Arch. Mech., 32, 5, pp. 633-643, Warszawa 1980

Turbulence management by means of grids(*)

A. CENEDESE, S. IANNETTA, P. MELE and M. MORGANTI (ROME)(1)

THE USE of devices such as grids, screens, perforated plates, honeycombs, labyrinths, etc. is generally adopted in all cases, in which the modification of the turbulence conditions is required. The device behaves at the same time as a generator and as a damper of turbulence; following Nagib, it may be considered as an operator which modifies the input turbulence $(u_1')_{in}$, $(u_2')_{in}$, $(u_3')_{in}$ in an output turbulence $(u_1')_{out}$, $(u_2')_{out}$, $(u_3')_{out}$. With this approach the input turbulence must be compared to the output turbulence not only in terms of $\overline{u'^2}$, but also in terms of the power density spectra. While a large number of papers concerns the turbulence behind grids, very few consider the modification of the turbulence spectra induced by these devices generally used. The present experimental work analyses the behaviour of the turbulence flow through a grid. The investigation is mainly devoted to the study of mechanisms of dissipation and turbulence transfer between different scales. The measurements have been performed by means of a laser anemometer system.

Dla modyfikacji warunków turbulencji stosuje się ogólnie takie urządzenia, jak siatki, ekrany, płyty perforowane, plastry pszczele, labirynty itp. Urządzenia te zachowują się zarazem jako generatory i tłumiki turbulencji; za Nagibem można je traktować jako operatory przekształcające turbulencję na wejściu $(u_1')_{in}$, $(u_2')_{in}$, $(u_3')_{in}$, w turbulencję na wyjściu $(u_1')_{out}$, $(u_2')_{out}$, $(u_3')_{out}$. Zgodnie z tym podejściem turbulencję wejściową należy porównywać z wyjściową nie tylko poprzez $\overline{u'^2}$, ale również przez widma gęstości mocy. Wiele prac zajmuje się turbulencją za siatkami, jednak tylko w nielicznych przypadkach rozpatruje się modyfikację widm turbulencji wprowadzoną za pomocą takich urządzeń. W niniejszej pracy doświadczalnej analizuje się przepływ burzliwy przez siatkę. Zajęto się w głównej mierze studiami nad mechanizmem dysypacji i przepływu turbulencji; pomiarów dokonano za pomocą anemometru laserowego.

Для модификации условий турбулентности применяются такие устройства, как сетки, экраны, перфорированнык плиты, пчелиные соты, лабиринты и т. п. Эти устройства являются так генераторами, как и демпферами турбулентности; согласно Нагибу можно их трактовать как операторы преобразующие турбулентность на входе $(u_1')_{in}$, $(u_2')_{in}$ $(u_3')_{in}$, в турбунентность на выходе $(u_1')_{out}$, $(u_2')_{out}$, $(u_3')_{out}$. Согласно с этим подходом входную турбулентность следует сравнивать с выходой не только через $\overline{u'^2}$, но тоже через спектры плотности мощности. Много работ занимается турбулентностью за сетками, однако только в немногих случаях рассматривается модификация спектров турбулентности, введенной при помощи этих устройств. В настоящей экспериментальной работе анализируется турбулентное течение через сетку. В главной мере занимаются исследованиями механизма диссипации и течения турбулентности; измерения проведены при помощи лазерного анемометра.

1. Introduction

THE USE of grids, screens, perforated plates, honeycombs, labyrinths, etc. is generally adopted in all the cases in which the modification of the turbulence conditions is required. These devices are often used as turbulence dampers. In fact they are frequently applied on the laboratory hydraulic circuits or in the wind tunnel, in order to reduce the turbu-

---

(*) Supported by C.N.R.

(1) At the request of the Authors it is noted that their names are listed in alphabetical order.

lence level. In other cases they are used as turbulence generators, i.e. in the labyrinth seals or in experimental studies on isotropic turbulence.

As a matter of fact the device can behave both as a generator and as a damper of turbulence.

The turbulence production process may be caused by instability of the turbulent shear flow or wakes generated by the device or by the boundary layer near the device. The damping process may be caused by the limitation on the transverse components of the velocity due to the presence of the rigid walls of the device. Consequently, the energy is transferred to smaller scales of motion where it is dissipated by the viscosity.

