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Session:

Wall-modeled large-eddy simulation of the transonic airfoil buffet at realistic high Reynolds number

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The conventional wall-resolved large-eddy simulation (WRLES), which resolves both the inner- and outer-layer parts of the turbulent boundary layer, requires an exceptionally high computational cost to simulate the boundary layers at high Reynolds number [1]. To avoid the rapid growth of required grid points in the WRLES at high Reynolds number, one attractive choice is to model the inner-layer turbulence.

In this abstract, we summarize our recent developments of the wall-modeling approach in LES of realistic high Reynolds number flows. Wall-modeled LES (WMLES) for the prediction of the onset of transonic airfoil buffet phenomena at high Reynolds number is also demonstrated.

Wall-modeling approach in LES

Our wall-modeling approach in LES is based on our prior studies for high Reynolds number compressible flows [2,3,4]. Generally speaking, the computations of WMLES suffers from the most persistent errors, so-called “log-layer mismatch.” Kawai and Larsson [2] pointed out the near-wall numerical and sub-grid modelling errors in WMLES and proposed a simple approach to remove the log-layer mismatch based solely on physical reasoning as shown in Fig. 1. This approach is then extended to flows without equilibrium assumption and applied to a shock wave/boundary-layer interacting separated flow [3] with the localized artificial diffusivity method [4] for robust shock capturing (Fig. 2).

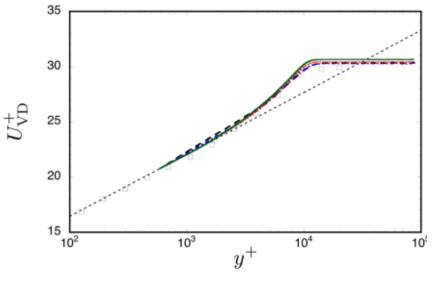

Fig. 1 van Driest-transformed mean velocity obtained by present WMLES.

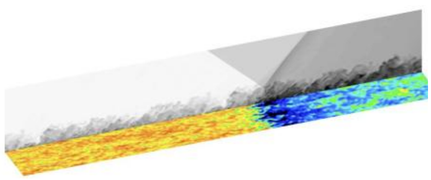

Fig. 2 Prediction of shock wave/boundary layer interactions with the present WMLES approach [3].

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Results

Flow conditions of transonic airfoil buffet are Re_c=3.0×10^6 and α=3.5deg [5]. Two freestream Mach numbers (buffet condition, M_∞=0.73; non-buffet condition, M_∞=0.715) are computed to assess the capability of WMLES for predicting the buffet onset. Figure 3 shows the mean pressure coefficient on the airfoil surface. The present WMLES successfully predicts the buffet onset, and the mean pressure at M_∞=0.73 shows a reasonable agreement with the experimental data [6]. Figure 4 shows the sound pressure level of the wall pressure fluctuations. This result indicates that the buffet motion and the high-frequency outer-layer turbulence structures are adequately captured in the WMLES. Figure 5 shows the snapshots of instantaneous streamwise velocity distribution at M_∞=0.73. The turbulent boundary layer starts to separate when the shock wave moves to upstream, and remains attached when the shock wave moves to downstream. These intermittent shock-induced separation and reattachment retain the periodic shock wave oscillations. Wall-modeling in the LES and the use of large-scale K supercomputer made it possible to apply the high fidelity LES to airfoil buffet phenomena that have a very low-frequency shock oscillation.

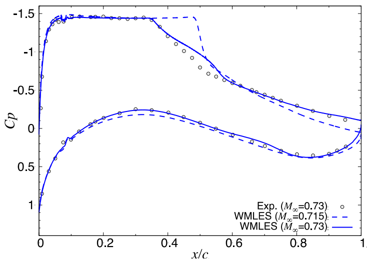


Fig. 3 Time-averaged pressure coefficient on the airfoil surface [5].

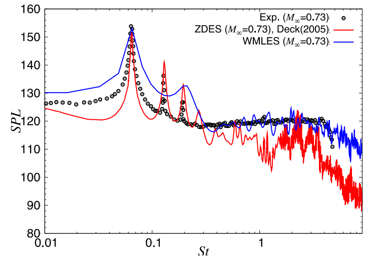
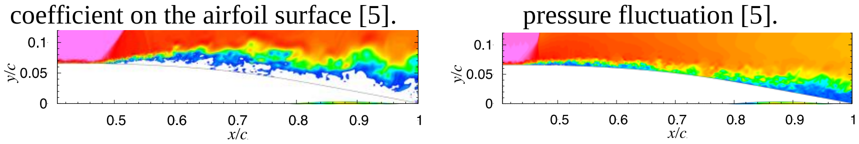


Fig. 4 Sound pressure level of the wall pressure fluctuation [5].



(a) shock wave to upstream (b) shock wave to downstream

Fig. 5 Snapshots of instantaneous streamwise velocity distribution u/u_∞ in the side view at buffet condition (M_∞=0.73) [5]. White areas indicate $u/u_\infty < 0$.

References

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