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Small axisymmetric contraction of grid turbulence

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Anisotropic grid turbulence ($\overline{w^2} = \overline{v^2} \simeq \overline{u^2}/1{\cdot}4$) is passed through an axisymmetric nozzle of small contraction ratio followed by a straight section. Inside the contraction $\overline{v^2}(=\overline{w^2})$ and $\overline{u^2}$ tend to equalize, but their ratio approaches the original pre-contraction value in the straight section behind the contraction. Experiments were repeated with three grids of different mesh sizes and gave similar results.

1. Introduction

The measurements of turbulence behind a square-mesh biplane grid made of round rods and placed in a uniform stream show that the mean square turbulent velocity fluctuations are characterized by $\overline{v^2} = \overline{w^2} \simeq \overline{u^2}/1{\cdot}4$, where u, v, and w are the turbulent velocities in the x, y, and z directions, respectively, and the mean velocity is along the x-axis (Corrsin 1942; Uberoi 1956, 1957). There is a very slow approach towards isotropy. If we extrapolate the data available for about 100 grid mesh lengths we find that $\overline{u^2}$ and $\overline{v^2}$ equalize at mesh lengths of the order of thousands. However, this extrapolation is open to serious objection since the decay law is sure to change at such large mesh lengths. This paper describes an attempt to make the grid-generated turbulence more nearly isotropic at short distances from the grid. A large amount of research has been done on the turbulence behind grids and in drawing various inferences from measured results it is often necessary to assume isotropy of the turbulence. It is desirable to know the nature and magnitude of the anisotropy.

In an incompressible fluid, in the absence of any moving surfaces or singularities the velocity fluctuations are entirely associated with fluctuating vorticity. Since $\overline{v^2} = \overline{w^2} < \overline{u^2}$ the mean square vorticity $\overline{\xi^2}$ (along the mean flow) is smaller than $\overline{\eta^2}$ or $\overline{\zeta^2}$ (perpendicular to it). Immediately behind the grid the vorticity in the wakes of the rods is almost entirely in η- and ζ-components and mixing downstream of the grid produces a nearly, but far from exact, isotropic distribution. In the absence of strong anisotropic forces we expect the anisotropic turbulence to become isotropic but measurements of turbulence decay far behind the grid show that the ratio $\overline{u^2}/\overline{v^2}$ is essentially constant. One way to increase $\overline{\xi^2}/\overline{\eta^2}$ and

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keep $\overline{\eta^2} = \overline{\zeta^2}$ is to pass the turbulence through an axisymmetric contraction. The mean square vorticity $\overline{\xi^2}$ increases due to stretching of the fluid along the direction of the mean flow while $\overline{\eta^2}$ and $\overline{\zeta^2}$ decrease but remain equal to each other (see figure 1 and Uberoi 1956).

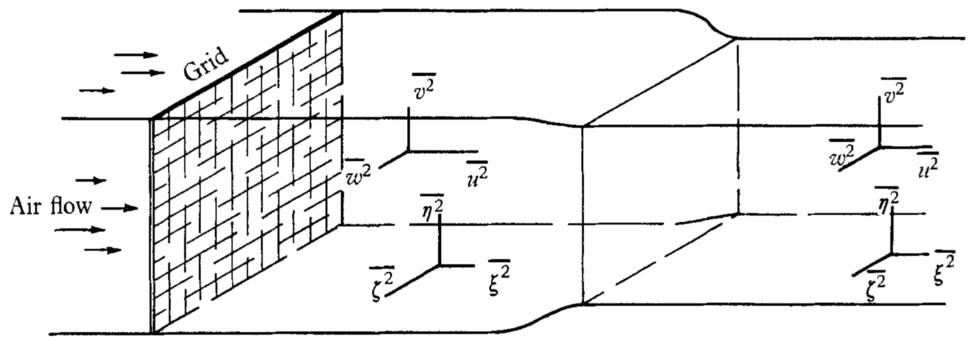

FIGURE 1. Schematic representation of the experiment.

