CONTROL OF TURBULENCE WITH A HIGH DEGREE-OF-FREEDOM ACTIVE GRID

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Abstract This abstract describes a significant advance in the technology used to generate turbulence in wind tunnels. We present a new active grid with many degrees of freedom, and demonstrate its ability to control the correlation length of the turbulent fluctuations it produced in a wind tunnel. The paddles of previous active grids were constrained to move together in rows and columns, meaning that the motions of the paddles were correlated across the full width and height of the tunnel. These motions, which were usually random, produced relatively intense turbulent fluctuations. In our grid, each of 129 paddles' positions could be moved independently with separate position-controlled servomotors. Because of this, we could introduce desired correlations between the motions of the paddles, by encoding them in the algorithm that set the paddle positions. We found that by changing the extent of the correlations between nearby paddles, we could control the spatial extent of the correlations in the turbulent fluctuations.

INTRODUCTION

Large-scale structures contain most of the energy in turbulence and therefore dominate transport by turbulence. Not only do we need to characterise these structures, but we need to control them, in order to understand and regulate their influence. In this work, we show that we controlled the size of the large scales by manipulating the flow in a wind tunnel with an active grid.

Active grids were developed only recently as a way to generate in wind tunnels high-Reynolds number flows with convenient properties [1]. Active grids work by stirring the flow with rotating paddles, rather than disturbing it through the wakes of stationary bars, as in a classical grid. Modern active grids generate not only high-Reynolds number flows, but also flows with tailored properties [2]. Such control is desirable where turbulence with certain statistical properties is needed, as is the case when the atmospheric boundary layer needs to be synthesised to observe its effect on wind turbines [3], or where the effects of variation of the large-scale properties of the turbulence on the small-scale dynamics need to be understood, which is one objective of fundamental turbulence research [4]. The nature of the large-scales is set by the geometry of the apparatus in an experiment. One advantage of the active grid is that its geometry is variable and can be adjusted during its operation. In the time since the first active grids [5, 6], our understanding of how to control the flow by changing aspects of the grid has advanced, but is not yet mature. Our active grid represents a next step in this progression.

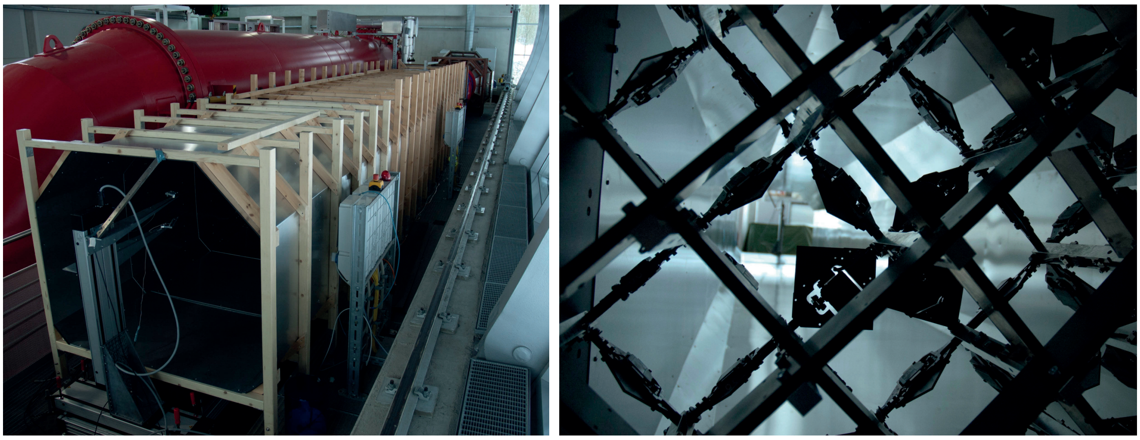

Figure 1. The picture on the left shows the Prandtl tunnel, whose inlet is in the distance, and whose outlet is in the foreground. The length of the test section is 10 m. The red Variable Density Turbulence Tunnel is visible next to the Prandtl tunnel. The picture on the right is a view down the length of the Prandtl tunnel through the active grid. The active grid consists of 129 independently position-controlled diamond-shaped paddles that tile the cross section of the tunnel. The mesh size, M, of the grid is 163 mm, measured along the diagonal of the paddles.

