NUMERICAL INVESTIGATION OF FLOW CHARACTERISTICS OVER DIMPLED SURFACE

by

Mingwei GE
School of Renewable Energy, North China Electric Power University, Beijing, China

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Flow characteristics over dimpled surface are studied numerically for a fully developed turbulent channel. The results show that dimples can effectively activate the near wall turbulence and cause an increase of total drag. The dimple depth also plays an important role in enhancement of hear transfer.

Key words: *dimpled surface, direct numerical simulation, flow characteristics, turbulent channel flow*

Introduction

Dimpled surface has drawn more and more interests in the scientific community for its considerable effectiveness in the enhancement of hear transfer and turbulent mixing. Compared with the other passive devices such as pimples, pin-fin arrays and rib tabulators, dimpled surface shows great superiority by causing a smaller pressure drop [1-3]. To give deep insights of the flow above dimpled surface, Isaev *et al*. [4] studied numerically the flow structures over a single dimple through an RANS-based simulation. A pair of horseshoe-like vortical structures was found in the dimple cavity. For more practical applications, dimple-arrayed channels were studied extensively. Through experiment, Ligrani *et al*. [5] and Burgess and Ligrani [6] observed a primary vortex pair periodically shedding in the central of the dimples. The experimental results show that the dimple depth significantly affects the intensity of the vortex pair but it is irrelative to its oscillation frequencies. Using k-ε model the flow characteristics were carefully studied by Park *et al*. [7]. An evident connection between the vortex pairs and the augmented eddy diffusivity for momentum and heat was reported [7]. The flow and heat transfer were also studied by either direct numerical simulation or large eddy simulation to show more instantaneous details of the flow structures [8, 9], focusing on the coherent structures in the near wall turbulence. Besides, the flow structures and thermal performances were also investigated by many scientists [10-14], and others. Most of the studies were mainly focusing on the spherical dimples, the study on the dimple shapes described by the other functions is still very lacking.

The cosine shaped dimples located on the lower wall in a staggered arrangement are investigated via direct numerical simulation in a fully developed turbulent channel. Four dimpledepths are involved in this study to show the effect of the dimple depth on the drag coefficients and flow characteristics.

Authors' e-mail: gmwncepu@163.com

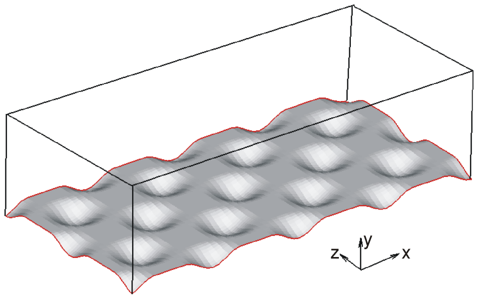

Figure 1. Schematic of the flow over arrays of dimples in a turbulent channel

Physical problem and numerical methods

Turbulent flow between two indefinite parallel plates with multi-dimples is studied numerically, as shown in fig. 1. The Navier-Stokes (N-S) equations for the incompressible Newtonian fluid are taken as the governing equations. The Reynolds number, Re_H, based on the bulk mean velocity and the half channel width H is 2850. The periodic boundary condition is used in the streamwise and spanwise directions. No slip boundary condition is used on the lower and upper walls. The profile of the dimples can be described by the following function:

$$\eta(x,z,t) \quad \begin{array}{ll} \dfrac{h}{2} \;\; 1 \quad \cos\dfrac{2\pi r}{D} \;, & r \quad D/2 \\ 0, & r \quad D/2 \end{array} \tag{1}$$

where $r = [(x - x_0)^2 + (z - z_0)^2]^{1/2}$; x_0, z_0 are the centre of each dimple, D is the diameter of the dimples, and h – the depth of the dimples from the wall on (x_0, z_0). A pseudo-spectral method is used to solve the 3-D N-S equations. The Fourier Galerkin and Chebyshev-Tau method are used for spatial discretization of the channel flow, and a 3-order time splitting method is adopted for advance of time. For more details see Ge *et al.* [15]. The computational domain spans 4π 2 2π in the streamwise, wall normal and spanwise directions, respectively, in accordance with 64 65 64 grids. The flow is started from a fully developed turbulent flow field in a flat channel. During numerical simulation, the flow rate is kept constant.

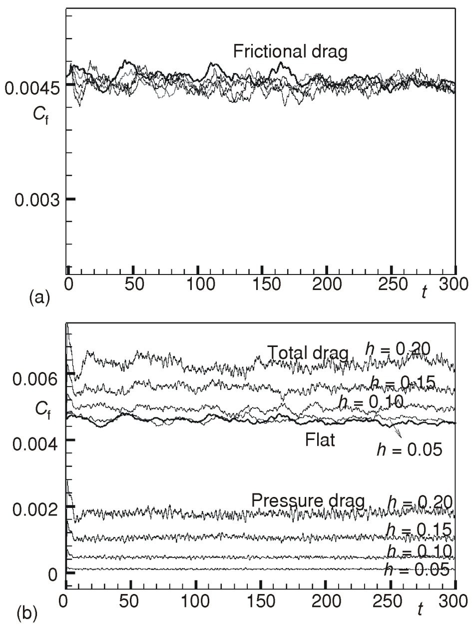

Figure 2. Time traces of the frictional drag, total drag, and pressure drag; thick solid line denotes the drag coefficient of the flat channel

Results and discussions

Sixteen dimples are placed on the lower wall of the channel in a staggered arrangement, fig. 1. The diameter of the dimples is selected to be 2.0 following Wang *et al.* [8]. Four different depths ($h = 0.05$, $h = 0.10$, $h = 0.15$, and $h = 0.20$) are investigated. Time evolutions of the frictional drag, total drag, and pressure drag coefficients for the dimpled surfaces are shown in fig. 2. For clarify, the evolution of the drag coefficient for the flat channel is also given for comparison. Interestingly, the frictional drags remain the value around 0.0046 for all the studied cases, regardless of the dimple depth. The shear stress is marginally reduced by the shallow dimples but the effect on the drag is overcome by the newly appearing pressure force. With the increase of dimple depth, both the pressure drag and total drag increase evidently. As can be observed, for the case $h = 0.2$, the total drag increase by about 30% compared with the flat channel.

