

Generation of inflow turbulence using the local differential quadrature method

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ABSTRACT: Inflow turbulence plays an important role in the field of computational wind engineering. Whereas, generation of inflow turbulence through preliminary numerical simulation of a turbulent boundary layer using traditional low-order numerical algorithms usually can not yield satisfied results corresponding with the prescribed statistics, especially as the power spectral density for lack of high-frequency energy. This paper extends the traditional differential quadrature method (DQM) to the direct numerical simulation (DNS) of inflow turbulence based on the idea of localization with a common staggered mesh. This local DQM can be viewed, to some extent, as a generalized finite difference method whose weighting coefficients can be obtained from different interpolation base functions. It is found that the polynomial interpolation base functions and the Fourier expansion both perform well for the local DQM in modeling turbulence. This method is successfully applied to generate inflow turbulence and good results obtained. Comparisons show that the mean property and turbulence intensity can be well preserved and the high-frequency energy is efficiently improved with increasing the number of locally referenced points of the local DQM.

KEYWORDS: generation of inflow turbulence; the local differential quadrature method; high-frequency energy; turbulent boundary layer; interpolation base functions; DNS.

1 INTRODUCTION

The advent of high-speed computer and the development of accurate numerical algorithms have provided an important third approach — Computational Wind Engineering (CWE), in addition to theory analysis and experiment, for researchers to study the effects of air flow on structures which are usually located at the bottom of the turbulent atmospheric boundary layer (ABL). It is well known that the characteristics of the turbulent ABL vary with the land surface roughness, and that the wind-induced responses of structures are determined mainly by the interaction of the atmospheric turbulence and the released vortex of structures. So the imposed inflow turbulence at the inlet boundary has to satisfy the prescribed requirements, and also the turbulence statistics should not change a lot in the empty wind tunnel (Blocken, *et al.* 2007; Murakami 1998). Besides, in practice, estimating time history of dynamic wind load on structures by performing an unsteady LES heavily depends on the accurate inflow condition at every time step. Therefore, a crucial precondition to the above research activities using CWE is to generate appropriate inflow boundary conditions in accordance with characteristics of the turbulent ABL, i.e. generation of inflow turbulence, which has been a hot research topic in the field of CWE for the past two decades (Nozawa and Tumura 2002).

At present, several methods have been developed to generate inflow turbulence and can generally be classified into two types. The first one is to artificially generate time series of velocity fluctuations by performing an inverse Fourier transformation for the prescribed spectral densities, i.e. the so called “synthetic method” (Kondo, *et al.* 1997, Murayama, *et al.* 1999, Mathey, *et al.* 2006, Huang, *et al.* 2010). The other is to directly conduct preliminary simulation of a turbu-

lent boundary layer using computational fluid dynamics (CFD) (Lund, *et al.* 1998, Nozawa and Tumura 2002, Kataoka and Mizuno 2002, Tabor and Baba-Ahmadi 2009), simply denoted here as “direct method”. A more comprehensive review of various methods commonly used for generation of inflow turbulence was given by Tabor and Baba-Ahmadi (2009) and Huang, *et al.* (2007) in which these methods were classified into three types, i.e. precursor database, synthetic method and recycling method. Here the precursor database and the recycling method are combined as the direct method because they are both based on CFD simulation. The synthetic method is relatively convenient and timesaving. And more importantly, the stochastic of its generated inflow turbulence can be guaranteed to satisfy the prescribed target characteristics. Kondo, *et al.* (1997) presented a method to deal with the divergence-free operation to ensure the continuity condition. Huang, *et al.* (2010) proposed a new inflow turbulence generator not only rigorously satisfying the divergence-free condition but also suitable for parallel computation. However, application of this method is limited by the fatal deficiency that its generated turbulent inflow data do not satisfy the Navier-Stokes equations. So the characteristics of the imposed inflow turbulence at the inlet can not be well preserved in the computational domain. In contrast, the direct method avoids this severe defect of the synthetic method, while requires a large computational load. Although the direct method has achieved great success in practice, it still has some defects, for example, it is relatively hard for the direct method to obtain satisfied results corresponding with the prescribed power spectral density for lack of high-frequency energy which is of great importance for analyzing the buffeting response of wind-sensitivity structures and for estimating wind energy utilization. This paper just focuses on the direct method as well as on the improvement to the high-frequency energy.

