

# Effects of External Turbulence upon the Axisymmetric Wake of a Disk

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## 1 INTRODUCTION

Measurements of the plane wake behind cylinders of circular and rectangular cross-section have shown that when turbulence is present in the external flow the axial development of the wake can be significantly increased (Symes et al., 1977). Measurements in the wake of a circular disk for a very low level of turbulence in the external flow and for two grid-generated turbulent flows were carried out for axial distances of 10 to 70 disk-diameters. The grid mesh-length  $M$  and the disk diameter  $D$  are chosen to characterize the integral length scales of the external flow and the wake flow respectively. The mesh-length of the coarser grid was twice that of the finer grid and it was possible by suitable axial location of the disk downstream of the grid to obtain a nearly constant ratio of turbulence intensity of the external flow to wake flow.

## 2 EXPERIMENTAL PROCEDURE

Measurements were carried out in the closed-loop wind tunnel of the Institute for Hydromechanics at the University of Karlsruhe. Air passes from the settling chamber through a smooth 10 : 1 contraction into the octagonally-shaped test section of 8 meter length and 1.5 m internal diameter, the ceiling of which was adjusted over the length of the test-section to give zero axial pressure gradient. The turbulence intensity of the axial velocity fluctuations in the test-section away from the walls is approximately 0.06 % referred to the free-stream velocity of  $10.1 \text{ ms}^{-1}$  at which all experiments were carried out. The sharp-edged disk of diameter  $D = 75 \text{ mm}$  and thickness 3 mm was mounted at the end of a short tube of length  $7.5 D$  which was rigidly supported by tensioning two sets of axially opposed fine steel wires (diameter 0.3 mm). Miniature turnbuckles at the tunnel-wall end of the supporting wire were used to position the disk-tube combination. The upstream end of the tube was disconnected from the air supply used in the jet-wake experiments and was sealed-off with a streamlined nose-piece (Figure 1).

Quadratic mesh-grids of round woven steel wire positioned at the beginning of the test-section were used to make the wind tunnel flow turbulent. The disk was located at an axial separation of 38 mesh-lengths from the finer turbulence grid ① and 59 mesh-lengths from the coarser turbulence grid ③. Both these axial positions correspond to a turbulence intensity of the axial velocity fluctuations referred to the free stream velocity of 1.8 %. The characteristics of the two grid flows chosen for this in-

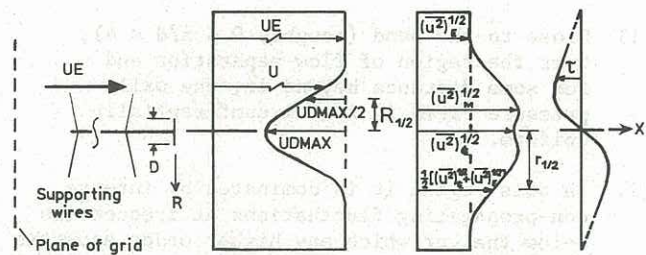


Figure 1 Flow configuration

vestigation together with the pressure coefficient  $C_p$  and the blockage ratio  $\sigma$  of each grid are given in Figure 2. Homogeneity of the mean velocity field, defined as variation over the cross-section of less than 1.5 % of the mean free-stream velocity was achieved within 35 and 55 mesh-lengths, respectively.

By radially displacing the four downstream supporting wires by approximately  $12^\circ$  from the upstream wires a significant improvement in the axial symmetry of the wake was achieved. The wakes of the supporting wires were nevertheless very apparent in the mean velocity profile approaching the disk and in the author's opinion are mainly responsible for the inability to achieve a perfectly axially symmetric wake downstream of the disk. The thickness of the boundary layer,  $\delta_{99}$ , along the supporting pipe (outside diameter 0.21  $D$ ) amounts to 0.16  $D$  measured at the downstream end in the absence of the disk.

Mean velocities were measured using a total-head tube of 2 mm outside diameter connected to an MKS Baratron Type 144 Pressure Meter and axial velocity fluctuations were measured using a DISA 55 P 01 hot wire probe connected to the DISA 55 M 01 constant temperature hot-wire anemometer. Measurement traverses extended one full wake-width into the undisturbed external flow and were taken in horizontal and vertical planes through the dynamically-determined axis of symmetry. The instantaneous velocity signal was linearised with a TSI Model 1072 Signal Linearizer and processed on-line by an Hewlett-Packard 5450 A Fourier Analyzer. The integral length scale  $L_{11,1}$  of the fluctuating  $u$ -velocity component in the  $X$ -direction was computed from the one-dimensional wave number spectrum  $E_{11}(k_1)$  which was obtained from the time spectrum  $F_{11}(f)$  assuming that away from the immediate vicinity of the body ( $D \geq 50$ ) Taylor's hypothesis of "frozen-turbulence" is valid.



