Numerical Simulation Shock Wave Buffet on an OAT15A Airfoil by IDDES hybrid methods

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Summary Unsteady shock wave buffet phenomenon on the upper surface of an OAT15A airfoil at Mach number of 0.73 and angle of attack of 3.5 degrees is predicted using IDDES hybrid methods. Periodical oscillations of shock waves in the streamwise direction and strong shear layers are captured. Then, two vortex generators (VG) in one span of 0.26 chord length are mounted in front of the shock wave region to suppress buffet. VGs significantly suppressed the RMS level of pressure.

GEOMETRY AND METHODS

In the present paper, strong unsteady shock wave buffet phenomenon induced by shockwave/boundary-layer interactions on the upper surface of an OAT15A supercritical airfoil at Mach number of 0.73 and angle of attack of 3.5 degrees is numerically predicted by RANS/LES hybrid method. An STVD scheme called S6WENO5, which is a combination of 6th-order centered scheme and 5th-order WENO interpolation scheme, is used with an adaptive function related to flow structures introduced into dissipation terms to implement low dissipation method in turbulence-dominant separation regions.

Firstly, the uncontrolled case is predicted by IDDES methods based on two-equation k-w SST model. The simulation is based on ONERA's wind tunnel experiment works on shock wave buffet of an OAT15A supercritical airfoil, which is a standard simulation case in EU's 7th framework for RANS/LES hybrid methods – ATAAC project. The airfoil has no sweep angle, a chord (C) length of 230mm and a span of 780mm. The maximum thickness is 12.3% chord length, and trailing edge thickness is about 0.5% chord length. At Mach number of 0.73 and 3.5 degrees angle of attack, strong buffet and boundary layer separation after the shock wave was observed. The simulation grid of 7.5M overall cells is shown in Fig. 1. The simulation region is rectangular with a height of 780mm. Spanwise boundary conditions are periodical, with a span length of 0.26C split in 64 evenly distributed cells. First cell height for the normal wall grids is about 5×10^{-6}C. In the streamwise direction, grid cells at shockwave regions on upper surface, downstream and in the wake regions, where small-scale flow structures induced by shock wave/boundary separation exist, are refined to meet the needs for LES methods: a requirement for same cell length in streamwise and spanwise direction. Fixed transition is switched on at 7%C streamwise location on upper surface.

Then, as buffet badly harms flight performance and aircraft structure lifespan, attempts to control or eliminate shock buffet with VGs are conducted. Two vortex generators (VG) both with an inclination angle of 30 degrees to the main flow directions are placed spanwisely in front of the shockwave region on the upper surface to suppress shock buffet. These are corotating standard VGs with VG heights comparable to boundary-layer height. The height (H) of VGs is about 0.0025C and they are placed at 0.3C streamwise from leading edge. The VG plates are rectangular with length L=8H, and a thickness treated as 0 for brevity. The spanwise distance between 2 VGs is about 36H. The simulation grid is based on the uncontrolled case, and is densified around VGs.

RESULTS AND ANALYSIS

The results simulated by IDDES method are shown in Fig.2. IDDES method successfully predicted buffet phenomenon. Flow fields obtained by simulation include a shockwave surface periodically oscillating both in streamwise position and strength, shear layers starting at shockwave root, and plenty of small-scale vortex structures generated from shear layer instability, which are demonstrated by contours for density gradient amplitude and isosurface for the Q criterion. The mean streamwise velocity profiles at 3 points on upper surface is shown in Fig.3 (Left).

The controlled case with 2VGs by IDDES methods obtained relatively more stable shock waves. The main shock wave location almost keeps fixed As shown in Fig.3., The averaged shock wave position is pushed down to about 0.45c streamwisely. The SPL spectrum of pressure at a sample point in wake region (x=C) is also shown in Fig.3. The pressure oscillation here is affected both by pressure waves induced by shock wave buffet and break-ups of small-scale structures. The main frequency peak is at 78Hz, which agrees with buffet frequency; 2nd-order peak is around 1600Hz, which corresponds to small-scale vortex break-ups. the SPL spectrum shows a 14dB decrease in 1st-order frequency peak, and a 11dB decrease at 2nd-order peak. Time-averaged lift coefficient increased from 0.892 to 0.986.