Generally, there are two approaches to enhance the high-frequency energy in CFD simulation of inflow turbulence. One is to use a fine grid, and the other using a high-precision algorithm which has been adopted in the present paper. The traditional high-order methods used in direct numerical simulation (DNS) of turbulence are compact finite difference, spectral and spectral elements methods. These methods are more accurate while not practical in CWE for their complexity and non-universality. This paper focuses on another high-order algorithm, the differential quadrature method (DQM) proposed by Bellman and Casti (1971). This method is highly accurate and conceptually simple, and has been reported to solve various problems of fluid mechanics. Nevertheless owing to the limitation of its quadrature rules, the traditional DQM has so far been used only for regular domain and laminar flows with a collocated mesh which commonly can not guarantee the continuity condition on boundaries and is prone to bring pressure oscillation. Sun and Zhu (2000) proposed an upwind local DQM to overcome some of the above difficulties. Shu, *et al.* (2003) developed a Local radial basis function-based differential quadrature (RBF-DQ) method, which is essentially a mesh-free approach, to expand its application. However, this method has never been used to turbulent flows and with a staggered mesh.

This paper extends the traditional DQM to turbulence simulation based on the idea of localization analogous to that of Sun and Zhu (2000), but with a common staggered mesh. An upstream grid number n_u and a downstream grid number n_d are introduced into the formulae of the present local DQM. By changing n_u and n_d , different upwind/central schemes of the local DQM can be obtained. Besides, the weighting coefficients can be calculated using different interpolation base functions. Two kinds of interpolation base functions, polynomial and Fourier, will be used and studied for turbulence simulation. Influences of several upwind schemes of the local DQM on high-frequency energy will also be investigated. In the next section, fundamentals of the traditional DQM and the local DQM are shown. Section 3 presents verification of this local DQM for turbulence modeling based on the channel flow. Then a recycling approach for generation of inflow turbulence used in this paper is introduced in Section 4. And Section 5 presents

and analyzes the numerical results of inflow turbulence generated using the present local DQM. Finally, some conclusions are summarized in Section 6.

2 THE LOCAL DIFFERENTIAL QUADRATURE METHOD

To roundly understand the local DQM, the traditional DQM is introduced. The idea of the traditional DQM is essentially an extension of the integral quadrature. It approximates an ordinary/partial derivative of a function with respect to a coordinate direction at a mesh point as the weighted linear sum of all the functional values in the whole domain along that direction. Details can be found in Shu (2000). Without losing generality, consider a one-dimensional function $f(x)$ defined in $[a, b]$. Using the DQM, the n th-order derivative of $f(x)$ with respect to x at a point x_i can be expressed as

$$f^{(n)}(x_i) = \sum_{k=1}^N w^{(n)}(i, k) f(x_k), \quad i=1, 2, \dots, N \text{ and } n=1, 2, \dots, N-1 \quad (1)$$

where $a=x_1 < x_2 < \dots < x_{N-1} < x_N=b$ are the discrete grid coordinates which can be arbitrarily distributed in space, N the total grid number in x direction, and $w^{(n)}(i, k)$ the corresponding weighting coefficient which can be calculated from various interpolation base functions. For example, weighting coefficients of the first-order derivative can be calculated using the polynomial interpolation base functions, the so-called PDQ by Shu (2000), as

$$\begin{cases} w^{(1)}(i, k) = \prod_{\substack{k=1 \\ k \neq i, j}}^N (x_i - x_k) / \prod_{\substack{k=1 \\ k \neq j}}^N (x_j - x_k), & \text{for } i \neq j \\ w^{(1)}(i, i) = - \sum_{j=1, j \neq i}^N w_{i,j}^{(1)}, & \text{for } i = j \end{cases} \quad (2)$$

or using the Fourier series expansion, the so-called FDQ by Shu (2000), as

$$\begin{cases} w^{(1)}(i, k) = \frac{\pi}{2(b-a)} \prod_{\substack{k=1 \\ k \neq i, j}}^N \sin \left[\frac{\pi(x_i - x_k)}{2(b-a)} \right] / \prod_{\substack{k=1 \\ k \neq j}}^N \sin \left[\frac{\pi(x_j - x_k)}{2(b-a)} \right], & \text{for } i \neq j \\ w^{(1)}(i, i) = - \sum_{j=1, j \neq i}^N w_{i,j}^{(1)}, & \text{for } i = j \end{cases} \quad (3)$$

Weighting coefficients for higher order derivatives can be directly obtained by using the matrix multiplication approach,

$$[w^{(n)}] = [w^{(1)}]^n \quad (4)$$

It can be seen from the above statement that the traditional DQM is, in fact, a global method because it connects the derivative of a function with respect to a coordinate direction at a given point with all the functional values along that direction in the computational domain. Just as stated in the first section, the traditional DQM is limited to regular domain and laminar flows on a collocated mesh because of its global quadrature rule. In order to extend its application, Sun and Zhu (2000) introduced the idea of localization combined with the upwind mechanism. Next, we will show a local DQM analogous to but different from that of Sun and Zhu (2000).

