

NUMERICAL SIMULATIONS OF FLOWS IN DIMPLED CHANNELS

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Summary Laminar and turbulent channel flows over dimples are studied using our parallel multiblock multigrid incompressible flow solver. ‘Horse-shoe’ vortex has been found in laminar regime. Due to the separation structures inside dimples large reduction of shear drag can be achieved. However, net reduction of total drag in laminar regime is rather minor because the inevitable increases of form drag. DNS of turbulent flow over dimpled channel has also been carried out. Flow visualization shows turbulent flow structures are more complex on dimpled channel than those on a flat wall channel. These results may help to explain the heat transfer augmentation effects of dimpled surfaces.

LAMINAR FLOW OVER DIMPLED SURFACE

A finite volume based parallel DNS code has been developed. A second order implicit fractional step algorithm [1] is employed in time splitting. Second order central difference scheme is used for spatial discretization. ‘Horse-shoe’ vortex has been found inside single dimple (Fig 1). Computational results agree very well with Isaev et al.[2]. Furthermore, the effects of flow and dimple parameters on this 3D flow structures are also studied. Reducing the Reynolds number causes this 3D vortex to become less stretched. When the Reynolds number gets to about 300, 3D vortex degenerates into a highly 2D vortex circulating inside the dimple. Further decreasing Reynolds number gradually reduces the length of separation zone. When Re reaches about 40, no separation zone can be observed. Flow particles simply ‘dive’ in and out of the dimple. Computations also show that the effects of reduction of dimple depth or dimple diameter are similar to effect produced by reducing Reynolds number. Edges are shown to have only minor effects on flow structure in laminar regime.

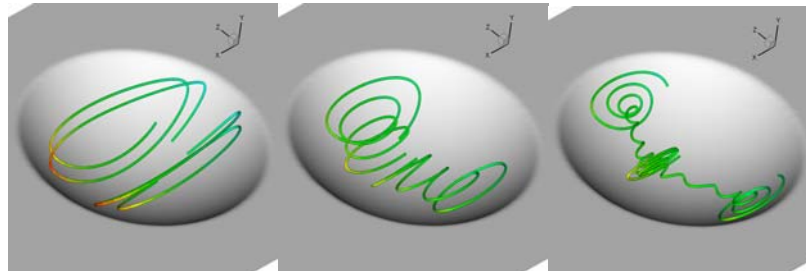


Fig 1. ‘Horse shoe’ vortex inside single dimple.

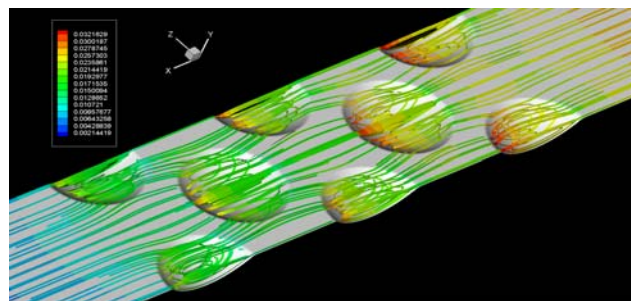


Fig.2 Flow structure inside multiple dimpled channel.

Without significant outside perturbations, ‘horse shoe’ vortex can also be observed in multiple-dimpled channel (Fig 2). Because of this circulating vortex structure inside each dimple large reduction of shear drag can be achieved. On the other hand, dimple- depressions inevitably augment form drag. Therefore, net reduction of total drag in laminar regime is rather minor. By shifting dimple bottom upstream, the pressure drag can be further reduced. Despite the increase in the shear drag at the same time, a slight improvement of the total drag can also be obtained.

TURBULENT FLOW OVER DIMPLED SURFACE

Turbulent mean flow structures induced by dimples have been studied using steady closure-models based on the assumption that large flow structures are statistically time-independent [3, 4]. Recent experiments reveal that there exist relatively large unsteady vortex structures periodically shedding from the dimples [5]. This experimental finding suggests the need for DNS of turbulent flow over the dimples to further elucidate the flow physics. Therefore, DNS of turbulent flow in a dimpled channel is also performed to study the unsteady near-flow structures induced by dimple depressions.

