INDUCED TURBULENCE INTENSITY OVER AND BEYOND A ROTATING DISK

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ABSTRACT

Measurements of the turbulence intensity over and beyond a smooth disk rotating in a quiescent air are presented in this study. The apparatus consists simply of a disk rotating horizontally about its vertical axis. A hot wire anemometer, with a single sensing wire, joined to the fully transistorized DISA 55M electronic circuit is employed in the measurements of the mean velocity as well as the turbulence intensity. A stroboscope is employed to measure the disk rotational speed and an oscilloscope is used to detect the transition region over the disk surface.

The results are presented to show the profiles of the turbulence intensity in the axial direction over the whole range of the boundary layer (at various radii), starting from the disk surface (or the disk-center plane) and ending at the edge of the boundary layer. Variations of the turbulence intensity with the radial direction (at constant values of the axial distance) are also investigated. In addition, the investigation is extended to include the effect of the disk rotational speed.

INTRODUCTION

The turbulent flow is of a great importance to engineers, since it represents the most commonly kind of flow which does exist in many engineering applications. Studies of turbulence have been a topic of continuing interest to experimentalists as well as analysts for many years. The following is a brief review to a few of the puplications. Flows about a normal wall and flows abrupt two and three-dimensional expansion have been studied by [1,2]; jets were investigated by [3]; two dimensional wakes have been studied by [4]; wakes behined slender bodies have been studied by [5,6]; and axisymmetric wakes have been investigated by [7,8].

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The mean flow over a disk rotating in a stagnant fluid was investigated by [9,10], and the mean flow beyond the disk periphery was investigated by [11,12]. Because it will help to understand the results of the present work, we shall review briefly the structure of the mean flow over and beyond the disk surface. Over the disk surface, a laminar region is formed near the disk axis; at larger radii ($1.8 \cdot 10^5 \leq R_e \leq 2.8 \cdot 10^5$), there is a transition region; at even greater radii ($R_e > 2.8\ 10^5$), a fully developed turbulent region is formed. Beyond the disk periphery (the wake of the disk), two regions, connected by a trainsition one, are formed. They are the near-rim region and the far-jet region (fully developed region). The starting of the far-jet region depends on the disk rotational speed. To the writers knowledge, however, no turbulence intensity data on the disk surface or beyond it have been appeared in the literature. To fill part of this gap, it appeared important to study the turbulence intensity within the aforementioned regions of flow. Since the characteristics of the turbulent flows in general can not be predicted at the present time, a study of the type discussed herein will serve many purposes: One is to examin the characteristic natures of the turbulence intensity associated with the present kind of flow; another is to increase the store of the experimental results from which suitable laws governing these characteristics may be developed.

EXPERIMENTAL APPARATUS AND MEASURING EQUIBMENTS

The apparatus consists of a smooth wooden disk ($R = 24.35$ cm and $t = 1.3$ cm), placed in the enviroment of stagnant air, which can rotate in a horizontal plane. The disk is connected to a vertical shaft which is aligned by two ball bearings, 30 cm apart. The shaft is driven by a 2 hp motor via pullies of variable diameters and a V-belt. A stroboskope is employed to measure the disk rotational speed, N, and an oscilloscope is used to detect the transition region (which joins the laminar and turbulent regions) over the disk surface.

A thermosystem anemometer is used to determine the mean components of Velocity and the root mean square of the fluctuating velcoity (turbulence intensity). A single hot wire is emplyed in the measurements. The wire is made of platinum coated tungeston, 5 μm diameter and 1 mm sensing length. The wire is placed parallel to the disk surface and its probe normal to that surface. The probe can move independently in two perpendicular directions (radial and axial) by the aid of a traversing mechanism. The limitations of the movements of the sensing wire are 36 cm in the radial direction (starting from the disk axis) and 7 cm in the axial direction (starting from the disk surface or from the disk-center plane).