Unlike the traditional DQM, derivative of a function with respect to a coordinate at an internal point is expressed as a weighted linear sum of the function values at partial grid points rather

than at all the grid points along that coordinate direction. In details, consider an internal point x_i , the derivative of $f(x)$ with respect to x at this point can be expressed as a weighted linear sum of the function values at q grid points near x_i along the x direction, that is to say

$$f^{(n)}(x_i) = \sum_{k=1}^q w^{(n)}(r, k) f(x_{i-r+k}) \quad (5)$$

where $q = n_u + n_d + 1$; n_u and n_d are the upstream grid number and the downstream grid number, respectively, and they should satisfy $n_u \geq 1$, $n_d \geq 0$ and $n_u \geq n_d$; The number r can be determined in terms of velocity $u(x_i)$ as follows

$$r = \begin{cases} n_u + 1 & u(x_i) \geq 0 \\ n_d + 1 & u(x_i) < 0 \end{cases} \quad (6)$$

It is clear that if $n_u > n_d$, an upwind scheme is obtained, and $n_u = n_d$ corresponds to a central scheme. Fig. 1 illustrates the grid distribution of the local DQM as $n_u=3$ and $n_d=2$.



Figure 1. Grid points used in the local DQM as $n_u=3$ and $n_d=2$

The difference of the present local DQM from that of Sun and Zhu (2000) just lies in the formula of r . In Sun and Zhu (2000), r is determined by

$$r = \begin{cases} q/2 + 1 & q \text{ is even, } u(x_i) \geq 0 \\ q/2 & q \text{ is even, } u(x_i) < 0 \\ (q+1)/2 + 1 & q \text{ is odd, } u(x_i) \geq 0 \\ (q+1)/2 - 1 & q \text{ is odd, } u(x_i) < 0 \end{cases} \quad (7)$$

Evidently, the local DQM of Sun and Zhu (2000) just has upwind schemes, besides the upwind grid number is larger than the downstream grid number by only one or two corresponding to the even or odd q , respectively. So the present local DQM is relatively more general.

It has to be indicated here that the weighting coefficient $w^{(n)}(r, k)$ in Eq. (5) should be calculated from the referenced q grid coordinates x_j ($j=i-r+1, \dots, i-r+q$) rather than from the N grid coordinates x_j ($j=1, \dots, N$) using Eq. (2) or Eq. (3). Besides, when an internal point x_i locates its position near the boundary, there may not be enough grid points to introduce upwind or central mechanisms. Then one should adjust n_u and n_d to guarantee that the referenced points are not outside the computational domain, and this treatment will inevitably compromise the accuracy near the boundary. However, this problem will not be considered in the present paper.

The formula (5) is just the present local DQM which imposes the differential quadrature rule on a local domain rather than on the whole domain. Actually this method can be considered, to some extent, as a generalized high-order finite difference method for the weighting coefficients can be obtained by using various interpolation base functions. For example, if the polynomial interpolation base functions are used, the local DQM is identical with the highest-order, i.e. $(q-1)$ th, finite difference scheme according to the demonstration of Shu (2000). And if the Fourier expansion is used, the local DQM is similar, to some extent, to the spectral element method. In

addition, because the differential quadrature rule is used locally, the staggered mesh can also be introduced. From this point, the local DQM is similar to the FDM and FVM except the values of weighting coefficients and the approach to calculate them.

3 VERIFICATION OF THE LOCAL DQM

In this section, the above local DQM is applied to model the channel flow at $Re_\tau=180$ to check its validation for turbulence simulation. Two kinds of interpolation base functions, polynomial and Fourier expansion, are used to calculate the weighting coefficients to study the effects of different base functions on numerical results. For convenient, the above two cases are denoted as “local PDQ” and “local FDQ”, respectively, for short. The governing equations used here, and also hereafter for generation of inflow turbulence, are the three-dimensional unsteady incompressible Navier-Stokes equations in Cartesian coordinate,

$$\begin{cases} \nabla \cdot \mathbf{V} = 0 \\ \mathbf{V}_t + (\mathbf{V} \cdot \nabla) \mathbf{V} + \nabla p / \rho = \nu \nabla^2 \mathbf{V} \end{cases} \quad (8)$$

where $\mathbf{V}=\{u,v,w\}^T$ is the velocity vector, p the pressure, ρ the density and ν the kinematic viscosity coefficient. A common staggered mesh is introduced: the pressure p is defined in the center of the cell, and the velocities u , v and w are defined on the surface center of the cell normal to x , y and z axis, respectively.

The traditional fractional step method is applied to solve the above equations. And the local DQM shown ahead is only used to discretize the convection terms in space while calculating the intermediate velocities, and the viscous terms are spatially discretized by the three-point second-order central difference scheme. In time, the first-order explicit Euler scheme is used for the unsteady terms, the second-order Adams-Bashforth scheme for the convection terms and Crank-Nicolson for the viscous terms.