There are many experimental and theoretical studies dealing with the turbulence generated by grids (see the bibliography of HINZE [1] and of CORRSIN [2] and the classical texts of BATCHELOR [3] and of TOWNSEND [4]). In the case of grid-generated turbulence, downstream of the grid, several time intervals along the longitudinal coordinate can be distinguished. Generally up to about 20 M from the grid (where M is the mesh dimension), the intensity of turbulence increases, more or less rapidly depending on the position with respect to the rods of the grid. After that the decay of the grid-generated turbulence can be divided into three time intervals: the initial interval, the transition interval and the final interval. In the initial interval, up to $100 \div 150$ M, the drain energy from the energy-containing eddies to the small eddies in the high wave number dissipative range occurs by means of inertial interactions. In the final period, for x/M greater than about 500, the viscous effects dominate the whole wave number range.

All the theoretical studies assume that the turbulence is isotropic and homogeneous. With these assumptions it can be found that the decay law is a power law

$$\bar{u}'^2 = ct^{-n},$$

where $n = 1$ for the initial period and $n = 5/2$ for the final period.

Furthermore for the final period the energy spectrum is

$$E(k, t) = Ck^4 e^{-2\nu k^2 t},$$

where k is the wave number, ν is the kinematic viscosity and t is the time. The assumption of self-preservation in the regions of the equilibrium range and of the energy-containing eddy range can be made, but self-preservation can not be obtained in the low wave number range.

Several theoretical formulae for the reduction factors of the spatial variations of the mean velocity and for the turbulence reduction factors can be found in the literature [5, 6, 7, 8].

Experimental results [7, 8, 9, 2, 10] show poor agreement between theory and experiment. As a matter of fact Hinze remarks that "one has to be very cautious when results of measurements in grid-generated turbulence are to be compared with theories derived from homogeneous isotropic turbulence". At this point the question arises whether the theoretical information derived from the isotropic and homogeneous turbulence are sufficient to use or to design these devices as turbulence manipulators.

It is noteworthy that, as pointed out by LOHERKE and NAGIB [11], the theory does not take into account the mechanism of generation of new turbulence by the grid. Furthermore TSUJ [12, 13] showed that the turbulence downstream of a grid depends on the upstream turbulence level and ROMICKI [14] showed that it depends on the gradient decay as well. Furthermore if the grid-generated turbulence is used in hydraulic channels or wind tunnels, the influence of the circuit walls cannot be neglected after a certain distance downstream of the grid.

For these reasons the NAGIB'S scheme [11, 15, 16] is adopted here and the device is considered as an operator which modifies the input turbulence in an output turbulence. Using this approach the input turbulence must be compared to the output, not only in global terms of u'^2, but also in terms of power density spectra. In a previous [17] experimental study the behaviour of the turbulence through grids in a uniform turbulent flow channel for one Reynolds number and three mesh dimensions was analysed. In the present study the investigation is mainly devoted to the analysis of the modification of the downstream spectrum of the turbulent velocities with respect to the upstream spectrum for several Reynolds numbers and for a greater range of mesh size.

2. Experimental apparatus

The experimental apparatus consists of a closed circuit hydraulic channel (Fig. 1). Water flows into the measuring channel from a feed tank equipped with a honeycomb and a convergent convector. The level of the feed tank can be suitably varied in order to obtain different Reynolds numbers.

The channel has a square cross-section with a 10 cm side D. In the test zone the channel walls are made of plexiglass. The first section of the test zone is about thirty D from the channel inlet. Preliminary measurements taken at various sections before the measurement zone showed that differences in velocity and in the root mean square of u' were negligible.

The velocity values were obtained by a laser Doppler anemometer installed on a platform which could be easily moved in all directions. The measurements were carried out by a backscattering procedure. The system was equipped with a frequency shifter, a Brag cell, in order to increase the sensitivity and thus to be able to measure very low velocities.

The spectral distributions functions of the turbulent velocity horizontal component $u'(t)$ were determined by means of a spectrum analyser, which uses the Fast Fourier Transform. Different time windows were used for a better resolution at low frequencies. A spectrum which is obtained as the average of 2560 spectra is used in the analysis.

3. Results

The measurements were carried out for three Reynolds numbers of the channel (8,000–16,000 and 24,000) and for four grids with square meshes the dimensions of which were: $M = 1$ mm, 2 mm, 4 mm and 12 mm.

