VORTEX STRUCTURE IN UNSTEADY SEPARATION AROUND A PITCHING AIRFOIL

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The flow field around a moving airfoil is a typical of unsteady flows and is complicated due to many parameters as well as the dynamic behavior of vortices. Many studies on unsteady separation around a moving airfoil have been carried out experimentally and in numerical simulations. Most of them have been performed[1] at the high Reynolds number region over Re = 10^6. Recently, a few studies on the unsteady separation have been developed at the low Reynolds number region due to the interest in MEMS[2] and human power vehicles[3]. However, the vortex structure in the unsteady separation around a moving airfoil at this Reynolds region is yet insufficiently understood.

In the present study, unsteady separation around pitching airfoils have been visualized at Re = 4.0×10^3 by two kinds of visualization methods, dyes flow and a Schlieren method, and the vortex structure in the unsteady separation has been discussed.

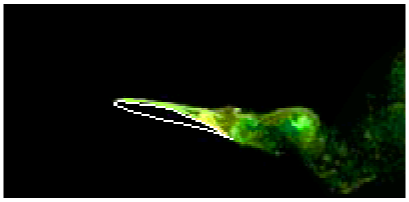
EXPERIMENTAL SYSTEMS

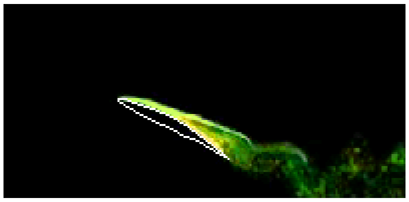
The visualization of the flow pattern around a pitching airfoil has been performed by two kinds of visualization systems, a dye-flow visualization system[4] with a 30-frames/second VTR camera and a Schlieren visualization system[5] with a 4500-frames/second high speed camera. The former showed streaklines of the separation around the pitching airfoil and flow patterns of the wake. The latter showed the existence of discrete vortices in the separation region. Two kinds of airfoils, NACA65-0910 and Blunt Trailing Edge (BTE), were tested. The non-dimensional pitching rate was $k = 0.377$, where $k = 2\pi f (c/2) / V_0$, f is the pitching frequency [Hz], c is the chord length of the airfoil [m] and V_0 is the main flow velocity [m/sec]. The pitching amplitude was fixed at $A = \pm6°$ and mean angle of attack $\alpha_m = 6°$ and 16°. The pitching motion along sinusoidal wave was performed around its mid-chord axis. The flow visualization was performed at Re = 4.0×10^3.

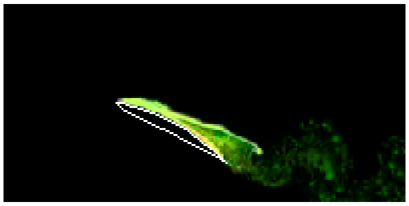
RESULTS AND DISCUSSION

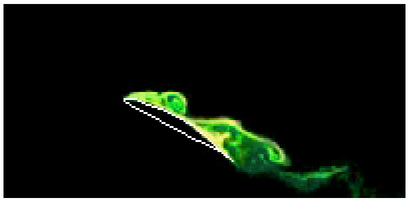
Structure of reattachment around a pitching airfoil

Figure 1 shows the flow patterns visualized the dyes flow system around a pitching NACA65-0910 during one period at $\alpha_m = 16°$. Figure 1(a), 1(b), 1(c), 1(d), 1(e) and (f) show the result from bottom dead position (α_m=10°), moving clockwise (α_m=16°), moving clockwise (α_m=18°), top dead position (α_m=22°), moving counterclockwise (α_m=18°) to moving counterclockwise (α_m=12°), respectively.


(a) Bottom dead position ($\alpha = 10^\circ$)


(b) Moving upward ($\alpha = 16^\circ$)


(c) Moving upward ($\alpha = 18^\circ$)


(d) Top dead position ($\alpha = 22^\circ$)


(e) Moving downward ($\alpha = 18^\circ$)

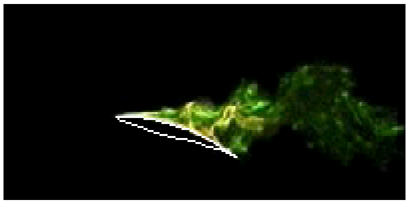
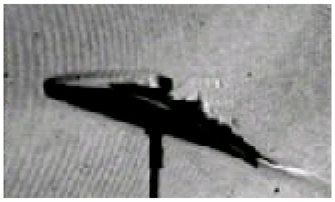
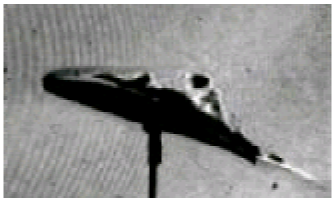
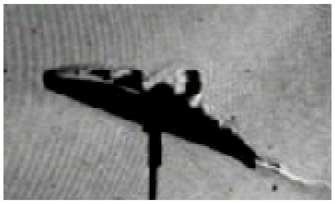
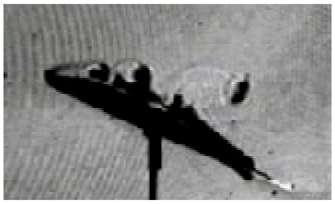

(f) Moving downward ($\alpha = 12^\circ$)

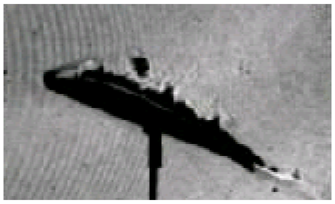
Fig. 1 Flow patterns around a pitching NACA65-0910 at α_m = 16°by dyes flow visualization


(a) Bottom dead position ($\alpha = 10^\circ$)


(b) Moving upward ($\alpha = 16^\circ$)


(c) Moving upward ($\alpha = 18^\circ$)


(d) Top dead position ($\alpha = 22^\circ$)


(e) Moving downward ($\alpha = 18^\circ$)


(f) Moving downward ($\alpha = 12^\circ$)

Fig. 2 Flow patterns around a pitching NACA65-0910 at α_m = 16°by schlieren visualization

(a) NACA65-0910

(b) BTE

When the angle of attack increased from the bottom dead position to the top dead position, the vortex shed from the leading edge had a strong vorticity with clockwise rotation in the separation region and reattached instantly to the suction surface, as shown Fig. 1 (d). As a result, the recirculation region was formed on the suction surface. This phenomenon has occurred also in case of the pitching BTE. However, it did not occur during one period at $\alpha_m = 6°$ or at lower non-dimensional pitching rate.

Figure 2 shows the vortex flow patterns around a pitching NACA65-0910 during one period at $\alpha_m = 16°$visualized by the Schlieren visualization system. The respective figure at the same level between Figs. 1 and 2 has the same angle of attack during one pitching cycle.

In Fig. 2 (a), one discrete vortex was generated in the separation region, the scale of which was small on the suction side. In this case Fig. 1 (a) indicated that the streakline was stable. As shown in Fig. 2 (c), however, one or two vortices were generated there as the angle of attack increased In this case Fig. 1 (c) indicated that the streakline became unstable. This instability meant the generation of the discrete big vortices. Figure 2 (d) visualized discrete vortices clearly at the top dead position. Compared this figure with Fig. 1 (d), the reattachment region consisted of two vortices.

CONCLUSIONS

In the pitching airfoil at low Reynolds number region, the separation vortex from the leading edge reattached instantly to the suction surface and the recirculation region was formed on the suction surface. In the separation region of the pitching airfoil, a few vortices were generated discretely. Especially, the reattachment region consisted of two vortices.

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