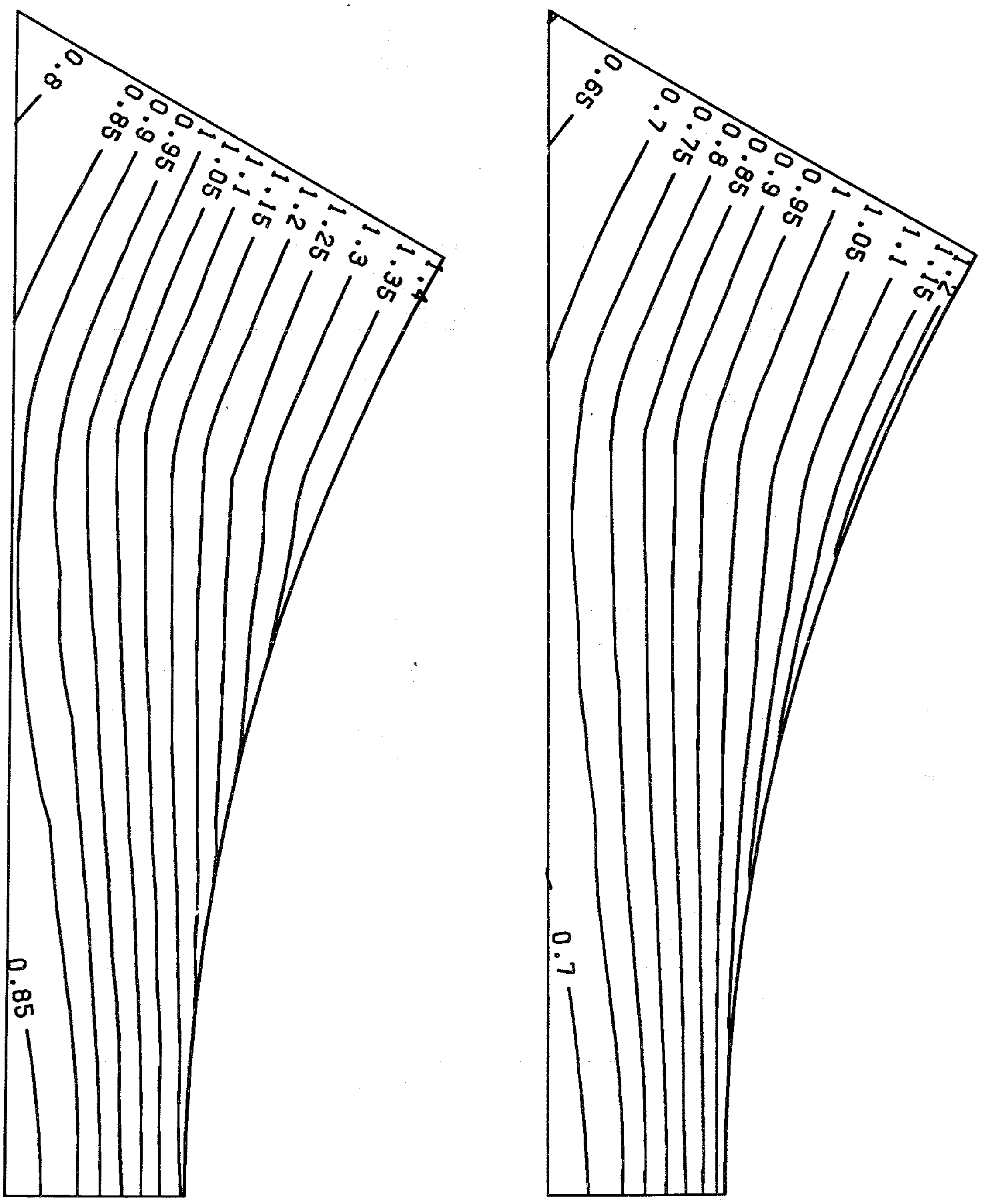
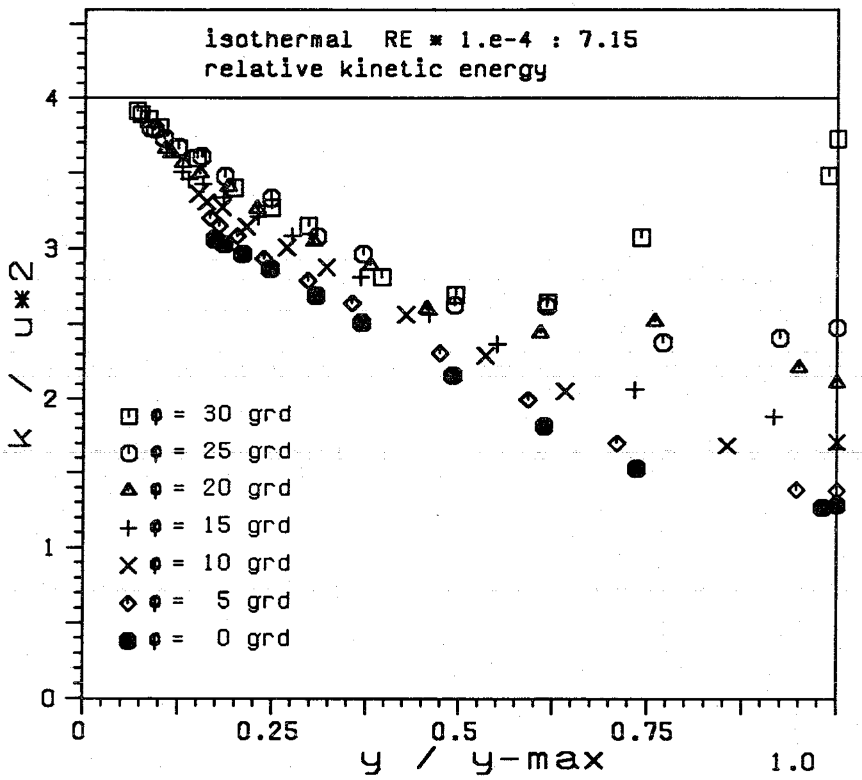


Fig.14 Turbulent intensity of the azimuthal velocity component



w' / u^* isothermal w' / u^* heated

Fig.15 Contour plot of the intensities of the azimuthal velocity component



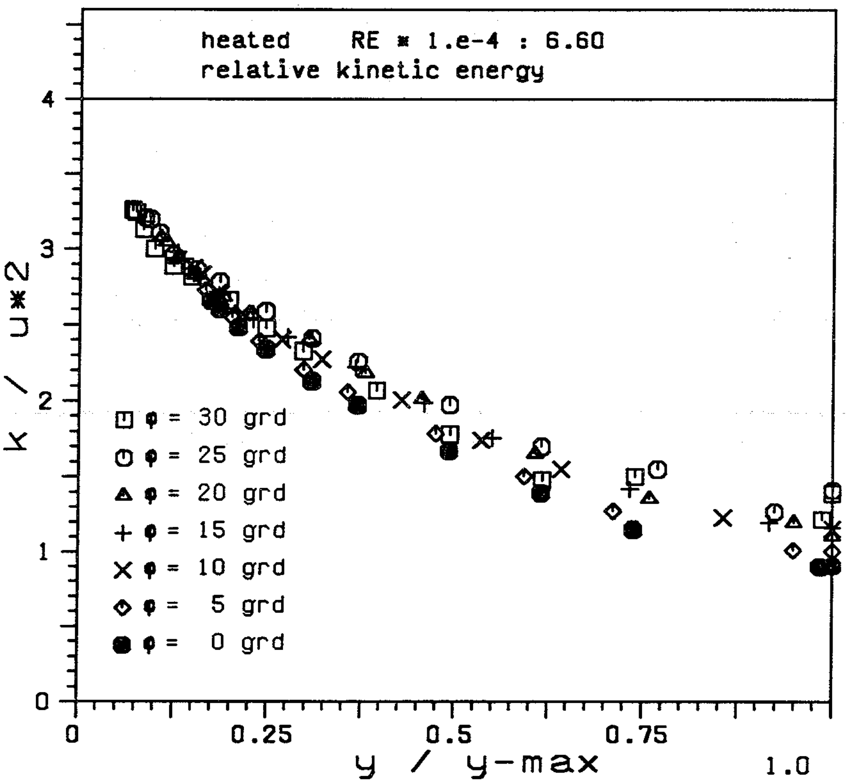
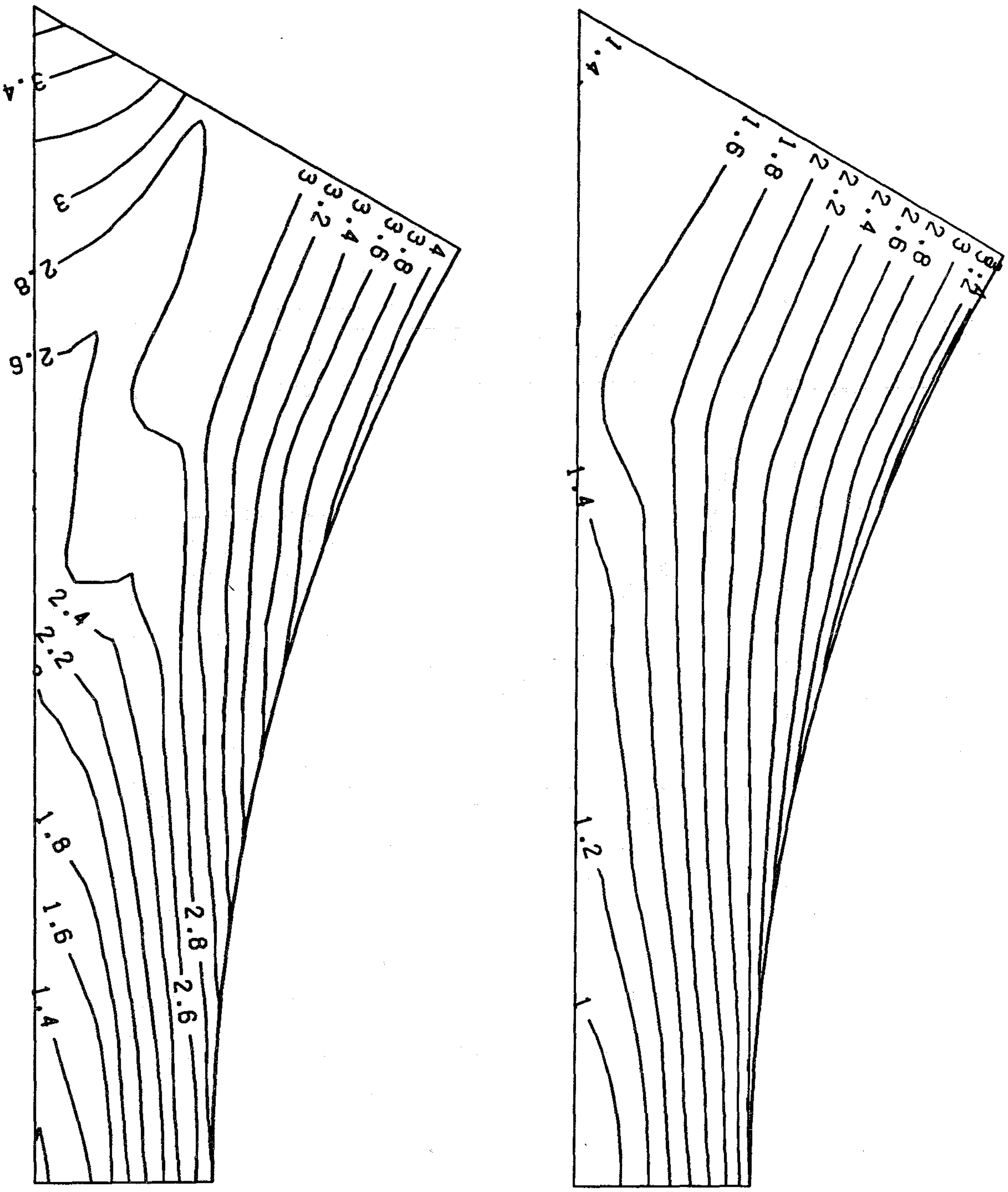


Fig.16 Turbulent kinetic energy



k / u*2 isothermal

k / u*2 heated

Fig.17 Contour plot of the kinetic energy

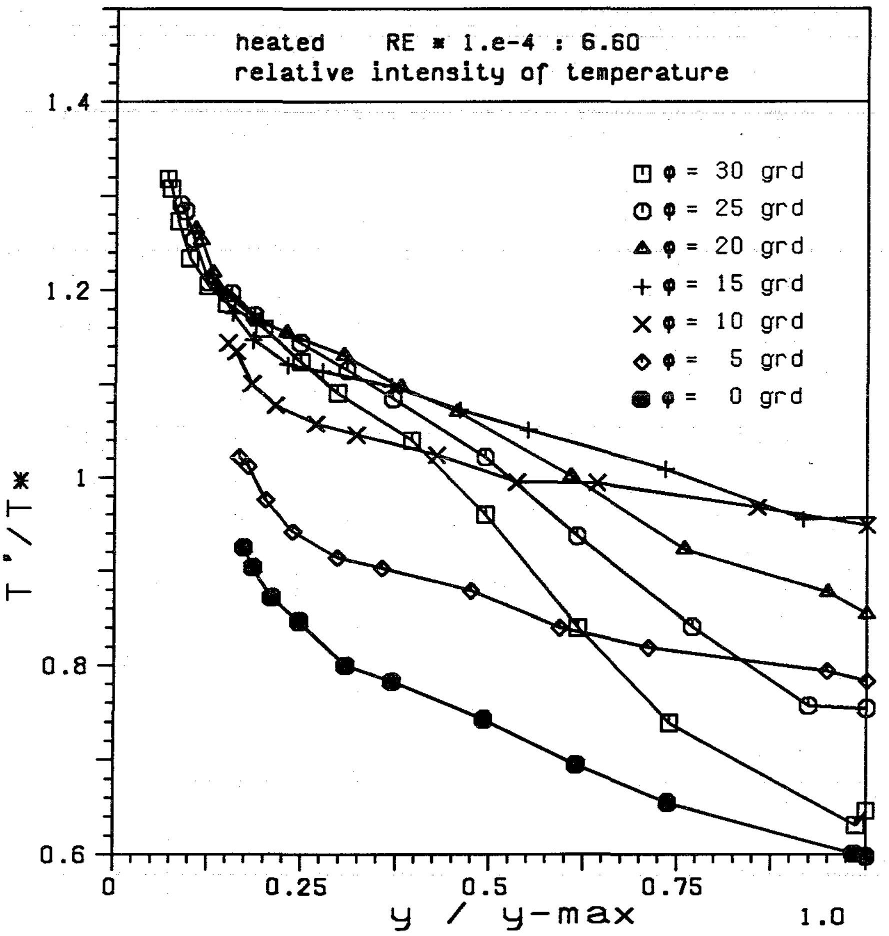
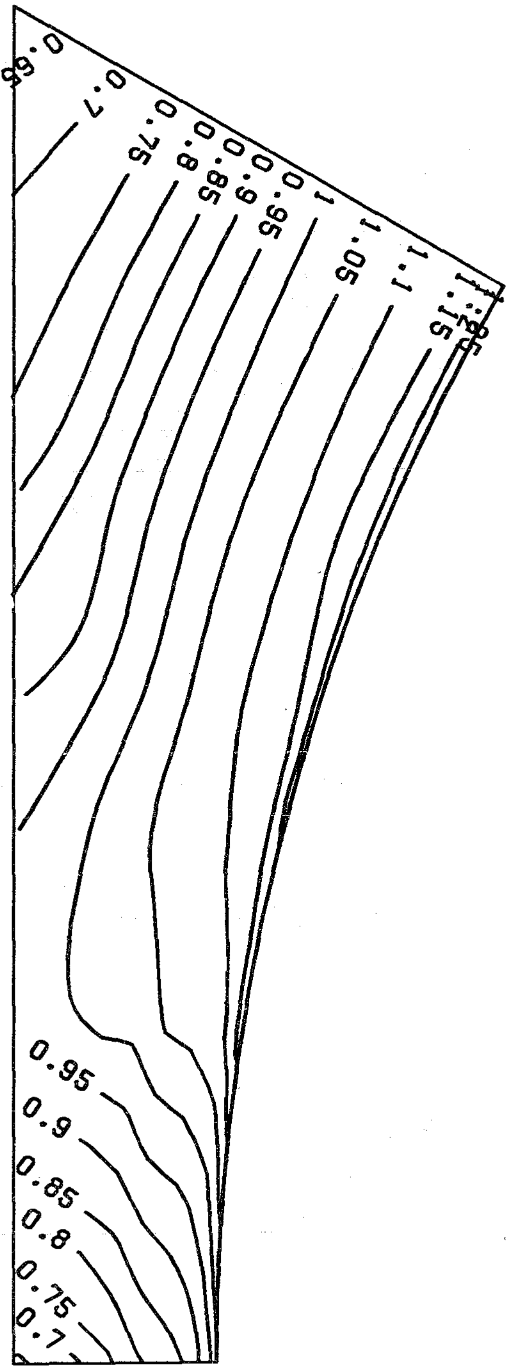


