Volume 7 Issue 1 (2019) 31-32 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

Synthetic Inflow Generator having Various Oscillations

Young-WOO YI, Hee-Chang LIM*
School of Mechanical Engineering, Pusan National University, Busandaehak-ro 63beon-gil 2, Geumjeong-gu, Busan, Korea

Article Info

Article history:
Received 12 December 2018
Received in revised form
2nd February 2019
Accepted 28 February 2019
Available online 15 March 2019

Keywords: LES, Synthetic inflow, Correlation, Various oscillation

Abstract

Large Eddy Simulation (LES), which has recently been developed and used for the climate local environment and turbulent boundary layer flow, can be applied for a variety of area. In particular, in order to achieve a faster performance, an artificial generation of inflow turbulent flow would be necessary to make the faster convergence as well as to maintain the real turbulent flow in the calculation domain. In this study, the synthetic inflow generator has been developed based on spatial and temporal correlation functions, which have a form similar to an exponential function. This inflow data having various oscillation obtained by the synthetic inflow generator imposed into the inlet condition of LES simulation on a channel with smooth wall. In the result, fully developed turbulent boundary layer was successfully generated in the computational domain. In addition, the variation of oscillating inflow was taken into account to observe the effect of the fully developed turbulent boundary layer.

1. Introduction

Generating an appropriate turbulent boundary layer in the numerical domain is important as it is a precondition for modeling the flow around bluff bodies such as building and structures. [1] It is used to estimate wind loads on structural models, to predict wind velocities around new developments, and to investigate the dispersal of airborne pollutants. In order to generate the turbulent boundary layer, the most direct method would be to simulate a laminar inflow and allow it to develop spatially over a suitably long domain, i.e. over a hundred times the thickness of the eventual boundary layer depth of interest. However, this method would be extremely expensive computationally.

Synthetic turbulence generation is of particular interest when only limited turbulence statistics data are available for the procedure. Hanna et al. [2] generated one-dimensional time series of inflow data based on an exponential correlation function to simulate flows over an array of cubes using LES. The time series were tailored to provide the required time scale and turbulence intensities and the subsequent LES was able to reproduce the main characteristics of the measurements. The merit of the method is its very high efficiency, but because no spatial correlation was imposed at inlet its accuracy is seriously limited. Because of the features of atmospheric boundary layer flows as inflow condition, one of the representative papers would be the work of Xie & Castro. [3] They implemented the urban boundary layer flows, which is high Reynolds number, fully developed turbulence and driven by weather scale motions. They used a digital-filter based method, which allows spatially varying turbulence scales on non-uniform grids to be imposed at the inlet.

In this study, the synthetic inflow generator having oscillating variation has been developed based on spatial and temporal correlation functions, which have a form similar to an exponential function. Since the filtering process is made by this correlation function, it firstly was processed to get filtered data by having a convolution of filter coefficients with a set of two-dimensional random data.

With the virtue of this technique, the integral length scale obtained by integrating the correlation function can be easily given for spanwise and wall-normal direction (i.e., vertical) component, separately. In order to validate the turbulent boundary layer profiles in the channel domain from the synthetic inflow generator, the paper compares those results with the existing data which was similarly obtained in the calculated and measured domain.

2. Numerical method

2.1Governing equation

The governing equation used in this study is the filtered Navier-Stokes equation and the discretization method is the finite volume method. The Smagorinsky model was used as a subgrid-scale model.

