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DNS-BASED OPTIMAL CONTROL OF SEPARATED FLOW OVER A HALF CIRCULAR CYLINDER

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In recent years, the closed loop control for flow field using micro devices receives much attention (Poggie, 2010), (Snyder, 2007). In previous studies, the flow control was performed and resulted in efficiently reducing the drag of a flat plate by introducing an optimal control law (Bewley, 2001). In addition to the drag reduction, it is important that a separation is prevented in the flight dynamics. The separation control has been studied well by using a blowing/suction jet or a plasma actuator from the point of view of theoretical and computational study. In order to improve a performance of the separation control, the optimal control is performed for the flow over a half circular cylinder in this study where as the separation control over a half circular cylinder is one of the conventional problems.

A flow geometry adopted in this study is shown in Fig. 1. The freestream velocity u_∞ is set to be the velocity scale, and the diameter of the half circular cylinder D is set to be the length scale. The freestream Mach number M_∞ is set to be 0.4, which ensures that the flow is subsonic over the entire domain. This relatively high Mach number is employed for the computational efficiency. The Reynolds number Re is set to be 4000, and the Prandtl number Pr is 0.7. To simulate unsteady laminar flow over the half circular cylinder, direct numerical simulation (DNS) is performed by solving the compressible Navier-Stokes equations in two dimensions. The jet position θ_{jet} is set at the angle of 104[deg.]. This angle is the optimal position in the previous study that the zero-net-mass flux jet position is optimized.

In this study, the inputs of the blowing/suction jet is optimized to preventing separation over a half circular cylinder by computational fluid dynamics (CFD) and adjoint-based optimization. The objective function is introduced as follows:

$$J = \int_{t=t_1}^{t=t_f} \int_{\xi=\xi_{\min},\eta=0.5D}^{\xi=\xi_{\max}} \alpha_1 \cdot p\cos\theta dS + \int_{\xi=\theta_{jet}-0.025D,\eta=0.5D}^{\xi=\theta_{jet}+0.025D} \alpha_2 \cdot \Phi dSdt.$$

The first term represents an objective function for a drag reduction by pressure. The drag by pressure is closely related the separation. The second term represents the cost function to reduce the input amplitude Φ that is the absolute value of velocity of the jet in this case. The α_1 and α_2 are weight functions. The first term only exists on the surface of the half circular cylinder and the second term only exists in jet width 0.05*D*.

Figure 2 shows the time variation of Φ. These solutions have not been yet determined if these converge. The case1 has α_1=0.5, α_2=1.0 and case2 has α_1=1.0, α_2=0.5. The initial condition of Φ is the sin function that is calculated in advance. When the weight function α_1 is larger, Φ is smaller and a suction part of the jet is expanded.
Figure 3 shows C_D that is the drag coefficient of the half circular cylinder in each case. The drag coefficient decreases as a result of adjoint-based optimization. The decrease in C_D results from preventing separation by the suction. The adjoint-based optimized jet operation has only a suction part without a blowing part. Therefore, suction might be because more effective for decreasing C_D and preventing separation over the half circular cylinder than blowing.

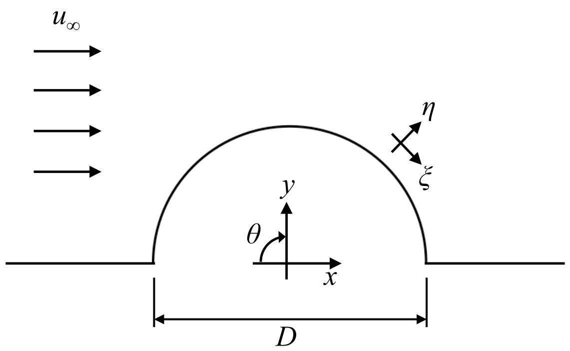

Fig. 1 Flow geometry

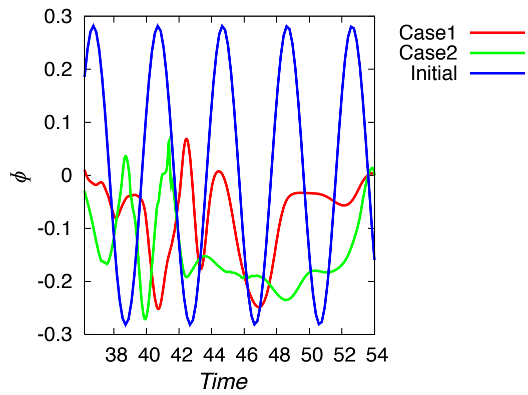

Fig. 2 Time variation of Φ

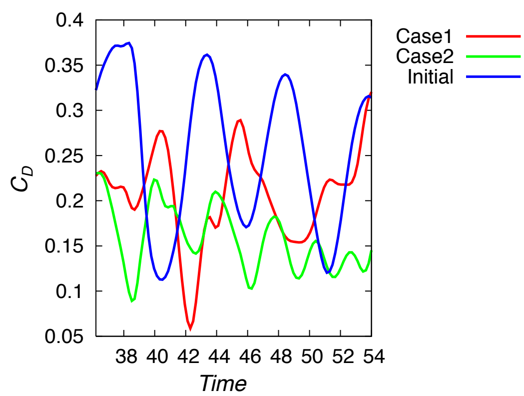

Fig. 3 Time variation of C_D

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