The DISA 55 M electric circuit is used to measure the mean voltage, e, and the fluctuating root mean square voltage, e'. The procedure for obtaining the mean components of velocity is presented in [10]. In the flowing, we explain how the turbulence intensity, V'/V is deduced from the output voltage signals. The correlation equation of the anemometer is assumed to be

$$E^2 - e_o^2 = BU^n \qquad (1)$$

where U is the total flow velocity acting on the probe, E is the total output voltage due to the effect of U, e_o is the voltage at stagnant conditions, B and n are constants. The value of the index n is assumed to equal to its value which was used in the calibration of the mean flow (see [10]). Taking the logarithm of equation (1) and differentiating, the following equation is obtained

$$\frac{2\,E\,.\,dE}{E^2 - e_o^2} = n\,\frac{dU}{U} \qquad (2)$$

In equation (2), dU is the difference between the total cooling velocity and its mean value, and dE is the difference between the total output voltage and its mean value. By considering dE as the root mean square of the fluctuating voltage (e'), the resulting dU represents the root mean square of the fluctuting velocity (V') (see [13]). In addition, as will be declared from the results, the magnitude of dU is small as compared to U. Thus a good approximation to the total values U and E is obtained by replacing them by their mean values V and e, respectively. Making use of the above considerations and rearranging equation (2), the following expression for the turbulence intensity V'/V is obtained

$$V'/V = \frac{2\,e.e'}{n(e^2 - e_o^2)} \qquad (3)$$

RESULTS AND DISCUSSIONS

The characteristics of the turbulence intensity over the disk surface are shown in fig.1. The figure illustrates the variation of the turbulence intensity with the nondimensional axial distance $\bar{Z}$ ($\bar{Z} = Z\sqrt{\omega/\nu}$) for different values of Reynolds number. Each profile extends from the disk surface and ends at the edge of the boundary layer. The three regions of flow are covered, and the profiles in each region can be declared according to the value of R_e which is assigned to each profile. These **Profiles** are indicated as follows (see [10]). In the laminar region, two profiles are drawn at $R_e = (1.08,\ 1.56) \cdot 10^5$. Four profiles are drawn in the transition region for values of R_e which extend from $1.837 \cdot 10^5$ to $2.57 \cdot 10^5$. Four profiles are drawn in the turbulent region for values of R_e which start at $3.06 \cdot 10^5$ and end at $3.7 \cdot 10^5$. As shown in Fig.1, the turbulence intensity in the laminar boundary layer is of small magnitudes which may be attributed to the **amplifier** noise and the turbulence level which exists in the axial inflow towards the disk surface. This value can be considred as the free turbulence level of the flow and its surroundings. The general trends of the profiles in the transition and turbulent regions are similar. They are smooth curves; starting very close to the disk surface by approximately a constant value (V'/V = 0.025); increasing by different rates (which depend on the value of R_e) until a peak value is reached; and then gradually decreasing to the free stream turbulence level at the edge of the boundary layer (notice that the boundary layer thickness increases as R_e increases). By observing the profiles at the beginning of the transition region (where $R_e = 1.837 \cdot 10^5$ and $1.92 \cdot 10^5$), one can notice that they are of some different behaviour. As seen from these profiles, the turbulence intensity increases by high rates in the region which is close to the disk surface, and attain peak values (0.08 to 0.09) which are relatively of higher magnitudes. On the other hand, at the end of the transition region, the profiles (at $R_e = 2.3 \cdot 10^5$ and $2.57 \cdot 10^5$) are very similar to those of the turbulent profiles, and the peak values range from 0.06 to 0.07. Two observations are of great importance; Firstly, inspection of Fig.1, shows that the turbulence intensity does not vanish at the edge of the boundary layer. The reason for this is due to the fact that the mean component of velocity in the axial direction does not vanish at the boundary layer edge , since there must be an inflow to compansate the radial outflow which occurs at the disk periphery. Secondly by inspecting the locations at which the peak values of the turbulence intensity occur, it was found that they are located approximately at the same position where the peak values of the mean axial component of velocity occur (see [10]). From the above two important observations, one may conclude that the turbulence intensity is a strong function of the mean axial component of velocity.

The behaviour of the turbulent intensity beyond the disk surface are shown in Figs.2 and 3, at speeds 635 rpm and 880 rpm, respectively. The profiles, in both figures, show the variation of the turbulence intensity with the axial distance, Z (measured from the disk-center plane). Each profile is drawn at a constant value of the radial distance, r. The trend of the profiles in Figs.2 and 3 are similar (with different magnitudes). Thus it is pereferable to discuss these trends in general. As shown, the minimum value of V'/V occurs at the disk-center plane. The turbulence intensity increases by different rates by moving in the traverse direction until it reaches a peak value, then it decreaces to the free stream turbulence level. One can notice that the trend of each profile depends on its radial location. The position of the peak value of the trubulence intensity is shown to move in the positive axial direction as r increases, and it is located approximately between one-third and one-half of the boundary layer thickness. An important notice may be observed at the edge of the boundary layer; at large radii, the flow looses its structural details, and hence the turbulence intensity is of higher magnitudes (as compared to the values at small radii). The effect of the disk rotational speed is obvious (by comparing fig. 2 and 3); where the turbulence intensity increaces as N increases. A final remark on Figs.2 and 3 is that they have good similarity with fig.1.