The computational domain is $2\pi \times 2 \times \pi$ in longitudinal (streamwise), vertical (wall-normal) and spanwise direction, respectively, with a coarse mesh, $65 \times 65 \times 65$. Uniform grid is used in the streamwise and spanwise direction, and unequal in vertical direction. The vertical grid size varies gradually from 0.005 ($y^+=0.9$) near the wall to 0.064 ($y^+=11.5$) at the center of the channel. Boundary conditions here are: a periodic condition for the streamwise and spanwise directions, a non-slip boundary condition for the upper and bottom floors.

Fig. 2 and Fig. 3 show the calculated mean velocity profiles and *root-mean-square (rms)* of velocity fluctuations using the local PDQ and the local FDQ, respectively, compared with numerical data of Del Alamo and Jimenez (2003).

Three central schemes, CS3($n_u = n_d = 1$), CS5($n_u = n_d = 2$) and CS7($n_u = n_d = 3$), and three upwind schemes, US4($n_u = 2, n_d = 1$), US6($n_u = 3, n_d = 2$) and US8($n_u = 4, n_d = 3$), are considered for the local DQM. Because the Reynolds number here is not very large, there is no distinct unphysical oscillation while using central schemes. The time step, Δt , for the local PDQ is specified as 0.0001 and 0.00005 respectively for the upwind and central schemes. For the local FDQ, Δt is fixed as 0.00005 for all schemes, and it is hard to obtain convergent results using a larger time step as that of PDQ.

As shown in Figs. 2 and 3, the results of the present local DQM have a good agreement with those of Del Alamo and Jimenez (2003) obtained by using the spectral method, though the present grid mesh is much coarse. It should be indicated here that CS3 and US4 of the local PDQ are identical with the traditional three-point second-order central difference and the four-point third-order upwind difference, respectively. It is clear that the present results are improved efficiently with increasing the number of referenced points, and the central schemes are more accu-

rate than the upwind schemes for possessing the least numerical diffusion. Comparisons between Fig. 2 and 3 indicate that the local PDQ and the local FDQ yield almost the same mean-velocity profiles, while some discrepancy for *rms* of velocity fluctuations. So it can be concluded that the local DQM is applicable for the turbulence simulation.

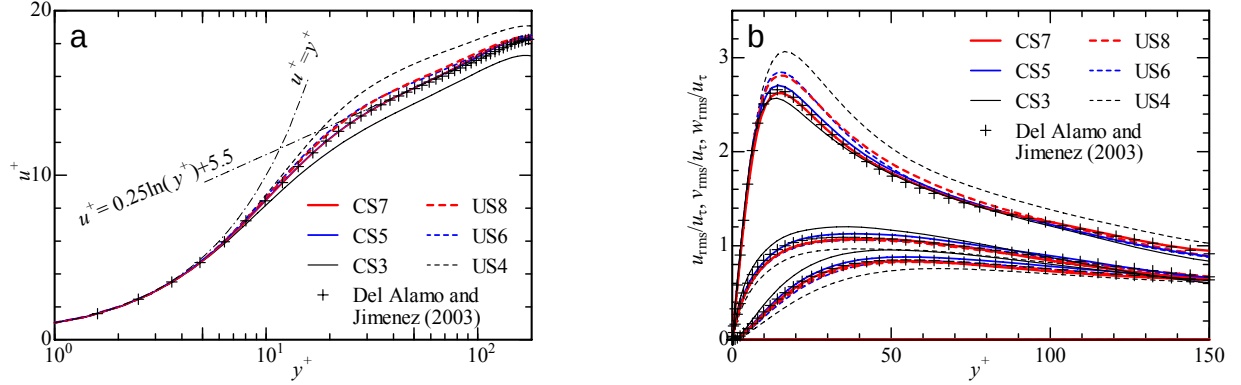


Figure 2. Numerical results of the local PDQ for the channel flow at $Re_\tau=180$: (a) Mean-velocity profiles; (b) *rms* of velocity fluctuations