Previously [17], the mean velocity horizontal components U and the R.M.S. $\sqrt{\overline{u'^2}}$ at the different sections were measured. Figure 2 shows the diagrams of the values obtained for $M = 2$ mm and Re = 24,000. Immediately downstream of the grid the flow

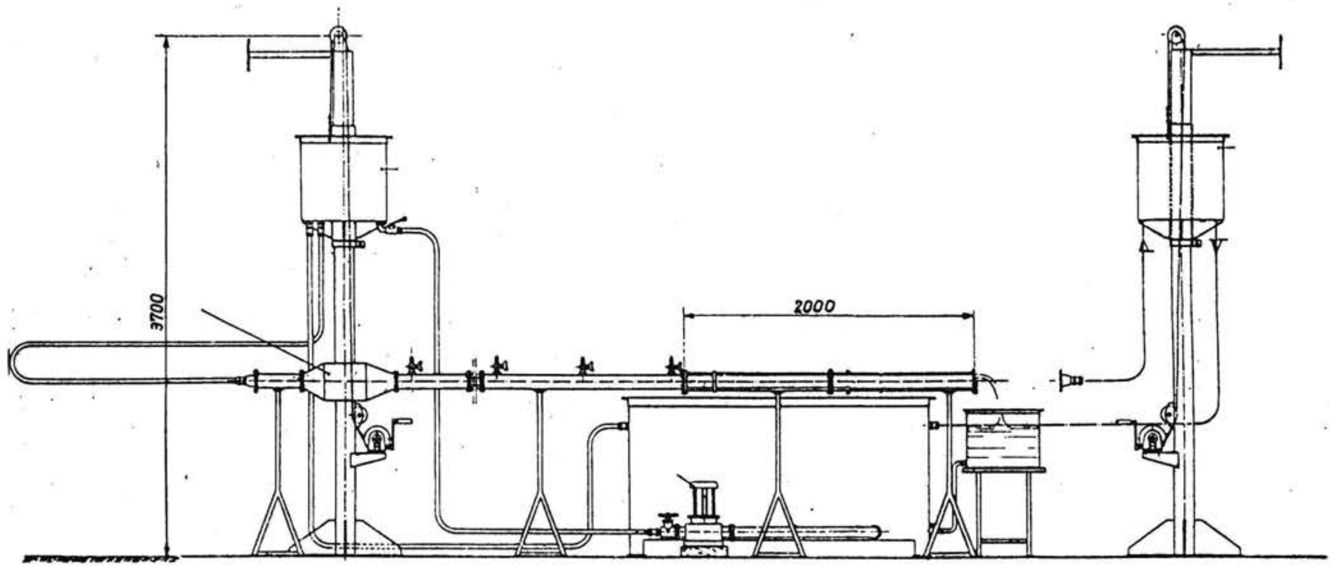

FIG. 1. Experimental apparatus.