Fig.4 shows the variations of the turbulence intensity with the radial direction at constant values of Z which are close to the disk surface (In the figure, Z is measured from the disk surface). The **Profiles** are extended from the disk axis to the wake region where r = 36 cm. Thus all regions of flow are covered by such procedure. Three different speeds are presented in the figure. As shown from the figure, each profile has two peak values; the first is located at the beginning of the transition region over the disk surface (notice that the transition region moves towards the disk center as N increases); the second is located beyond the disk periphery in the near-rim region where high entrainments occur (see [12]). Moving further beyond the second peak value, the far-jet region (fully developed flow) is reached. It is clear from Fig.4 that the turbulence intensity appear to has lower values in the far-jet region as compared to its values in the near-rim region) with a decreasing trend as one moves in the radial direction. By comparing the magnitudes of the turbulence intensity in the turbulent region over the disk surface with those in the far-jet region, we notic that the later has slightly higher values. Finally Fig.4 shows that, as concluded before, the effect of the disk rotational speed is to increase the magnitude of the turbulence intensity.

CONCLUSIONS

The following important conclusions are drawn from the present experimental study.

For flow over the disk surface in the transition and turbulent regions, the profiles in the axial direction are similar. They are smooth curves with a single peak (its value ranges from 0.06 to 0.07). The turbulence intensity value of the disk furface is approximately one-third of its peak. At the beginning of transition the peaks are of higher magnitudes (range from 0.08 to 0.09) and occur close to the disk surface. The axial locations of the peaks depend on the value of R_e. The characteristics of the turbulence intensity, in the axial direction, beyond the disk periphery are similar to those over the disk surface. The locations of the peaks depend on the values of r and N. The effect of the disk rotational speed is to increase the turbulence intensity.

The behaviour of the turbulence intensity in the radial direction at constant values of Z (close to the disk surface) were investigated allover the whole flowfield. The profiles are of two peaks; the first is located at the beginning of the transition region (on the disk surface); and the second is located just beyond the disk periphery in the near-rim region. The magnitudes of the turbulence intensity in the far-jet region are of lower values than those in the near-rim region, and they are slightly higher than those in the turbulent region (over the disk surface).

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NOMENCLATURE

N	Disk rotational speed, rpm
R_e	Reynolds number $= \omega r^2/\nu$
r	radius, measured from the axis of rotation
V	$(u^2 + v^2 + w^2)^{0.5}$
$V' = \sqrt{V'^2}$	$(u'^2 + v'^2 + w'^2)^{0.5}$
u, v, w	mean velocity components in the radial, tangential, and axial directions, respectively.
u', v', w'	Fluctuating velocity components in the radial, tangential, and axial directions, respectively.
Z	axial direction
ω	$2\pi N/60$, rad/sec.
ν	Kinematic viscosity.