2. Experimental results

The experiments were conducted in a 2 ft. × 2 ft. low-turbulence wind tunnel which is fully described in Uberoi (1956). The free-stream turbulence without the grid is too small to be of any consequence. The vertical walls of the tunnel expand a little to compensate for the boundary-layer growth and the mean velocity U is constant along the tunnel in the absence of the contraction. At 30 in. downstream of the grid the four tunnel walls are fully lined. The thickness of the liner increases from 0 to 1·75 in. within a few inches and then remains constant. This produces a small axisymmetric contraction of the wind-tunnel cross-sectional area followed by a straight section of smaller area which is 90 in. long. The geometric ratio of the pre- and post-contraction cross-sectional areas is 1 : 0·80. The measurements of the mean velocity U along the centre-line of the tunnel, the contraction and the straight section following the contraction show that as far as the mean velocity is concerned the effective contraction ratio is 1 : 0·78 (see figure 2).

The first set of experiments were performed with a 2 in.-square-mesh biplane grid made of round wooden rods of $\frac{1}{2}$ in. diameter at a Reynolds number $UM/\nu = 37{,}200$, where M is the mesh size. Measurements of $\overline{u^2}$, $\overline{v^2}$, the ratio $\overline{u^2}/\overline{v^2}$ and the mean velocity U on the centre-line of the tunnel behind the grid, through the contraction and farther downstream are shown in figure 2. The ratio $\overline{u^2}/\overline{v^2}$ is approximately 1·4 behind the grid, decreases to a value less than one in the contraction and monotonically increases in the uniform section behind the contraction tending to approach its pre-contraction value. The straight section behind the contraction extends to 90 in. and is not long enough to show that the ratio $\overline{u^2}/\overline{v^2}$ returns to its pre-contraction value. It was decided to repeat the experiment with a 1 in.-square-mesh biplane grid made of round wooden rods of $\frac{1}{4}$ in. diameter. For the same contraction and mean velocity distribution the straight section behind the contraction is effectively twice as long for the 1 in. grid as for the 2 in. grid when distances are measured in terms of mesh lengths. The measurements of $\overline{u^2}$, $\overline{v^2}$, the ratio $\overline{u^2}/\overline{v^2}$ and the mean velocity U for the 1 in.-

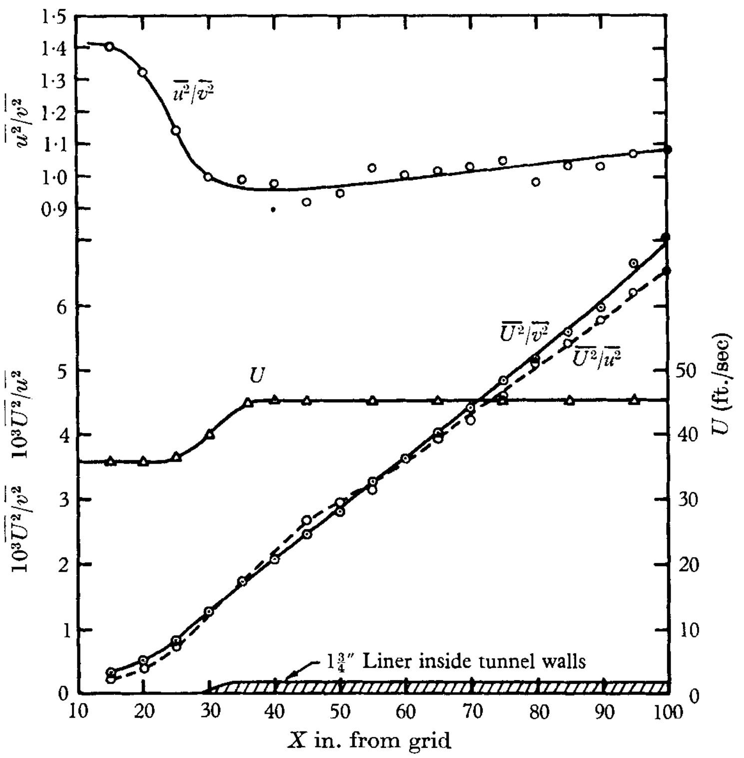

FIGURE 2. Measurements of U, $\overline{u^2}$, $\overline{v^2}$ and the ratio $\overline{u^2}/\overline{v^2}$ for the 2 in. grid at a mesh Reynolds number $UM/\nu = 37{,}200$.

