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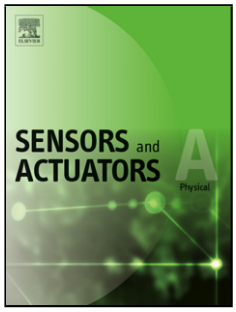

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ACCEPTED MANUSCRIPT

High temperature gradient calorimetric wall shear stress micro-sensor for flow separation detection

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Highlights

- A MEMS calorimetric sensor for bi-directional wall shear stress measurement is presented
- Thermal and electrical characterizations are performed
- The calibration of the sensor in a wind tunnel is performed
- The sensor is able to detect flow separations in a turbulent flows

Abstract

The paper describes and discusses the design and testing of an efficient and high-sensitivity calorimetric thermal sensor developed for bi-directional wall shear stress measurements in aerodynamic flows. The main technical application targeted is flow separation detection. The measurement principle is based on the forced convective heat transfer from a heater element. The sensor structure is composed of three parallel substrate-free wires presenting a high aspect ratio and supported by periodic perpendicular SiO2 micro-bridges. This hybrid structure takes advantages from both conventional hot-films and hot-wires, ensuring near-wall and non-intrusive measurement, mechanical toughness and thermal insulation to the bulk substrate, and it allowed to add the calorimetric sensor functionality to detect simultaneously the wall shear stress amplitude and direction. The central wire is made of a multilayer structure composed of a heater element (Au/Ti) and a thermistor (Ni/Pt/Ni/Pt/Ni) enabling measurement of the heater temperature and a layer of SiO2 between them for electrical insulation. The upstream and downstream wires are thermistors enabling operation in the calorimetric mode. This design provides a high temperature gradient and a homogeneous temperature distribution along the wires. The sensor operates in both constant current and constant temperature modes, with a feedback on current enabled by uncoupling heating and measurement. Welded on a flexible printed circuit, the sensor was flush mounted on the wall of a turbulent boundary layer wind tunnel. The experiments, conducted in both attached and separated flow configurations, quantify the sensor response to a bi-directional wall shear stress up to 2.4 Pa and demonstrate the sensor ability to detect flow separation.

Keywords

MEMS sensors; Wall shear-stress sensor; Flow separation detection; Flow control

1. Introduction

Active flow control systems are developed to promote air safety, reduce energy consumption or increase aircraft efficiency. A potential candidate for applying flow control strategy is flow separation which is mostly unwanted for many applications and even dangerous in aviation. It can increase drag and energy losses and decrease lift. The measurement of wall shear stress is thereby needed for identifying the location of this phenomenon for implementing a control strategy ([1], [2]). For a Newtonian fluid like air, the shear stress τ in a 2D-flow is given by Equation (1):

$$\tau = \mu \cdot (\partial u/\partial y)_{wall} \quad (1)$$

where μ is the air dynamic viscosity, u is the flow velocity parallel to the wall, and y is the axis normal to the wall as defined in Figure 1 (a). Figure 1 illustrates two main kinds of flow separation: the boundary layer separation due to an adverse pressure gradient occurring on a surface with no sharp edges in (a), and another one due to a geometrical obstacle (cavity, obstacle, sharp edges...) in (b).

On an airfoil-like surface like in Figure 1 (a), it is known that an adverse pressure gradient can produce a separation of the boundary layer by decreasing the velocity gradient at the wall and consequently decreasing the friction, before the separation, and

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