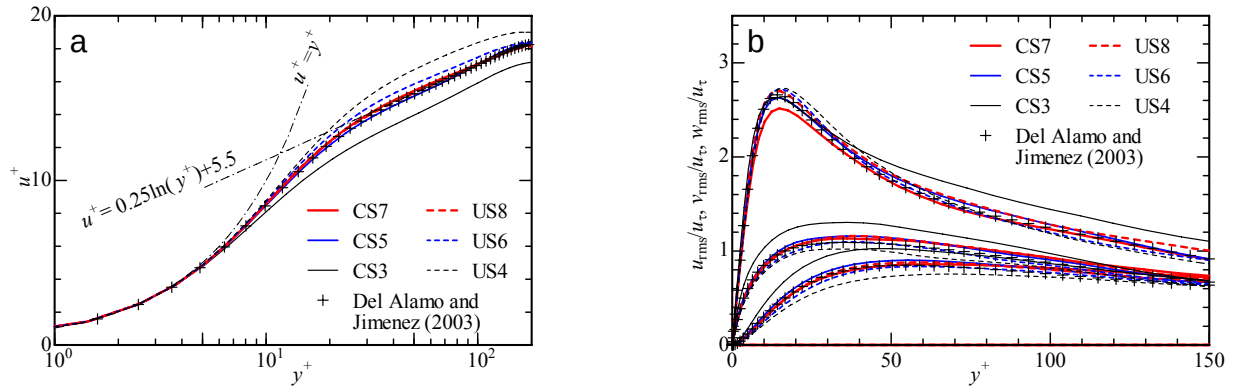


Figure 3. Numerical results of the local FDQ for the channel flow at $Re_\tau=180$: (a) Mean-velocity profiles; (b) *rms* of velocity fluctuations

4 APPROACH FOR GENERATING INFLOW TURBULENCE

The most widely used direct method for generation of inflow turbulence is the recycling method in which the velocity in a downstream plane is extracted and rescaled for the inflow boundary. In this method, the region used to generate turbulence is usually referred to as “driver region”, and the second region that we are interested in is usually referred to as “main region”. Lund, *et al.* (1998) first proposed this rescaling recycling method to generate developing turbulent inflow data for LES. Kataoka and Mizuno (2002) simplified Lund’s method by assuming that the boundary layer thickness is constant within the driver section. Nozawa and Tumura (2002) extended Lund’s method to a rough-wall boundary layer flow using a roughness block arrangement. For simplicity, the simplified recycling method proposed by Kataoka and Mizuno (2002) is adopted in this paper to generate inflow turbulence, and its detailed process is shown in Fig. 4.

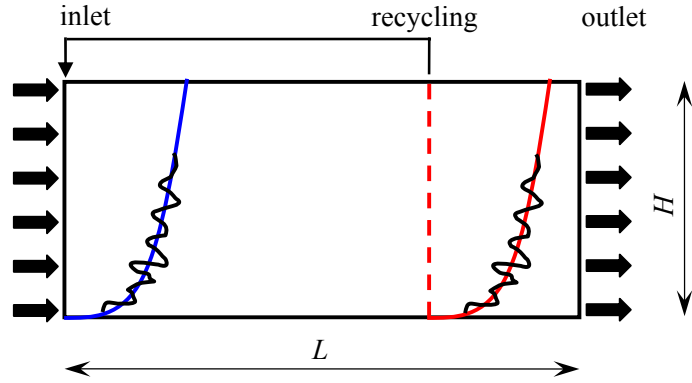


Figure 4. Sketch map of Kataoka's recycling method

A mean velocity profile is prescribed at the inlet, and only the fluctuating part is directly extracted from the recycling station to the inlet boundary without rescaling. The velocity components at the inlet are given as follows,

$$\begin{cases} u_{\text{inlt}}(y, z, t) = \langle u \rangle_{\text{inlt}}(z) + \phi(\eta) \times \{u(y, z, t) - \langle u \rangle(y, z)\}_{\text{recy}} \\ v_{\text{inlt}}(y, z, t) = \phi(\eta) \times \{v(y, z, t) - \langle v \rangle(y, z)\}_{\text{recy}} \\ w_{\text{inlt}}(y, z, t) = \phi(\eta) \times \{w(y, z, t) - \langle w \rangle(y, z)\}_{\text{recy}} \end{cases} \quad (9)$$

where the subscripts denote the values at the inlet (inlt) and the recycling (recy) station, and $\langle \cdot \rangle$ represents a time-averaged value. $\langle u \rangle_{\text{inlt}}$ is set as the prescribed velocity profile. The added damping function $\phi(\eta)$ blocks the velocity fluctuation from developing in the free stream. Kataoka (2008) gave the damping function as

$$\begin{cases} \phi(\eta) = \frac{1}{2} \left\{ 1 - \tanh \left[\frac{8.0(\eta - 1)}{0.82 - 0.4\eta} \right] \right\} / \tanh(8.0) \\ \eta = y/\delta \quad (\delta : \text{boundary layer thickness}) \end{cases} \quad (10)$$

Other boundary conditions are: a convection outflow boundary condition for the outlet, a free-slip boundary condition for the ceiling, a non-slip boundary condition for the bottom and a periodic condition for the spanwise boundary.