Fig.18 Turbulent intensity of the temperature



T 'T '/ T*T*

Fig.19 Contour plot of the intensity of the temperature fluctuation

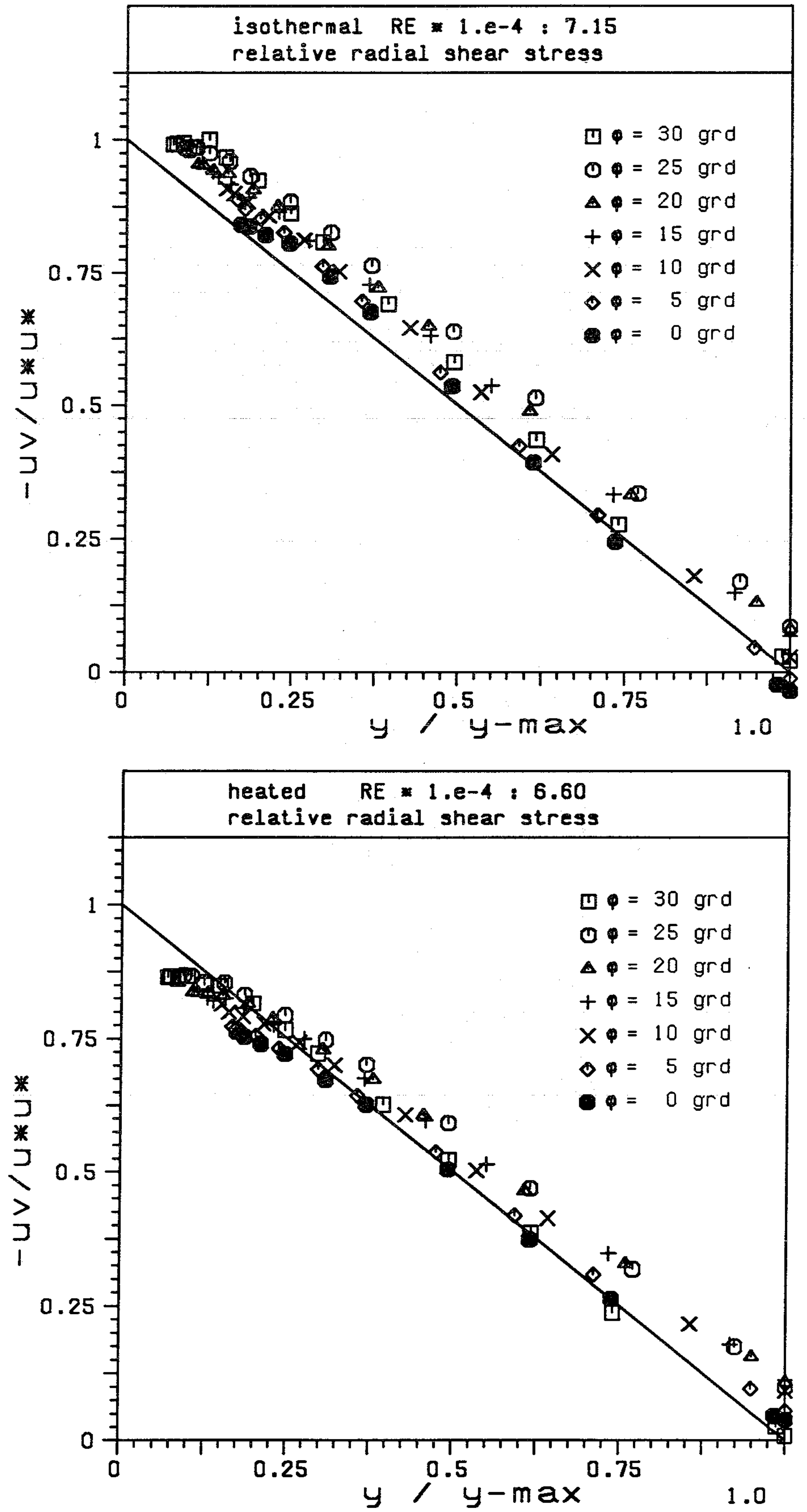
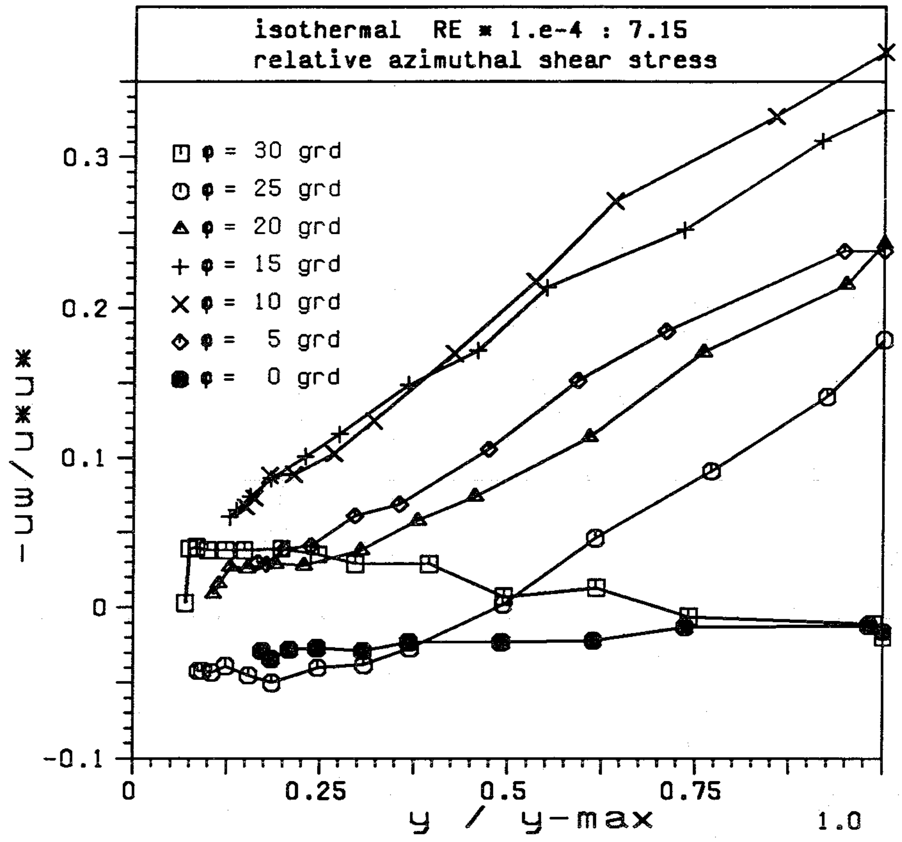


Fig.20 Relative turbulent shear stress normal to the wall



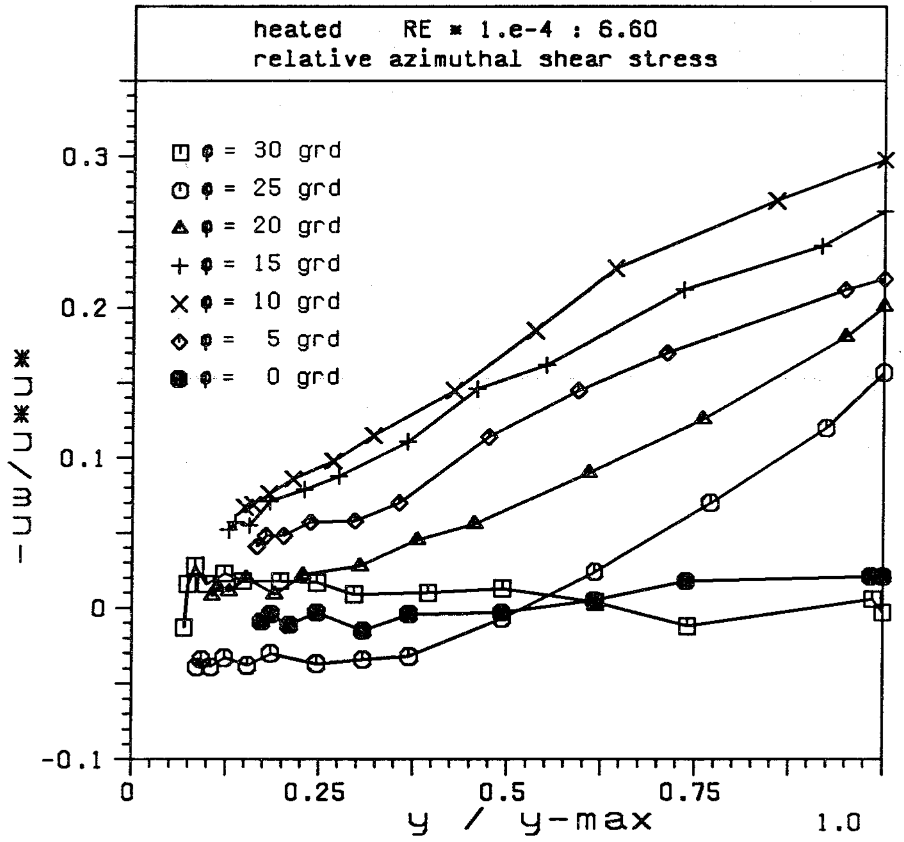
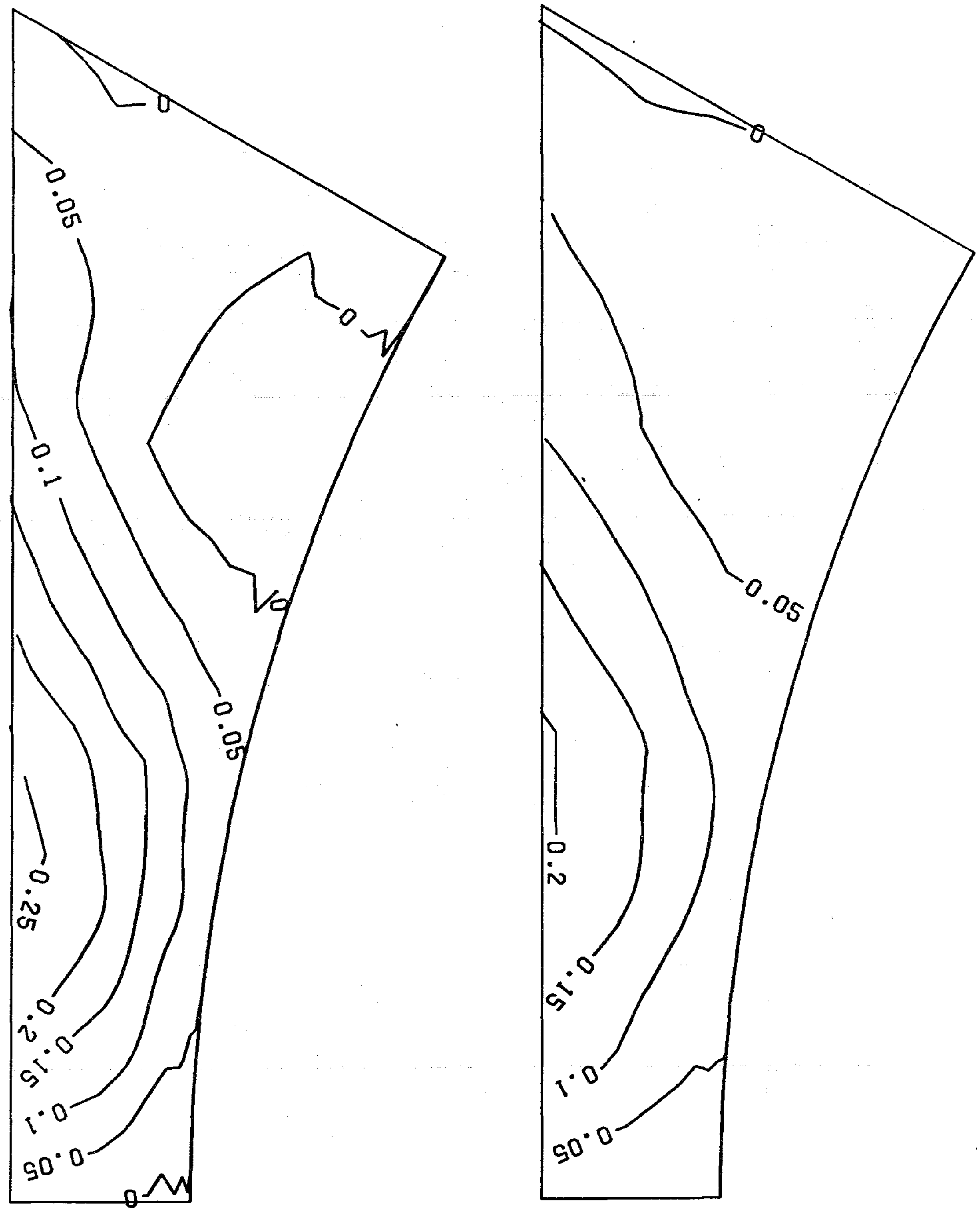


Fig.21 Relative turbulent shear stress in azimuthal direction



-u'w'/ u*2

w'T'/ u*T*

Fig.22 Distribution of turbulent shear stress and heat flux in azimuthal direction

