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Passive and Active Control of Turbulent Flows

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It is well known that the greater transport of mass, momentum, and heat by turbulent flows has a significant effect on the efficiency of thermofluid systems. This effect is sometimes desirable; for example, to increase the rate of heat transfer in a heat exchanger. The effect of turbulence can also be undesirable, such as when the large momentum diffusivity of turbulent flows results in an excessive skin-friction drag within pipelines and over marine tankers. In all these scenarios, turbulence control techniques have been sought to manipulate the turbulent flow for an increase of system efficiency. This special issue covers recent developments in the broad area of turbulence control and includes both passive and active techniques.

The turbulence control strategies that do not require an energy input are categorized as “passive” techniques. They are typically simple, reliable, and some have been used in industry for several decades. For example, a rough texture on the internal surface of a pipe for enhancing heat transfer, or a helical fin on the exterior of a chimney stack for reducing turbulence-induced vibration. In this special issue, two passive techniques for reducing skin-friction drag in liquid pipe flows are covered: polymer drag reducers and superhydrophobic surfaces. Xi[1] provides an extensive review of the current knowledge of polymer drag reduction and highlights the long-standing questions in this research field. In addition, two experimental investigations by Farsiani et al.[2] and Shah & Yarusevych[3] further characterize the effect of polymer drag reducers on the velocity statistics and coherent structures of wall-bounded turbulent flows. The use of superhydrophobic surfaces for skin-friction reduction is investigated experimentally by Rowin & Ghaemi[4], wherein the scaling of turbulence statistics for a channel flow over a superhydrophobic surface is studied. The special issue also includes an experimental investigation by Carpio et al.[5], in which the use of a porous material for an airfoil trailing-edge is evaluated as a passive technique for reducing the acoustic noise scattered due to the turbulent flow.

“Active” turbulence control techniques cover a variety of systems that require energy input for turbulence manipulation. An active system, in its simplest form, may only consist of actuators that operate steadily. For example, the numerical investigation of Hickey at al.[6] implements streamwise-aligned, constant-input heat strips to modify the local fluid viscosity and density, and consequently also the turbulent structures. This investigation reveals a 6% reduction of skin-friction drag for an optimal heat intensity and spatial arrangement of the strips. In another novel example of active systems, Zhao et al.[7] investigated using oscillatory Lorentz forces along the circumference of a cylinder whose axis is aligned with the flow direction. They achieved up to 42% drag reduction, although their investigation shows that the power input for generating the Lorentz force is larger than the energy saved by reducing the skin-friction drag.

More complex implementations of active control can minimize the energy input and increase the efficiency of a control strategy using a combination of sensors and actuators that are managed by a control algorithm. To develop such a system, it is important to understand the flow physics and explore the modeling possibilities. In this special issue, Wang et al.[8] carried out an investigation of instability and periodicity in a separated flow using a bi-global instability as a precursor for developing control strategies. Fang & Tachie[9] explored the possibility of modeling the flapping motion of a separated flow using single- or two-point measurements of velocity. Their results identify the optimal sensor location and performance for reconstructing the temporal behavior and energy of the flapping motion. Güemes et al.[10] evaluated the capability of extended proper orthogonal decomposition and convolutional neural networks for identifying the large-scale motions of wall-bounded turbulent flows from wall shear stress probes. These efforts are essential for developing closed-loop control systems. Finally, Raibaudo et al.[11] performed a complete closed-loop control to stabilize the wake of a triangular cluster of rotating cylinders. They applied a novel machine learning approach based on genetic algorithms to optimize the actuation performance.

It is clear from the broad range of applications described above that the possibilities of turbulence control are immense. We hope that this special issue will provide examples of the state-of-the-art in this rapidly evolving field.

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