CONTROL STRATEGIES - ACTUATORS AND SENSORS†

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I. Introduction

Any active flow control system necessarily includes actuators and, for the case of systems employing feedback control, sensors. The modeling, design, fabrication, and testing of these transducers can be complicated, expensive, and time consuming, often requiring numerous design cycles with less than satisfactory results. The purpose of this chapter is to review recent progress in popular actuators and microelectromechanical systems (MEMS) unsteady pressure and shear-stress sensors for flow control applications. The chapter is broken into two parts; a discussion of actuators precedes that of sensors. As with any engineering system, a design cannot proceed without a statement of often conflicting technical requirements. Therefore each major section begins with a brief discussion of basic terminology and design specifications, followed by their specific interplay with potential flow control objectives.

In the case of actuators, there are numerous types, and space does not allow a comprehensive discussion of all of these. Therefore only the most popular or promising are discussed after beginning with some historical perspective. In addition, a section is included on actuators potentially suitable for high-speed flows. In all cases, we attempt to summarize key advantages and disadvantages of each, along with unresolved research issues. Suggestions for metrics to consider when using actuators in active flow control applications are also provided.

In the case of sensor development, which is a discipline in and of itself, we restrict our attention to wall-mounted dynamic sensors, which are important because of the practical requirement that control of real flows requires [ideally] non-intrusive dynamic sensing at the bounding walls of the flow domain. Attention is focused on MEMS unsteady surface pressure and wall shear stress sensors because of their ability to provide high spatial and temporal resolution measurements. This section begins with "sensor fundamentals," which provides the motivation for MEMS sensors. Key choices in flow control applications are then summarized, describing recent sensors that both highlight progress and reveal current research topics.

II. Actuators

A. Historical Perspective

One of the most famous experiments in fluid dynamics was performed by Schubauer and Skramstad (actually performed prior to World War II) concerning laminar boundary layer transition on a flat plate (1947). The authors stated that *"It was soon realized that a study of boundary-layer oscillations could be carried out to better advantage if they were not caused by accidental disturbances occurring in the wind tunnel but were produced by a controlled disturbance of known amplitude and frequency at some chosen position."* After experimenting with using sound from a loudspeaker to excite the boundary layer, they began to develop an electrodynamic ribbon oscillator. They settled on placing a 0.002 inch thick, 0.1 inch wide, and 3 foot long phosphor bronze strip at an approximate distance of 0.006 inches from the plate surface. Scotch cellulose tape was used to set the standoff distance and hold a 12-inch segment ribbon in place in the central region of the plate. Rubber bands were used to apply the tension required to maintain stability of the ribbon so that it did not vibrate without excitation. The ribbon was vibrated normal to the surface by a controllable electromagnetic force. This force was generated by the interaction between the alternating current running through the ribbon and the magnetic field generated by a permanent magnet on the opposite side of the plate. Two hot wires were used to measure the amplification or decay of the nominally two-dimensional disturbances produced by the ribbon. Interestingly, the authors also experimented with feedback control, noting that the "*system could be made to oscillate by connecting the amplified output of the hot wire to the ribbon.*"