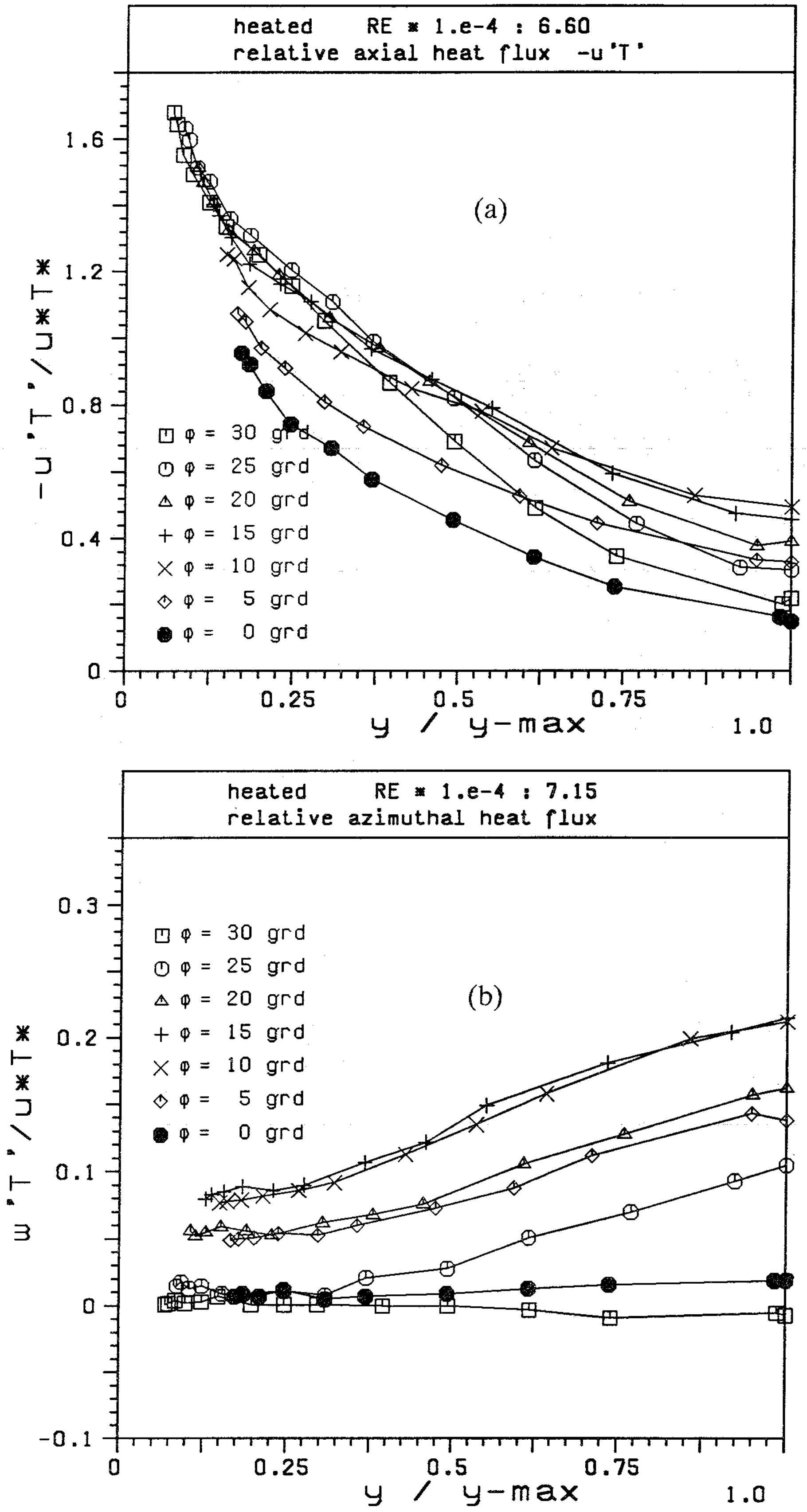


Fig.23 Turbulent heat flux in axial (a) and azimuthal (b) direction

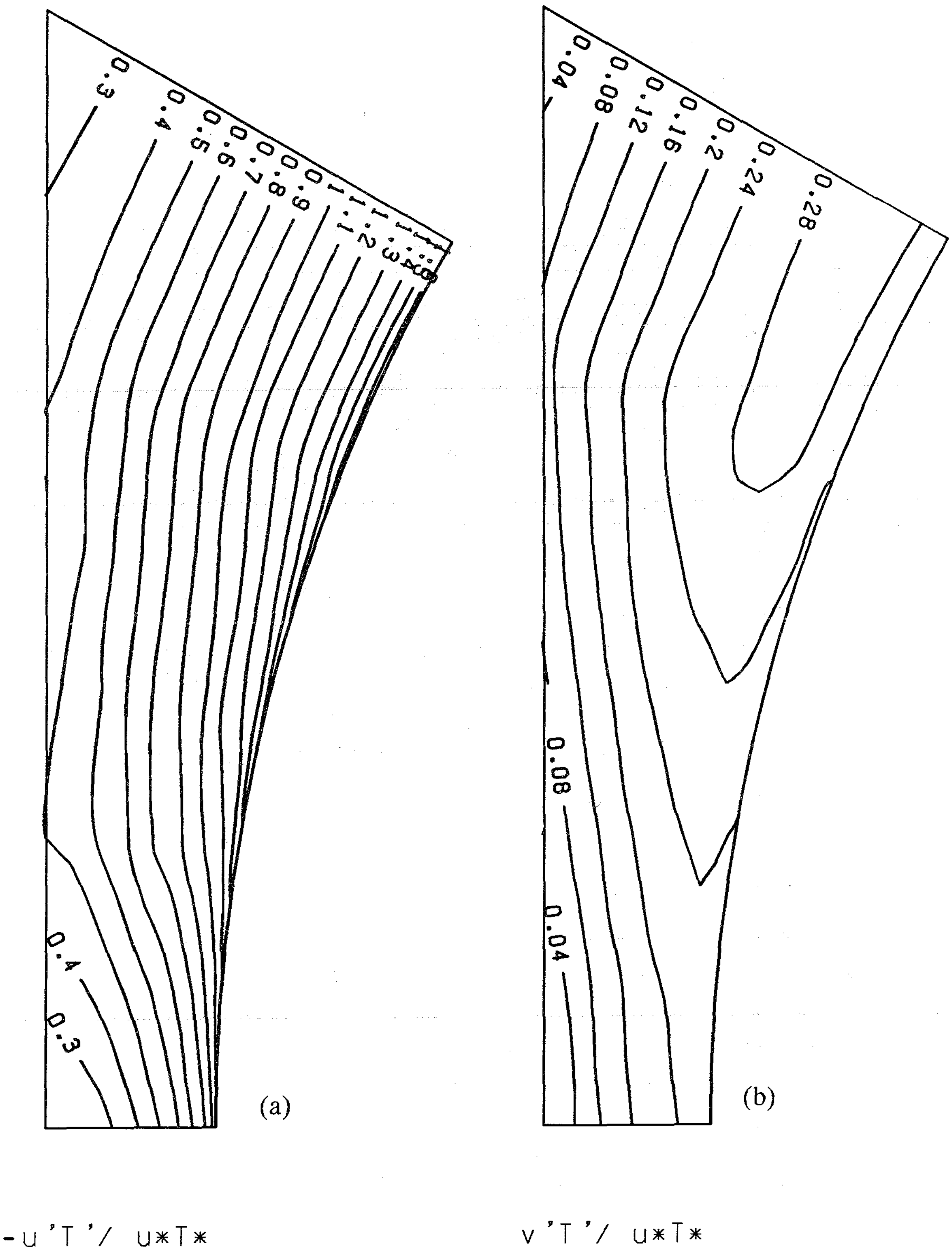


Fig.24 Contour plot of turbulent heat flux in axial (a) and in radial (b) direction

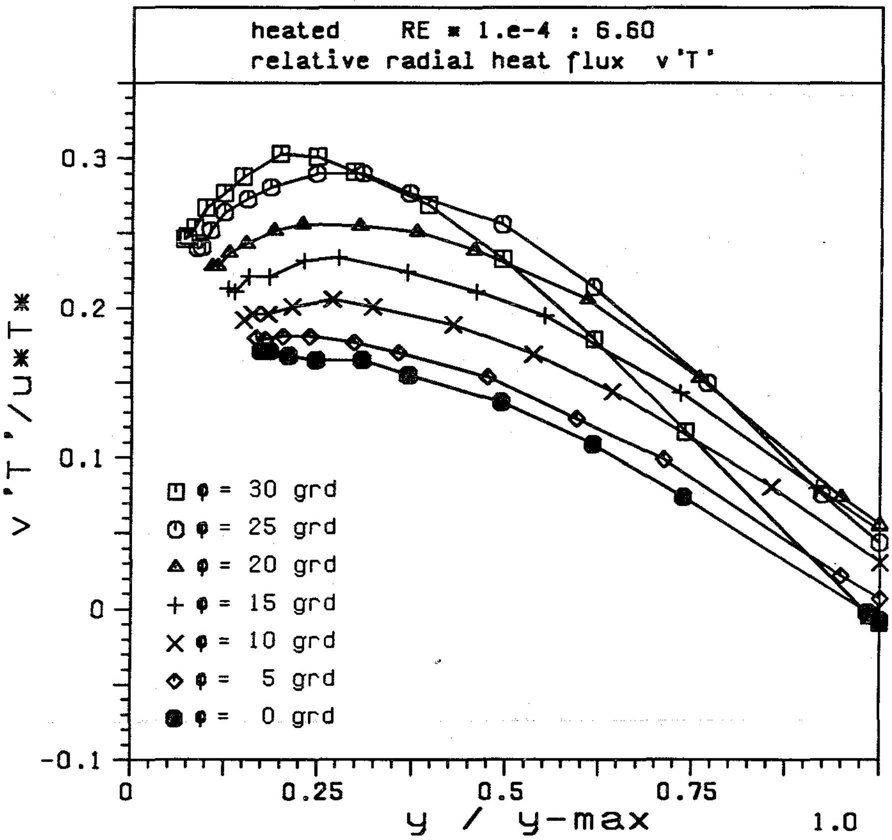
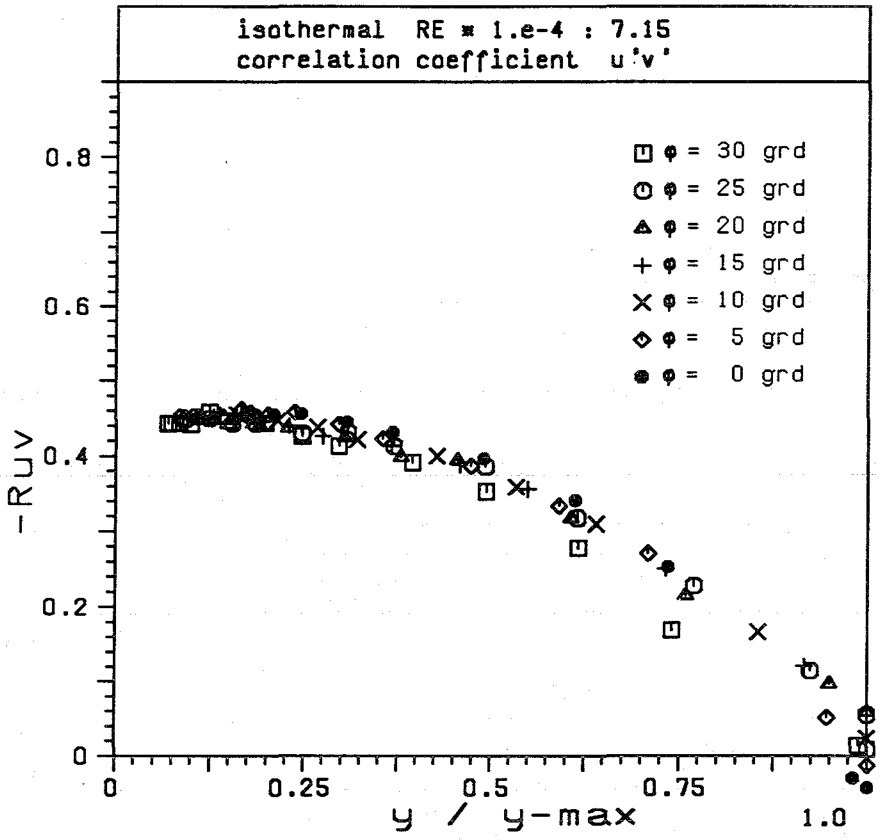


Fig.25 Relative turbulent heat flux in radial direction



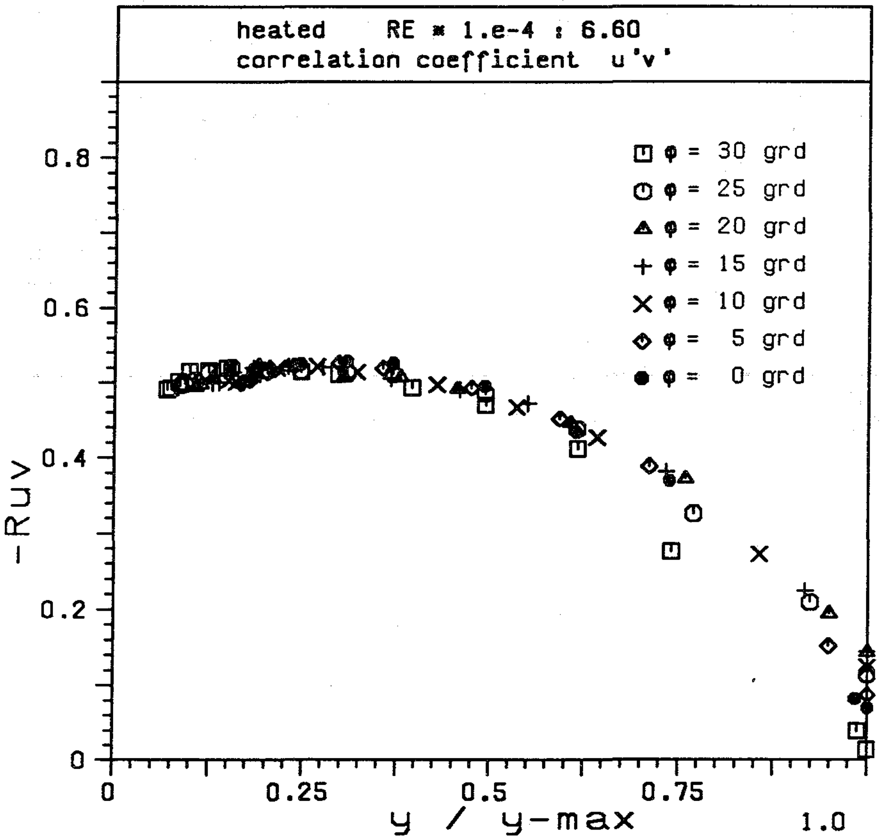
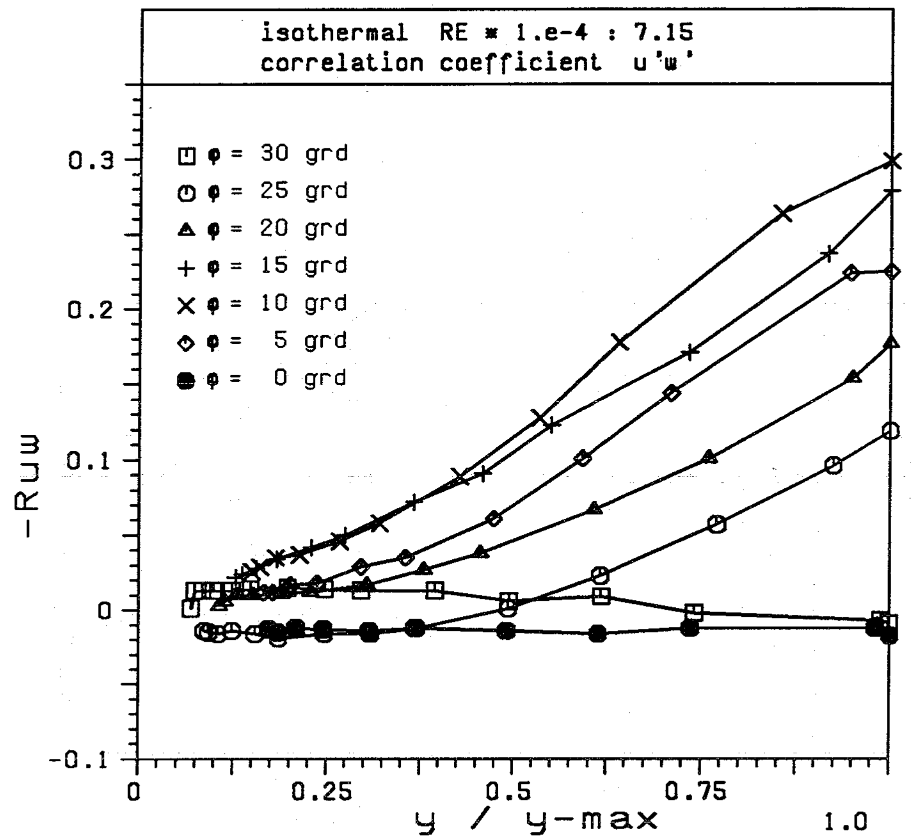