In this study, DNS of turbulent flow over smooth wall channel [6] is first repeated to check the accuracy of the current code. The Reynolds number based on total pressure gradient Re_{Π} is set at 180. With a stretched grid of 128^3 , the computational error for the total shear is found to be less than 2% for the flow. Thereafter, turbulent flow in a channel with dimples on the lower wall is simulated, based on the same average streamwise pressure gradient (Fig. 3). Separated mean flow structures can be observed inside the dimples (Fig. 4). With the same average pressure gradient (or pressure drop) maintained for both smooth and dimpled channels, a significant reduction of flux is observed for the latter case. This suggests that there would be a significant increase in the drag for the dimpled channel if the same flow rate is maintained through both channels. Furthermore, particles are released along a line parallel to the z-axis at $y=10$. Results show that the particle line distorts much more rapidly in the dimpled channel, showing greatly enhanced mixing (Figs. 5). These results may help to explain the heat transfer augmentation effects of dimpled surfaces.

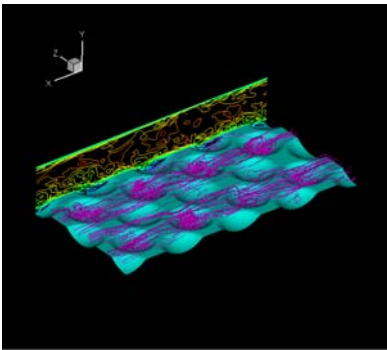


Fig.3 Turbulent flow structure inside a multiple dimpled channel.

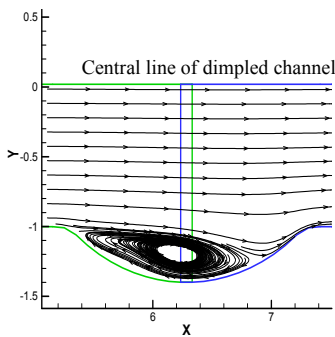


Fig. 4 2D section of 3D mean flow.

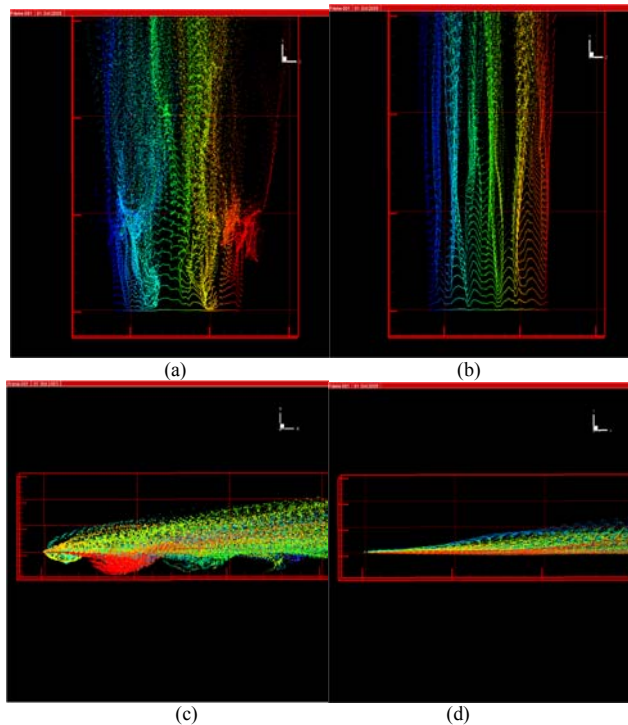


Fig. 5 Smoke line released along a line parallel to z-axis at $y=10$ (a) dimpled channel (top view) (b) smooth wall channel (top view); (c) dimpled channel (side view); (d) smooth wall channel (side view). Flow direction along x-axis, particles are colored by their z coordinates).

Reference

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