Wiener filters in active-feedback drag reduction of turbulent channel flow

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Feedback control of developed turbulence was first demonstrated[1] in the form of an instantaneous and pointwise opposition control with an empirically adjusted coefficient. Högberg & Bewley[2] then applied modern optimal control to the linearized Navier-Stokes equations in order to develop a spatially localized convolution kernel and tested the controller so obtained on a turbulent DNS with encouraging results. Quadrio & Luchini[3] suggested that a larger amount of physical information could be embodied in the controller if the linearized problem was replaced by a linear response of the full turbulent flow to external disturbances, and presented preliminary results for the computation of such linear response from a DNS.

Luchini et al.[4] presented an optimal controller based on the linear response of the turbulent flow, and announced the first successful test of such a controller on the DNS of a fully developed turbulent flow. There it was emphasized that the standard optimal-control approach based on Kalman filters and matrix Riccati equations does not apply to this problem because the state equations of the system are not available, and because the noise to be damped is composed of the actual turbulent fluctuations rather than a white noise.

The impasse was overcome by replacing the Kalman filter with a Wiener filter (known to be theoretically equivalent, but based on the input-output response rather than on state equations). For this purpose an original technique was developed in order to transform the control problem into a filtering problem, in a similar way as the so-called "separation principle" does in Kalman's approach.

In this conference the Wiener-based optimization technique will be illustrated, and its drag-reduction potential explored. Following the initial test, the technique has been applied to several possible feedback configurations involving one or all velocity components at the wall as actuators and one or all stress components as sensors. Attention has also been paid to comparing the energy gain offered by the drag reduction with the energy spent to operate the actuators themselves. A key ingredient has been the adoption of the dissipation rather than the kinetic energy as optimization objective.

A numerical version of the Wiener-Hopf method allowed us to quickly compute the controller convolution kernel corresponding to any given set of physical quantities chosen as actuators and sensors.

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[1] Choi et al. *J. Fluid Mech.* **262**, 75 (1994).
[2] Högberg & Bewley, Automatica (2001).
[3] 9th Eur. Turbulence Conference, Southampton 2-5 July 2002.
[4] 58th APS-DFD meeting, Chicago 20-22 Nov. 2005.