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

Validation of local SGS models for high Reynolds number flow

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Key Words: High Performance Computing (HPC), Computational Fluid Dynamics (CFD), Large Eddy Simulation (LES), local SGS model, OpenFOAM

ABSTRACT

LES results are strongly governed by the reliability of the SGS model as well as the quality of numerical grids and choice of numerical schemes. Therefore, for turbulence at high Reynolds numbers around complex geometries, the development of an SGS model that balances (i) applicability for massive parallel simulation, (ii) numerical stability, and (iii) generality and the accuracy of prediction are important for applying LES to engineering problems. For (i) and (ii), it is preferable that the model coefficient is locally determined to prevent data communication among extra-neighbouring nodes and that its value has a positive sign to avoid negative viscosity. Further, for (iii), it is preferable that as many empirical values can be removed as possible. From this perspective, in this research, a coherent structure model (CSM) [1] and wall adapting local eddy-viscosity (WALE) model [2] were chosen to SGS models, and the accuracy of prediction was verified by simulating turbulence at high Reynolds numbers.

To validate the numerical code, we first performed LES calculation for channel flow, and the numerical results were compared with the DNS results [3]. The Reynolds number based on the friction velocity and the length of channel half-width is 300, and the total number of cells is 5 million. We found that the turbulent statistics such as mean velocity and root mean squares are in good agreement with the DNS results, and numerical errors from the DNS results are within 3% at the maximum. Next, we increased the total number of cells from 5 million to 270 million and measured scale out behaviour based on flat-MPI up to 4096 CPUs on the K-computer. To reduce the calculation time, we tried decreasing communication costs by utilizing characteristic of interconnection networks used in the K computer. Specifically, the number of domain is chosen in multiples of that of one TOFU unit, which consists of 2x3x2 nodes. Figure 1 shows that the scaling with greater than 90% efficiency occurs up to 2048 CPUs, which is more than 30 percent increase compared to the performance of randomly selected.

Next, we performed LES calculations for flow around a two-dimensional shape of ridge under the same conditions used in experiments by Uchida [4]. The total cell number is from 10 million to 80 million, and number of CPUs is from 256 to 1024. The turbulent statistics such as the mean velocity and the turbulent intensity are compared with results obtained by experimental and other standard turbulence models. Here, the standard Smagorinsky model [5] is chosen to LES model, and the SST k-ω model model [6] and the Spalart-Allmaras model [7] are chosen to RANS models. Figure 2 plots the vertical profiles of the streamwise mean velocity at $x = 3h$, where x and h are streamwise distance from the ridge and the ridge height, respectively. We found that the numerical result by the CSM model is in qualitative agreement with the experimental result. This is due to the difference in Reynolds stress generation in each model, therefore contributions from the production term, pressure-strain tensor term and dissipation term on the generation of the Reynolds stress in each model will be reported in subsequent work.

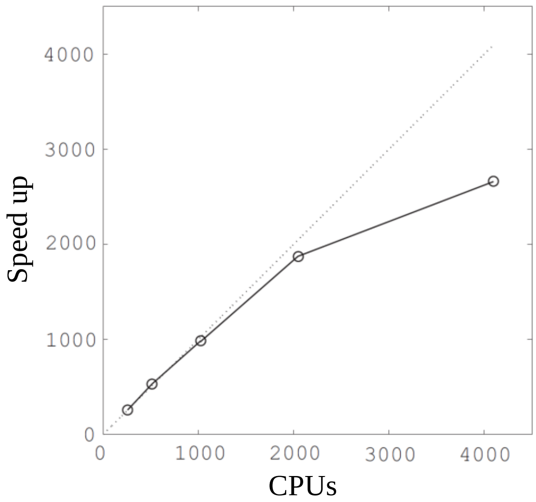

Figure1 Performance of strong scalability up to 4096 CPUs.

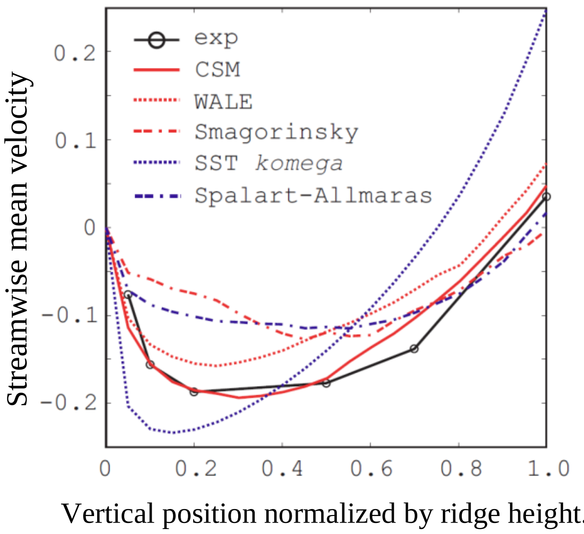

Figure2 Vertical profiles of the streamwise mean velocity after the ridge.

REFERENCES

[1] H.Kobayashi, F.Hama and X.Wu, Int. J. Heat and Fluid Flow Vol. **29,** pp. 640–653, 2008.
[2] F.Nicoud and F.Ducros, Flow, Turbulence, and Combustion, Vol. **62**, pp.183-200, 1999.
[3] K.Iwamoto, Y.Suzuki and N.Kasagi, Int. J. Heat and Fluid Flow, Vol. **23**, pp. 678-689, 2002.
[4] T.Uchida, K.Sugitani and Y.Ohya, , J. Wind Eng., Vol. **29**, pp.35-43, 2004.
[5] J.Smagorinsky, Monthly Weather Review, Vol. **91**, pp. 99-164, 1963.
[6] F.R.Menter, AIAA Journal, vol. **32**, pp.1598-1605, 1994.
[7] P.R.Spalart, and S.R.Allmaras, Recherche Aerospatiale, No. **1**, pp. 5-21, 1994.