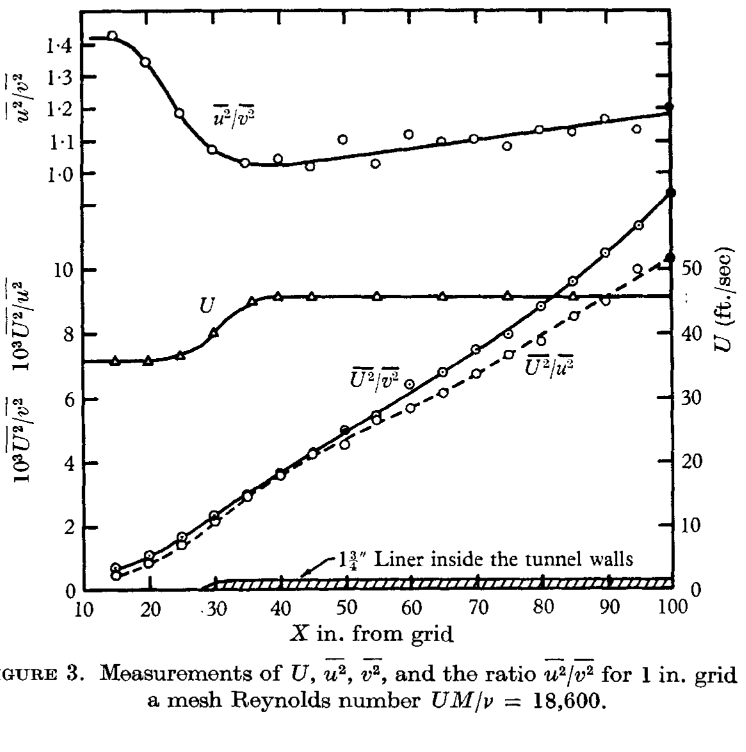

FIGURE 3. Measurements of U, $\overline{u^2}$, $\overline{v^2}$, and the ratio $\overline{u^2}/\overline{v^2}$ for 1 in. grid at a mesh Reynolds number $UM/\nu = 18{,}600$.

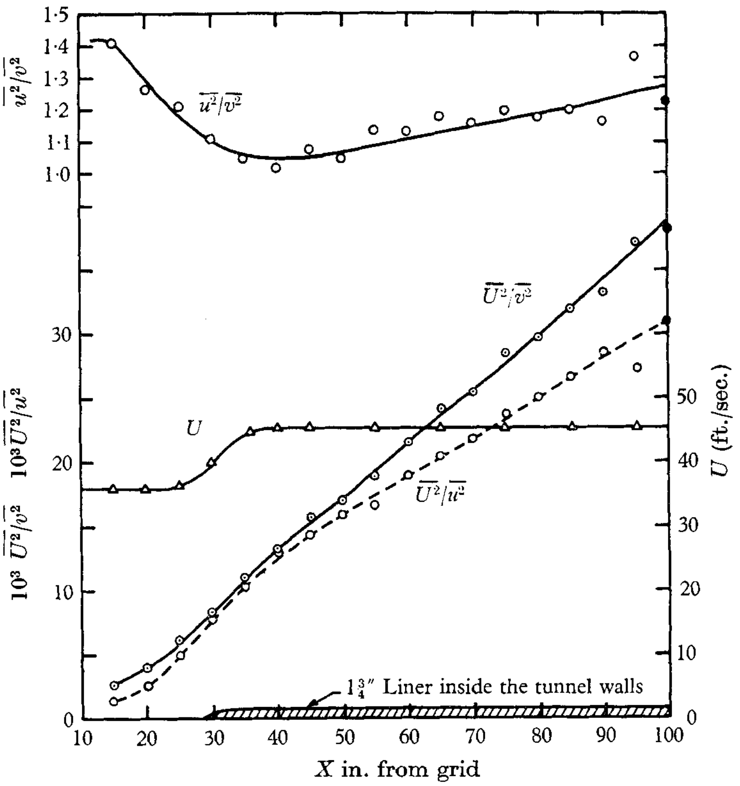

FIGURE 4. Measurements of U, $\overline{u^2}$, $\overline{v^2}$ and the ratio $\overline{u^2}/\overline{v^2}$ for $\frac{1}{2}$ in. grid at a mesh Reynolds number $UM/\nu = 9300$.