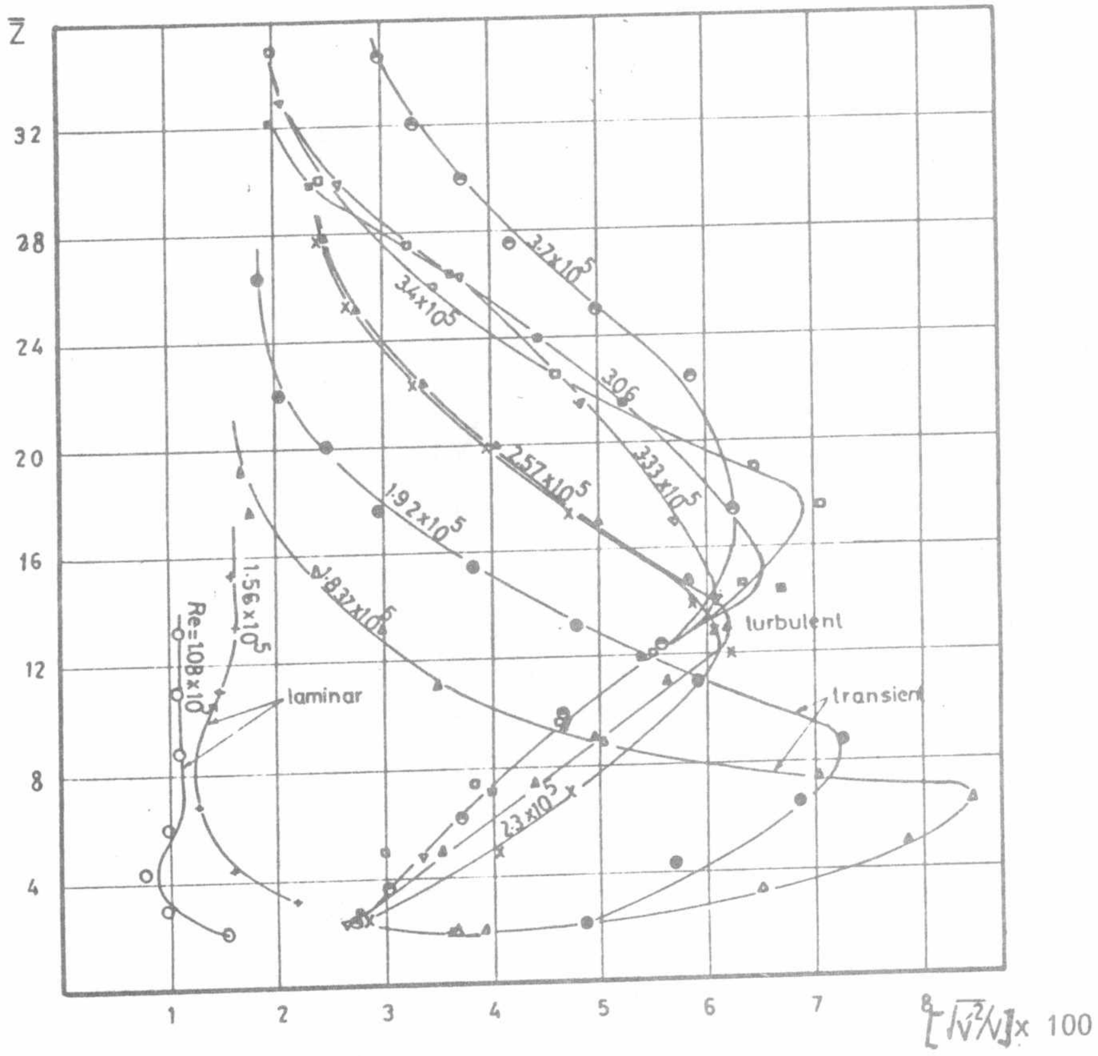

Fig.1. Variations of the turbulence intensity with the axial direction (over the disk surface).

