EXPERIMENTAL AND NUMERICAL STUDY OF OSCILLATING GRID TURBULENCE SUBJECTED TO SYSTEM ROTATION

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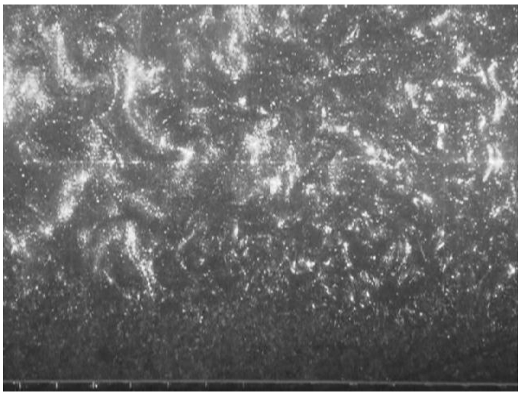
Abstract The oscillating grid turbulence subjected to system rotation is investigated experimentally and numerically. The flow visualization for the rotating turbulence elucidates distinct vortex structures appearing near and far regions from the grid. The numerical simulation reveals the initial development of quasi-two-dimensional longitudinal vortex structures appearing in the rotating system. Experimental and computational results clarify the effect of the rotation on turbulence statistics and flow structures.

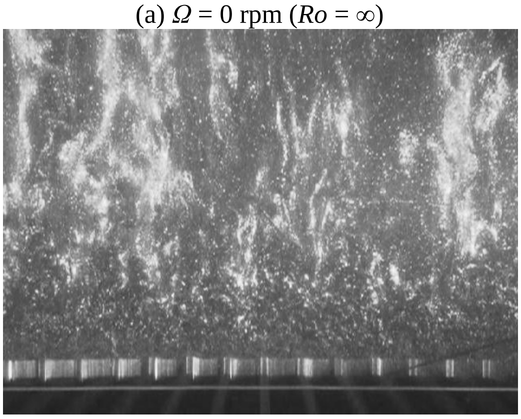
Experimental and numerical outlines

The oscillating grid turbulence subjected to system rotation is investigated experimentally and numerically. The experimental apparatus is similar to that of Hopfinger and Toly [1]. The experiment was conducted in a transparent rectangular box of dimensions of 800×800 mm and 600 mm height filled with tap water on a rotating table. The turbulence is generated with an oscillating grid made of square bars having mesh size M = 30 mm and M/d = 5 where d is the bar diameter. The oscillation stroke and frequency are S = 40 mm and f_g = 3 Hz, respectively. The table rotation numbers (around $+x_3$ axis) are Ω = 0 and 14 rpm which correspond to the Rossby number ($Ro = f_g/2\Omega$) of ∞ and 1.02, respectively. The Reynolds number is $Re = f_g S^2/\nu = 4780$.

The corresponding direct numerical simulation (DNS) is carried out with the secondary conservative second order finite difference scheme for moving grids proposed by Morinishi and Koga [2]. The computational box has dimensions of $4M \times 4M$ (in x_1-x_2 plane) and $20M$ height (in x_3 direction). The numerical mesh number is 160×160×200 in the computational box. The periodic boundary conditions are used in x_1 and x_2 directions, and the no-slip wall boundary conditions are used on the walls at $x_3 = -10M$ and $+10M$. The initial velocity field is stationary.



(a) Ω = 0 rpm (Ro = ∞)



(b) Ω = 14 rpm (Ro = 1.02)

Figure 1. Experimental flow visualization.

Results and discussions

Figure 1 shows the results of experimental flow visualization of the upper region of the oscillating grid. The flow is visualized by a laser sheet with aluminum flake suspension. Three-dimensional turbulence structures appear near the oscillating grid for both stationary and rotating systems. On the other hand, quasi-two-dimensional longitudinal vortex structures appear above the three-dimensional structures for the rotating system as shown in Hopfinger et al. [3].

Figure 2 shows the comparison of fluctuating velocity between experimental and numerical results. A PIV system is used for the experimental measurement. The rms fluctuating intensity of u_1 is normalized by $V_{gmax} = \pi f_g S$. As mentioned in the study of grid through turbulence [4], the decay of fluctuating intensity of the oscillating grid is also inhibited by the system rotation. In addition, the DNS results well reproduce the experimental decaying behavior.

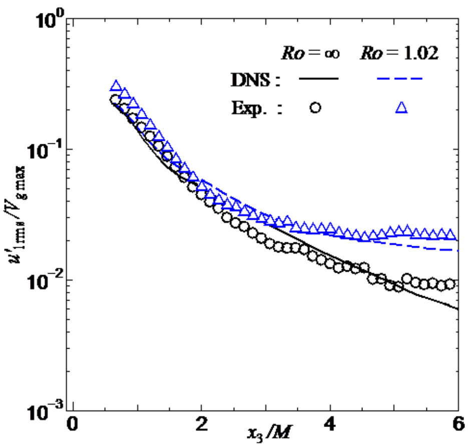


Figure 2. Comparison of experimental and computational fluctuating intensity of u_1.

