Turbulence Structure and Scalar Transfer in Regular and Fractal Grid Turbulence

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1. Introduction

Grid generated turbulence using a biplane square grid has been widely used to generate nearly isotropic turbulence in both wind tunnel and water channel. Recently, turbulence generated by "fractal grids" has been experimentally investigated [(1), (2)]. The purpose of this study is to investigate the flow field and turbulent diffusion of a passive scalar in the spatially developing regular and fractal grid turbulence by means of the direct numerical simulation (DNS). The comparisons of turbulence and scalar diffusion fields are made between the regular and the fractal grid turbulence at the same mesh Reynolds number.

2. DNS

Fig. 1 shows the schematic of the fractal grids and computational domain simulated in the present DNS. Following the experiments [(1)], three kinds of fractal grids, namely, fractal cross, fractal I and fractal square grids, are numerically constructed using the immersed boundary method. A classical biplane grid (regular grid) is also constructed for comparison. For scalar diffusion, two types of passive scalar fields are calculated for the regular and fractal square grids: the one is a diffusion of a passive scalar with a constant mean gradient and the other is a scalar mixing layer (see the snapshot shown in Fig. 2).

The computational domain and grid numbers are listed in Table 1. The fractional step method based on the third-order Runge-Kutta method is used to solve the governing equations. To ensure the numerical accuracy, fully conservative high order accurate finite different schemes for full staggered grid system [(3)] are used. For the detail of the numerical procedure, see our published paper [(4), (5)]. The mesh Reynolds number Re_M is set at 2,500 for all the cases.

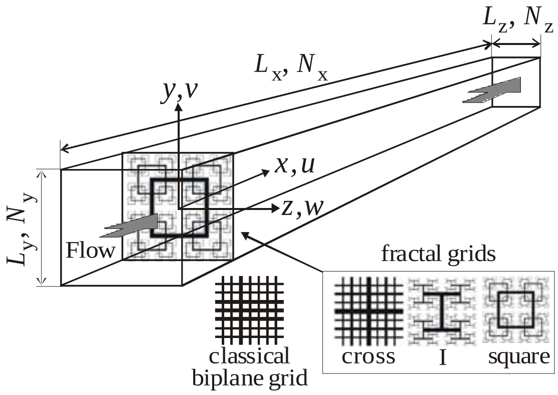

Fig .1 Schematic of turbulence-generating grids and computational domain

Table 1 Computational domain and grid numbers

Grid type	$L_x \times L_y \times L_z$	Grid numbers
Regular (Uniform temp. grad.)	$115.2 \times 8 \times 8$	$1280 \times 160 \times 160$
Regular (mixing layer)	$64.0 \times 8 \times 8$	$768 \times 160 \times 160$
Fractal Cross	$115.2 \times 16 \times 16$	$1280 \times 320 \times 320$
Fractal I	$115.2 \times 16 \times 16$	$1280 \times 320 \times 320$
Fractal Square (Uniform temp. grad.)	$115.2 \times 16 \times 16$	$1280 \times 320 \times 320$
Fractal Square (mixing layer)	$64.0 \times 16 \times 16$	$768 \times 320 \times 320$

Fig. 2 Instantaneous scalar field for the mixing layer downstream of the fractal square grid

3. Summary of the results

1. The fractal square grid generates quasi homogeneous and isotropic turbulence in the far downstream region of the grid, whereas the fractal cross and I grids do not generate homogeneous and isotropic turbulence even in the far downstream region of the grids (under the present grid parameters and mesh Reynolds number).
2. The fractal grid generates the high-Reynolds-number turbulence compared with the regular grid turbulence using a biplane square mesh grid at the same mesh Reynolds number.
3. Scalar fluctuation and turbulent scalar flux in the fractal grid turbulence is larger than those in the regular grid turbulence. The results suggest that the scalar mixing is more enhanced in the fractal grid turbulence in comparison with the regular grid turbulence at the same mesh Reynolds number.

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