LOCAL HEAT FLUX MEASUREMENTS USING A MICRO-MACHINED INTEGRATED PROBE

Eléonore Rusaouën[1,2,3], Bernard Castaing [1], Francesca Chillà [1], Philippe-Emmanuel Roche [2,3] & Julien Salort[1]

[1]*Laboratoire de Physique, ENS de Lyon, Lyon, France*
[2]*Institut NEEL, Univ. Grenoble Alpes, F-38042 Grenoble, France*
[3]*Institut NEEL, CNRS, F-38042 Grenoble, France*

Abstract Thermal flows are ubiquitous in natural and industrial systems, this is why they have been studied for decades. In these kinds of flows, an important quantity is the local heat flux, but it remains experimentally nearly unstudied since it is difficult to measure it. We introduce a new local convective heat flux probe, based on a joint measurement of temperature and velocity within the flow.

CONTEXT AND PURPOSE

Thermally driven and thermal forced flows are ubiquitous in atmospheric, industrial or domestic systems. It is essential to understand them. The heat flux is an important parameter of those problems. The local heat flux along a given direction in the bulk has two contributions : a molecular diffusion term proportionnal to $\overrightarrow{gradT}$, and a convective term. The last one is derived from the product of energy and velocity. In the Bousssinesq approximation, it reduces to the product of velocity and temperature fluctuations with respect to the average temperature. In Rayleigh-Bénard turbulent convection, coherent structures called plumes, which transport some heat, are an open subject of study, see [2]. They are associated with fluctuations of temperature and velocity and travel into the flow. Thus, to understand those plumes, it is necessary to access to the local convective heat flux which means the correlation between velocity and temperature fluctuations at the same point. This is one of the problems which can be investigated with a local convective heat flux probe based on a joint measurement of temperature and velocity.

PRINCIPLE AND FIRST RESULTS OF THE PROBE

The entire probe, sensitive part, metals deposits and supporting structure, see figure 1(a), is micro-machined directly in a silicium wafer whose surface is thermally oxided. The oxide layer, $1.5\mu m$ thick, is the base material of a cantilever. At the end of the process, the cantilever is $375\mu m$ long, $30\mu m$ large and thus $1.5\mu m$ thick, see figure 1(b). With this geometry, the probe is adaptated to air flows. The deflection of the probe is measured using a strain gauge in nickel/chromium alloy deposited on the cantilever. This gauge is part of a Wheatstone bridge whose other resistances are deposited on a stiff part of the supporting structure. The end of the cantilever is shaped as a disc, to enhance the drag applied by the flow. A thin layer of platinum is patterned on this disc. A measurement of the resistivity of this layer grants access to the temperature, at the location where the fluid velocity is measured. The arms are designed in order to reduce the invasivity of the sensor, see figure 1(a).

The calibration of this sensor demonstrates sensitivity to both signed velocity and temperature, as illustrated in figure 2(a). Insert of figure 2(b) presents the pdf of temperature fluctuations over a heated plate in turbulent regime. Its shape is characteristic of the passing-by of thermal plumes (see [3]), and the velocity spectrum in a wind tunnel is consistent with velocity fluctuations signal, see figure 2(b). This validates the probe response to fluctuations.

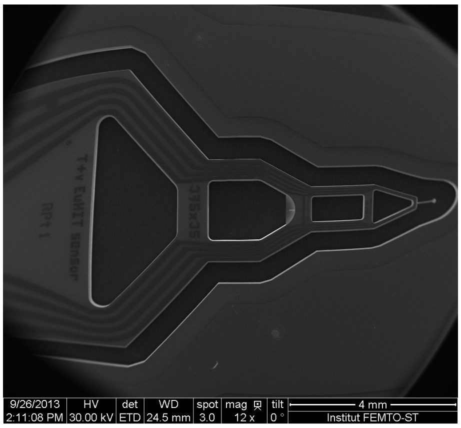
We shall also present joint temperature and velocity measurements and discuss the local convective heat flux obtained.