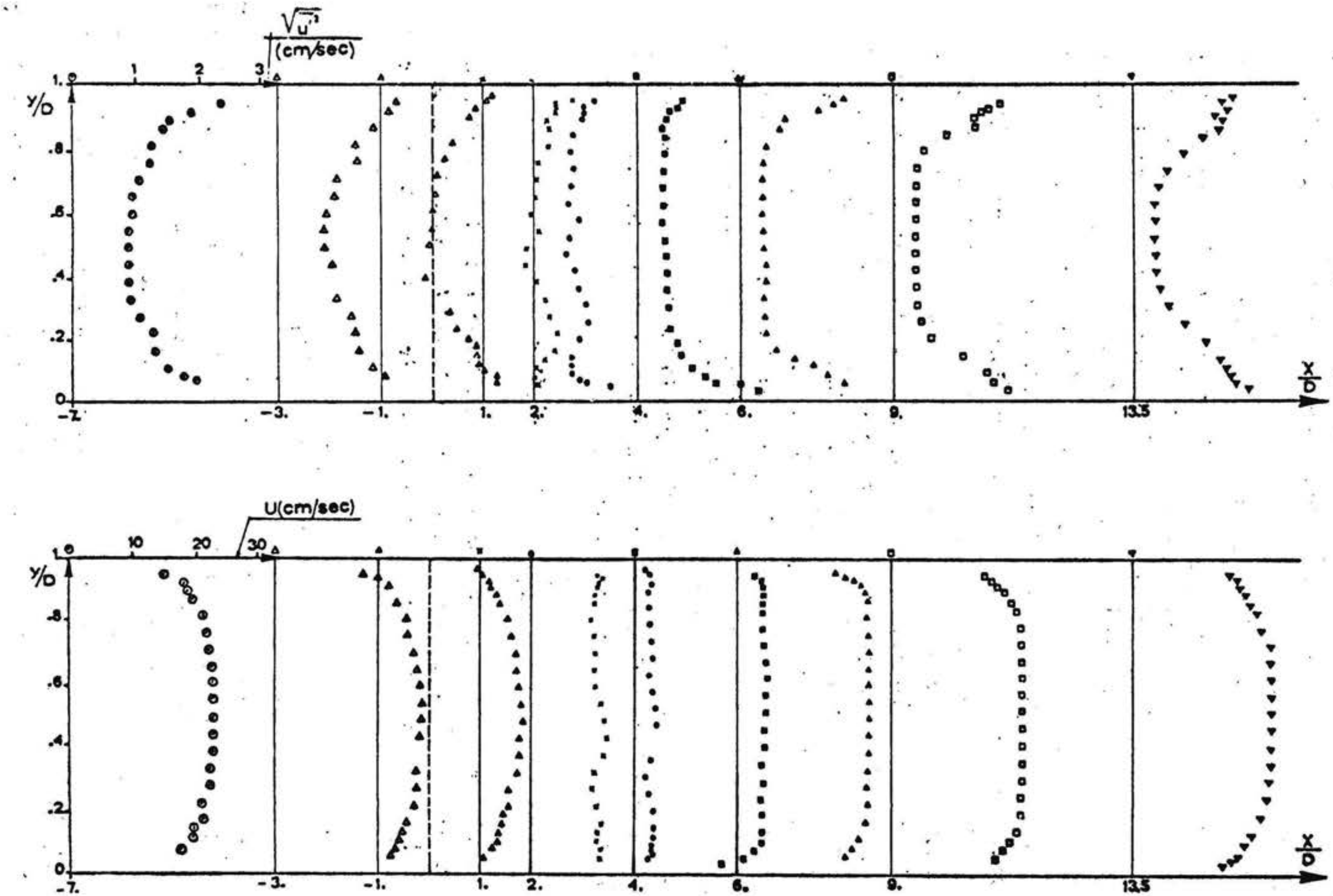

FIG. 2. Mean velocity and R.M.S. velocity profiles, V and $\sqrt{\overline{u'^2}}$ along the longitudial coordinate of the test zone.

is very chaotic with frequent and irregular peaks of U and $\overline{u'^2}$. In this zone the energy is extracted from the mean flow, and converted into turbulent energy with large diffusion and dissipation due to viscosity.

The values of U and $\sqrt{\overline{u'^2}}$ are not here reported because they are not meaningful. At a distance from the grid $x/D = 1$, for all the considered grids, the flow appears more homogeneous. The diagrams show a very large central zone not affected by the presence of the walls and a very small lateral zone (about 0.05 D) affected by the walls.

At a distance $x/D = 4$ the diagram of U and $\sqrt{\overline{u'^2}}$ are nearly flat in the central zone. For all the considered cases the ratio between the R.M.S. of u' $(\sqrt{\overline{u'^2}})$ in this zone and the R.M.S. of u' $(\sqrt{\overline{u_0'^2}})$ upstream of the grid falls between 0.4 and 0.6. The width of the lateral layer affected by the walls increases in the downstream direction. At a distance $x/D = 13.5$, the last available test section, the central zone with flat diagrams of velocity still occupies half a width of the channel.

In the zone with flat diagrams of velocity the viscous dissipation of energy related to the mean values is negligible. So are the production of turbulent energy, extracted from the main flow, and the diffusion. That is, in this zone prevails a quasi-equilibrium condition, in which also the values of $\sqrt{\overline{u'^2}}$ do not show any variations.

For the four grids and for the three Reynolds numbers, the frequency spectra of the axial horizontal velocity in the four positions, upstream of the grid, downstream of the grid at a distance $x/D = 0.18$, $x/D = 0.4$ and $x/D = 4$ were obtained.

Each spectrum has been normalized with respect to the downstream spectrum $E_0(\omega)$, in order to be able to analyse how the grid modifies the spectral distribution. The ratio $E(\omega)/E_0(\omega)$ is assumed to be specified by

$$\frac{E}{E_0} \sim \omega, x, U_0, M, D, \nu,$$

where ω is the frequency, x is the representative coordinate of the distance from the grid, U_0 is the velocity of the mean flow before the grid, M and D are the dimensions of the mesh and the channel and ν is the kinematic viscosity. In dimensionally-homogeneous form

$$\frac{E}{E_0} = f\left(\frac{\omega D}{U_0}, \frac{x}{D}, \frac{M}{D}, \mathrm{Re}\right).$$

Figures 3a, b, c, d show the values of the ratio E/E_0 for all the tested values of Re and M/D parameters except for the case $M = 12$ mm and $x/D = 0.18$. This case corresponds to a measurement point that is only 1.5 times the dimension of the mesh from the grid. In this zone small displacement of the measurement point from the axis gives very different values of turbulence.