Fig.26 The correlation coefficient $-R_{uv}$



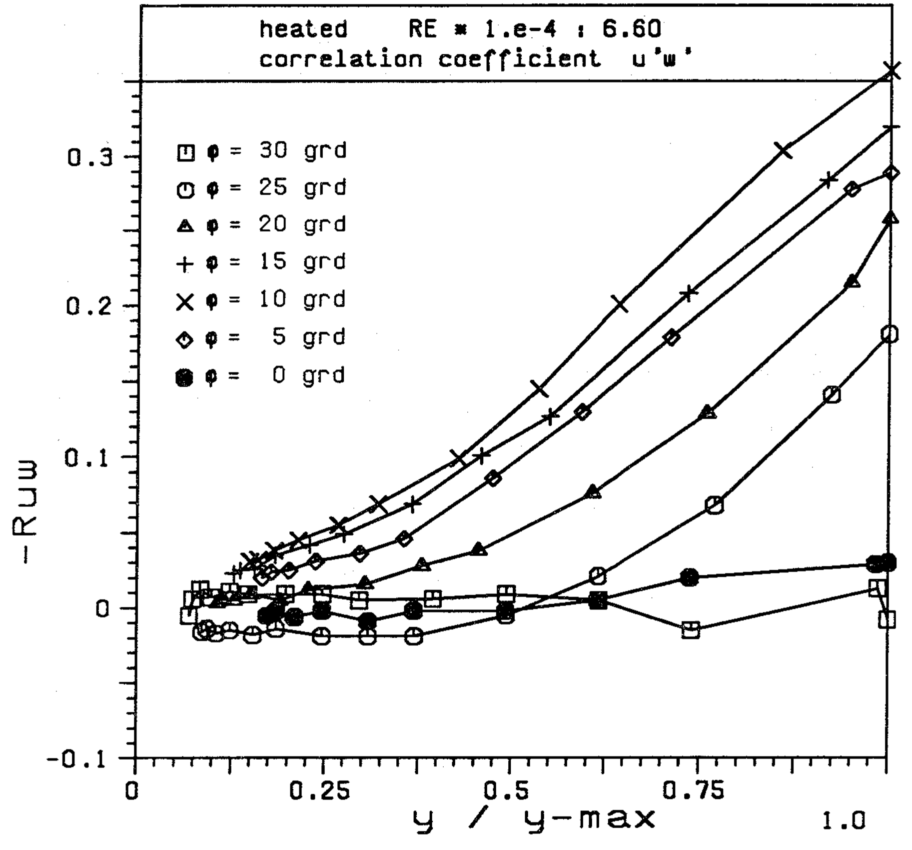


Fig.27 The correlation coefficient $-R_{uw}$

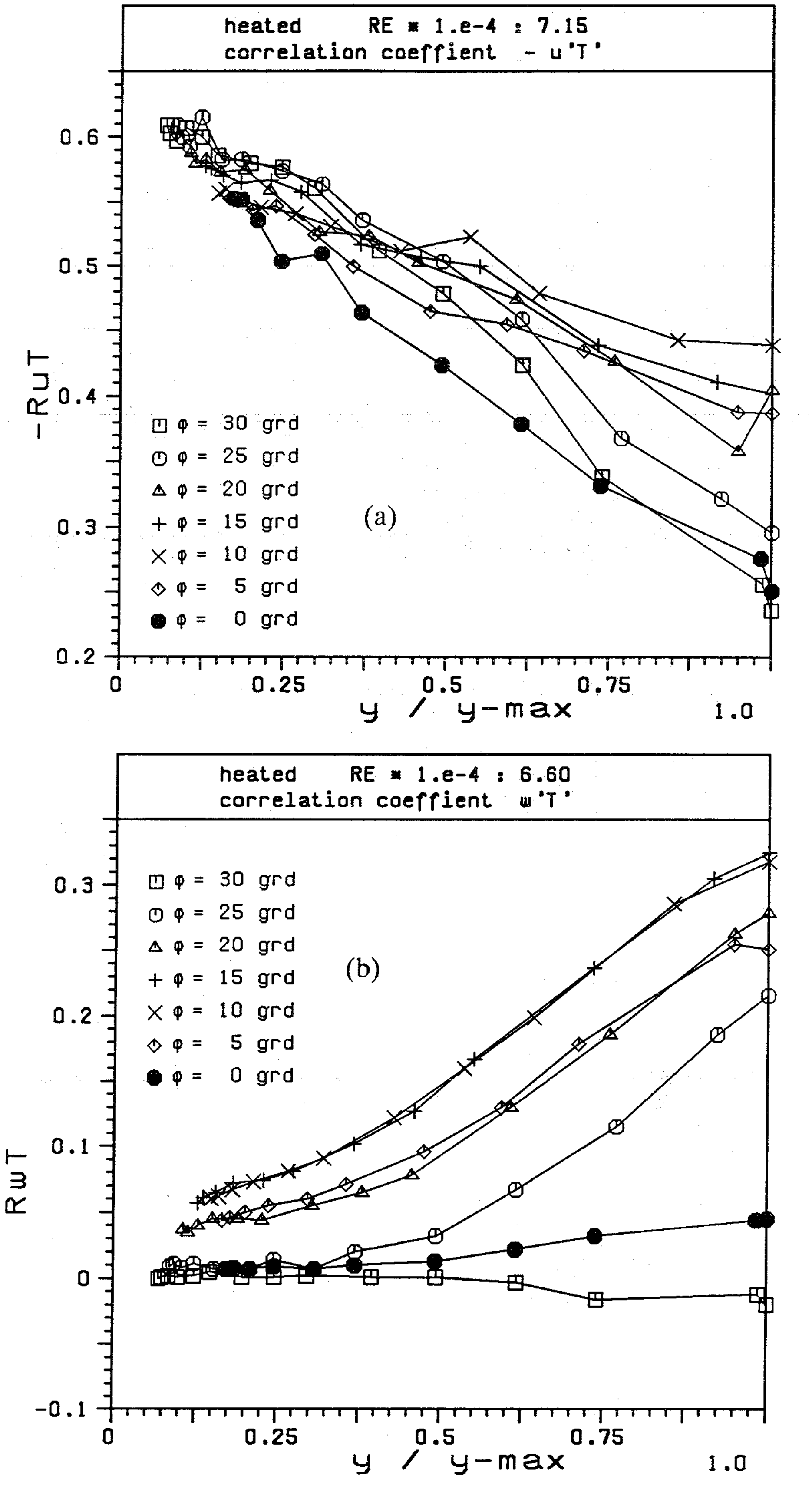


Fig.28 The correlation coefficient $-R_{u\theta}$ (a) and $R_{w\theta}$ (b)

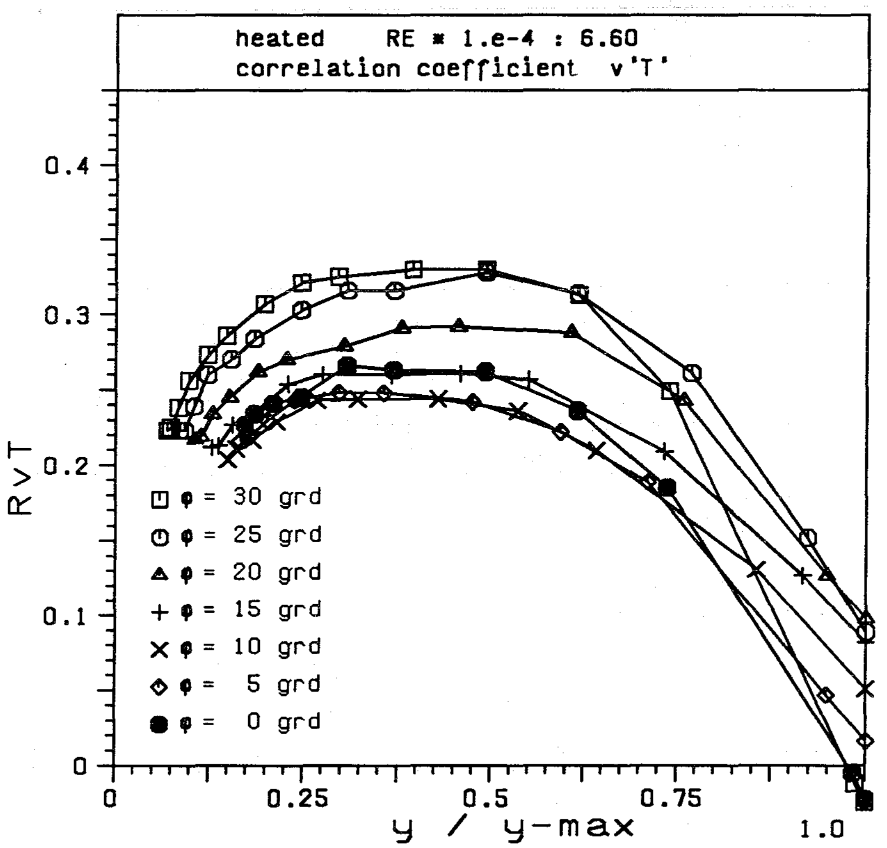


Fig.29 The correlation coefficient $R_{v\theta}$

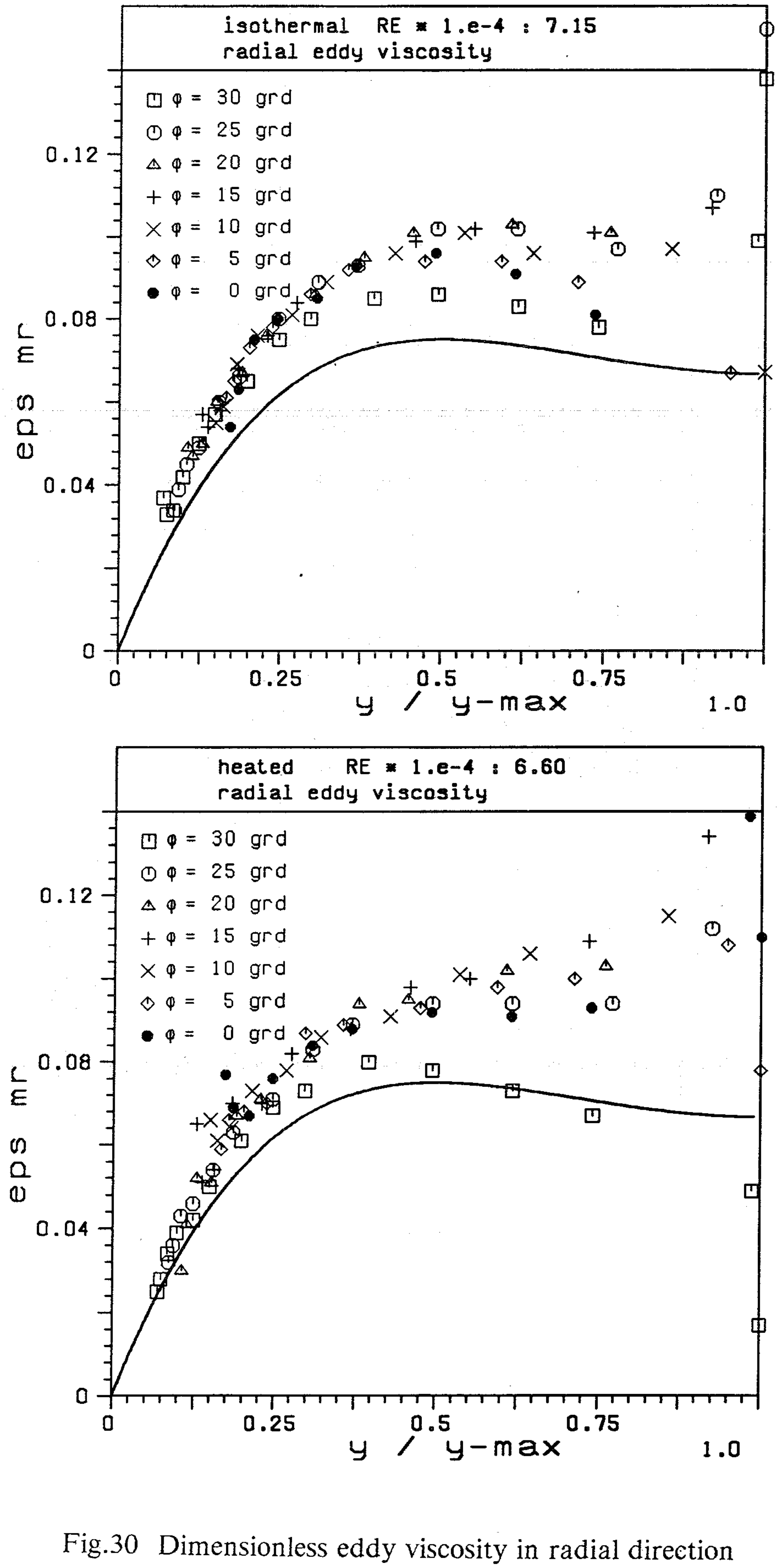
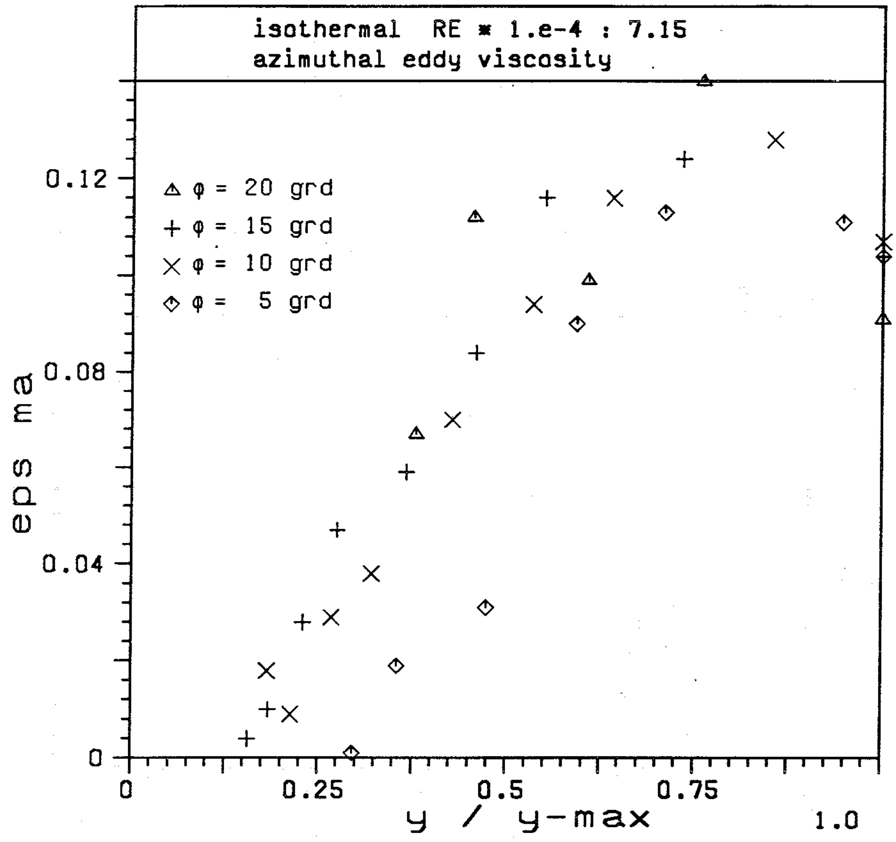