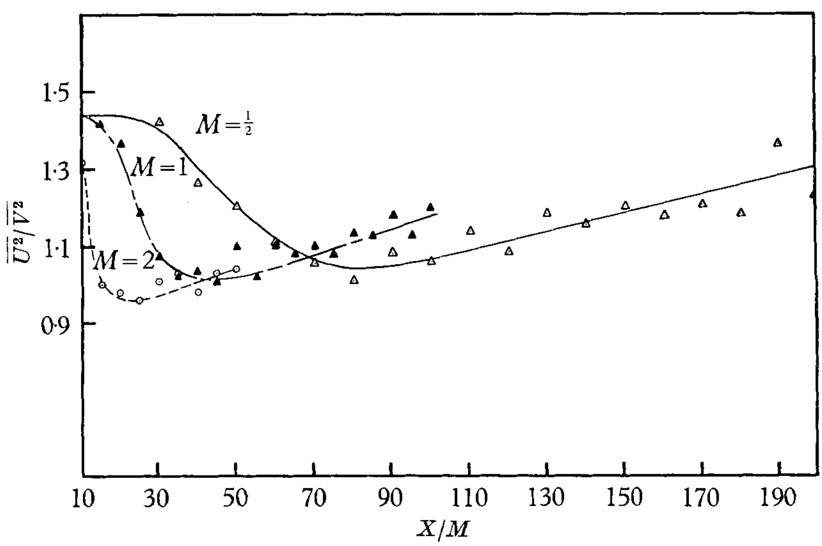

FIGURE 5. Relative effect of a fixed contraction on turbulence generated by similar grids of three mesh sizes.

mesh grid at a Reynolds number $UM/\nu = 18{,}600$ are shown in figure 3. The maximum effect of contraction on the ratio $\overline{u^2}/\overline{v^2}$ for turbulence generated by the 1 in. grid is smaller than that for the 2 in. grid and farther downstream from the contraction the ratio more nearly approaches its pre-contraction value. The third set of experiments were performed with the same contraction and mean velocity using a $\frac{1}{2}$ in.-square-mesh grid made of round woven wires of $\frac{1}{8}$ in. diameter. The measurements at a Reynolds number $UM/\nu = 9300$ are given in figure 4 and again show that downstream from the contraction the $\overline{u^2}/\overline{v^2}$ nearly returns to its pre-contraction value. The effect of contraction on the ratio $\overline{u^2}/\overline{v^2}$ for all three grids is shown in figure 5. The effect of a fixed contraction on the turbulence decreases with decreasing mesh size of the grid. In all cases the ratio $\overline{u^2}/\overline{v^2}$ tends to return to its original pre-contraction value.

3. Discussion

The effect of contraction on the turbulence depends on the ratio of the rate of deformation of a vortex filament due to mean flow changes and that due to turbulence. If the deformation due to mean flow is so rapid that the orientation of a vortex filament does not change in passing through the contraction then the turbulence is most affected by it. The effect decreases if the contraction of the mean flow is so slow that a vortex filament is considerably deformed and its orientation changed by the turbulence as it passes through the contraction. It follows that the effect of a fixed contraction decreases with decreasing mesh size. This explains the fact that after the contraction the ratio $\overline{u^2}/\overline{v^2}$ is higher for smaller grids than for the 2 in.-mesh grid. The above argument is strictly correct if the contraction is imposed on the turbulence at the same dimensionless time. In the present experiments the contraction is placed at a fixed distance from the grids and therefore the turbulence generated by the three grids is subjected to the same contraction at three different dimensionless times. However, the argument is still qualitatively correct.

The results indicate that after passing through the contraction the ratio $\overline{u^2}/\overline{v^2}$ tends to return to its pre-contraction value. If we consider the spectral distribution of the turbulent energy, then the anisotropy of the grid turbulence may be such that the deformation due to contraction cannot remove the anisotropy in every spectral range. However, we had hoped that this imperfect cancellation of anisotropy might be improved by the tendency of the turbulence towards equipartition of energy among the three components. Previous experiments show that when the turbulence is made strongly anisotropic it tends towards equipartition (Uberoi 1957). Further work will be directed towards the measurement of the effect of small contraction on the spectrum of turbulence.

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