11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

LARGE-EDDY SIMULATION OF TURBULENT FLOW OVER A WALL UNDERGOING STREAMWISE TRAVELING-WAVE MOTION

Wu-Yang Zhang, Wei-Xi Huang, Chun-Xiao Xu and Gui-Xiang Cui

Department of Engineering Mechanics, Tsinghua University, Beijing 100084, China,
xucx@tsinghua.edu.cn

Key Words: *Turbulent Flow, Moving Wall, Large-Eddy Simulation, Nonlinear SGS Model.*

Large-eddy simulation (LES) is a promising tool for predicting engineering complex turbulent flows. Hitherto most of the studies are focused on the flows with static geometries, and we are still very lack of the knowledge on turbulent flows interacting with the moving boundaries. Experiences are especially needed for large-eddy simulations of turbulent flows over moving and deforming walls. In the present work, direct (DNS) and large-eddy simulations (LES) are performed to turbulent flows in a channel with a wall undergoing streamwise traveling-wave motion to accumulate the knowledge on turbulence properties near a moving wall and to evaluate and develop the appropriate subgrid-scale models.

For the great efficiency and high accuracy, the spectral method is used to simulate the channel flows with more complicated time-dependent wall geometries. Instead of the equations written in the covariant or contra-variant form in general curvilinear coordinate [1,2], in the present study, the velocity components are still defined in the physical space and the governing equations are written and solved in the computational space [3,4] to avoid the extra terms resulting from the covariant or contra-variant vectors which make the computation much more expensive. For spatial discretization, Fourier series are used in the horizontal directions and Chebyshev polynomials are adopted in the vertical direction. Time advancement is accomplished by a third-order time-splitting method. Compared with the previous schemes [1,3,4], the present scheme keeps the spectral accuracy while the computational cost is greatly reduced.

The direct numerical simulations are first performed to the turbulent flows in a channel with the bottom wall moving in the wall-normal direction (y) in the form of the streamwise (x) traveling wave, $y_{\mathrm{wall}} = a \sin k (x - c\ t)$. The computational domain spans $4\pi\times2\times2\pi$. The amplitude of the wall deformation is $a = 0.125$, and the streamwise wave number $k = 2$. Two Reynolds numbers based on the channel width and the mean wall friction velocity, $Re_\tau = 300$ and 400, are considered with three different wave speed $c = 0$, 0.4 and 1.2. The grids in the streamwise (x), wall-normal (y) and spanwise (z) directions are $192\times192\times192$ and $576\times192\times384$ for the lower and higher Reynolds numbers, respectively. The results at $Re_\tau = 300$ are compared with those of [4] to validate the present numerical methods and the codes. They show good agreements.

Figure 1 shows the distribution of the mean streamlines and the contours of streamwise velocity, vertical velocity, and pressure at $Re_\tau \approx 400$, $c = 0$ and 0.4, respectively. The separation is obviously suppressed by the moving wall, as indicated in [4]. The results by large-eddy simulations will be presented in the congress. Various SGS models will be evaluated, especially the nonlinear model which shows a good performance in the simulation of the rotating turbulent channel flows [5].

The computation was performed on the "Explorer 100" cluster system of Tsinghua National Laboratory for Information Science and Technology. Support from the National Natural Science Foundation of China (Grant Nos. 10925210, 11322221, 11132005) and the Specialized Research Fund for the Doctoral Program of Higher Education is acknowledged.

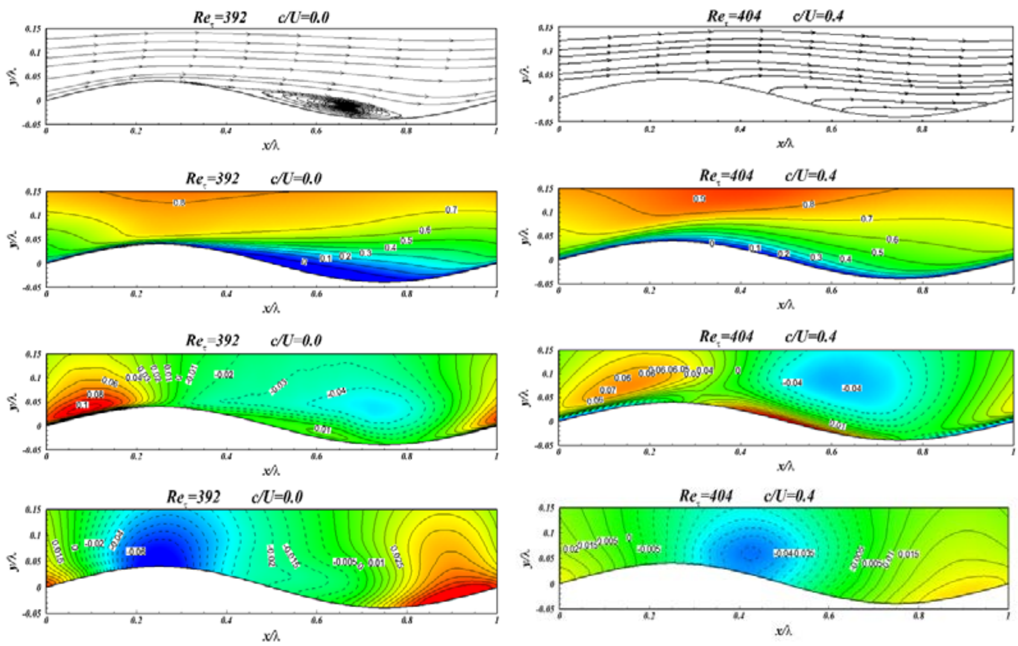

Figure 1. Distribution of the mean streamlines, streamwise velocity, vertical velocity and pressure (from top to bottom) at c = 0 (left) and 0.4 (right).

REFERENCES

[1] H.A. Carlson, G. Berkooz and J.L. Lumley, Direct numerical simulation of flow in a channel with complex time-dependent wall geometries: a pseudospectral method. *Journal of Computational Physics*, Vol. 121, pp. 155-175, 1995.

[2] H. Luo and T.R. Bewley, On the contravariant form of the Navier-Stokes equations in time-dependent curvilinear coordinate systems. *Journal of Computational Physics*, Vol. 199, pp. 355-375, 2004.

[3] S. Kang and H. Choi, Active wall motions for skin-friction drag reduction. *Physics of Fluids*, Vol. 12, pp. 3301-3304, 2000.

[4] L. Shen, X. Zhang and D.K.P. Yue and M.S. Triantafyllou, Turbulence flow over a flexible wall undergoing a streamwise traveling wave motion. *Journal of Fluid Mechanics*, Vol. 484, pp. 197-221, 2003.

[5] Z.X. Yang, G.X. Cui, Z.S. Zhang and C.X. Xu, A modified nonlinear sub-grid scale model for large eddy simulation with application to rotating turbulent channel flows. *Physics of Fluids*, Vol. 24, No. 7, pp. 075113, 2012.