Acknowledgement

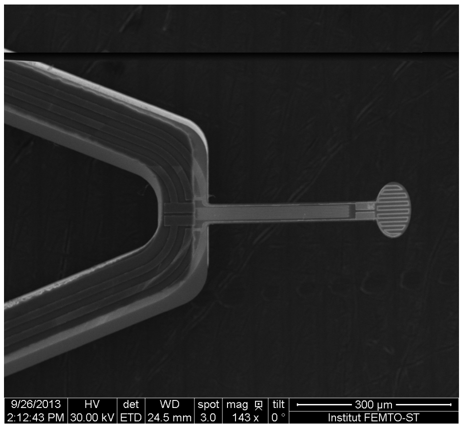
We thank the Labex iMust from Université de Lyon, grant ANR-10-LABX-0064, and the european community project EuHit, WP 21, for their financial supports. The probe design and fabrication was performed as exogeneous project in the MIMENTO/Femto-ST facility, in Besancon (France), in the frame of the French CNRS Renatech RTB Network. In particular, we warmly thank L. Robert, J.-Y. Rauch, E. Herth, J. Valentin, V. Petrini, E. Courjon and J.-C. Jeannot for their help. We also acknowledge the help of P. Mauduit, B. Capitaine and J. Marot at ENS Lyon for their help on the support electronics, and T. Crozes at Nanofab in Institut Néel for his help with the wire bonding.

References

[1] J. Salort, A. Monfardini and P.-E. Roche. Cantilever anemometer based on a superconducting micro-resonator: Application to superfluid turbulence. *Review of Scientific Instrument* **83**: 2012.
[2] F. Chilla and J. Schumacher. New perspectives in turbulent Rayleigh-Bénard convection. *The European Physical Journal E* **35**: 2012.
[3] A. Belmonte, A. Tilgner and A. Libchaber. Temperature and velocity boundary layers in turbulent convection. *Physical Review E* **50**: 1994

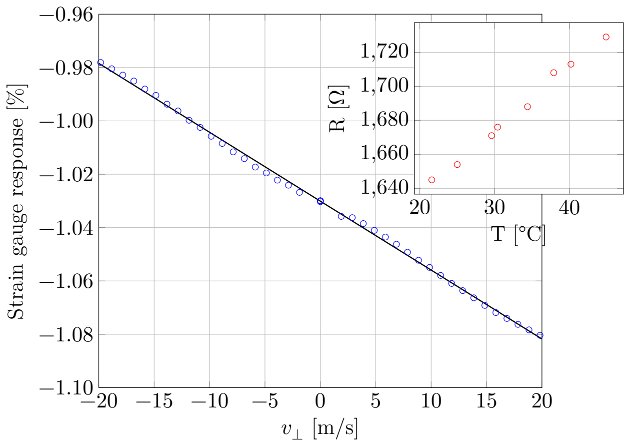


(a) Global view of the probe before it is detached from the wafer substrate. The structure suporting the sensitive part of the probe is design to reduce invasisvity.

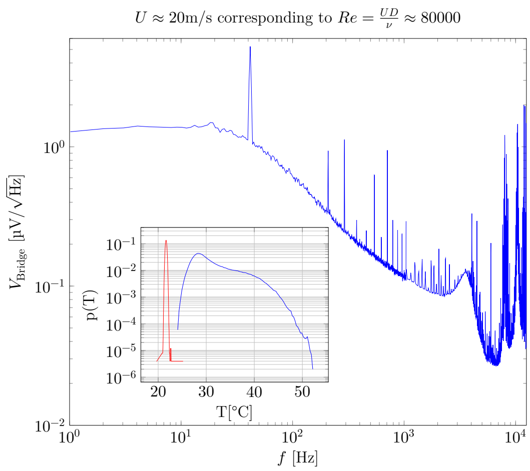


(b) Zoom on the sensitive part. The right part of the picture shows the cantilever where is located the strain gauge, and the disc with the thermistor. The left part shows the supporting arms.

Figure 1. Pictures of the heat flux probe.



(a) Mean unbalance of the Wheatstone bridge in an air flow produced by a jet. Insert: Mean resistance of the thermistor as a function of temperature.



(b) Spectrum of the raw strain gauge signal in a wind tunnel at a Reynolds number close to 80000, $Re = \frac{UD}{\nu}$ where D is the diameter of the outlet nozzle of the wind tunnel, ν the kinematic viscosity and U the velocity. Insert : probability density function of temperature over a plate heated to 60 °C, in red without flow and in blue with flow.

Figure 2. Characterisation of the probe.