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CONCLUSIONS

The IDDES results successfully captured the shock wave buffet phenomenon and the flow structures induced by shock wave/boundary layer interactions. Predictions on VG controlled case show that shockwave buffet is effectively suppressed by VGs.
As one of the future works, another on-going prediction is based on a 2-VG case with streamwise location pushed back from 0.3C to 0.2C. The results are still waiting to be compared, which will be shown in the full texts.

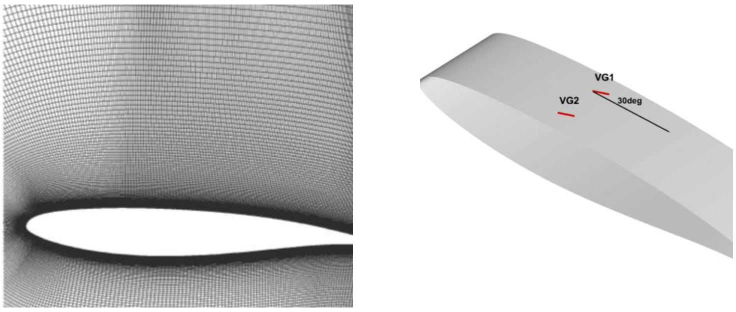

Fig. 1 Grid for OAT15A airfoil (Left) and 2VGs' configuration (Right)

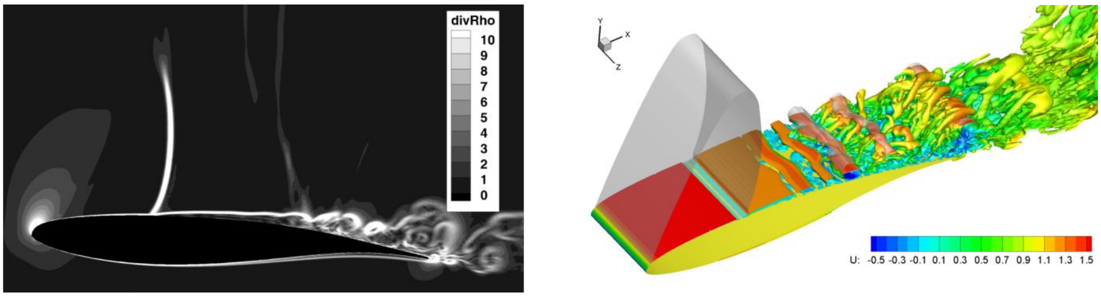

Fig. 2 Instantaneous spanwise slice of density gradient amplitude countour (Left: density gradient amplitude; Right: Q criterion)

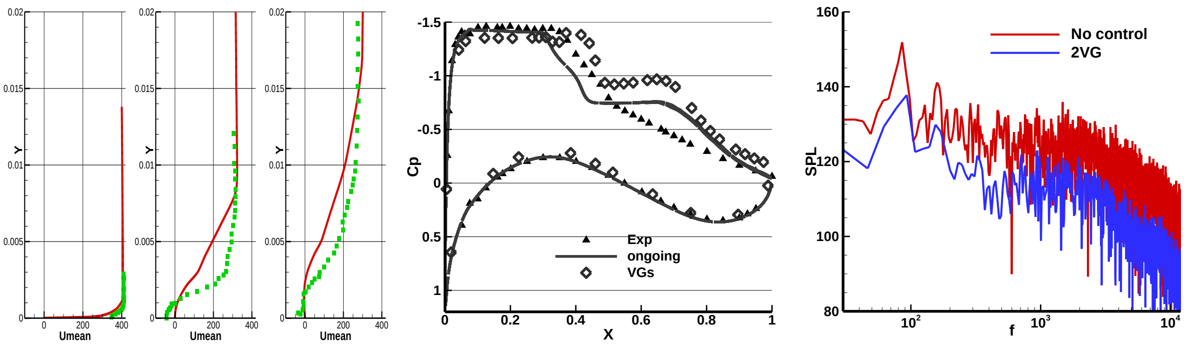

Fig. 3 Mean U Profile (x/C=0.28;0.55;0.75) (Left);Time-averaged pressure coefficient (Center);
SPL spectrum for fluctuating pressure at a sample point in wake (Right)

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