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主 論 文 の 要 旨

論文題目 Direct Numerical Simulations on Grid-Generated Turbulence （格子生成乱流に関する直接数値シミュレーション）

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論 文 内 容 の 要 旨

Direct numerical simulations of turbulence generated by the fractal and single square grids with the uniform inlet velocity are performed. Moreover, turbulence generated by a single square grid subject to additional artificial turbulence (homogeneous and isotropic turbulence with a normalized rms velocity of $u_{rms,et}/U_{in} = 0.097$) is also carried out.

In Chapter 1, the research background and the related previous studies are briefly introduced.

In Chapter 2, the mathematical model and the numerical methods as well as the schematics of the computational domain and the single and fractal square grids are given. Following previous experiments, the grid (e.g., single or fractal square grid) is set near the inlet of the domain in the present numerical study.

In chapter 3, the turbulence generated by the single square grid is numerically investigated. The main findings drawn from the simulation in this chapter can be summarized as follows.

1. For the single square grid with mean inlet velocity, the normalized rms velocity u_{rms}/U (U is the local mean velocity) reaches its maximum value at $X_{peak} \simeq 0.45X_*$ (X_* is the wake interaction length scale), which is similar to the corresponding value for the fractal square grid. Hence, it is confirmed that for the fractal square grid, the location of turbulence intensity peak X_{peak} is largely determined by the scale of the largest grid bar.

2. Fluid motions at $X/X_* \simeq 0.2$ ($X/L_0 \simeq 1.88$ in the present case, where L_0 is the length of the grid bar) are strongly dependent on the wake interactions generated by the grid bar. The similar characteristic for turbulent flow generated by the fractal square grid indicates the dominant effects of the interactions of the

largest wakes at $X/X_* \simeq 0.2$.

3. The intermittent factor γ shows that the wake interactions begin at $X/X_* \simeq 0.1$ ($X/L_0 \simeq 0.94$) downstream of the grid. And γ approaches 1 at $X/X_* \simeq 0.4$ ($X/L_0 \simeq 3.76$).

4. Behind the single square grid, the (R,Q) and (Q_W,Q_S) maps suggest that at $X/X_* < 0.2$ ($X/L_0 < 1.88$), the fluid motions are distinctly different from those of turbulent channel flows, turbulent mixing layers, and isotropic turbulence. Here, R and Q are the third and second invariants of the velocity gradient tensor and Q_W and Q_S are the second invariants of the rate-of- rotation and rate-of-strain tensors, respectively. With the spatial development, the joint PDFs of the (R,Q) and $(Q_W,-Q_S)$ maps at $X/X_* = 0.4$ ($X/L_0 = 3.76$) adopt their well-known shapes.

In chapter 4, turbulence generated by the fractal square grid is investigated. For the fractal-generated turbulence, the following conclusions are obtained.

1. A fractal square grid contains two parts, the main part (largest square grid) and the supplement part (relatively small ones). The influences of the supplement part only last for a short distance from the grid, whereas the largest square grid mainly determines the turbulence characteristics in the downstream region.

2. The existence of the high energy decay region is confirmed behind the fractal square grid, where turbulence has high decay exponent n.

3. A fractal square grid can indeed stir higher turbulence levels in the near field region, whereas the values of Taylor-microscale-based turbulent Reynolds number Re_λ and u_{rms}/U_{in} for the single and fractal square grids at the end of simulation section (i.e., $X/X_* = 1.4$ or $X/L_0 = 13.2$) are comparable. The widely held belief that the fractal square grid can generate unconventional high levels of turbulence fluctuations is related to the improper use of the effective mesh size M_{eff}.

In chapter 5, it is proposed that a typical fractal square grid, which consists of various-size square grids that are self-similar, can effectively be split into two parts: a main part containing the largest square grid and a supplementary part containing smaller fractal iterations. Turbulence generated by a supplementary part can be regarded as additional turbulence. To confirm this hypothesis, an additional simulation is performed, which is the simulation of turbulence generated by a single square grid with additional artificial turbulence. The main findings are as follows.

1. With the inclusion of additional homogeneous isotropic turbulence ($u_{rms;et}/U_{in} = 0.097$), the turbulence behind the single square grid has similar characteristics to fractal-generated turbulence (e.g., a faster wake decay rate,

small value of X_{peak}/L_0, excellent agreement of λ/L_0 (λ is the Taylor microscale), and high energy decay rate).

2. The fractal square grid can be regarded as an efficient additional turbulence generator in the near field region.

Based on previous discussions, in Chapter 6 the main contributions of this thesis are summarized as follows:

1. Simulation results of the fractal square grid directly contribute to the understanding of the fractal-generated turbulence.

2. Previous studies suggested that the unusual behavior of turbulence behind the fractal square grid is related to its multi-scale grid structure; the fractal square grid can produce wakes of different scales. By comparing the simulation results of the single and fractal square grids, the influences of the relatively smaller fractal iterations on the generated turbulence are estimated.

3. The present single square grid is a part of the regular grid, which is widely used to generate quasi homogeneous and isotropic turbulence. Moreover, behind the single square and regular grids the wake-interaction patterns are similar. So the numerical investigation of the single-square grid-generated turbulence is helpful to investigate the physical characteristics of the turbulent flow generated by the regular grid, especially in the near-field region.

4. The mixing rate of scalar in multiscale/fractal-generated turbulence is important. The present numerical findings provide insight into the design of high performance industrial devices such as static mixers by using multiscale/fractal grids.