The grid with $M = 12$ mm was considered for the following reason. In the previous study [17] measurements were carried out for $M = 1$ mm, 2 mm, 4 mm at the same Reynolds number. Those experimental results as well as the present ones showed an amplification of the spectral contributions immediately downstream of the grid for frequencies $\omega M/U$ less than 1. Moreover, the previous study showed that the amplifications were

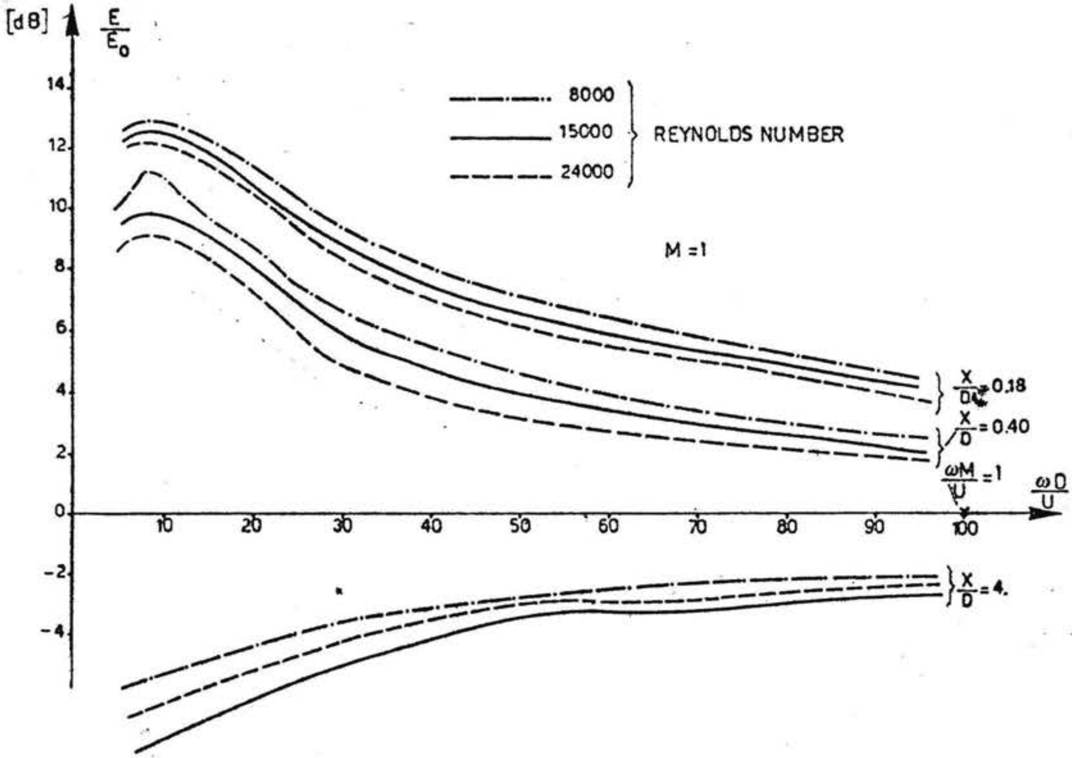

FIG. 3a. Velocity frequency spectrum $E(\omega)$ referred to the undisturbed spectrum $E_0(\omega)$ at different X/D for $M = 1$.