***Corresponding Author,**
E-mail address: hclim@pusan.ac.kr

2.2 Synthetic inflow method

The instantaneous value of the velocity u_i may written as

$$u_i = \bar{u}_i + a_{ij}\psi_j \tag{1}$$

where $\bar{u}_i$ is mean, a_{ij} is amplitude tensor[8] and ψ_j is unscaled fluctuation ($\bar{\psi}_j = 0$, $\overline{\psi_j\psi_j} = 1$). The correlations in most turbulent shear flow have similar features, whereas it has an advantage of the correlation function that the correlation function approximates to the form of exponential function[3].

$$\psi_m = \sum_{j=-N}^{N} b_j r_{m+j} \tag{2}$$

$$b_j = \tilde{b}_j \Bigg/ \left(\sum_{l=-N}^{N} \tilde{b}_l^2\right)^{1/2}, \text{where } \tilde{b}_j = \exp\left(-\frac{\pi|l|}{n}\right) \tag{3}$$

$$\psi_{m,l} = \sum_{j=-N}^{N}\sum_{k=-N}^{N} b_j\, b_k r_{m+j,l+k} \tag{4}$$

$$\psi_i(t+\Delta t, y, z) = \psi_i(t,y,z)\, exp\left(-\frac{\pi\Delta t}{2T}\right) + \psi_i(t,y,z)\left[1 - exp\left(-\frac{\pi\Delta t}{T}\right)\right]^{0.5} \tag{5}$$

where b_j is filter coefficient, r_m is random sequence, N is related with length scale.Eq(3) is two dimensional form of ψ_m . The fluctuation $\boldsymbol{\psi_i}(t+\Delta t, y, z)_i$ of the next time step can be calculated using Eq. (5) using the fluctuation $\psi_i(t,y,z)$ at the previous time step. T is a lagrangian time scale.

3. Channel flow

3.1 Boundary condition

The Reynolds number is derived as Re_τ = 150 with the friction velocity (u_τ) and the half height (d) of the channel. Figure 1 shows the schematics of computational channel domain. The boundary conditions are a no-slip condition on the top and bottom with $y^+ <$ 1, a periodic boundary condition on the lateral direction, and a zero gradient condition on the outlet. The synthetic turbulence obtained by the synthetic inflow generation model was interpolated into the inlet plane.

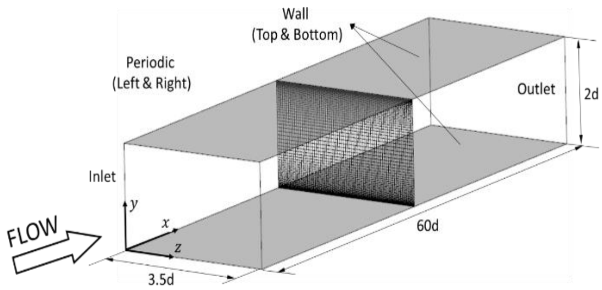

Fig. 1 Schematics of computational channel domain

Figure 2 shows the length scale obtained from the DNS database [4] and the length scale applied to the synthetic inflow generation. Figure 2(a) shows the streamwise direction length scale, L_x, distribution along the wall-normal direction. Figure 2(b) shows the length scale for y- and z-direction.

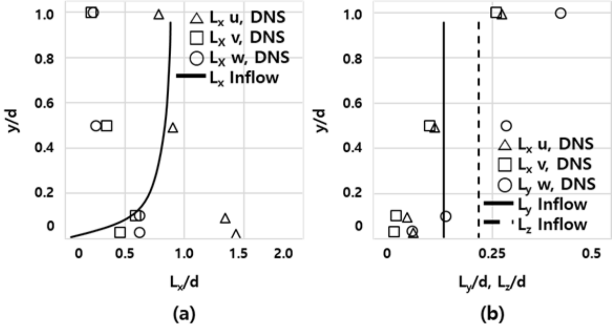

Fig. 2 Profiles of integral length scales in the inlet , L_z^*

3.2 Results and discussion

This study generates the synthetic inflow having turbulent properties in the domain. Based on the results from synthetic inflow generator, it would have a high priority to validate some parameters such as mean and fluctuating quantities, and Reynolds stresses with the aim to confirm the boundary layer fully developed. The current study basically applied four different turbulent inflow data for generating the inflow turbulence – flat, sinusoidal, triangular, and trapezoidal shapes, which is called as Ch01, 02, 03, and 04, respectively.