Fig.30 Dimensionless eddy viscosity in radial direction



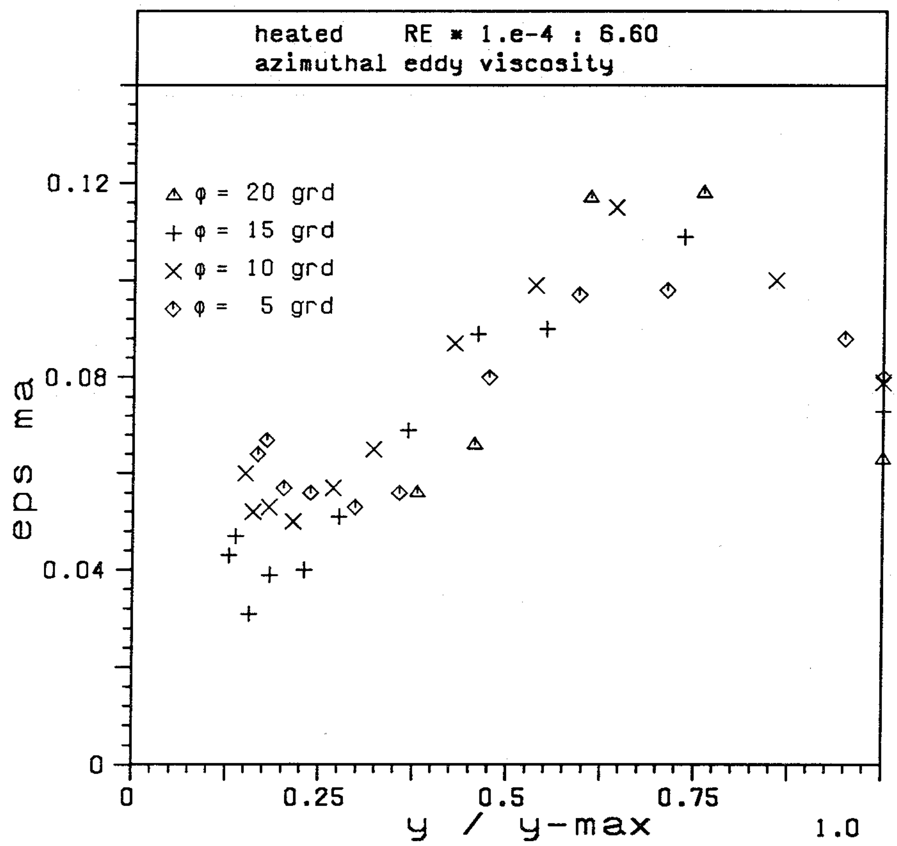


Fig.31 Dimensionless eddy viscosity in azimuthal direction

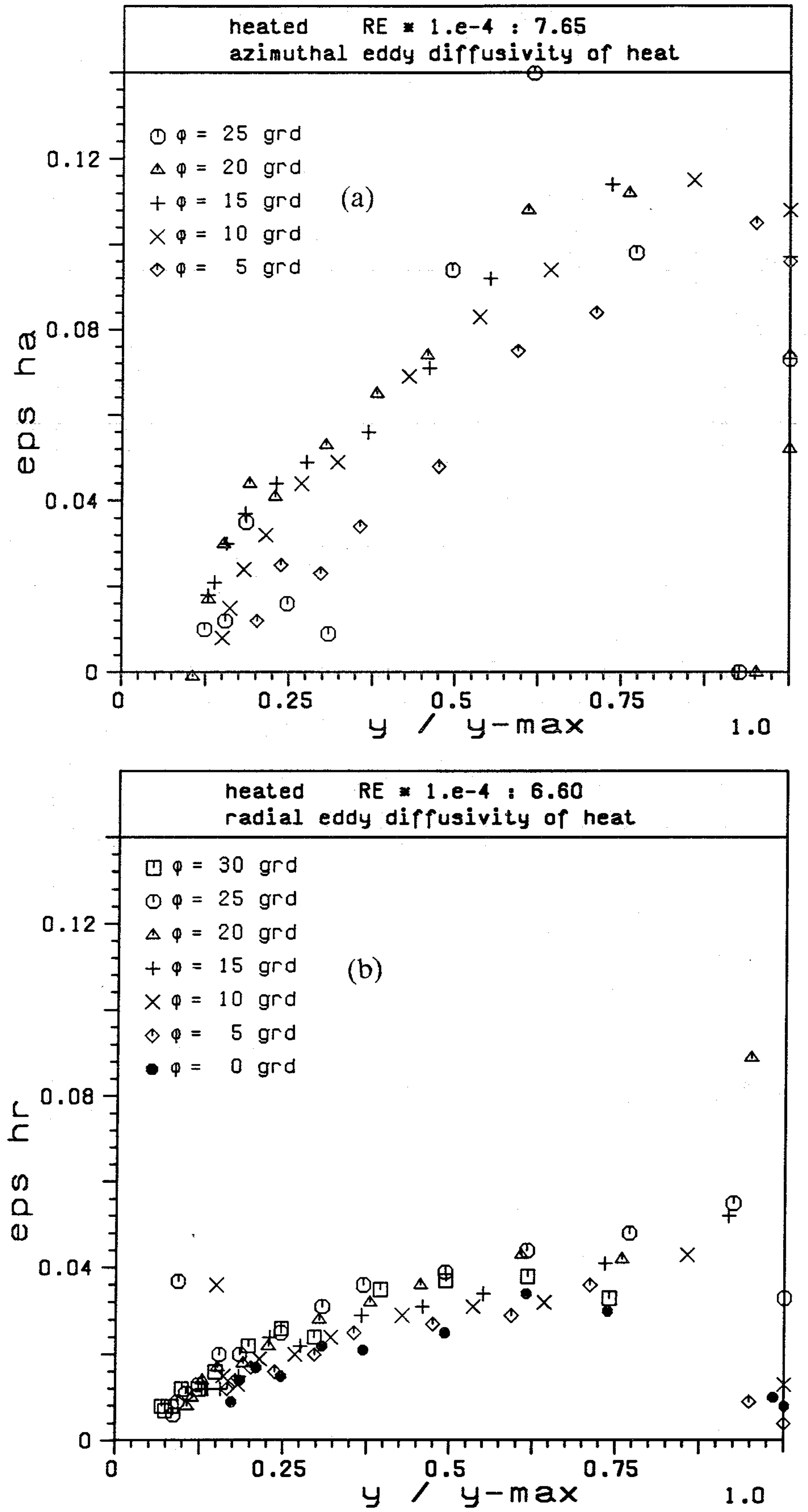


Fig.32 Dimensionless eddy diffusivity of heat in azimuthal (a) direction and in radial direction (b)

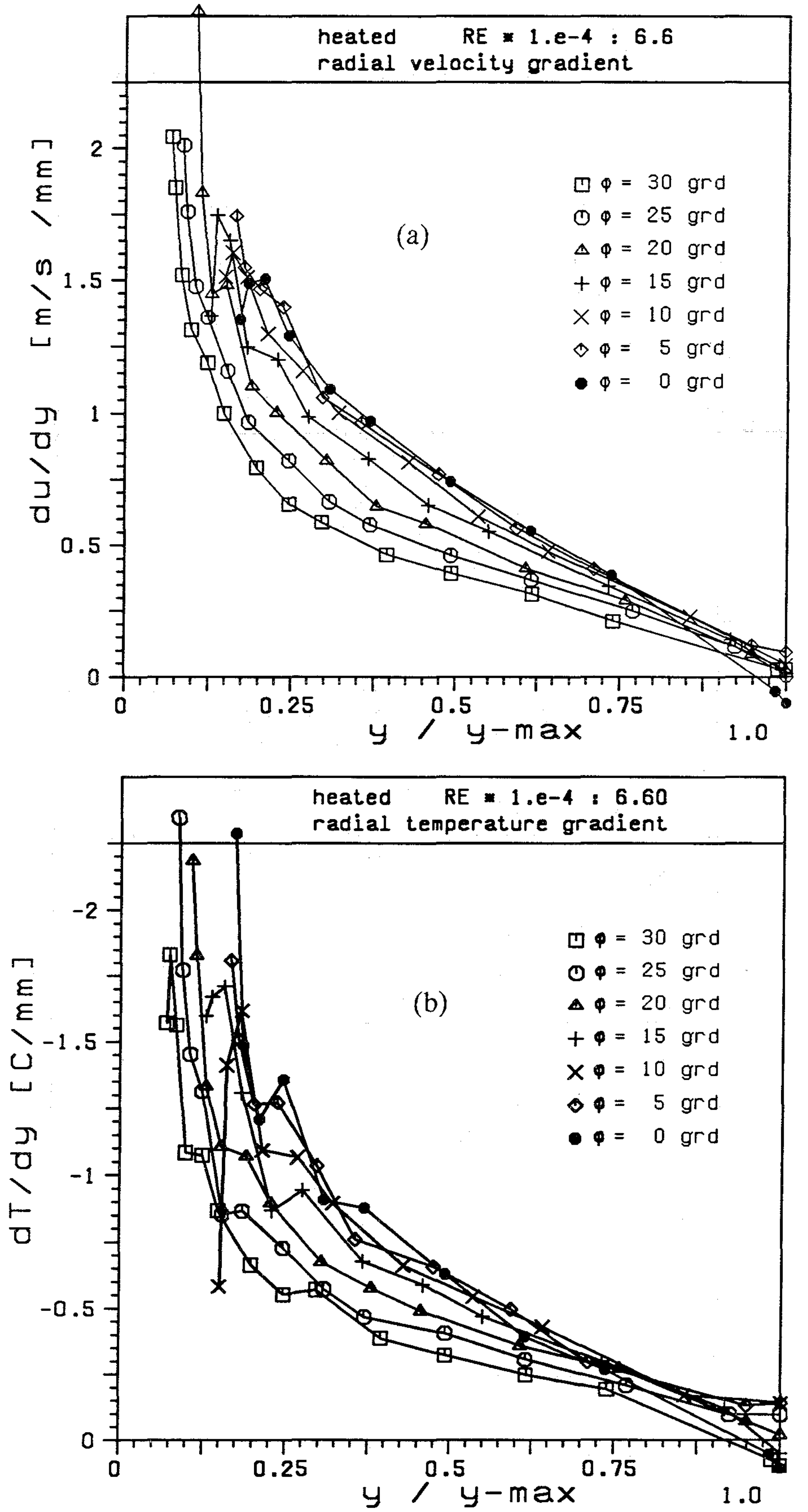
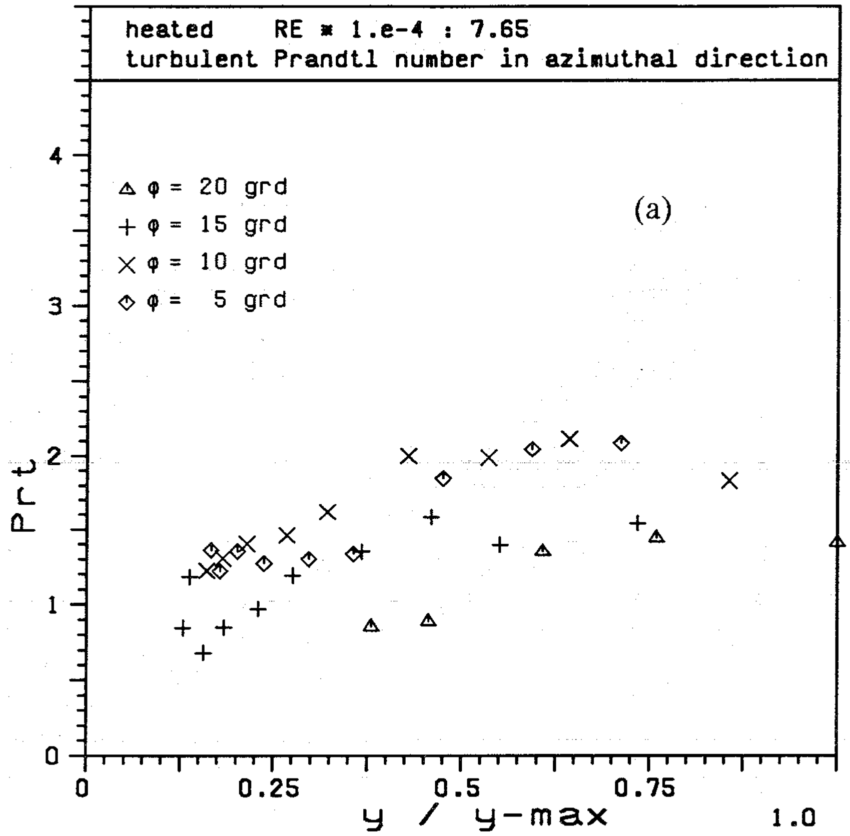


Fig.33 Radial gradients of the mean velocity (a) and temperature (b)



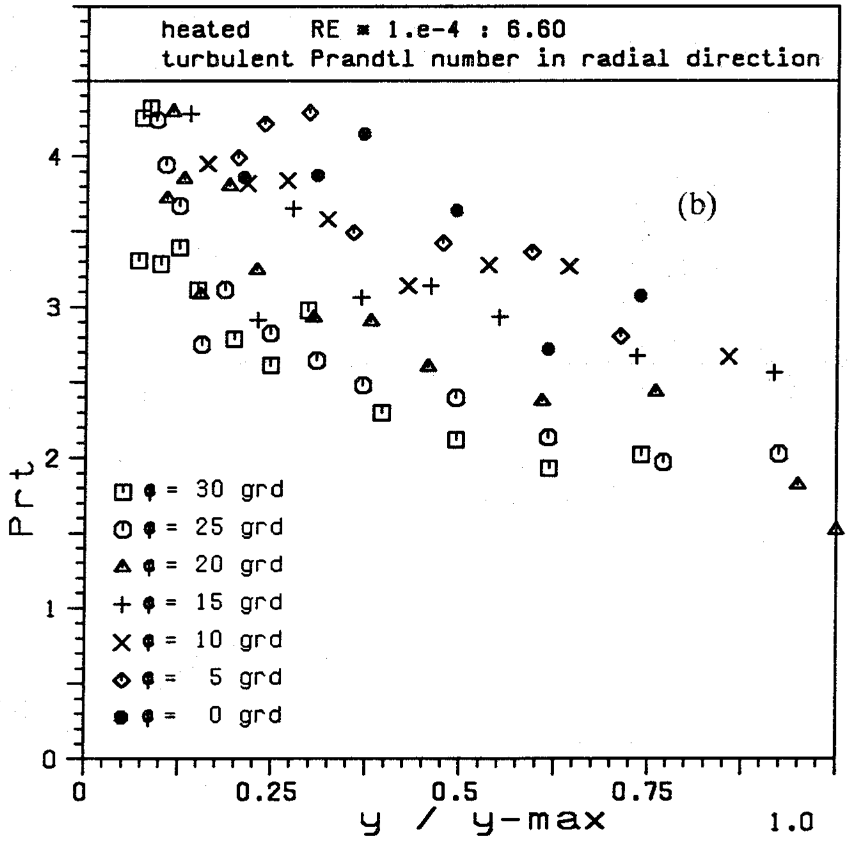


Fig.34 Turbulent Prandtl number in azimuthal (a) and in radial (b) direction

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 0 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023

Reference wall temperature Tw = 69.00 [C]
Local friction velocity u* = 1.105 [m/s]
Average friction velocity u* = 1.163 [m/s]
Average velocity in the central channel Ub = 22.69 [m/s]
Wall heat flux q = 1369.1 [W/m*m]
Local friction temperature T* = 1.140 [K]
Average friction temperature T* = 1.085 [K]
Average fluid temperature Tb = 52.74 [C]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1721	85.6	.7953	16.34	2.661	1.871	.811	1.077	.763	-.009	.503	-.005	-.120	2.803	.206	3.372	-.008	3.192	.077	.000
1.50	.1844	91.8	.8016	16.46	2.602	1.846	.806	1.069	.754	-.004	.507	-.002	-.124	2.800	.186	3.309	-.003	3.178	.069	.000
1.70	.2090	104.0	.8150	16.74	2.482	1.799	.799	1.042	.741	-.011	.515	-.006	-.122	2.797	.174	3.241	-.010	3.174	.067	.000
2.00	.2459	122.3	.8335	17.12	2.339	1.740	.790	1.012	.722	-.003	.525	-.002	-.116	2.863	.169	3.186	-.011	3.133	.076	.000
2.50	.3074	152.9	.8593	17.65	2.130	1.650	.772	.969	.674	-.015	.529	-.009	-.149	2.844	.181	3.156	-.008	3.134	.084	.000
3.00	.3689	183.5	.8822	18.12	1.973	1.584	.753	.932	.627	-.004	.525	-.002	-.171	2.944	.221	3.142	-.020	3.201	.088	.000
4.00	.4918	244.7	.9194	18.88	1.672	1.448	.704	.865	.505	-.003	.495	-.002	-.234	3.162	.292	3.235	-.027	3.301	.092	.000
5.00	.6148	305.9	.9483	19.48	1.394	1.305	.662	.803	.374	.005	.434	.005	-.275	3.497	.240	3.835	-.033	3.391	.091	.000
6.00	.7377	367.0	.9687	19.90	1.150	1.168	.611	.749	.264	.018	.370	.020	-.270	3.808	.311	3.586	-.027	3.449	.093	.000
8.00	.9836	489.4	.9865	20.26	.900	.992	.565	.704	.046	.021	.082	.029	-.054	4.134	.039	3.675	-.011	3.451	-.120	.000
8.13	1.0000	496.9	.9860	20.25	.904	.996	.565	.705	.039	.021	.070	.030	-.047	4.232	.014	3.704	-.016	3.465	-.056	3.779

y [mm]	y ymax	y+	Tw-T Tw-Tb	T+	T' T*	-u'T' u*T*	v'T' u*T*	w'T' u*T*	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
1.40	.1721	85.6	.6702	11.54	.925	.958	.171	.007	.553	.227	.007	.107	3.138	.009	.000	8.512	.000
1.50	.1844	91.8	.6795	11.70	.904	.923	.171	.008	.552	.234	.008	.087	3.053	.014	.000	4.767	.000
1.70	.2090	104.0	.6916	11.91	.872	.842	.168	.007	.536	.241	.007	.075	3.106	.017	.000	3.861	.000
2.00	.2459	122.3	.7129	12.28	.847	.744	.165	.012	.504	.245	.014	.073	3.335	.015	.000	5.144	.000
2.50	.3074	152.9	.7390	12.73	.800	.673	.165	.005	.510	.266	.007	.035	3.246	.022	.000	3.874	.000
3.00	.3689	183.5	.7621	13.13	.783	.578	.155	.007	.464	.263	.010	.048	3.651	.021	.000	4.149	.000
4.00	.4918	244.7	.7991	13.76	.743	.456	.137	.009	.424	.262	.013	.024	3.856	.025	.000	3.641	.000
5.00	.6148	305.9	.8256	14.22	.695	.344	.109	.013	.379	.236	.022	.000	4.339	.034	.000	2.720	.000
6.00	.7377	367.0	.8407	14.48	.655	.255	.074	.016	.332	.185	.032	-.074	4.473	.030	.000	3.074	.000
8.00	.9836	489.4	.8593	14.80	.601	.163	-.002	.019	.276	-.005	.044	-.200	4.604	.010	.000	.000	.000
8.13	1.0000	496.9	.8587	14.79	.598	.149	-.007	.019	.251	-.022	.045	-.178	4.847	.008	-.675	-6.784	-5.595