Figure 3(a) shows the mean velocity along a vertical line through the center of a dimple. The mean velocity profile for the flat channel is also given out for comparison. Above the dimpled surfaces, the mean flow velocities are clearly increased. But in the dimples, the mean velocities occur to be negative for the case $h = 0.15$ and $h = 0.2$, which indicates flow separations in the cavity of the dimples. For more clarify, the streamlines in a (x-y) plane across the center of a dimple are shown in fig. 4. For the very shallow dimples ($h = 0.05$ and $h = 0.1$), the mean flow can pass the dimples smoothly. But for the deeper dimples, flow separation occurs and a spanwise vortex is formed in the cavity of the dimple. With the increase of the dimple depth, the separation in the cavity becomes larger and larger. The distribution of the Reynolds stress using to show the activity of the turbulence in quantity is also exhibited in fig. 3(b). The results show that the Reynolds stress is greatly enhanced by the dimples in the near wall region. With the increase of the dimple depth, the peak location of the Reynolds shear stress is shifted closer to the wall with a larger value. It can be concluded that the mean flow is effectively changed and the near wall turbulence is significantly excited by the arrays of the dimples located on the lower wall.

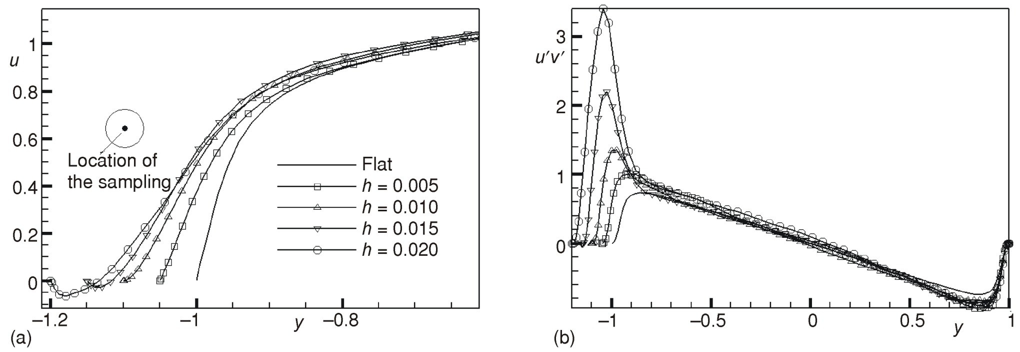

Figure 3. Mean statistics along a vertical line across the center of the dimples; (a) mean velocity and (b) Reynolds stress

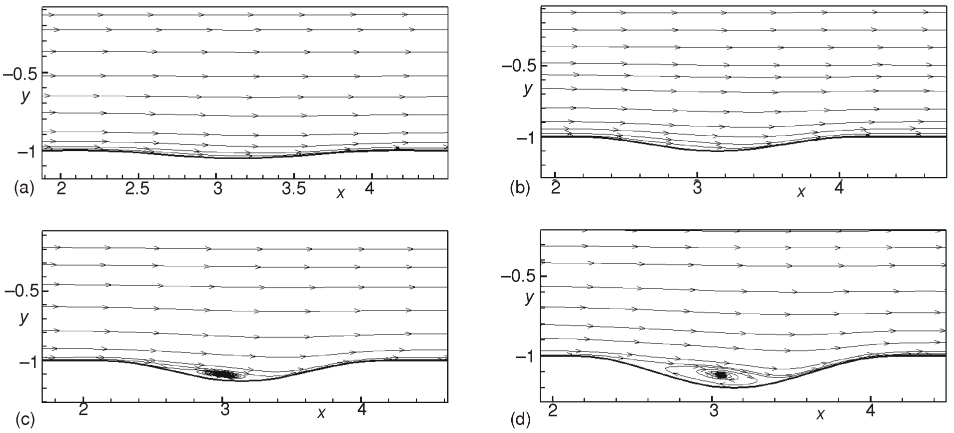

Figure 4. Streamlines for the mean flow field in a x-y plane across the center of a dimple; (a) *h* = 0.05, (b) *h* = 0.1, (c) *h* = 0.15, and (d) *h* = 0.2

Conclusions

Turbulent flow over arrays of dimples is studied via direct numerical simulation in a channel at a low Reynolds number. The shape of the dimple is described by a cosine function. Four depths ($h = 0.05$, $h = 0.10$, $h = 0.15$, and $h = 0.2$) are involved in this study. It is found that both the mean flow and near wall turbulent fluctuations can be significantly affected by the cosine shaped dimples. The deeper of the dimple, the larger of the flow separation occurs in the cavity and the higher of the Reynolds stress generated in the near wall turbulence, companioned by a larger pressure drag and a larger total drag.

Acknowledgments

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