5 GENERATION OF INLFOW TURBULENCE USING THE LOCAL DQM

Generation of inflow turbulence using traditional low-order numerical algorithms usually suffers the difficulty of bad statistics, especially as the power spectral density for lack of high-frequency energy. An efficient approach to solve this defect is to use a finer mesh which consequently results in a large computational load. Another efficient way is to use high-order methods. In this section, the local DQM will be used to generate inflow turbulence at two relatively high Reynolds numbers, $Re_0 \approx 1120$ and 1460 , based on the recycling approach presented in Section 4. At these high Reynolds numbers, it is hard for the central schemes of the local DQM to obtain convergent results because of large numerical oscillation. In addition, the local PDQ and the local FDQ have almost the same behavior in turbulence simulation just as shown in Section 3. So, only upwind schemes of the local PDQ are used here, which undoubtedly introduce some nu-

merical diffusion. However, our focus will mainly be put on preservation and the high-frequency energy.

5.1 Details for the calculation

It is assumed that the boundary layer thickness is constant in the recycling section from the inlet to the recycling station (Kataoka and Mizuno 2002), so the streamwise length of the recycling section can not be very large. Referring to the work of Kataoka and Mizuno (2002) and Kataoka (2008), the streamwise length of the recycling section is specified here as δ , and the whole computational domain is $L=1.5\delta$ in flow direction, $H=1.6\delta$ in vertical direction and 1.2δ in spanwise direction. A relatively coarse mesh, $50 \times 90 \times 40$ in streamwise, vertical and spanwise direction, is generated. Uniform grid is used in the streamwise and spanwise direction, and unequal in vertical direction. The vertical grid size varies from 0.0012δ near the wall to 0.078δ at the ceiling. The discretization schemes are the same as those of Section 3 and the same staggered mesh is used. The damping function of Eq. (10) is applied.

Two different mean-velocity profiles of power law are prescribed at the inlet boundary with exponent $\alpha=0.21$ and 0.17 for $Re_\theta \approx 1120$ and 1460 , respectively.

5.2 Results and comparisons

Fig. 5 shows the calculated mean-velocity profiles at several positions, $x/\delta=0.25, 0.75$ and 1.25 , in streamwise direction compared with target ones, numerical data of Jimenez, *et al.* (2009) at $Re_\theta \approx 1100$ and experimental data of DeGraaff and Eaton (2000) at $Re_\theta \approx 1430$.

Only three upwind schemes, US4($n_u=2, n_d=1$), US6($n_u=3, n_d=2$) and US8($n_u=4, n_d=3$), are considered here. As shown in Fig. 5, the calculated mean-velocity profiles of the above three schemes all have a good agreement with the target one while the discrepancy becomes a little larger at downstream. As a whole, the mean-velocity profile is well preserved in the computational domain.

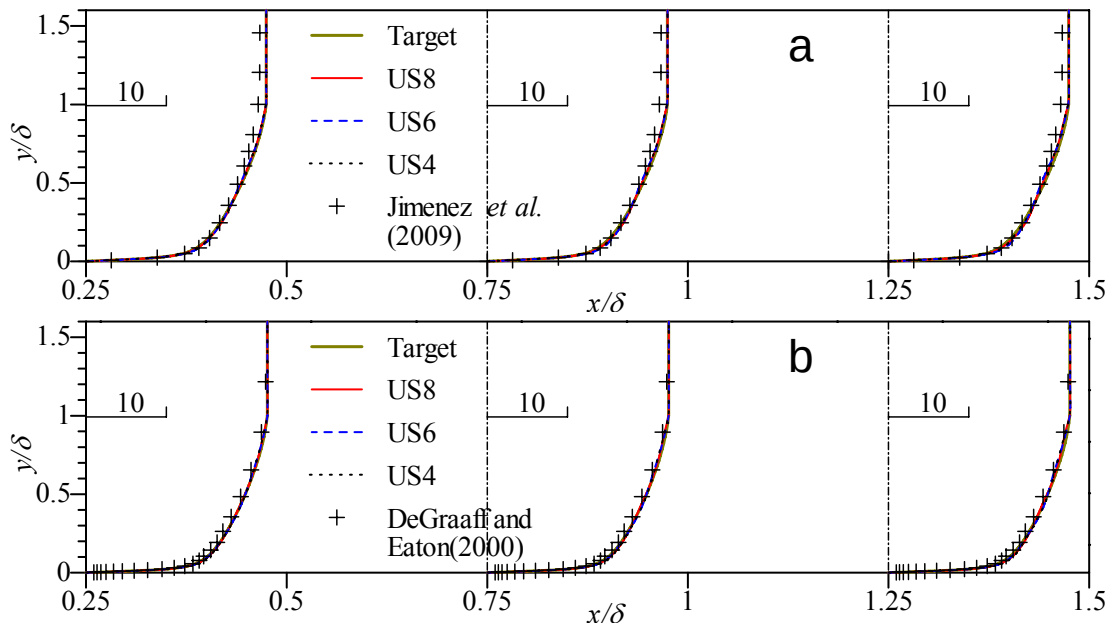


Figure 5. Calculated *rms* profiles: (a) $\alpha=0.21$ and $Re_\theta \approx 1120$; (b) $\alpha=0.17$ and $Re_\theta \approx 1460$

