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Detached-eddy simulation of NASA-CRM transonic buffet

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Introduction

In prediction of aerodynamics, it is expected to cover the flight envelope of the aircraft. One of the challenges is to predict the transonic buffet onset using computational fluid dynamics (CFD). In the flowfield, shock wave over the wing interacts with the shallow separation of the boundary layer[1]. Therefore it is difficult to predict the buffet phenomena by CFD and some researchers attempt to improve the unsteady computation method such as RANS/LES hybrid methods[2,3]. In JAXA, we are also developing the Navier-Stokes flow solver which is aimed at the prediction of transonic buffet.

In this study, we perform the unsteady computations of massive and shallow separation on NACA 0012 airfoil and on NASA-CRM wing configuration by using the detached-eddy simulation and attempt to predict the transonic buffet.

Computation methods

As an unstructured mesh based flow solver, FaSTAR (FaST Aerodynamic Routines)[4] developed by JAXA is employed. The three-dimensional compressible Navier-Stokes equations are discretized by finite volume method. A simple low-dissipation AUSM (SLAU) scheme is employed to evaluate the numerical flux functions. Second-order spatial accuracy is realized by U-MUSCL interpolation and gradients at cell center are reconstructed by a Green-Gauss-based weighted least squares method (GLSQ), and Venkatakrishnan-like limiter extended for unstructured mesh is used. For time integration, three-point backward difference scheme and LU-SGS implicit method are employed for physical time stepping and for sub-iteration, respectively. The number of sub-iteration is eighty in this study. For unsteady turbulence calculations, Spalart-Allmaras DES is employed.

Results

Figure 1 shows the obtained pressure coefficients on the surface of NACA 0012 airfoil at 45 degree angle of attack, which is the massive separation. The flow conditions are M=0.2 and Re=1.0x10^5. As the comparison with RANS result, c_p on the upper side obtained by DES agrees quite well with that of the experimental data[5].

The DES results of the shallow separation of the boundary layer on NACA 0012 airfoil are shown in Fig. 2 and 3. Figure 2 shows the typical flowfield with M=0.72, Re=1.0x10^7 and 5.4 degree angle of attack. In this figure, the Mach contours and the iso-surfaces of the second invariant of velocity gradient colored by Mach contours are shown. It can be seen that the turbulent boundary layer develops behind the shock wave. Figure 3 shows the standard deviation of the lift coefficient ΔC_L . The obtained ΔC_L increases as the angle of attack increases indicating the appearance of high-speed buffet.

Finally, the contours on the upper surface of NASA-CRM three-dimensional wing are shown in Fig. 4. It can be seen that the fluctuations of C_p occur because of turbulent flow behind the shock wave.

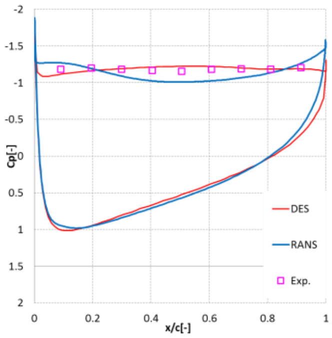

Figure 1 pressure coefficients on NACA 0012 airfoil.

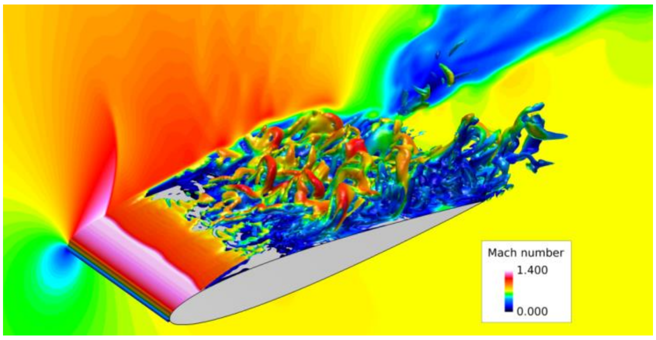

Figure 2 Mach contours and the iso-surfaces of the second invariant of velocity gradient.

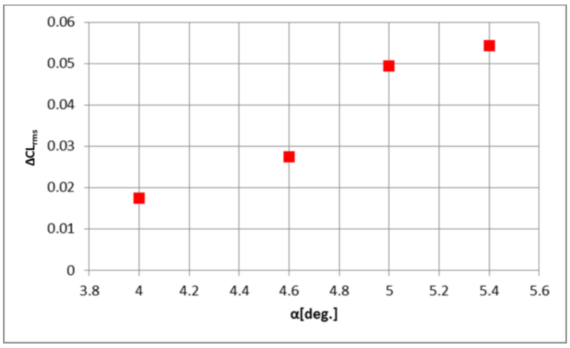

Figure 3 Standard deviation of lift coefficient ΔC_L

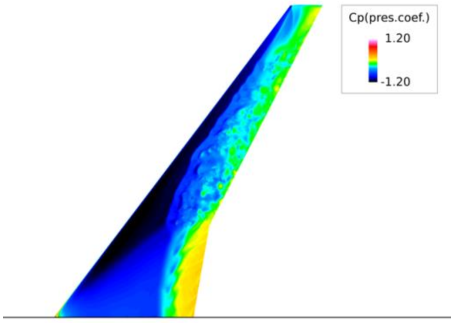

Figure 4 C_p contours on the upper surface of NASA-CRM

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