On the development of an optical MEMS sensor for instantaneous wall-shear stress measurements in wall-bounded turbulent flows

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Obtaining accurate measurements of instantaneous wall-shear stress in wall-bounded turbulent air flows is notoriously difficult[1], but is a quantity which has both fundamental[2] and industrial[3] importance. Presented is the design, development and implementation of a series of new optical Micro-Electro-Mechanical (MEMS) sensors designed to allow direct measurements of instantaneous wall-shear stress. The sensors consist of rectangular pad on the order of 100 μm $\times$ 100 μm, suspended by micro-springs to sit flush to the aerodynamic surface in a 5mm $\times$ 5mm die: see Fig. 1(a). Aluminium gratings are patterned onto the underside of the rectangular pad and onto a fixed transparent substrate to generate a Moiré fringe pattern. As the turbulent air flows over the wall, the miniaturised sensor pad moves tracking the instantaneous motion of the turbulence impacting onto the wall, causing an instantaneous shift in the sensor's Moiré fringe pattern. To capture this instantaneous motion, high powered LEDs are focused onto the backside of the MEMS sensor via a lens in a sensor package, and rippled in sequence at a frequency much higher than any frequencies in the flow. The reflected light is captured by a photodiode within the sensor package: see Fig. 1(b). Each ripple through the LEDs captures an instantaneous snap shot of the wall-shear stress experienced by the MEMS sensor. Sensors have been designed to operate over a broad range of wind-speeds of up to 80 ms^{-1}. The sensitivities of these devices range from 10 nmPa^{-1} to 800 nmPa^{-1} with resonance frequencies allowing for linear responses up to 10's of kHz. During wind tunnel testing, excellent agreement in the instantaneous wall-shear stress is observed between the MEMS sensors and from LDV, which uses the near-wall gradient technique, directly above each MEMS sensor, at low wind speeds. This work has been supported by Northern Accelerator and the EPSRC under grant numbers EP/T020946/1 & EP/R511584/1.

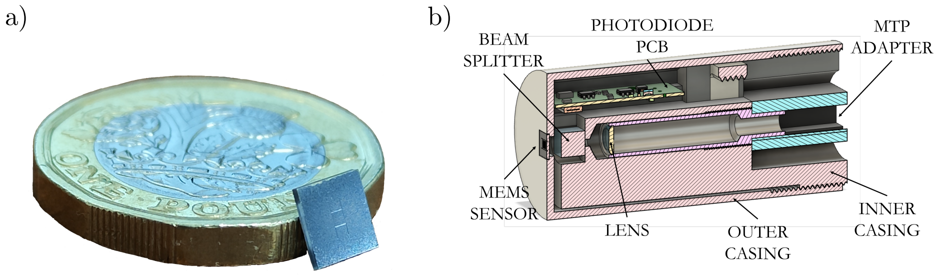

Figure 1: (a) Photograph of a MEMS wall-shear stress sensor. (b) Cross-section view of the sensor packaging.

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[1]Örlü and Vinuesa, *Measurement Science and Technology* **31**, 112001 (2020).

[2]Monkewitz et al., *Physics of fluids* **20**, 105102 (2008).

[3]Schrauf, *Measurement Science and Technology* **31**, 112001 (2020).