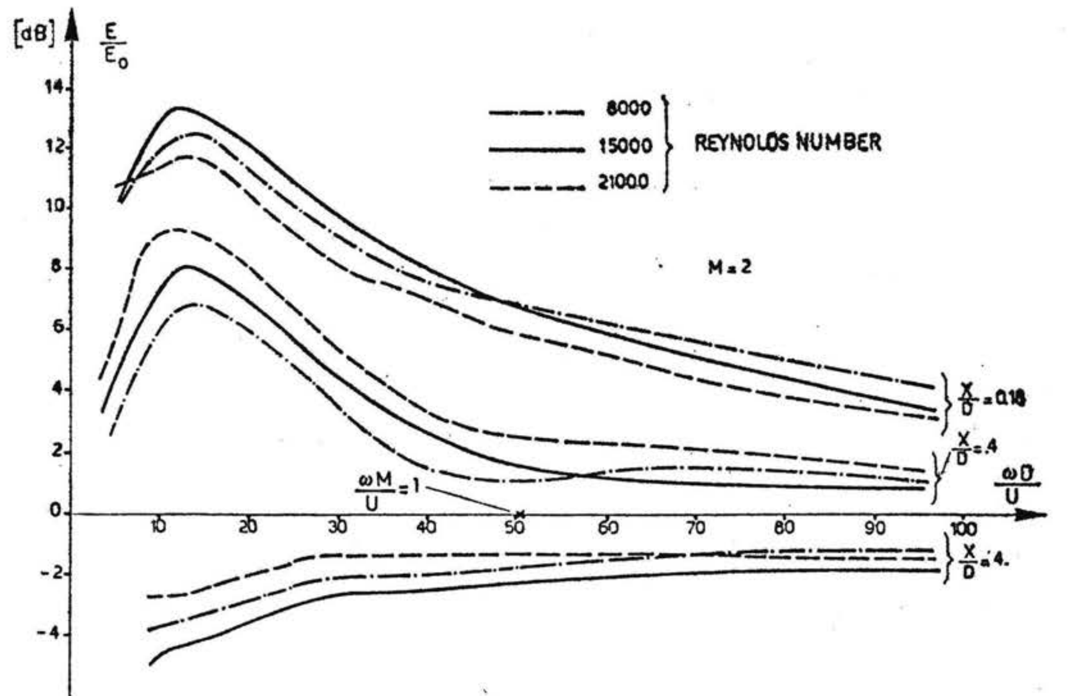

FIG. 3b. Velocity frequency spectrum $E(\omega)$ referred to the undisturbed spectrum $E_0(\omega)$ at different X/D for $M=2$.

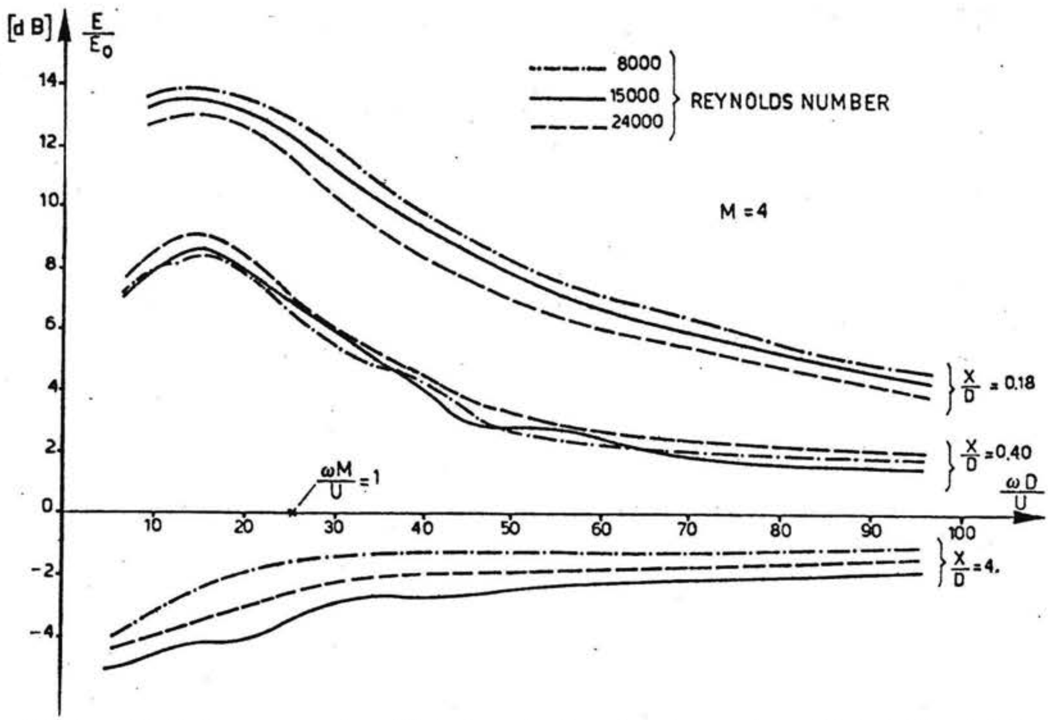

FIG. 3c. Velocity frequency spectrum $E(\omega)$ referred to the undisturbed spectrum $E_0(\omega)$ at different X/D for $M = 4$.