Figure 3 shows the evolution of quasi-two-dimensional vortex structures by using the DNS data in detail at Ro = 1.02. Vortex structures are visualized by iso-surfaces of axial vortex component of ω_3. Here, red and blue surfaces correspond to cyclonic and anticyclonic structures, respectively. Initially, three-dimensional vortex structures appear near the oscillating grid (Fig.3 (a)). At $f_g t = 20$, finger like structures which are beginning of quasi-two-dimensional longitudinal vortex structures appear above the three-dimensional vortex structures (Fig.3 (b)). It seems that structures above the grid gaps are cyclonic, while structures above the grid intersections are anticyclonic. Structures under the grid are vice versa. The finger like structures are then elongated with time (Fig.3 (c)) and arrive at the walls. After arriving at the walls, the mixing of structures are promoted with keeping qasi-two-dimensionality, and finally quasi-two-dimensional longitudinal vortex struxtures are formulated as shown in Fig.1 (b) and Fig.3 (d).

At the conference presentation, the effect of rotation on other turbulence statistics will be presented.

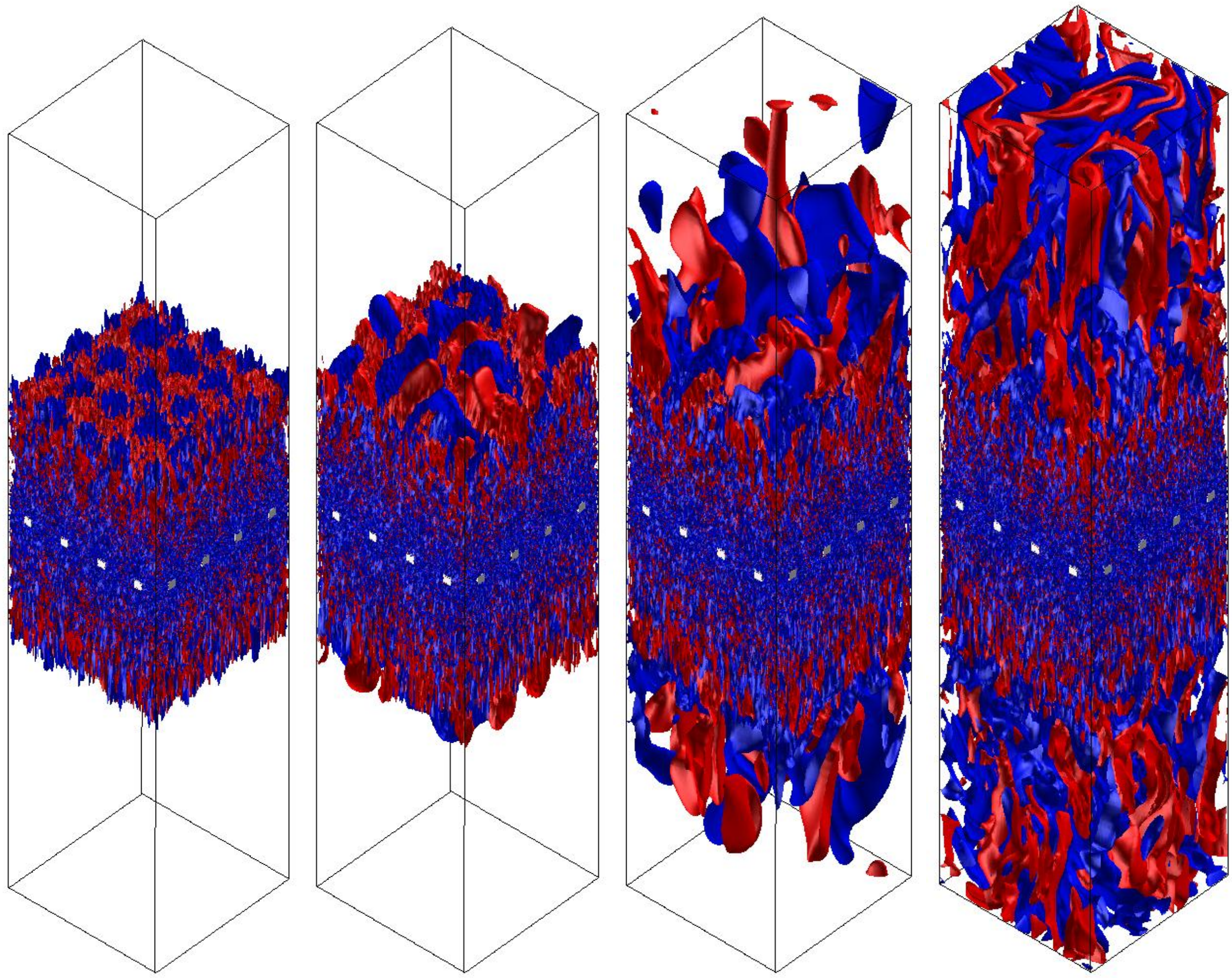


Figure 3. Evolution of quasi-two-dimensional vortex structures at $Ro = 1.02$. Structures are visualized by iso-surfaces of axial vortex component of ω_3 (red : $\omega_3/f_g = +0.3$, blue : $\omega_3/f_g = -0.3$).

References

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