The Effects of Actuation Frequency on the Separation Control over an Airfoil using a Synthetic Jet

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Micro devices for a separation control recently attract a lot of attention because they have following advantages compared to conventional devices: “steady jet” and “vortex generator”: less energy consumption, simpler structures, and more effective control on unsteady flow fields. In this study, we focus on “synthetic jet” which is one of the most advanced micro device to control a separated flow. A synthetic jet consists of a cavity and an orifice connected to the cavity of which bottom oscillates with a small amplitude (see Fig.1).

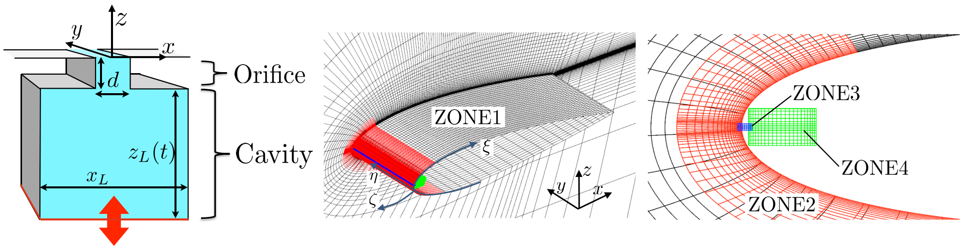


Figure 1: Geometric configuration of a synthetic jet and computational grids

The periodic oscillation of the cavity bottom produces blowing and suction flow periodically from the orifice exit[2][3][4]. Recently, three-dimensional unsteady analyses of the flow field are getting more and more significant with regards to the physics of the separation control focusing on a turbulent structure. For example, You and Moin conducted LES[5] for the separation control around an airfoil, and the aerodynamic coefficients well correspond to those of experimental results. They also reported that the key mechanism of separation control is not only the modification of two-dimensional boundary layer profile by adding or removing momentum in freestream direction, but also three-dimensional turbulent mixing. However, they have not quantitatively discussed turbulent statistics of controlled flow fields, and the mechanism of separation control has not been clearly classified yet.

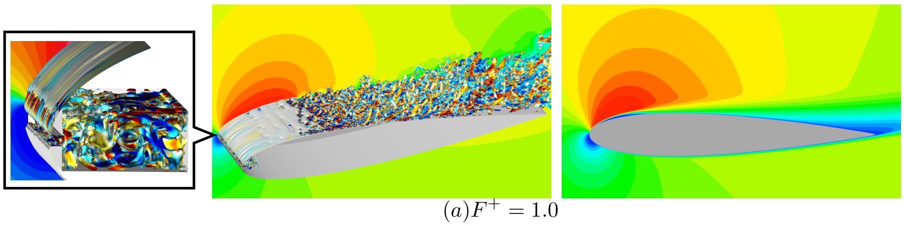
Table 1: Aerodynamic coefficients (SJ at L.E.)

F^+	Position	C_L	C_D	L/D
Non-controlled	–	0.427	0.151	2.82
1.0	L.E.	1.10	0.0775	14.2
6.0	L.E.	1.10	0.0669	16.4
10	L.E.	1.09	0.0670	16.1

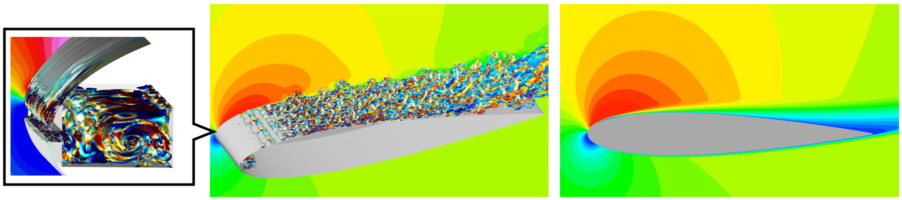
Table 2: Aerodynamic coefficients (SJ at 5%)