Figure 3 compares the current results of turbulent boundary layer with the existing data such as DNS (Kasagi data) and the typical boundary layer profiles. In the figure, the DNS data agrees well with the law of the wall in the region of wall. On the other hand, the calculation has better precision than DNS data in the logarithmic layer region. 0

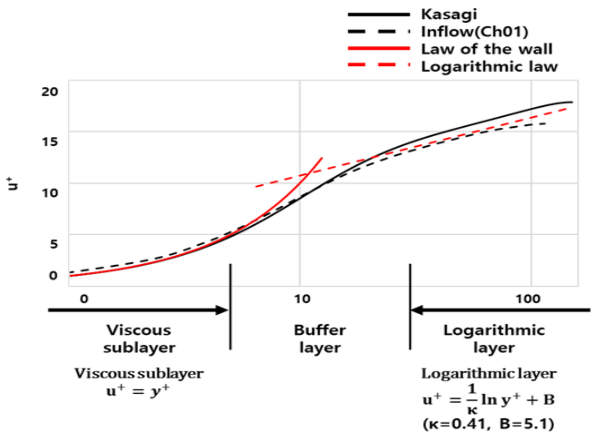

Fig. 3 Comparison of u^+ among DNS (Kasagi) data, synthetic inflow data, and theoretical results

Figure 4 shows the distribution of wall shear stress for 4 cases with different inflow conditions. It can be seen that the change in the inflow applied to the entrance has a significant effect on the recovery of wall shear stress. However, the flow in the downstream gets to converge.

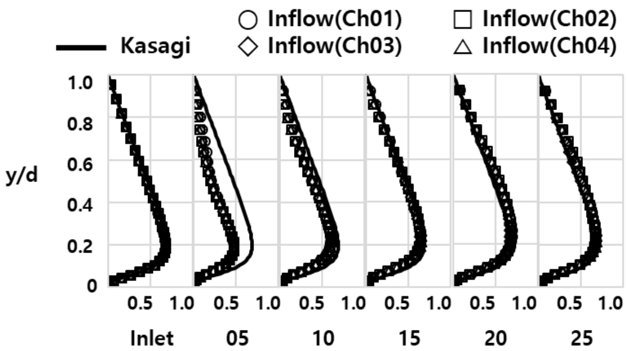

Fig. 4 Statistics of turbulence at inlet and x/d =50

4. Conclusions

In this study, turbulent boundary layer was successfully simulated in the channel domain using LES with different inflow data obtatineed by the synthetic inflow generator.

The DNS data agrees well with the law of the wall in the region of wall. On the other hand, the calculation has better precision than DNS data in the logarithmic layer region.

Regardless of the inlet length scales, the fully developed turbulent boundary layer on downstream region had alomost similar statistics.

Acknowledgment

This work was supported by "Human Resources Program in Energy Technology" of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20164030201230). In addition, this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2016R1A2B1013820).

References

[1] A Hunt. Wind-Tunnel Measurements of Surface Pressures on Cubic Building Models at Several Scales, Journal of Wind Engineering and Industrial Aerodynamics,10, (2), 1982, 137-163.

[2] SR Hanna, S Tehranian, B Carissimo, RW Macdonald, R Lohner. Comparisons of model simulations with observations of mean flow and turbulence within simple obstacle arrays, Atmospheric Environment, 36, (32), 2002, 5067-5079.

[3] ZT Xiem, IP Castro. Efficient generation of inflow conditions for large eddy simulation of street-scale flows, Flow Turbulence and Combustion, 81, (3), 2008, 449-470.

[4] K Iwamoto, Y Suzuki, N Kasagi. Database of Fully Developed Channel Flow-TH TLAB Internal Report No. ILR-0201, Rapport technique, THTLAB, Dept. of Mech. Eng., The Univ. of Tokyo (CH12_PG.WL7), 2002.