Flow control - overview

The flow control group for this year's summer program explored the use of *sensorless, zero-net-mass-flux* (ZNMF) oscillatory control devices for separation control and turbulence suppression. The research topics spanned from fundamentals focusing on the determination of optimal control parameters to practical applications. The key objectives of the group were to gain physics- or theory-based guidelines for optimizing the control parameters, to evaluate the effectiveness of ZNMF control devices for flow control applications, and to assess the predictive capability of numerical methods for flow control applications using ZNMF jets. This year's program consists of four research papers. The first three papers deal with separation control using ZNMF jets and the last paper aims at skin-friction reduction due to turbulence suppression.

In the first paper, Kotapati, Mittal, Marxen, You, Kitsios, Ooi, and Soria attempted to address the fundamental questions regarding the optimization of control parameters. They employed flow configurations especially designed for investigating ZNMF jet-based active control of canonical separated flows. A systematic investigation of the effects of the frequency and the streamwise location of the actuator was carried out. In an elliptic airfoil configuration, they found that ZNMF oscillations at a frequency corresponding to the separation zone or the shear layer draws a better response as compared to excitation at the wake vortex-shedding frequency. Results also show that locating the ZNMF actuator at the separation point leads to a more effective separation control, whereas ZNMF oscillations inside the separation bubble do not significantly alter the separation.

A numerical study performed by Kitsios, Kotapati, Mittal, Ooi, Soria, and You revealed how the boundary layer properties of an airfoil are modified with the variation of the angle of attack and with the actuation of leading-edge mounted ZNMF jets. Results indicate that ZNMF jets decrease the momentum thickness of the boundary layer by attracting high momentum fluid toward the wall and as a result, delay the flow separation point further downstream.

Hahn and You assessed the predictive capability of the unsteady Reynolds-averaged Navier-Stokes (URANS) approach for a dynamic stall application with ZNMF jet control. The study suggests that presently available RANS turbulence models should be significantly improved to account for the correct dynamics of a separated shear layer and unsteady separation and reattachment. The URANS results also demonstrate challenging aspects of dynamic-stall control, indicating the necessity of introducing more sophisticated control strategies, such as intermittent control, feedback loop or combination with large-scale spatial modulations.

Finally, Jovanović, Moarref, and You explored the use of ZNMF oscillations in the form of an upstream traveling wave for transition control in channel flows. They developed models for investigating the dynamics of velocity fluctuations in the presence of stochastic outside disturbances and showed how changes in control parameters affect the turbulent kinetic energy. The method uses a receptivity analysis of the linearized NS equations as a basis for a selection of control parameters for turbulence suppression. They found that properly designed streamwise traveling waves can be used to weaken intensity of both the streamwise streaks and the Tollmien-Schlichting waves in transitional channel flows.

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