TABLE I

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 5 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023

Reference wall temperature Tw = 69.00 [C]
Local friction velocity u* = 1.121 [m/s]
Average friction velocity u* = 1.163 [m/s]
Average velocity in the central channel Ub = 22.69 [m/s]
Wall heat flux q = 1369.1 [W/m*m]
Local friction temperature T* = 1.124 [K]
Average friction temperature T* = 1.085 [K]
Average fluid temperature Tb = 52.74 [C]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1659	86.9	.8045	16.28	2.729	1.903	.814	1.082	.773	.041	.499	.020	-.075	2.836	.185	3.371	-.053	3.205	.059	.160
1.50	.1778	93.1	.8117	16.43	2.680	1.884	.809	1.074	.767	.048	.503	.024	-.079	2.830	.184	3.340	-.053	3.200	.066	.168
1.70	.2015	105.5	.8247	16.69	2.549	1.830	.804	1.049	.756	.048	.514	.025	-.079	2.830	.155	3.260	-.053	3.181	.068	.141
2.00	.2371	124.2	.8442	17.09	2.393	1.766	.793	1.019	.732	.057	.523	.031	-.074	2.829	.163	3.202	-.061	3.180	.070	.139
2.50	.2963	155.2	.8706	17.62	2.207	1.689	.780	.976	.693	.058	.527	.036	-.090	2.863	.166	3.139	-.082	3.181	.087	.132
3.00	.3556	186.2	.8927	18.07	2.061	1.631	.760	.940	.644	.070	.519	.046	-.099	2.950	.203	3.161	-.094	3.202	.089	.138
4.00	.4741	248.3	.9319	18.86	1.790	1.515	.721	.874	.538	.114	.493	.086	-.143	3.102	.266	3.283	-.137	3.315	.093	.199
5.00	.5926	310.4	.9605	19.44	1.507	1.380	.672	.809	.419	.145	.452	.130	-.175	3.251	.302	3.444	-.164	3.383	.098	.241
6.00	.7112	372.5	.9825	19.89	1.275	1.253	.635	.760	.309	.170	.389	.179	-.148	3.472	.272	3.578	-.180	3.435	.100	.244
8.00	.9482	496.6	1.0036	20.31	1.012	1.088	.590	.702	.097	.212	.152	.278	.101	3.855	.024	3.772	-.182	3.378	.108	.218
8.44	1.0000	522.8	1.0057	20.36	1.004	1.081	.590	.700	.056	.219	.088	.289	.106	3.796	-.038	3.773	-.181	3.397	.078	.200

y [mm]	y ymax	y+	Tw-T Tw-Tb	T+	T' T*	-u'T' u*T*	v'T' u*T*	w'T' u*T*	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
1.40	.1659	86.9	.6809	11.54	1.022	1.075	.180	.049	.553	.216	.044	-.020	3.163	.012	.118	5.054	1.363
1.50	.1778	93.1	.6895	11.69	1.012	1.051	.179	.050	.551	.219	.046	-.026	3.154	.014	.137	4.690	1.222
1.70	.2015	105.5	.7034	11.92	.976	.972	.181	.051	.544	.230	.050	-.047	3.215	.017	.104	3.993	1.356
2.00	.2371	124.2	.7232	12.26	.942	.912	.181	.054	.547	.243	.055	-.102	3.181	.016	.109	4.217	1.274
2.50	.2963	155.2	.7542	12.78	.914	.811	.177	.053	.525	.248	.060	-.139	3.272	.020	.101	4.292	1.302
3.00	.3556	186.2	.7766	13.16	.903	.737	.170	.060	.500	.248	.071	-.155	3.376	.025	.103	3.496	1.337
4.00	.4741	248.3	.8133	13.79	.879	.621	.154	.073	.465	.242	.096	-.206	3.587	.027	.108	3.426	1.848
5.00	.5926	310.4	.8439	14.30	.840	.528	.126	.088	.455	.222	.130	-.249	3.500	.029	.118	3.364	2.047
6.00	.7112	372.5	.8643	14.65	.819	.448	.099	.112	.435	.189	.179	-.330	3.523	.036	.117	2.807	2.087
8.00	.9482	496.6	.8834	14.97	.794	.335	.022	.143	.388	.047	.255	-.409	3.610	.009	.122	.000	1.797
8.44	1.0000	522.8	.8864	15.03	.783	.328	.007	.138	.387	.016	.251	-.397	3.600	.004	.097	.000	2.061

TABLE I cont.

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 10 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023

Reference wall temperature Tw = 69.00 [C]
Local friction velocity u* = 1.144 [m/s]
Average friction velocity u* = 1.163 [m/s]
Average velocity in the central channel Ub = 22.69 [m/s]

Wall heat flux q = 1369.1 [W/m*m]
Local friction temperature T* = 1.101 [K]
Average friction temperature T* = 1.085 [K]
Average fluid temperature Tb = 52.74 [C]

y	y	y+	U	U+	k'	u'	v'	w'	-u'v'	-u'w'	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
[mm]	ymax		Ub		u* 2	u*	u*	u*	u* 2	u* 2										
1.40	.1497	88.7	.8263	16.38	2.878	1.966	.825	1.099	.815	.067	.503	.031	-.031	2.848	.174	3.373	-.057	3.228	.066	.133
1.50	.1604	95.1	.8332	16.52	2.835	1.949	.819	1.095	.800	.069	.501	.032	-.032	2.841	.155	3.327	-.060	3.219	.061	.114
1.70	.1818	107.7	.8472	16.80	2.710	1.899	.817	1.070	.792	.076	.511	.038	-.016	2.855	.143	3.293	-.060	3.201	.064	.116
2.00	.2139	126.7	.8654	17.16	2.577	1.846	.811	1.042	.778	.086	.520	.045	-.016	2.865	.135	3.224	-.081	3.208	.073	.111
2.50	.2674	158.4	.8929	17.70	2.404	1.777	.801	1.005	.744	.098	.522	.055	-.024	2.862	.140	3.177	-.100	3.180	.078	.125
3.00	.3209	190.1	.9164	18.17	2.276	1.729	.787	.970	.701	.115	.515	.069	-.040	2.905	.167	3.195	-.115	3.208	.086	.143
4.00	.4279	253.5	.9570	18.97	2.009	1.621	.754	.906	.608	.145	.497	.099	-.082	2.963	.217	3.266	-.155	3.281	.091	.193
5.00	.5348	316.9	.9881	19.59	1.744	1.500	.717	.850	.503	.185	.467	.145	-.121	2.989	.254	3.396	-.194	3.353	.101	.218
6.00	.6418	380.2	1.0119	20.06	1.553	1.411	.687	.801	.414	.226	.427	.201	-.213	6.730	.225	3.541	-.207	3.421	.106	.253
8.00	.8557	507.0	1.0433	20.69	1.231	1.236	.643	.721	.217	.271	.273	.304	.025	3.601	.070	3.693	-.210	3.329	.115	.221
9.35	1.0000	591.2	1.0516	20.85	1.154	1.187	.637	.702	.093	.298	.124	.357	.071	3.497	-.093	3.725	-.175	3.250	.246	.174

y	y	y+	Tw-T	T+	T'	-u'T'	v'T'	w'T'	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
[mm]	ymax		Tw-Tb		T*	u*T*	u*T*	u*T*									
1.40	.1497	88.7	.7070	11.47	1.144	1.253	.192	.077	.557	.204	.060	-.037	3.041	.036	.104	1.838	1.278
1.50	.1604	95.1	.7127	11.56	1.135	1.240	.196	.078	.560	.211	.062	-.044	3.041	.015	.093	3.952	1.226
1.70	.1818	107.7	.7313	11.87	1.101	1.154	.196	.079	.552	.217	.067	-.076	3.096	.013	.088	4.971	1.308
2.00	.2139	126.7	.7521	12.20	1.078	1.087	.201	.082	.546	.229	.073	-.099	3.076	.019	.079	3.823	1.405
2.50	.2674	158.4	.7828	12.70	1.058	1.017	.206	.086	.541	.243	.081	-.135	3.088	.020	.085	3.842	1.463
3.00	.3209	190.1	.8098	13.14	1.046	.961	.201	.093	.531	.244	.091	-.161	3.110	.024	.088	3.586	1.621
4.00	.4279	253.5	.8527	13.84	1.024	.850	.189	.113	.512	.244	.122	-.171	3.043	.029	.096	3.143	2.000
5.00	.5348	316.9	.8853	14.37	.995	.782	.169	.136	.523	.236	.160	-.182	2.946	.031	.110	3.279	1.991
6.00	.6418	380.2	.9132	14.82	.994	.673	.144	.159	.479	.210	.199	-.169	3.041	.032	.120	3.269	2.116
8.00	.8557	507.0	.9442	15.32	.968	.530	.081	.199	.443	.131	.286	-.161	3.018	.043	.121	2.671	1.832
9.35	1.0000	591.2	.9551	15.50	.948	.494	.031	.212	.439	.051	.318	-.151	2.956	.013	.099	.000	1.751

TABLE I cont.

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 15 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023
Reference wall temperature Tw = 69.00 [C] Wall heat flux q = 1369.1 [W/m*m]
Local friction velocity u* = 1.174 [m/s] Local friction temperature T* = 1.073 [K]
Average friction velocity u* = 1.163 [m/s] Average friction temperature T* = 1.085 [K]
Average velocity in the central channel Ub = 22.69 [m/s] Average fluid temperature Tb = 52.74 [C]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1284	91.0	.8501	16.43	2.979	2.002	.828	1.125	.827	.052	.499	.023	-.023	2.808	.166	3.378	-.033	3.220	.065	.080
1.50	.1375	97.5	.8570	16.57	2.934	1.983	.828	1.118	.821	.057	.500	.025	-.020	2.789	.146	3.335	-.029	3.240	.051	.087
1.70	.1559	110.5	.8728	16.87	2.830	1.943	.827	1.096	.826	.055	.514	.026	-.008	2.817	.123	3.272	-.048	3.199	.054	.057
2.00	.1834	130.0	.8907	17.22	2.698	1.892	.822	1.069	.808	.071	.520	.035	-.007	2.804	.121	3.242	-.057	3.181	.070	.071
2.50	.2292	162.5	.9190	17.76	2.536	1.830	.813	1.031	.776	.079	.522	.042	-.021	2.774	.124	3.213	-.071	3.212	.070	.073
3.00	.2751	195.0	.9424	18.22	2.419	1.785	.806	1.001	.750	.088	.521	.049	-.047	2.807	.141	3.198	-.090	3.194	.082	.094
4.00	.3667	260.0	.9834	19.01	2.220	1.708	.784	.953	.676	.111	.505	.069	-.298	8.601	.173	3.251	-.119	3.237	.088	.127
5.00	.4584	325.0	1.0153	19.62	1.987	1.611	.754	.899	.597	.146	.491	.101	-.122	2.988	.205	3.302	-.143	3.276	.098	.164
6.00	.5501	390.0	1.0422	20.14	1.760	1.509	.724	.848	.515	.162	.472	.127	-.169	3.030	.226	3.410	-.160	3.308	.100	.165
8.00	.7335	520.1	1.0809	20.89	1.421	1.344	.678	.759	.348	.212	.382	.208	-.777	26.301	.156	3.527	-.166	3.332	.109	.201
10.00	.9168	650.1	1.1031	21.32	1.196	1.210	.658	.703	.179	.241	.225	.284	-.728	30.406	-.019	3.608	-.120	3.240	.134	.000
10.91	1.0000	707.5	1.1064	21.39	1.162	1.189	.656	.692	.113	.264	.145	.320	-.409	19.628	-.113	3.626	-.085	3.186	.645	.135

y [mm]	y ymax	y+	Tw-T Tw-Tb	T+	T' T*	-u'T' u*T*	v'T' u*T*	w'T' u*T*	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
1.40	.1284	91.0	.7423	11.67	1.215	1.405	.213	.080	.578	.212	.057	.014	2.940	.012	.094	5.300	.847
1.50	.1375	97.5	.7519	11.82	1.202	1.371	.211	.084	.576	.213	.061	.003	2.940	.012	.073	4.285	1.183
1.70	.1559	110.5	.7719	12.14	1.176	1.303	.221	.085	.571	.227	.065	-.008	2.955	.012	.083	4.614	.683
2.00	.1834	130.0	.7994	12.57	1.147	1.224	.221	.089	.565	.235	.072	-.036	2.956	.015	.084	4.667	.851
2.50	.2292	162.5	.8273	13.01	1.121	1.164	.232	.086	.567	.254	.074	-.048	2.917	.024	.075	2.916	.973
3.00	.2751	195.0	.8553	13.45	1.114	1.110	.234	.091	.558	.260	.081	-.058	2.915	.022	.079	3.657	1.193
4.00	.3667	260.0	.9011	14.17	1.098	.970	.224	.107	.517	.260	.102	-.038	3.004	.029	.094	3.066	1.353
5.00	.4584	325.0	.9383	14.75	1.073	.877	.211	.122	.507	.261	.127	-.027	2.991	.031	.103	3.141	1.587
6.00	.5501	390.0	.9696	15.24	1.051	.792	.195	.149	.500	.257	.167	.021	2.943	.034	.118	2.934	1.400
8.00	.7335	520.1	1.0123	15.92	1.009	.595	.143	.181	.439	.209	.237	.077	3.036	.041	.130	2.674	1.545
10.00	.9168	650.1	1.0395	16.34	.955	.476	.080	.205	.411	.127	.305	.115	3.087	.052	.000	2.566	.000
10.91	1.0000	707.5	1.0416	16.38	.956	.457	.052	.215	.402	.082	.325	.117	3.130	-.090	.089	-7.198	1.515

TABLE I cont.