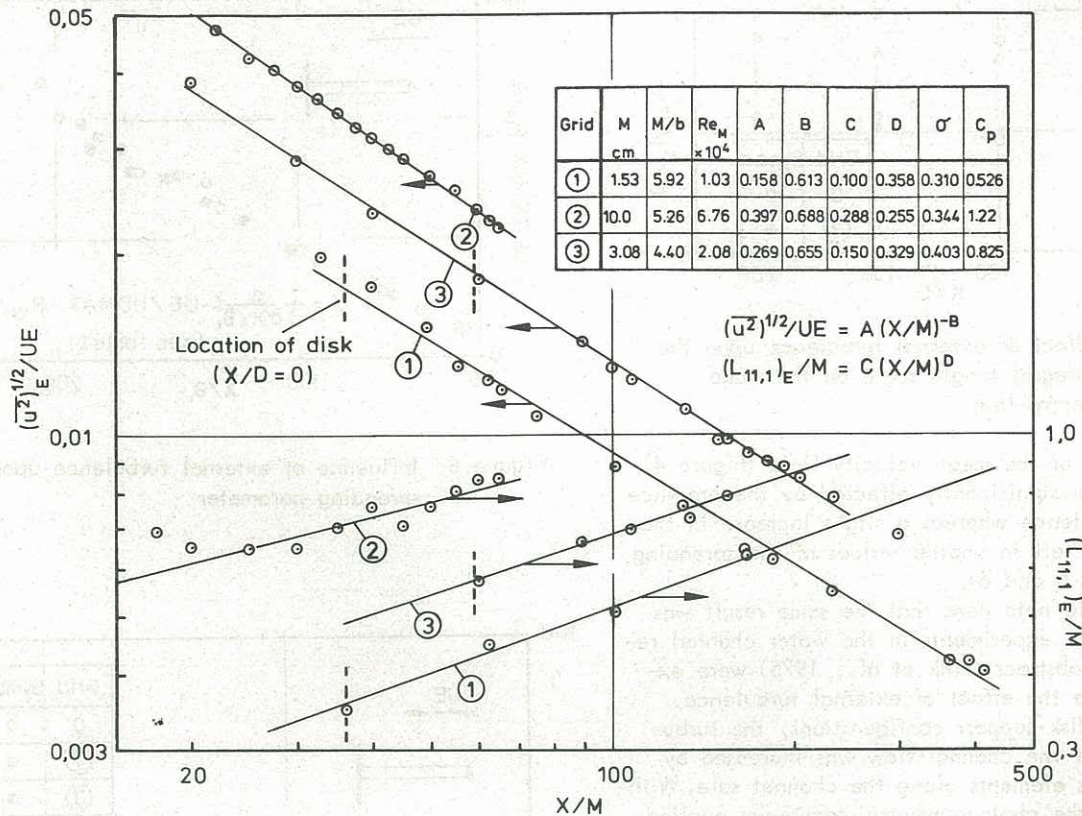


Figure 2 Axial development of turbulence intensity and integral length scale of the external flows

$$(L_{11,1})_E / D = \pi / 2 \cdot E_{11}(k_1=0) / (\overline{u^2})_E$$

The length and velocity scales of the mean velocity field  $R_{1/2}$  and  $UD_{MAX}$  are defined in Figure 1 as are the length and velocity scales of the turbulence quantities  $r_{1/2}$  and  $(\overline{u^2})_E^{1/2}$ .

The spreading parameter  $S$  as defined by Townsend was evaluated from the data

$$S = \frac{1}{3} \frac{d}{dX/\theta_1} (-UE / UD_{MAX} \cdot R_{1/2} / \theta_1)$$

where  $\theta_1$  is the wake momentum thickness which was calculated by integrating the momentum equation over the flow cross-section.

### 3 RESULTS

The presence of the supporting wires and the boundary layer of the horizontal tube significantly influences the mean velocity profile approaching the disk and a direct comparison with existing measurements is therefore difficult. The measurements for the case of low external turbulence show however reasonable agreement with those of Carmody (1964) and Ermshaus (1970), (Figures 6 and 7). The overall consistency of the measurements was checked by computing the wake momentum thickness  $\theta_1$  from the horizontal mean-velocity traverse at each downstream location (Table I).

TABLE I

MEAN VALUES OF WAKE MOMENTUM THICKNESS, DRAG COEFFICIENT AND SPREADING PARAMETER

Grid	X/D	$\theta_1 / D$	$C_D$	$S$
no grid	10-70	-0.300	0.72	0.82
①	10-70	-0.289	0.67	0.76
③	10-60	-0.324	0.84	0.67

On the centre-line of the wake the velocity scale of the turbulence field  $(\overline{u^2})_E^{1/2}$  is for  $X/D \geq 20$  approximately 5 times greater than that of either of the external turbulence fields chosen for this investigation. The ratios of the integral length scales of the wake with and without external turbulence to that of the external turbulence ③ are shown in Figure 3. From this figure it can be seen that the integral length scale of turbulence in the wake is approximately twice that of the external turbulence ③ and the presence of external turbulence has had no measurable influence upon the length scale of turbulence in the wake.



