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Dissimilar control of momentum and heat transfer in turbulent channel flow

Y. Hasegawa[ab] and N. Kasagi[a]

Because of the importance of fundamental knowledge on turbulent heat transfer for further decreasing entropy production and improving efficiency in various thermo-fluid systems, we revisit a classical issue whether enhancing heat transfer is possible with skin friction reduced or at least not increased as much as heat transfer. The answer that numerous previous studies suggest is quite pessimistic because the analogy concept of momentum and heat transport holds well in a wide range of flows.

In the present study, we introduce the suboptimal control theory for achieving dissimilar control in one of the most canonical thermo-fluid system, namely, turbulent flow with heat transfer in a smooth and straight channel. The Fréchet differentials obtained clearly show that the responses of velocity and temperature fields to a given control input are quite different due to the fact that the velocity is a divergence-free vector while the temperature is a conservative scalar. By exploiting this inherent difference, the dissimilar control can be achieved even in flows where the averaged momentum and heat transport equations have the same form.

For example, Fig. 1 a) shows the time traces of the friction coefficient C_f and the Stanton number St after wall blowing/suction is applied as a control input at t = 0. The amplitude of the control input is kept 5 % of the bulk mean velocity. Both C_f and St are increased due to the present control. The analogy factor $2\mathrm{St}/C_f$, which should be close to unity in uncontrolled flow, is also shown in Fig. 1 b). It is clearly observed that $2\mathrm{St}/C_f$ is increased from unity after the control is applied, indicating that the heat transfer is more enhanced than the skin friction. In the full paper, we will discuss the detailed mechanisms of the dissimilarity between the momentum and heat transport in the present control.

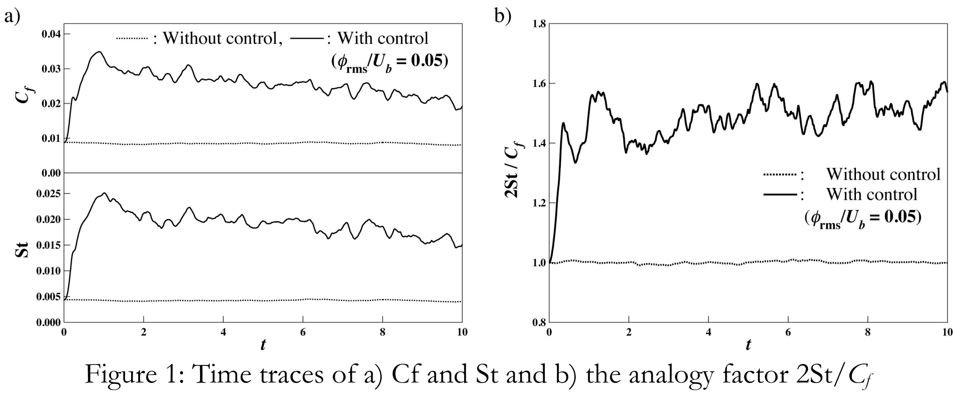

Figure 1: Time traces of a) Cf and St and b) the analogy factor $2\mathrm{St}/C_f$ after the control is applied at $t = 0$.

[a] Dept. Mech. Eng., The University of Tokyo, Japan.
[b] Cetner of Smart Interfaces, TU Darmstadt, Germany.