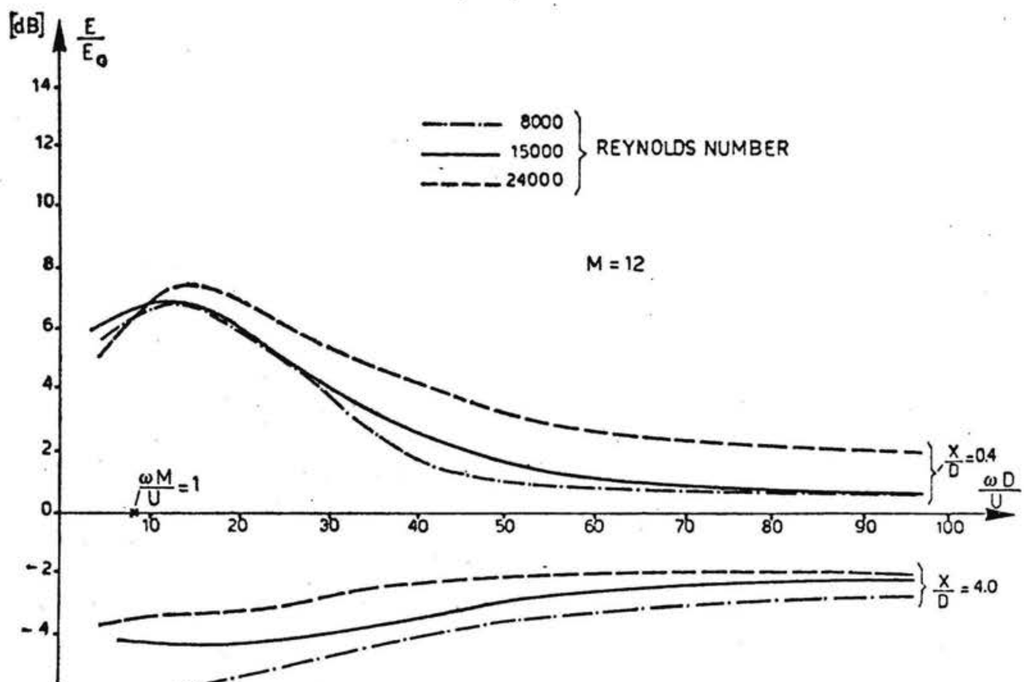

FIG. 3d. Velocity frequency spectrum $E(\omega)$ referred to the undisturbed spectrum $E_0(\omega)$ at different X/D for $M = 12$.

very small for frequencies $\omega M/U$ greater than 1. In this study a greater dimension of the mesh was also considered in order to see if this condition is general or limited to small M dimensions.

For all the considered grids and Reynolds numbers the diagrams of the ratio E/E_0 are similar. Immediately downstream, at point $x/D = 0.18$, the grid produces an amplification of the turbulent energy with a maximum falling at a frequency $\omega D/U_0$ between 10 and 20. It is noteworthy that for $M = 12$ mm the value $\omega M/U = 1$ shown on the abscissa axis is positioned in the high amplification zone. The amplification decreases for low frequencies; for $\omega D/U_0 < 1$ no contributions of the power density spectrum are to be expected.

Moving downstream of the grid the turbulent energy decreases and the amplifications of the spectral contributions with respect to the undisturbed values rapidly decrease, maintaining a similar shape (with a maximum falling between $\omega D/U_0 = 10 \div 20$); this zone corresponds to that of very large dishomo geneity of U and $\sqrt{\overline{u'^2}}$.

In the flat velocity diagram zone, $x/D = 4.0$, there are no appreciable variations of the spectra moving toward the x-direction. The spectral contributions in this zone are damped with respect to the undisturbed values (upstream of the grid). The damping value decreases as the frequency rises.

At high frequencies the spectral contributions are neither amplified nor damped, that is, the spectra for those frequencies are self-preserving and are not affected by the presence of the grid.

For the considered values, the ratio E/E_0 do not seem to be greatly affected by the parameters M/D and Re.

In fact, their effects might be included in the experimental errors.

4. Conclusions

The function of the grid is to extract energy from the mean flow and convert it into turbulence energy in a range of low frequencies, that is, in the large-scale motion. This range, which is not very extensive, can be called the energy extraction range.

The characteristic wave numbers for this range should be the dimensions of the channel and of the mesh. The dimension of the channel determines the lowest wave numbers of this range. No amplification for $\omega D/U < 1$ may be expected (Fig. 4).

The large-scale motions are unstable and break into smaller scale motions which obtain energy from them. As the energy is transferred to smaller and smaller scales, the motions become less dependent on the structure of the largest scales. At the smaller scales of motion only the rate of the energy dissipation is to be considered; consequently, the turbulent structure does not depend upon the nature of the large-scale motion.

From ε, the rate of the energy dissipation and ν, the kinematic viscosity, the time scale $\tau = (\nu/\varepsilon)^{\frac{1}{2}}$ can be formed. In the tested zones the energy losses due to the grid are almost independent of the dimension M, while they depend on the square of the main flow velocity $\varepsilon \simeq k\nu U^2$. This may explain why the normalized energy spectrum remains similar with respect to $\omega D/U$ and not with respect to $\omega M/U$.