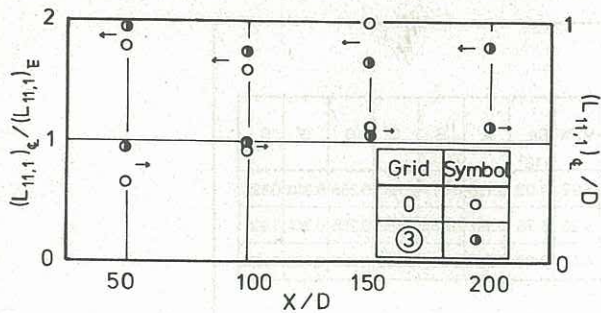


Figure 3 Effect of external turbulence upon the integral length scale on the wake centre-line

The length scale of the mean velocity field (Figure 4) also has not been significantly effected by the presence of external turbulence whereas a slight increase in the velocity scale is felt in smaller values of the spreading parameter (Figures 5 and 6).

It is interesting to note here that the same result was obtained when the experiments in the water channel referred to in the abstract (Fink et al., 1975) were extended to include the effect of external turbulence. Using the same disk-support configurations, the turbulence intensity of the channel flow was increased by placing roughness elements along the channel sole. Within the limits of the photogrammetric technique applied, increasing the surface roughness produced no change in the length scale of the mean velocity field downstream of the disk-jet origin.