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 20 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023

Reference wall temperature Tw = 69.00 [C] Wall heat flux q = 1369.1 [W/m*m]
Local friction velocity u* = 1.197 [m/s] Local friction temperature T* = 1.052 [K]
Average friction velocity u* = 1.163 [m/s] Average friction temperature T* = 1.085 [K]
Average velocity in the central channel Ub = 22.69 [m/s] Average fluid temperature Tb = 52.74 [C]

y	y	y+	U	U+	k'	u'	v'	w'	-u'v'	-u'w'	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
[mm]	ymax		Ub		u* 2	u*	u*	u*	u* 2	u* 2										
1.40	.1063	92.8	.8649	16.39	3.080	2.040	.830	1.144	.838	.008	.494	.003	-.003	2.783	.153	3.397	-.018	3.227	.030	.004
1.50	.1139	99.4	.8744	16.57	3.050	2.025	.831	1.143	.836	.014	.497	.006	-.022	3.292	.127	3.339	-.010	3.249	.041	-.004
1.70	.1291	112.7	.8879	16.83	2.945	1.986	.830	1.122	.836	.011	.507	.005	.007	2.786	.122	3.304	-.024	3.208	.052	-.030
2.00	.1518	132.6	.9081	17.21	2.828	1.939	.831	1.097	.831	.020	.515	.009	.014	2.792	.094	3.254	-.038	3.189	.051	-.012
2.50	.1898	165.7	.9358	17.74	2.683	1.885	.827	1.062	.816	.009	.523	.005	-.017	2.753	.090	3.200	-.036	3.183	.067	-.113
3.00	.2277	198.9	.9587	18.17	2.570	1.844	.821	1.033	.788	.022	.521	.012	-.067	3.780	.108	3.185	-.062	3.195	.071	-.038
4.00	.3037	265.2	1.0001	18.95	2.406	1.781	.807	.994	.730	.028	.508	.016	-.244	7.248	.134	3.208	-.078	3.185	.081	-.037
5.00	.3796	331.5	1.0314	19.55	2.186	1.687	.787	.952	.674	.045	.507	.028	-.182	4.541	.174	3.231	-.097	3.212	.094	.084
6.00	.4555	397.8	1.0589	20.07	2.013	1.615	.765	.912	.607	.056	.491	.038	-.490	12.258	.193	3.262	-.111	3.247	.095	.098
8.00	.6073	530.4	1.1017	20.88	1.654	1.456	.715	.820	.464	.090	.446	.076	-1.520	44.227	.222	3.385	-.134	3.316	.102	.175
10.00	.7591	663.0	1.1332	21.48	1.357	1.300	.681	.746	.329	.126	.372	.129	-1.768	59.373	.148	3.440	-.124	3.365	.103	.176
12.50	.9489	828.7	1.1542	21.88	1.197	1.216	.665	.685	.156	.181	.195	.215	-3.940	154.039	-.040	3.467	-.043	3.257	.163	.000
13.17	1.0000	871.5	1.1560	21.91	1.105	1.140	.669	.679	.109	.201	.144	.258	-.994	37.111	-.081	3.474	-.006	3.232	.351	.094

y	y	y+	Tw-T	T+	T'	-u'T'	v'T'	w'T'	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
[mm]	ymax		Tw-Tb		T*	u*T*	u*T*	u*T*									
1.40	.1063	92.8	.7764	11.94	1.265	1.515	.228	.056	.588	.217	.037	.054	2.911	.008	.098	3.722	.036
1.50	.1139	99.4	.7886	12.13	1.253	1.471	.228	.052	.580	.219	.035	.056	2.926	.010	.086	4.296	-.041
1.70	.1291	112.7	.8076	12.42	1.219	1.410	.237	.056	.583	.234	.040	.025	2.919	.014	.088	3.850	-.344
2.00	.1518	132.6	.8291	12.75	1.193	1.326	.243	.059	.573	.245	.045	.027	2.966	.017	.090	3.083	-.128
2.50	.1898	165.7	.8632	13.27	1.167	1.263	.252	.056	.575	.262	.045	.003	2.931	.018	.077	3.807	-1.472
3.00	.2277	198.9	.8931	13.73	1.155	1.191	.256	.053	.559	.270	.044	.013	2.982	.022	.076	3.246	-.506
4.00	.3037	265.2	.9404	14.46	1.131	1.062	.255	.062	.527	.279	.055	.019	3.001	.028	.094	2.931	-.395
5.00	.3796	331.5	.9781	15.04	1.097	.971	.251	.068	.524	.291	.065	.039	2.987	.032	.098	2.907	.856
6.00	.4555	397.8	1.0111	15.55	1.071	.870	.239	.076	.503	.292	.078	.080	3.003	.036	.110	2.604	.892
8.00	.6073	530.4	1.0607	16.31	1.001	.688	.206	.106	.474	.288	.130	.144	3.026	.043	.129	2.376	1.353
10.00	.7591	663.0	1.1008	16.93	.923	.511	.153	.128	.427	.243	.186	.180	3.144	.042	.122	2.436	1.446
12.50	.9489	828.7	1.1268	17.33	.877	.379	.074	.158	.358	.127	.263	.198	3.365	.089	.000	1.822	.000
13.17	1.0000	871.5	1.1287	17.36	.854	.392	.056	.162	.405	.098	.279	.178	3.178	.231	.067	1.520	1.413

TABLE I cont.

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 25 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023
Reference wall temperature Tw = 69.00 [C] Wall heat flux q = 1369.1 [W/m*m]
Local friction velocity u* = 1.197 [m/s] Local friction temperature T* = 1.052 [K]
Average friction velocity u* = 1.163 [m/s] Average friction temperature T* = 1.085 [K]
Average velocity in the central channel Ub = 22.69 [m/s] Average fluid temperature Tb = 52.74 [C]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.0862	92.8	.8665	16.43	3.211	2.083	.837	1.175	.865	-.039	.496	-.016	.029	2.783	.136	3.393	-.012	3.271	.032	.000
1.50	.0923	99.4	.8748	16.58	3.199	2.078	.839	1.172	.869	-.034	.498	-.014	.007	3.306	.125	3.341	-.019	3.228	.036	.000
1.70	.1046	112.7	.8888	16.85	3.109	2.043	.843	1.155	.867	-.039	.503	-.017	.036	2.784	.108	3.277	-.014	3.216	.043	.000
2.00	.1231	132.6	.9074	17.20	2.957	1.982	.841	1.131	.856	-.033	.514	-.015	.037	2.740	.078	3.244	-.011	3.211	.046	.000
2.50	.1539	165.7	.9357	17.74	2.863	1.948	.843	1.104	.855	-.038	.520	-.018	.009	3.459	.073	3.183	-.023	3.187	.054	.000
3.00	.1847	198.8	.9586	18.17	2.782	1.917	.842	1.086	.832	-.030	.515	-.014	-.173	6.867	.057	3.223	-.016	3.218	.063	.000
4.00	.2462	265.1	.9986	18.93	2.587	1.837	.837	1.047	.794	-.037	.516	-.019	-.072	3.841	.100	3.149	-.045	3.150	.071	.000
5.00	.3078	331.4	1.0309	19.54	2.409	1.765	.824	1.013	.748	-.034	.514	-.019	-.136	4.078	.128	3.156	-.065	3.165	.083	.000
6.00	.3693	397.7	1.0584	20.06	2.257	1.706	.806	.977	.702	-.032	.511	-.019	-.295	7.519	.160	3.165	-.071	3.165	.089	.000
8.00	.4925	530.2	1.1035	20.92	1.976	1.596	.765	.905	.592	-.007	.485	-.005	-1.416	38.708	.214	3.235	-.101	3.189	.094	.000
10.00	.6156	662.8	1.1405	21.62	1.700	1.478	.726	.826	.469	.024	.438	.021	-2.936	87.590	.229	3.315	-.105	3.266	.094	.000
12.50	.7695	828.5	1.1739	22.26	1.552	1.445	.681	.732	.319	.070	.326	.068	-8.361	272.911	.193	3.411	-.072	3.354	.094	.000
15.00	.9234	994.2	1.1949	22.65	1.268	1.286	.655	.663	.175	.120	.210	.141	-9.428	349.376	.061	3.468	.026	3.342	.112	.000
16.25	1.0000	1074.7	1.1985	22.72	1.412	1.384	.657	.648	.100	.157	.115	.181	-11.627	405.710	-.022	3.501	.093	3.365	.785	.062

y [mm]	y ymax	y+	Tw-T Tw-Tb	T+	T' T*	-u'T' u*T*	v'T' u*T*	w'T' u*T*	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
1.40	.0862	92.8	.7912	12.09	1.291	1.635	.240	.015	.609	.223	.009	.043	2.859	.006	.000	4.902	.000
1.50	.0923	99.4	.8037	12.28	1.284	1.600	.241	.018	.600	.223	.011	.040	2.859	.009	.000	4.242	.000
1.70	.1046	112.7	.8224	12.57	1.254	1.516	.252	.013	.593	.239	.008	.035	2.912	.011	.000	3.944	.000
2.00	.1231	132.6	.8494	12.98	1.209	1.474	.264	.015	.615	.260	.011	.000	2.810	.013	.000	3.673	.000
2.50	.1539	165.7	.8798	13.44	1.197	1.361	.273	.009	.583	.270	.007	.006	2.945	.020	.000	2.752	.000
3.00	.1847	198.8	.9068	13.86	1.173	1.311	.281	.009	.583	.284	.007	-.020	2.864	.020	.000	3.115	.000
4.00	.2462	265.1	.9551	14.59	1.144	1.206	.290	.011	.574	.303	.009	.001	2.922	.025	.000	2.827	.000
5.00	.3078	331.4	.9959	15.22	1.115	1.110	.290	.008	.564	.316	.007	.027	2.881	.031	.000	2.646	.000
6.00	.3693	397.7	1.0265	15.68	1.085	.991	.277	.021	.536	.316	.020	.082	2.951	.036	.000	2.480	.000
8.00	.4925	530.2	1.0828	16.54	1.022	.822	.256	.028	.504	.328	.032	.150	2.968	.039	.000	2.399	.000
10.00	.6156	662.8	1.1249	17.19	.937	.635	.214	.051	.459	.314	.067	.214	3.195	.044	.000	2.135	.000
12.50	.7695	828.5	1.1667	17.83	.841	.445	.150	.070	.368	.261	.115	.245	3.589	.048	.000	1.972	.000
15.00	.9234	994.2	1.1883	18.16	.757	.313	.076	.093	.322	.152	.186	.235	3.615	.055	.000	2.028	.000
16.25	1.0000	1074.7	1.1955	18.27	.754	.306	.044	.105	.296	.089	.216	.248	4.014	.033	.054	.000	1.133

TABLE I cont.

RUN NO. 01 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 30 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 66023

Reference wall temperature Tw = 69.00 [C]
Wall heat flux q = 1369.1 [W/m*m]
Local friction velocity u* = 1.200 [m/s]
Local friction temperature T* = 1.049 [K]
Average friction velocity u* = 1.163 [m/s]
Average friction temperature T* = 1.085 [K]
Average velocity in the central channel Ub = 22.69 [m/s]
Average fluid temperature Tb = 52.74 [C]

y	y	y+	U	U+	k'	u'	v'	w'	-u'v'	-u'w'	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
[mm]	ymax		Ub		u* 2	u*	u*	u*	u* 2	u* 2										
1.40	.0691	93.1	.8624	16.30	3.260	2.099	.839	1.186	.865	-.013	.491	-.005	.037	2.792	.132	3.392	-.001	3.250	.025	.000
1.50	.0740	99.7	.8710	16.46	3.246	2.091	.840	1.187	.867	.016	.493	.006	.043	2.789	.116	3.363	.003	3.276	.028	.000
1.70	.0839	113.0	.8858	16.74	3.130	2.048	.840	1.167	.862	.028	.501	.012	.060	2.796	.092	3.305	-.001	3.225	.034	.000
2.00	.0987	132.9	.9040	17.09	3.003	1.998	.843	1.142	.868	.016	.515	.007	.062	2.758	.071	3.231	-.008	3.189	.039	.000
2.50	.1234	166.2	.9322	17.62	2.887	1.954	.843	1.116	.851	.023	.516	.011	.043	2.747	.058	3.175	.002	3.157	.042	.000
3.00	.1480	199.4	.9560	18.07	2.817	1.925	.850	1.097	.849	.018	.519	.009	.007	3.512	.051	3.194	.010	3.146	.050	.000
4.00	.1974	265.9	.9958	18.82	2.659	1.862	.848	1.064	.816	.018	.517	.009	-.128	5.581	.080	3.131	.005	3.122	.061	.000
5.00	.2467	332.4	1.0271	19.41	2.477	1.785	.833	1.035	.766	.017	.515	.009	-.148	5.149	.108	3.141	.004	3.125	.069	.000
6.00	.2961	398.8	1.0548	19.94	2.326	1.722	.819	1.007	.723	.009	.512	.005	-.257	7.122	.140	3.115	.010	3.142	.073	.000
8.00	.3947	531.8	1.1002	20.80	2.070	1.628	.782	.937	.627	.010	.493	.006	-1.207	32.926	.199	3.177	.007	3.162	.080	.000
10.00	.4934	664.7	1.1384	21.52	1.781	1.510	.736	.858	.522	.013	.470	.009	-2.194	63.150	.252	3.244	.010	3.201	.078	.000
12.50	.6168	830.9	1.1768	22.24	1.478	1.385	.679	.754	.386	.004	.412	.005	-4.798	156.616	.307	3.380	.018	3.314	.073	.000
15.00	.7402	997.1	1.2069	22.81	1.502	1.439	.633	.667	.238	-.012	.276	-.015	-10.089	306.409	.272	3.506	.004	3.433	.067	.000
20.00	.9869	1329.4	1.2281	23.22	1.215	1.291	.579	.579	.026	.006	.039	.013	-15.657	605.780	.000	3.540	-.004	3.546	.049	.000
20.27	1.0000	1344.9	1.2285	23.22	1.389	1.438	.582	.582	.009	-.003	.014	-.008	-19.257	675.414	-.005	3.527	-.011	3.546	.017	-.049

y	y	y+	Tw-T	T+	T'	-u'T'	v'T'	w'T'	-RuT	RvT	RwT	S t	F t	eptv	eptw	Prtv	Prtw
[mm]	ymax		Tw-Tb		T*	u*T*	u*T*	u*T*									
1.40	.0691	93.1	.7918	12.13	1.318	1.683	.246	.001	.609	.223	.000	.045	2.869	.008	.000	3.309	.000
1.50	.0740	99.7	.8024	12.30	1.308	1.646	.248	.002	.603	.225	.001	.039	2.848	.007	.000	4.254	.000
1.70	.0839	113.0	.8243	12.63	1.273	1.555	.254	.004	.597	.238	.002	.018	2.885	.008	.000	4.318	.000
2.00	.0987	132.9	.8466	12.97	1.234	1.496	.267	.002	.607	.256	.001	-.004	2.870	.012	.000	3.284	.000
2.50	.1234	166.2	.8818	13.51	1.205	1.411	.277	.003	.600	.273	.002	-.014	2.865	.012	.000	3.393	.000
3.00	.1480	199.4	.9106	13.95	1.186	1.337	.288	.007	.586	.286	.005	-.031	2.889	.016	.000	3.112	.000
4.00	.1974	265.9	.9598	14.71	1.159	1.251	.303	.001	.580	.307	.001	-.014	2.888	.022	.000	2.789	.000
5.00	.2467	332.4	.9941	15.23	1.124	1.158	.301	.001	.577	.321	.001	.006	2.875	.026	.000	2.613	.000
6.00	.2961	398.8	1.0304	15.79	1.091	1.054	.291	.001	.561	.325	.002	.042	2.874	.024	.000	2.978	.000
8.00	.3947	531.8	1.0867	16.65	1.040	.868	.269	.000	.512	.330	.001	.153	3.010	.035	.000	2.299	.000
10.00	.4934	664.7	1.1307	17.33	.960	.693	.233	.000	.479	.330	.001	.236	3.084	.037	.000	2.119	.000
12.50	.6168	830.9	1.1738	17.99	.840	.492	.179	-.003	.424	.313	-.003	.301	3.391	.038	.000	1.932	.000
15.00	.7402	997.1	1.2078	18.51	.739	.347	.117	-.009	.339	.249	-.016	.290	4.149	.033	.000	2.020	.000
20.00	.9869	1329.4	1.2330	18.89	.631	.202	-.004	-.005	.256	-.012	-.012	.208	4.375	-.013	.000	-3.636	.000
20.27	1.0000	1344.9	1.2316	18.87	.646	.219	-.009	-.007	.236	-.024	-.020	.249	5.365	-.006	-.014	-2.788	3.528