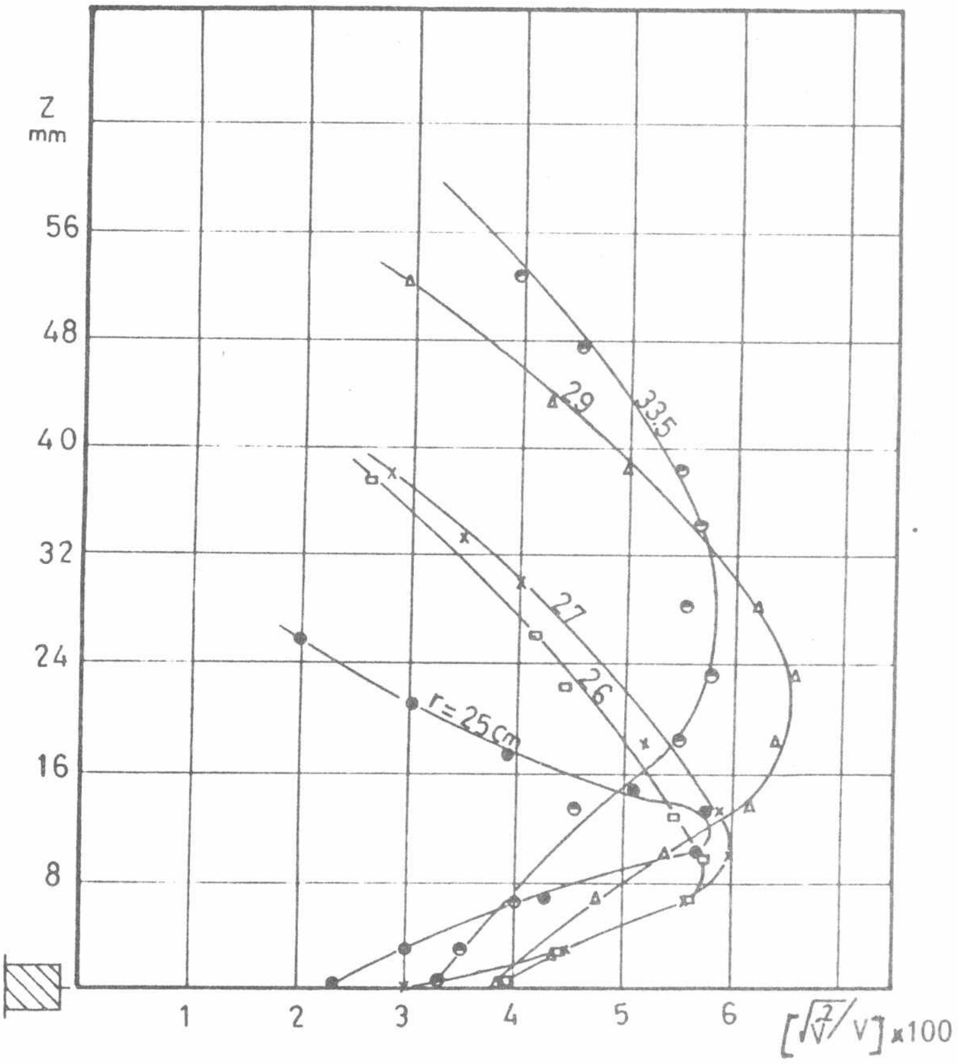

Fig.2. Variations of the trubulence intensity with the axial direction (beyond the disk periphery), N = 635 rpm.

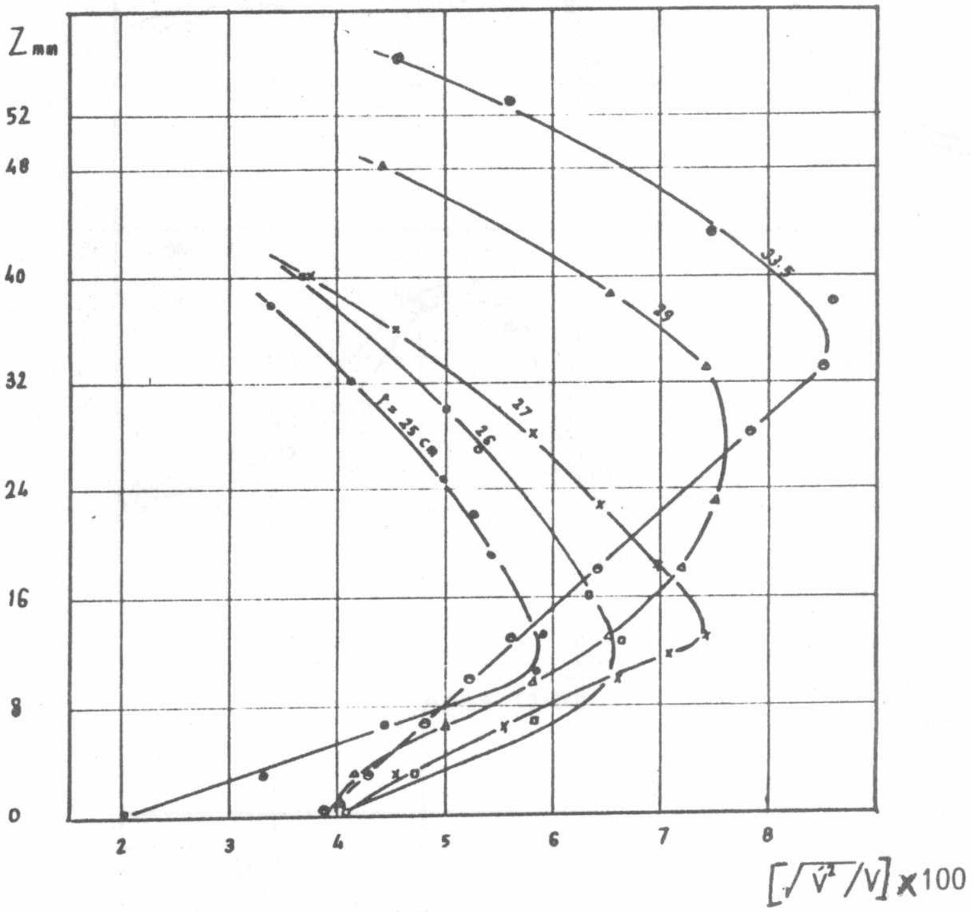

Fig.3. Variations of the trubulence intensity with the axial direction (beyond the disk periphery), N = 880 rpm.