Fig. 6 shows the calculated rms of the streamwise velocity fluctuation in wall unit, u_{rms}/u_τ , compared with the numerical results of Jimenez *et al.* (2009) at $Re_\theta \approx 1100$ and experimental data of DeGraaff and Eaton (2000) at $Re_\theta \approx 1430$. Like the mean velocity, the profile of rms can also be well preserved in the computational domain. However, all the three upwind schemes overestimate rms within the height of δ and underestimate it above this height. Good agreement is shown for the higher order scheme, US8, although there is a large discrepancy in the outer region. This may attribute to the selection of the damping function. In our trial calculations, it is found that the rms , especially in the outer region, heavily depends on the selection the damping function. However, we are not going to discuss this problem, because our focus is not here.

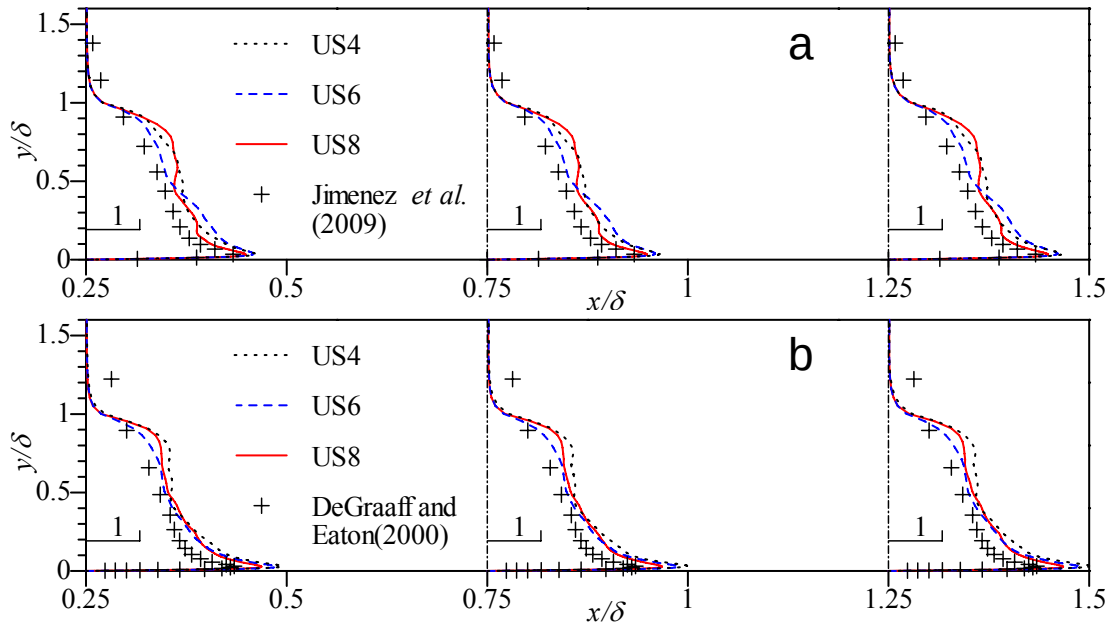


Figure 6. Calculated rms profiles: (a) $\alpha=0.21$ and $Re_\theta \approx 1120$; (b) $\alpha=0.17$ and $Re_\theta \approx 1460$

From the above results and comparisons, it can be concluded that the recycling method based on the local DQM can generate relatively satisfied mean and rms results. Besides, this method has a good preservation which may mainly attribute to the short streamwise length of the computational domain.

Fig. 7 shows the power spectral densities of the along-wind velocity fluctuation at $x/\delta=0.75$, $y=0.075\delta$ ($y^+ \approx 32$) and $z/\delta=0.6$ for $Re_\theta=1120$ and at $x/\delta=0.75$, $y=0.075\delta$ ($y^+ \approx 43$) and $z/\delta=0.6$ for $Re_\theta=1460$, compared with the Karman spectrum. The data of US4 follows the Karman spectrum until $n\delta/U=2.3$, US6 until $n\delta/U=3.5$ and US8 until $n\delta/U=4.3$ for $Re_\theta \approx 1120$. The improvement of high-order schemes to the high-frequency energy is remarkable. And similar conclusions can be obtained for $Re_\theta \approx 1460$. This can also be obtained from the corresponding time histories of the along-wind velocity as shown in Fig. 8.