TABLE I cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 30 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = 1.048 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.0692	96.0	.8654	16.80	3.914	2.225	1.005	1.366	.991	.003	.443	.001	.053	2.794	.201	3.439	-.004	3.219	.037	.000
1.50	.0741	102.9	.8727	16.94	3.890	2.216	1.008	1.360	.993	.039	.444	.013	.050	2.799	.180	3.401	.002	3.209	.033	.000
1.70	.0840	116.6	.8882	17.24	3.858	2.203	1.016	1.353	.994	.040	.444	.013	-.008	4.008	.150	3.357	.000	3.217	.034	.000
2.00	.0988	137.1	.9077	17.62	3.802	2.184	1.021	1.338	.986	.038	.442	.013	-.007	3.793	.127	3.313	.002	3.207	.042	.000
2.50	.1235	171.4	.9357	18.17	3.662	2.129	1.025	1.319	1.000	.038	.458	.013	.007	2.730	.118	3.234	.012	3.179	.050	.000
3.00	.1482	205.7	.9588	18.62	3.598	2.106	1.029	1.304	.967	.038	.447	.014	-.148	5.826	.114	3.204	.005	3.163	.057	.000
4.00	.1976	274.3	.9985	19.39	3.402	2.033	1.024	1.273	.924	.039	.444	.015	-.162	5.294	.131	3.176	.004	3.131	.065	.000
5.00	.2470	342.9	1.0309	20.02	3.269	1.991	1.015	1.241	.863	.035	.427	.014	-.912	24.294	.164	3.182	.008	3.139	.075	.000
6.00	.2964	411.4	1.0582	20.55	3.150	1.957	1.001	1.209	.808	.029	.413	.013	-1.912	50.025	.192	3.188	.006	3.133	.080	.000
8.00	.3952	548.6	1.1044	21.44	2.812	1.848	.958	1.132	.691	.029	.391	.013	-3.149	87.087	.246	3.257	.004	3.156	.085	.000
10.00	.4940	685.7	1.1421	22.18	2.695	1.839	.911	1.048	.581	.007	.353	.006	-5.652	151.783	.301	3.388	.006	3.256	.086	.000
12.50	.6176	857.2	1.1805	22.92	2.646	1.911	.841	.930	.435	.013	.278	.009	-11.941	339.077	.324	3.530	.012	3.382	.083	.000
15.00	.7411	1028.6	1.2086	23.47	3.074	2.164	.776	.819	.277	-.006	.169	-.002	-16.282	438.186	.306	3.650	.012	3.512	.078	.000
20.00	.9881	1371.4	1.2321	23.92	3.483	2.399	.728	.730	.029	-.011	.014	-.007	-18.491	455.697	.003	3.804	.008	3.808	.099	.000
20.24	1.0000	1387.9	1.2323	23.93	3.726	2.451	.739	.740	.021	-.020	.009	-.009	-18.506	463.499	-.031	3.914	.022	3.957	.138	.000

TABLE II

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 25 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = 1.051 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.0863	96.2	.8669	16.79	3.799	2.188	.999	1.347	.985	-.042	.451	-.014	.018	3.060	.206	3.422	-.010	3.214	.034	.000
1.50	.0924	103.1	.8754	16.96	3.787	2.185	1.000	1.341	.981	-.042	.449	-.015	.036	2.804	.191	3.402	-.010	3.215	.039	.000
1.70	.1047	116.9	.8899	17.24	3.730	2.160	1.009	1.332	.986	-.043	.452	-.016	.010	3.081	.153	3.345	-.013	3.210	.045	.000
2.00	.1232	137.5	.9099	17.63	3.670	2.140	1.013	1.317	.975	-.039	.450	-.014	-.029	3.777	.139	3.303	-.014	3.191	.049	.000
2.50	.1540	171.8	.9377	18.16	3.609	2.115	1.025	1.301	.960	-.045	.443	-.016	-.075	4.265	.115	3.278	-.022	3.189	.060	.000
3.00	.1848	206.2	.9616	18.63	3.478	2.072	1.015	1.276	.932	-.050	.443	-.019	-.077	3.609	.131	3.215	-.024	3.176	.066	.000
4.00	.2464	274.9	1.0015	19.40	3.335	2.020	1.015	1.248	.884	-.040	.431	-.016	-.410	11.392	.144	3.223	-.055	3.164	.080	.000
5.00	.3081	343.7	1.0333	20.02	3.080	1.925	.995	1.210	.826	-.038	.431	-.016	-.386	10.052	.177	3.224	-.067	3.176	.089	.000
6.00	.3697	412.4	1.0612	20.56	2.964	1.898	.977	1.169	.764	-.027	.413	-.012	-1.681	44.405	.212	3.240	-.076	3.183	.093	.000
8.00	.4929	549.9	1.1066	21.43	2.628	1.785	.932	1.089	.639	.002	.386	.001	-2.921	80.569	.260	3.323	-.092	3.229	.102	.000
10.00	.6161	687.4	1.1423	22.13	2.620	1.846	.885	1.005	.514	.046	.318	.023	-7.983	228.056	.273	3.425	-.117	3.341	.102	.000
12.50	.7701	859.2	1.1765	22.79	2.379	1.799	.828	.892	.335	.091	.228	.057	-12.422	379.048	.230	3.531	-.076	3.429	.097	.000
15.00	.9242	1031.0	1.1965	23.18	2.409	1.850	.806	.821	.170	.141	.115	.096	-16.049	488.466	.085	3.658	.008	3.472	.110	.000
16.23	1.0000	1115.1	1.2007	23.26	2.478	1.901	.805	.801	.085	.179	.055	.119	-16.917	501.702	.009	3.613	.075	3.457	.150	.000

TABLE II cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 20 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = 1.046 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1063	95.8	.8630	16.79	3.661	2.147	.990	1.316	.955	.009	.450	.003	.004	2.814	.212	3.397	-.016	3.207	.049	-.130
1.50	.1139	102.6	.8708	16.95	3.630	2.134	.996	1.310	.953	.016	.449	.006	-.009	3.107	.194	3.409	-.019	3.198	.047	-.112
1.70	.1291	116.3	.8864	17.25	3.567	2.114	.995	1.294	.943	.027	.448	.010	-.023	3.166	.185	3.361	-.025	3.188	.050	-.116
2.00	.1519	136.8	.9060	17.63	3.500	2.088	1.001	1.279	.937	.026	.448	.010	-.015	2.820	.162	3.335	-.033	3.185	.060	-.107
2.50	.1899	171.0	.9345	18.19	3.411	2.060	1.000	1.255	.907	.029	.440	.011	-.142	5.444	.154	3.274	-.043	3.194	.067	-.099
3.00	.2278	205.2	.9587	18.66	3.264	2.005	.997	1.230	.876	.028	.438	.012	-.194	5.701	.158	3.265	-.050	3.192	.076	-.076
4.00	.3038	273.6	.9995	19.45	3.045	1.928	.981	1.187	.802	.038	.424	.017	-.421	10.758	.189	3.264	-.084	3.205	.086	-.018
5.00	.3797	342.1	1.0321	20.09	2.890	1.887	.958	1.140	.722	.058	.399	.027	-1.386	37.721	.213	3.305	-.091	3.239	.095	.100
6.00	.4557	410.5	1.0594	20.62	2.605	1.774	.929	1.093	.649	.074	.394	.038	-1.059	28.237	.243	3.354	-.123	3.284	.101	.167
8.00	.6075	547.3	1.1026	21.46	2.443	1.760	.876	.999	.489	.114	.318	.067	-4.975	145.464	.260	3.460	-.143	3.338	.103	.148
10.00	.7594	684.1	1.1340	22.07	2.519	1.853	.840	.919	.332	.171	.215	.101	-10.466	304.087	.181	3.577	-.125	3.408	.101	.210
12.50	.9493	855.1	1.1548	22.47	2.212	1.705	.818	.848	.131	.216	.097	.154	-10.809	335.129	.010	3.599	-.060	3.349	.151	.000
13.17	1.0000	900.0	1.1561	22.50	2.109	1.667	.822	.845	.082	.243	.059	.177	-11.322	362.788	-.037	3.633	-.030	3.372	1.118	.136

TABLE II cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 15 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = 1.026 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1283	94.0	.8451	16.76	3.508	2.093	.991	1.286	.940	.060	.453	.022	-.004	2.842	.220	3.424	-.037	3.200	.057	-.019
1.50	.1375	100.7	.8529	16.91	3.458	2.082	.982	1.272	.930	.065	.455	.024	-.004	2.828	.224	3.380	-.050	3.190	.054	.001
1.70	.1558	114.2	.8683	17.21	3.427	2.072	.986	1.261	.916	.074	.448	.028	-.005	2.884	.190	3.354	-.046	3.206	.058	.008
2.00	.1833	134.3	.8879	17.60	3.341	2.042	.985	1.241	.892	.086	.443	.034	-.019	2.888	.178	3.312	-.053	3.182	.068	.019
2.50	.2291	167.9	.9165	18.17	3.213	1.999	.982	1.211	.865	.101	.441	.042	-.088	3.915	.182	3.280	-.074	3.185	.076	.052
3.00	.2750	201.5	.9406	18.65	3.084	1.957	.971	1.182	.811	.116	.427	.050	-.184	5.861	.194	3.281	-.089	3.219	.084	.086
4.00	.3666	268.6	.9812	19.45	2.813	1.854	.951	1.133	.728	.149	.413	.072	-.301	7.865	.207	3.349	-.117	3.271	.093	.109
5.00	.4583	335.8	1.0138	20.10	2.570	1.772	.917	1.075	.631	.172	.389	.091	-.752	20.852	.246	3.392	-.142	3.317	.099	.154
6.00	.5500	402.9	1.0406	20.63	2.370	1.703	.887	1.023	.537	.214	.356	.123	-1.813	54.304	.248	3.502	-.162	3.379	.102	.212
8.00	.7333	537.2	1.0796	21.40	2.064	1.601	.832	.926	.333	.252	.251	.171	-4.508	145.691	.183	3.624	-.163	3.414	.101	.229
10.00	.9166	671.5	1.1015	21.84	1.882	1.522	.812	.874	.149	.311	.121	.237	-6.055	209.444	.023	3.744	-.112	3.372	.107	.000
10.91	1.0000	731.6	1.1053	21.91	1.664	1.396	.803	.853	.068	.331	.062	.279	-3.389	128.582	-.051	3.671	-.101	3.284	.165	.191

TABLE II cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 10 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = .999 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y	y	y+	U	U+	k'	u'	v'	w'	-u'v'	-u'w'	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
[mm]	ymax		Ub		u* 2	u*	u*	u*	u* 2	u* 2										
1.40	.1496	91.5	.8188	16.67	3.365	2.048	.979	1.255	.909	.067	.453	.026	-.012	2.854	.232	3.413	-.056	3.197	.055	-.006
1.50	.1603	98.1	.8272	16.84	3.309	2.030	.974	1.243	.900	.073	.455	.029	-.014	2.873	.231	3.380	-.062	3.204	.059	-.003
1.70	.1816	111.1	.8419	17.14	3.275	2.017	.980	1.233	.885	.088	.448	.035	-.007	2.916	.192	3.351	-.067	3.209	.069	.040
2.00	.2137	130.8	.8606	17.52	3.147	1.976	.969	1.204	.858	.089	.448	.037	-.024	2.922	.197	3.309	-.072	3.183	.076	.021
2.50	.2671	163.5	.8891	18.10	3.010	1.927	.963	1.175	.813	.103	.439	.046	-.074	3.582	.193	3.284	-.095	3.216	.081	.064
3.00	.3205	196.1	.9128	18.59	2.878	1.882	.949	1.146	.753	.125	.422	.058	-.099	3.757	.206	3.287	-.115	3.237	.089	.083
4.00	.4274	261.5	.9531	19.41	2.566	1.769	.912	1.082	.646	.170	.400	.089	-.121	3.178	.243	3.355	-.154	3.302	.096	.153
5.00	.5342	326.9	.9838	20.03	2.294	1.661	.879	1.027	.525	.218	.359	.128	-.196	5.708	.264	3.522	-.181	3.379	.101	.207
6.00	.6410	392.3	1.0087	20.54	2.056	1.572	.838	.969	.409	.271	.310	.178	-.535	18.280	.252	3.612	-.210	3.453	.096	.256
8.00	.8547	523.1	1.0413	21.20	1.686	1.407	.782	.882	.181	.327	.167	.264	-.845	36.155	.096	3.760	-.195	3.342	.097	.282
9.36	1.0000	610.7	1.0479	21.34	1.708	1.434	.777	.866	.029	.370	.024	.299	-2.553	100.301	-.062	3.786	-.174	3.325	-.417	.235

TABLE II cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 5 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = .977 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y [mm]	y ymax	y+	U Ub	U+	k' u* 2	u' u*	v' u*	w' u*	-u'v' u* 2	-u'w' u* 2	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
1.40	.1656	89.5	.7979	16.62	3.203	1.984	.969	1.236	.889	.030	.462	.012	-.040	2.884	.255	3.392	-.044	3.155	.061	-.053
1.50	.1774	95.9	.8058	16.79	3.152	1.965	.969	1.226	.871	.029	.458	.012	-.042	2.889	.236	3.368	-.048	3.162	.065	-.052
1.70	.2011	108.6	.8199	17.08	3.084	1.944	.964	1.207	.853	.039	.455	.017	-.044	2.951	.221	3.327	-.059	3.160	.073	-.078
2.00	.2366	127.8	.8388	17.48	2.936	1.885	.956	1.184	.827	.041	.459	.018	-.079	2.887	.216	3.289	-.060	3.157	.078	-.061
2.50	.2957	159.8	.8664	18.05	2.789	1.836	.942	1.149	.763	.061	.442	.029	-.104	3.016	.221	3.266	-.074	3.191	.086	.004
3.00	.3549	191.7	.8894	18.53	2.640	1.784	.923	1.116	.697	.069	.423	.035	-.130	3.179	.236	3.276	-.086	3.236	.092	.048
4.00	.4731	255.6	.9281	19.34	2.309	1.658	.877	1.049	.562	.106	.387	.061	-.171	3.411	.283	3.396	-.118	3.352	.094	.077
5.00	.5914	319.5	.9577	19.95	1.997	1.525	.832	.987	.424	.152	.334	.101	-.196	3.841	.284	3.596	-.126	3.447	.094	.223
6.00	.7097	383.4	.9800	20.42	1.702	1.390	.781	.927	.295	.185	.271	.144	-.140	4.223	.264	3.698	-.149	3.467	.089	.282
8.00	.9463	511.2	1.0031	20.90	1.388	1.217	.731	.871	.046	.238	.052	.224	.064	4.712	.035	3.865	-.143	3.461	.067	.275
8.45	1.0000	538.9	1.0040	20.92	1.382	1.218	.726	.866	-.012	.238	-.013	.225	-.037	9.719	-.025	3.851	-.132	3.439	-.241	.258

TABLE II cont.

RUN NO. 02 CENTRAL CHANNEL NO. 2 SUBCHANNEL AV ANGULAR POSITION 0 DEG REFERENCE : LOCAL REYNOLDS NUMBER = 71361

Local friction velocity u* = .969 [m/s]
Average friction velocity u* = 1.017 [m/s]
Average velocity Ub = 20.3 [m/s]

y	y	y+	U	U+	k'	u'	v'	w'	-u'v'	-u'w'	-Ruv	-Ruw	S u	F u	S v	F v	S w	F w	epsv	epsw
[mm]	ymax		Ub		u* 2	u*	u*	u*	u* 2	u* 2										
1.40	.1716	88.8	.7903	16.59	3.059	1.926	.961	1.218	.841	-.029	.454	-.013	-.069	2.942	.238	3.356	.000	3.146	.054	.000
1.50	.1839	95.1	.7987	16.77	3.030	1.917	.960	1.209	.838	-.034	.455	-.015	-.081	2.910	.234	3.337	-.001	3.148	.063	.000
1.70	.2084	107.8	.8127	17.06	2.964	1.893	.955	1.197	.822	-.028	.455	-.012	-.087	2.901	.228	3.300	.002	3.146	.075	.000
2.00	.2452	126.9	.8310	17.44	2.867	1.856	.951	1.177	.806	-.027	.457	-.013	-.113	2.887	.226	3.256	-.011	3.159	.080	.000
2.50	.3065	158.6	.8589	18.03	2.689	1.789	.934	1.142	.743	-.029	.445	-.014	-.147	2.998	.230	3.250	-.005	3.185	.085	.000
3.00	.3678	190.3	.8819	18.51	2.510	1.722	.912	1.106	.676	-.023	.431	-.012	-.188	3.109	.247	3.267	-.005	3.231	.093	.000
4.00	.4904	253.7	.9196	19.30	2.159	1.588	.855	1.032	.536	-.023	.396	-.014	-.258	3.430	.308	3.352	-.010	3.346	.096	.000
5.00	.6130	317.1	.9480	19.90	1.817	1.429	.806	.970	.393	-.022	.341	-.016	-.303	3.778	.320	3.549	-.003	3.431	.091	.000
6.00	.7356	380.6	.9699	20.36	1.531	1.293	.750	.910	.245	-.013	.253	-.012	-.278	4.178	.304	3.654	-.008	3.477	.081	.000
8.00	.9808	507.4	.9887	20.75	1.268	1.141	.699	.864	-.024	-.012	-.030	-.012	-.213	12.251	.047	3.808	.003	3.453	-.040	.000
8.16	1.0000	515.9	.9892	20.76	1.286	1.144	.709	.870	-.036	-.016	-.043	-.017	-.023	5.636	.006	3.872	.010	3.498	-.069	.000

TABLE II cont.