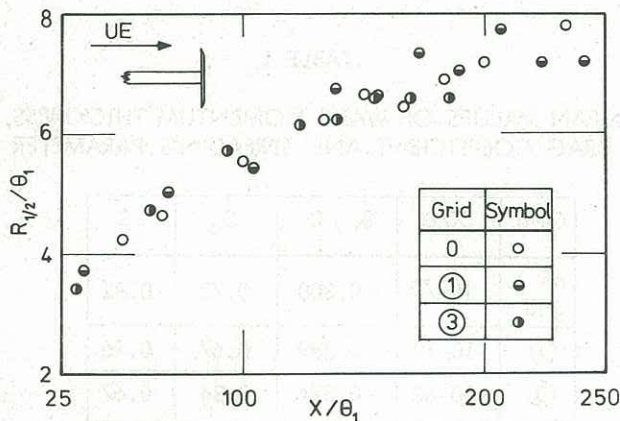


Figure 4 Influence of external turbulence upon the wake half-width

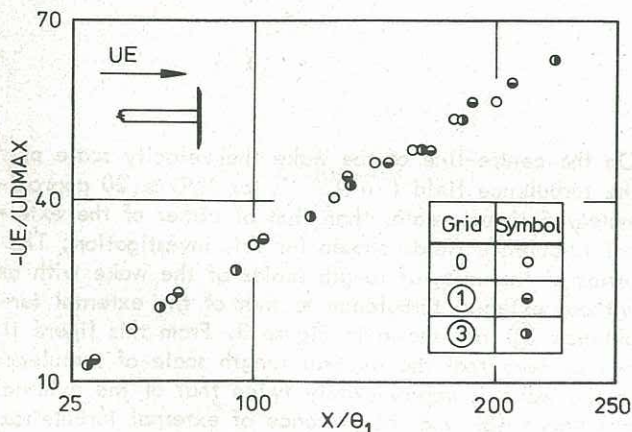


Figure 5 Effect of external turbulence upon the velocity scale

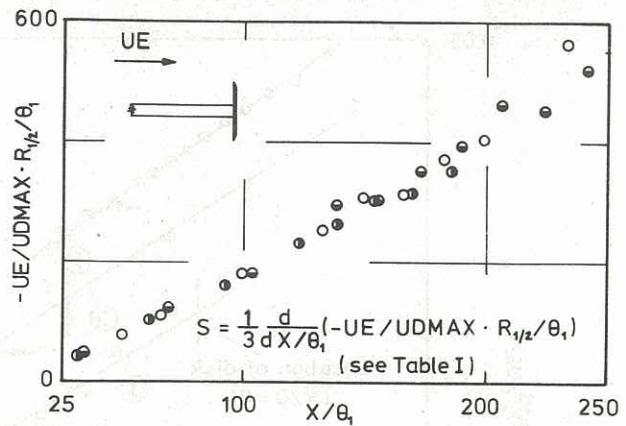


Figure 6 Influence of external turbulence upon the spreading parameter

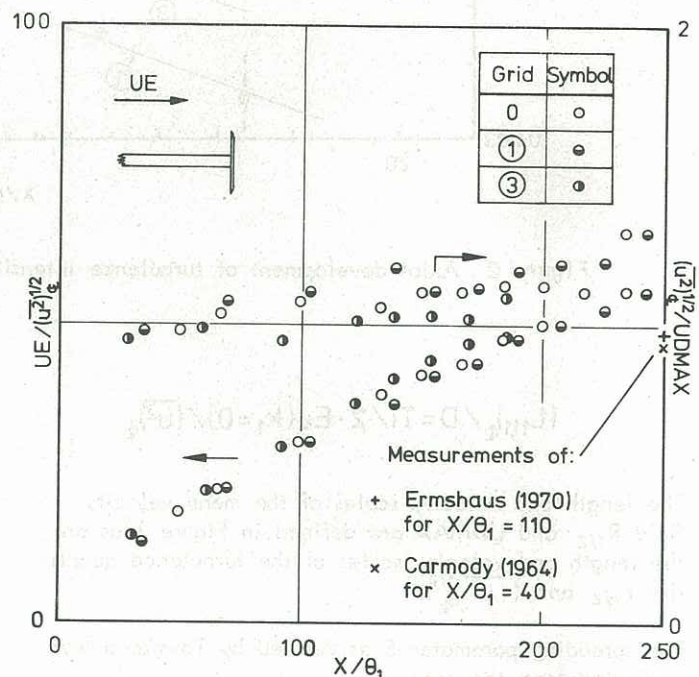


Figure 7 Influence of external turbulence upon the axial normal stress parameter (axisymmetric wake)

The ratio of the axial normal stresses to the mean defect-velocity on the wake axis is shown in Figure 7. The increase in the ratio with increasing downstream distance for all three external flows implies that a moving equilibrium, defined by Townsend (1976) as a state characterized by a constant ratio between turbulence and mean velocity scales is not attained close to the disk, although a constant value with increasing downstream coordinate may be asymptotically approached.

This result contrasts with the measurements carried out in the plane wake of a circular cylinder where a moving equilibrium condition is obtained, however, the presence of external turbulence of sufficiently large length scale leads to higher values in the equilibrium ratio (Figure 8). A twofold increase in the equilibrium ratio was achieved in the latter study using a one-plane wooden grid, the characteristics of which are presented as grid ② for



completeness in Figure 2. The inability to achieve an acceptably homogeneous mean velocity field within 45 mesh-lengths over a  $6 \times 6$  mesh-area precluded its use in the present experiment.

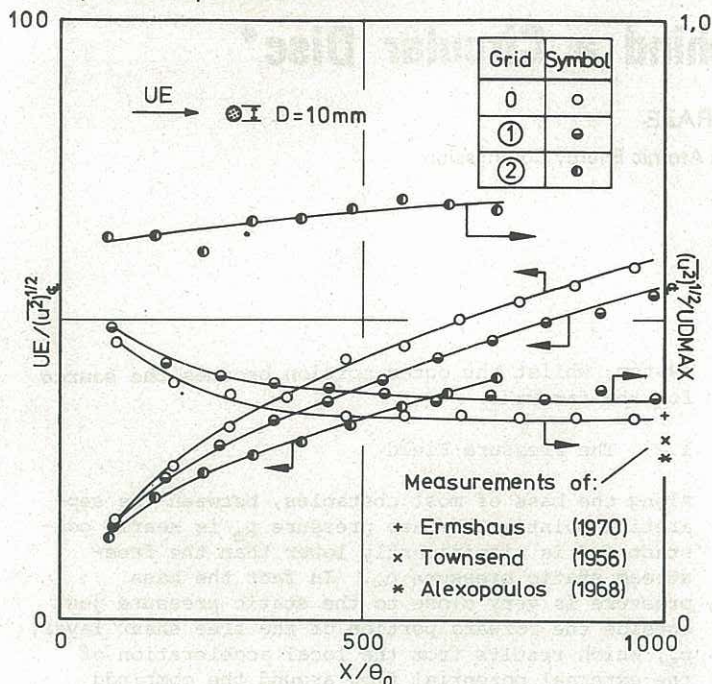


Figure 8 Influence of external turbulence upon the axial normal stress parameter (plane wake)

#### 4 CONCLUSIONS

The preliminary results of this experimental investigation concerning the influence of turbulence in the ambient flow upon the axially symmetric wake of a disk lead to the following conclusions.

For a constant ratio of turbulence velocity scale of the external turbulence to that of the wake no enhancement of the wake mean flow scales is observed when external turbulence is present.

An increase in the length scale of the external turbulence by a factor of approximately 3 giving an external turbulence to wake length scale ratio of  $1/2$  had no significant effect upon wake development.

As for the case of extremely low external turbulence a state of moving equilibrium may also be asymptotically approached when a relatively small-scale external turbulence is present.

#### 5 REFERENCES

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