APPARATUS

Our active grid advances active grid technology because there are many more degrees of freedom in the motions of its paddles than in previous grids. There are 129 degrees of freedom, whereas others have about 20. This gives an

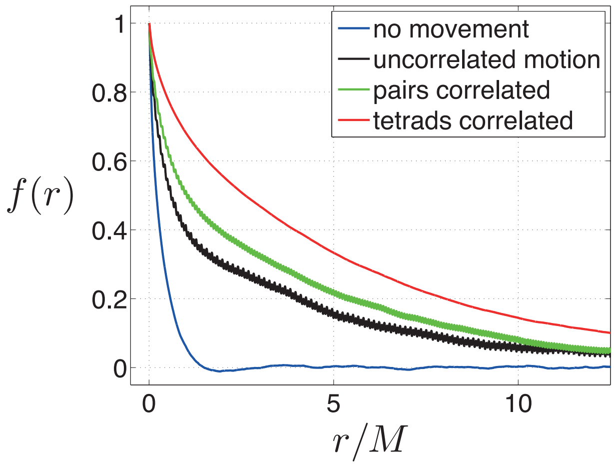

Figure 2. Correlation functions measured downstream of our active grid. We operated the grid according to four algorithms described in the text, which correspond to the four curves shown here. When the paddles did not move (blue), the correlations extended about as far as the distance between paddles, M. Independent random motion of the paddles (black) yielded longer correlation lengths. Yet longer correlation length were generated when the paddles moved together in groups of two (green) and four (red).

unprecedented level of control over the turbulence generated by the grid. Each degree of freedom corresponds to a single diamond-shaped paddle, the collection of which tile the cross section of the tunnel. Each paddle has its own computer-controlled servomotor that adjusts the angle of the paddle relative to the mean flow about an axis perpendicular to the flow. The paddles block the flow locally to a degree that depends on the angle of the paddle. The paddle angles change over time according to a stochastic algorithm.

We performed our experiments in a tunnel built originally in the Kaiser-Wilhelm Institute of Ludwig Prandtl by Fritz Schulz-Grunow from 1936-1938. As seen in Fig. 1, it is an open-return tunnel. A new test section was built from 1 mm aluminium sheet metal and 50 mm square fireproofed wooden posts. The test section is 10 m long, with a cross section 1.5 m wide. The maximum flow speed in the tunnel is 12 m/s. The measurements were made with Dantec hot-wire anemometers at a station in the middle of the cross section of the tunnel, and about 9 m downstream of the grid.

RESULTS

We collected data with the active grid operating in four different ways: (1) with the paddles aligned with the flow and stationary, (2) with the paddles each moving according to independent stochastic algorithms, (3) with pairs of paddles moving together according to this algorithm, and (4) with tetrads of paddles moving together. The three last conditions correspond to increases in the degree to which the paddle motions were correlated over the face of the grid. Previous active grids correspond to the case where all paddles in each row or column of typically eight to ten paddles moved together.

One way to characterise large-scale structure is through the two-point correlation function, $f(r) = \langle u(x+r)u(x)\rangle / \langle u^2 \rangle$. The further the correlations extend in r, the larger is the typical structure of flow. As can be seen in Fig. 2, we found that by increasing the degree of correlation between neighbouring paddles, we extended the correlations between turbulent fluctuations to larger r. That is, our conclusion is reasonable: larger coordinated motions of the active grid produced larger coordinated motions in the flow. This systematic control of the large-scale can now be exploited for both applied or fundamental problems.

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