Only one second, from 6 to 7, of the time history is presented in Fig. 8 for a clear show. Mean velocities of the three time histories are almost the same. It can be seen clearly from Fig. 8 that the curves become smoother and smoother with decreasing the order of the local PDQ from US8 to US4. It means that smaller vortex can be represented using higher-order schemes of the local DQM at the same mesh.

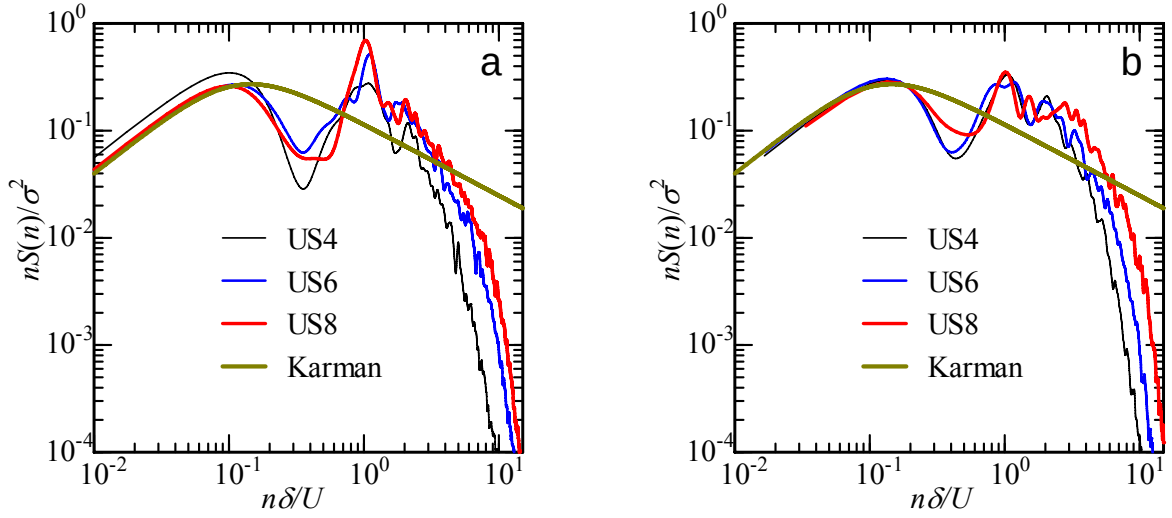


Figure 7. Calculated power spectral densities: (a) $\alpha=0.21$ and $Re_\theta \approx 1120$; (b) $\alpha=0.16$ and $Re_\theta \approx 1460$

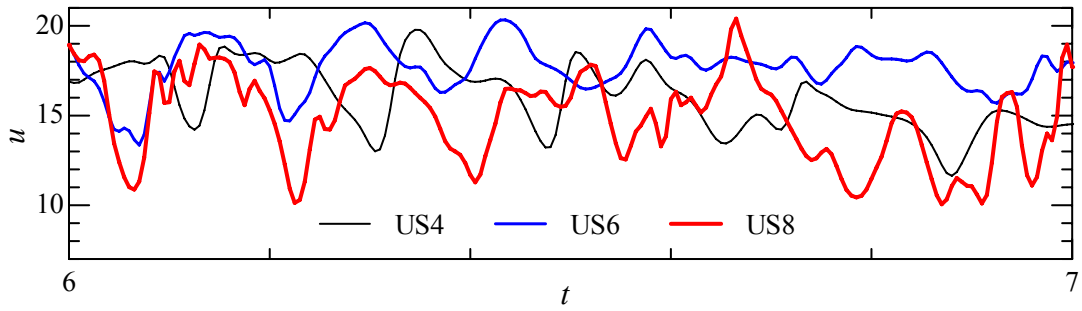


Figure 8. Time histories of the along-wind velocity for $Re_\theta \approx 1120$ at $x/\delta=0.75$, $y/\delta=0.056$, and $z/\delta=0.6$

6 CONCLUSIONS

In this paper, a local DQM is developed from the traditional global DQM based on the idea of localization combined with a common staggered mesh, different from existing ones. This method can be viewed as a generalized finite difference method. An upwind grid number and a downstream grid number are introduced into the formulae of this local DQM. Different upwind/central schemes of the local DQM can be obtained by changing these two numbers. The local PDQ whose weighting coefficients are obtained by polynomials and the local FDQ whose weighting coefficients calculated by the Fourier expansion are both applied to the channel flow with several upwind/central schemes. Results indicate that the local PDQ and the local FDQ both perform well, and the central schemes are more accurate than the upwind ones for possessing the least numerical diffusion. Finally, the local PDQ is successfully applied to generate inflow turbulence with several upwind schemes. The mean properties and turbulence intensities can be well preserved in the computational domain. With increasing the referenced grid number, the high-frequency energy is efficiently enhanced.

7 ACKNOWLEDGEMENTS

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