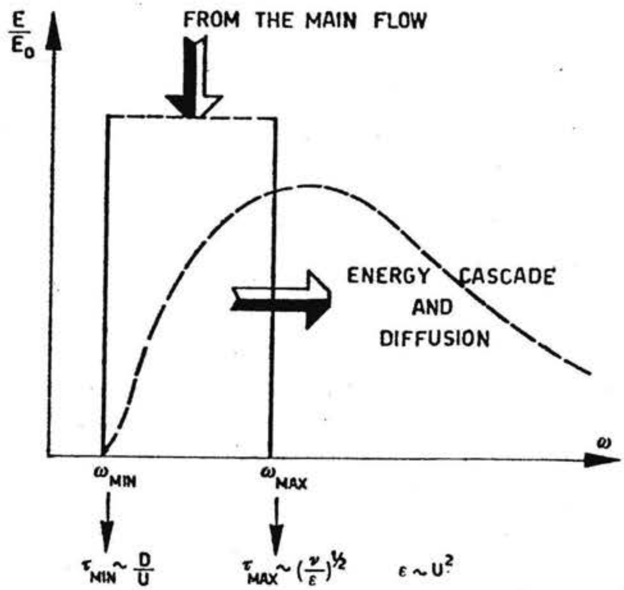

FIG. 4. Simplified behaviour scheme.

With increasing distance from the grid, the amplification decreases. That is, the increase of turbulent energy due to the grid is dissipated without the possibility of being re-integrated. This process occurs until the zone of the flat velocity diagrams is reached. In this zone turbulent energy is neither produced nor dissipated and the spectra remain almost unvaried with the changing x-coordinates.

The authors thank Mr. G. Tei (Hydraulics Institute, Rome) who cooperated in the experimental apparatus installation.

References

1. J. D. HINZE, *Turbulence*, McGraw-Hill Book Company, 1975.
2. S. CORRSIN, *Turbulence: experimental methods*, Handbuch der Physik, 1963.
3. G. K. BATCHELOR, *The theory of homogeneous turbulence*, Cambridge University Press, 1967.
4. A. A. TOWNSEND, *The structure of turbulent shear flow*, Cambridge University Press, 1956.
5. L. PRANDTL, *The attainment of a steady air stream in wind tunnels*, NACA Tech. Mem., 726, 1933.
6. A. R. COLLAR, *The effect of a gauze on the velocity distribution in a uniform duct*, Brit. Aero. Res. Counc., Rep. and Mem., 1867, 1939.
7. G. I. TAYLOR and G. K. BATCHELOR, *The effect of wire gauze on small disturbances in a uniform stream*, Quart. Journ. Mech. and Applied Math., 2, 1, 1949.
8. H. L. DRYDEN and G. B. SCHUBAUR, *The use of damping screens for the reduction of wind-tunnel turbulence*, J. Aero. Sci., 14, 4, 1947.
9. A. A. TOWNSEND, *The passage of turbulence through wire gauze*, Quart. Journ. Mech. and Applied Math., 4, 3, 1851.
10. G. B. SCHUBAUER, W. G. SPANGENBERG and P. S. KLEBANOFF, *Aerodynamic characteristics of damping screens*, NACA Tech. Note, 2001, 1950.

11. R. I. LOEHRKE and H. M. NAGIB, *Experiments on management of free-stream turbulence*, AGARD Report, 598, 1972.
12. H. TSUJI and F. R. HAMA, *Experiment on deacy of turbulence behind two grids*, J. of Aero. Sci., 12, 1953.
13. H. TSUJI, *Experimental studies on the characteristics of isotropic turbulence behind two grids*, J. Phys. Soc. Japan, **10**, 7, 1955 and **11**, 10, 1956.
14. Z. M. ROMICKI, *Introductory study of the turbulence gradient effect on turbulence decay behind grid*, Bull. Acad. Polon. Sci., Série Sci. Tech., **23**, 11, 1975.
15. R. I. LOEHRKE and H. M. NAGIB, *Control of free stream turbulence by means of honeycombs; a balance between suppression and generation*, J. Fluid Engineering, Trans. ASME, Series D, 98, 1976.
16. R. A. WIGELAND, M. AHMED and H. M. NAGIB, *Management of swirling flows with application to wind-tunnel design and V/Stol testing*, AIAA Paper, 77-595, June 1977.
17. A. CENEDESE, S. IANNETTA, P. MELE and M. MORGANTI, *Modifiche della struttura della turbulenza mediante griglie*, XVI Conv. Idraulica e Costr. Idr. Torino, Settembre 1978.

UNIVERSITY OF ROME, ITALY.

Received November 2, 1979.