Effect of Orifice Depth of Synthetic Jet Actuator on Boundary Layer Control

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Introduction. Synthetic jets are produced by periodic ejection and suction of fluid from an orifice induced by movement of a diaphragm inside a cavity, and a synthetic jet actuator is a useful tool for active flow control. For the synthetic jet, the effect of the orifice depth on the vortex ring behavior has not been completely clarified yet. In this study, we compared the boundary layer control effects of two types of orifice depth. The differences in boundary layer control effects were investigated by visualizing the behavior of the vortex ring. It was confirmed that the orifice depth of the synthetic jet affected the rolling up of the shear layer and the behavior of the vortex ring was different.

Experimental method and condition. Fig. 1 shows the schematic of a synthetic jet. The main flow direction was X, the height direction was Y, and the span direction of the airfoil was Z. In the present study, two types of orifice depth $D_H$, 2mm and 8mm were used, as depicted in Fig.2. The synthetic jet was produced by an oscillating diaphragm at the bottom of cavity. The diaphragm was attached to a speaker which was driven with square wave signals of chosen frequencies and amplitudes. In this experiment, the diaphragm oscillation frequency $f$ was set at 100Hz. The details of the synthetic jet actuator were indicated in the previous report(1). The flow field was investigated by smoke flow visualization and PIV. The visualization of the behavior of the synthetic jet in the turbulent boundary layer was performed by injecting smoke into the cavity. The jet issued vertically from the lower wall. The jet-to-freestream ratio, $VR(=U_j/U_\infty)=1.0$, dimensionless stroke length, $L(=U_j/D_j)=2.8$ are defined where $U_\infty$, $U_j$, $D$ are the freestream velocity, time-averaged jet velocity and the orifice diameter(=7mm), respectively.

Results. It was concluded from the PIV results that the case of $D_H = 2$ makes effective boundary layer control. Fig. 3 shows the visualization of the flow field where synthetic jets are blown out into the freestream. Also, Fig. 4 shows the visualization results in the x-z cross-section (from the top). Each (a) (b) shows the results when $D_H = 8$ and 2. Also, the yellow dashed line in the results indicates the boundary layer thickness, and the boundary layer outer edge is located at $Y/D = 2.0$. The red dashed line in Fig. 4 shows the position of the orifice. It was found that the vortex ring was rolled up and collapsed at different positions by changing the orifice depth. Furthermore, the behavior of the towed leg is different. The duration of rolling up of the vortex ring when $D_H = 2$ is less than that when $D_H = 8$. The interaction between the freestream and the jet creates a towed leg connecting the vortex ring and the wall (blue circle in Fig. 3). This trailing leg has large turbulence in the blowout phase and small vortices swirl in various directions (Fig. 4①,②). In the suction phase, it becomes a vortex pair by interfering with the freestream (Fig. 4④). It can be seen from Fig. 4 that at $D_H = 2$, this vortex pair moves further downstream compared to $D_H = 8$. In the case of $D_H = 2$, it was often observed that the vortices spouted from the leg pulled in the suction phase (white arrow in Fig. 3). Compared with $D_H = 8$, it seems that the amount of the momentum exchange promoted in boundary layer larger when $D_H = 2$.

References.