Numerical Analysis of Stabilizing Effect of Longitudinal Wall-Oscillation for Tow Dimensional Channel Flow

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Abstract: The effect of longitudinal wall-oscillation for the stability of two dimensional channel flow is numerically investigated using the direct numerical simulation (DNS). In ordinary circumstances, the flow between two flat plates transits from laminar to turbulent state when the Reynolds number determined by typical quantities of the flow exceeds a critical value. With longitudinal wall-oscillation, however, it is found that the transition is accelerated or decelerated depending on the parameters of the wall-oscillation even if the Reynolds number is fixed to supercritical condition. From the flow visualization, it is clearly shown that the development of the streaks near the walls are suppressed by the wall-oscillation for the accelerated case. Also, the results obtained by the Floquet analysis support the features shown by the DNS.

Keywords: Channel flow, wall-oscillation, transition, stability, DNS, Floquet

1 Introduction

It is well known that spanwise wall-oscillation can reduce friction drag of the channel flow [1]. Quadrio and Ricco numerically demonstrated that the amount of drag reduction is of about 44% [2]. Since the study for the channel flow with longitudinal wall-oscillation is little, the present study will deal with this system. In contrast to the flow with spanwise oscillation, this system is basically two dimensional, that is, can be described by an exact solution of two-dimensional boundary layer equation. Using this advantage and the periodicity of the flow field, this system is also investigate the linear stability analysis with the Floquet theory.

2 DNS analysis

A schematic view of the modified channel flow investigated here is shown in Fig.1. Here, Ω and U_w are frequency and amplitude of the longitudinal wall-oscillation. Thus, parameters describing this system are Ω, U_w, and the Reynolds number defined as $R \equiv h U_{max}/\nu$, where U_{max} is the maximum value of the mean flow, ν the kinematic viscosity and h a half distance between two walls. In the present study, R is fixed to 10,000, which is a supercritical condition.

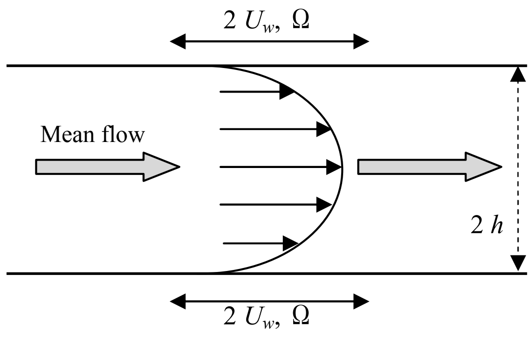

Figure 1: Schematic view and parameter of a modified channel flow.

Figure 2 shows the variation of energy of each Fourier mode. k_x means the streamwise wave number, and k_y the spanwaise. It is clearly shown that the transition for the case of (Ω, U_w) = (0.05,0.3), Fig. 2(b), is accelerated comparing with the non oscillating case of 2(a). In these case, the flow field is visualized by the vorticity (Fig.3). It is found that, in the oscillating case, the streaks existing near the walls are relatively short. It can be conjectured that the wall-oscillation suppress the development of streaks, and then, the absence of the streaks brings forward the transition.

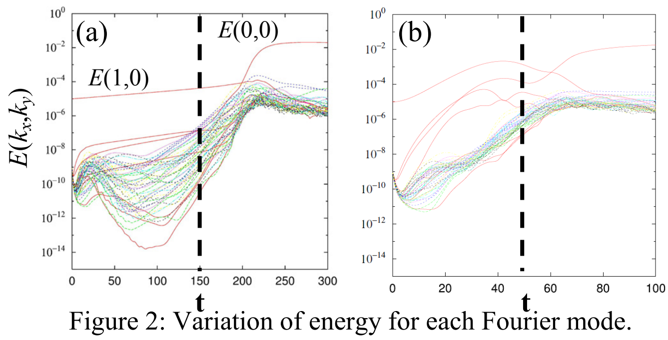

Figure 2: Variation of energy for each Fourier mode.
(a) : $(\Omega, U_w) = (0,0)$, (b) :(0.05,0.3).

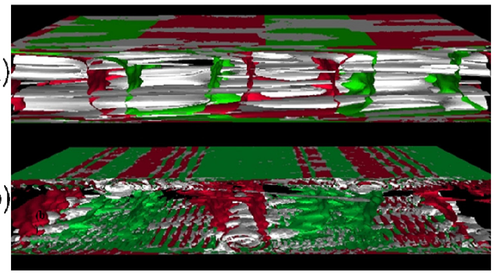

Figure 3: Contour of vorticity for the case of (a) instance at t=150 of Fig.2(a), (b) at t=50 of Fig.2 (b). The flow comes from the left hand side.

Depending on Ω and U_w, the transition is accelerated or decelerated comparing with the non-oscillating case. The result of parametric study is shown in Figure 4. Although the situation is supercritical, the decelerated area exists in the parameter space.

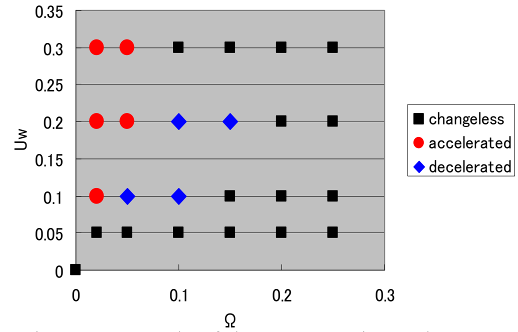

Figure 4: Result of the parametric study.

3 Floquet analysis

In order to understand this feature more clearly, the Floquet theory is employed, which describes the stability of periodic systems. For this analysis, the time-dependent Orr-Sommerfeld equation is used with the velocity profiles obtained by the superposition of the 2-D Poiseuille flow with the Stokes layer because of the linearity of the government equation. In the Floquet theory, the stability can be estimated by the Floquet exponents. If this eigenvalue is negative, the system is stable, and unstable for the opposite case. Figure 5 shows the contour of the Floquet exponents on the parameter space. The solid line corresponds to the neutral curve. The area of "decelerated" region of Fig.4 roughly agrees with the inside of the neutral curve.

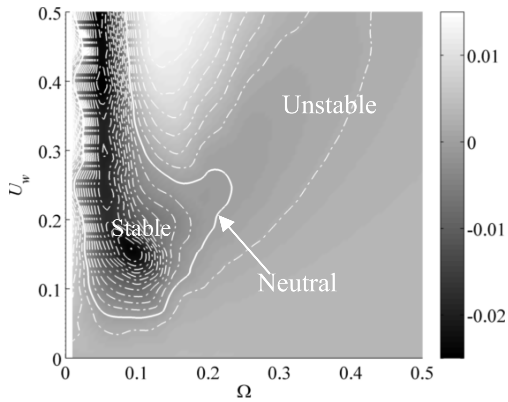

Figure 5: Contour of the eigenvalue obtained by the Floquet analysis.

4 Conclusions

DNS analysis shows that the longitudinal wall-oscillation affects the stability of the channel flow, and the transition is accelerated or decelerated depending on the parameters. For the accelerated transition case, it is cleared from the flow visualization that the development of streak like structure near the walls is suppressed by wall-oscillation. The Floquet analysis shows the existence of stable region at the parameter space even in the supercritical condition, and supports well the DNS analysis.

References

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