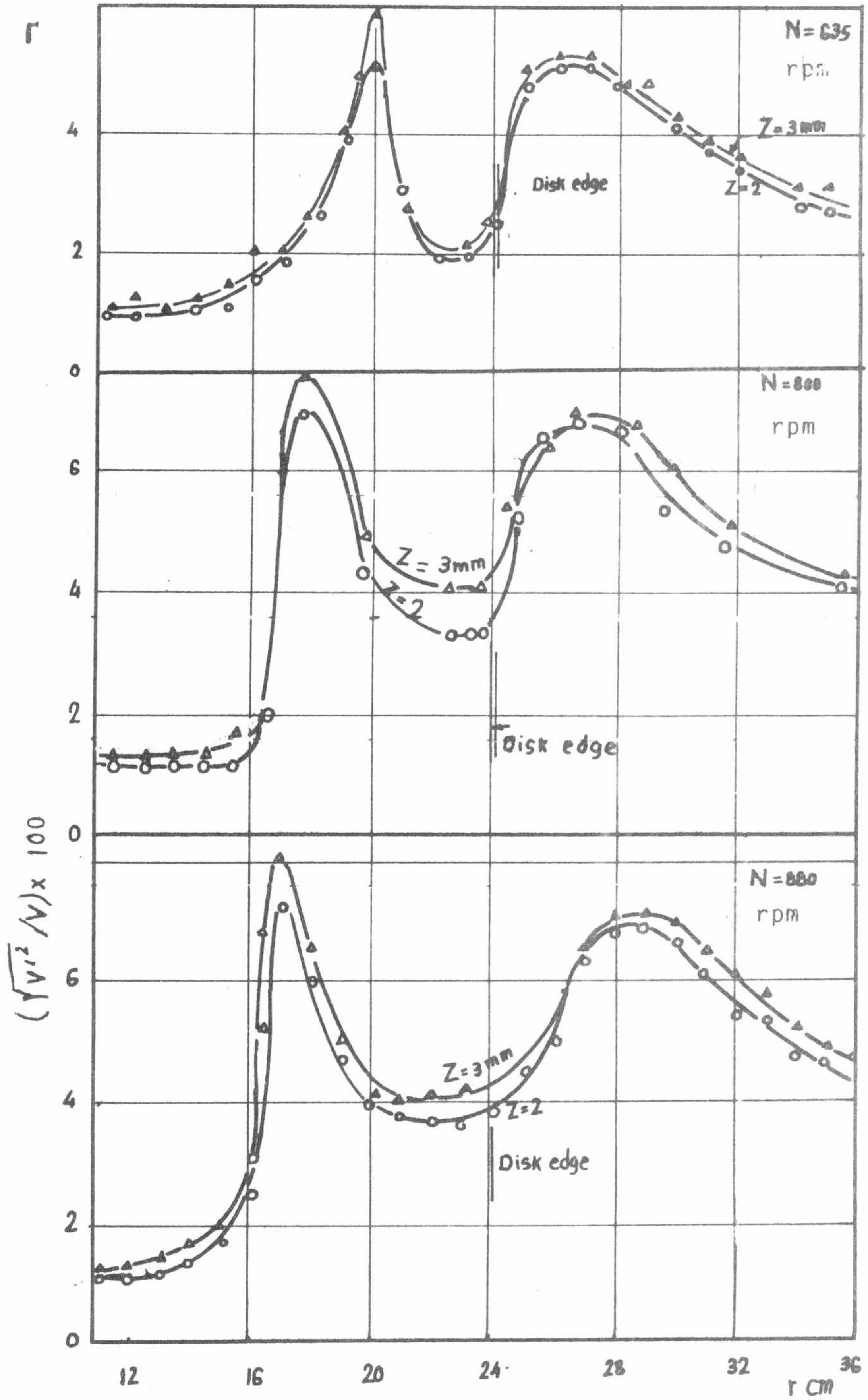

Fig.4. Variations of the turbulence intensity with the radial direction at different disk rotational speeds.