F^+	Position	C_L	C_D	L/D
Non-controlled	–	0.427	0.151	2.82
1.0	5%	1.16	0.0795	14.6
6.0	5%	1.15	0.0658	17.5
10	5%	1.08	0.0662	16.3

We aim to clarify the effects of actuation frequency on the separation control and classify its mechanism especially in terms of turbulent statistics. In this study, a large eddy simulation using a 6th-order compact scheme is conducted for the separation control around a NACA0015 airfoil (the Reynolds number based on the length of a wing chord is set to $63,000$). Note that the total number of grid points is approximately 30 million, and the grid of cavity (ZONE4 in Fig. 1) is deformed according to the oscillation of the cavity bottom[1].The synthetic jet is located at leading edge (0% of chord length) and 5% of chord length; the actuation frequency is set to $F^+ = 1.0, 6.0$ and 10 where F^+ is a nondimensional frequency normalized by the freestream and chord length; the momentum coefficient C_μ which corresponds to the ratio of momentum induced by the synthetic jet and that of freestream is set to 0.002.



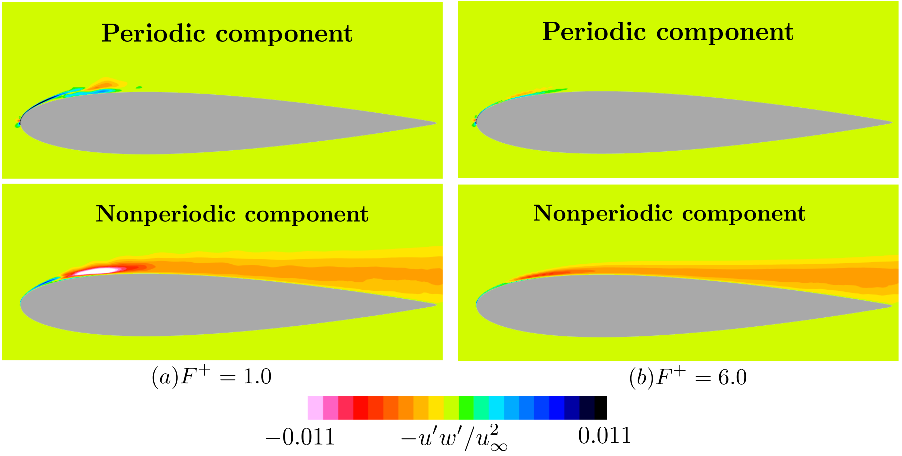
$(a) F^+ = 1.0$



$(b) F^+ = 6.0$

Figure 2: Time averaged and instantaneous flow fields in the case of $F^+ = 1.0$ and 6.0 where the synthetic jet is located at the leading edge (0%). The isosurface is second invariant of the velocity gradient tensor.

As a result of the computation, all the cotrolled cases in Table 2 show an enhancement of the lift and reduction of the drag compared to the non-controlled case. In terms of the actuation frequency, the cases of $F^+ = 6.0$ attains higher C_L/C_D than those of $F^+ = 1.0$ and 10. Figure 2 show time-averaged and instantaneous flow fields where the isosurface is the second invariant of velocity gradient tensor. In the instantaneous flow fields of both $F^+ = 1.0$ and 6.0, a turbulent transition occurs near the leading edge. The phase averaging procedure is also conducted for the attached flow by based on the actuation frequency, i.e., $F^+ = 1.0$, 6.0 and 10. Figure 3 quantitatively indicates that the turbulent component of Reynolds shear stress dominates the induction of a momentum from the freestream. Note that flow fields shown in this abstract are limited to the cases that the synthetic jet is located at leading edge and F^+ is set to 1.0 and 6.0. More detailed discussion on flow fields, e.g., using FFT and linear stability analysis for a turbulent transition on the separation bubble, will be presented in the final paper.



$(a) F^+ = 1.0$ $(b) F^+ = 6.0$

Figure 3: Periodic and nonperiodic (turbulent) component of the Reynolds shear stress $-u‘w‘$ where the synthetic jet is located at the leading edge (0%). w is a vertical component of the flow velocity.

References

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