EXPERIMENTS WITH SUPER-MINIATURE HOT-FILM PROBE FOR SUB-KOLMOGOROV RESOLUTION IN HIGH-REYNOLDS-NUMBER TURBULENCE

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Abstract This is a report on implementation of the next stage of a project motivated by the discovery of far more important role played by the sub-Kolmogorov scales than commonly believed in high Reynolds number turbulence such as manifestations of nonlocal nature of turbulence involving direct and bidirectional coupling of conventionally-defined inertial and dissipative ranges showing (a) that both concepts are ill-posed and (b) that further progress requires sub-Kolmogorov resolution. The main results and issues that prompted the present work are in [1]–[2] and references therein. The final goal is manufacturing a multi-sensor probe of much smaller scale than available today with access to quantities like vorticity and strain at sub-Kolmogorov scales in high-Reynolds-number flows such as performed by Gulitski et al. [3] in the atmospheric surface layer at $Re_\lambda \sim 10^4$. This requires manufacturing a single-sensor probe of length of the order ~50 μ or even smaller to be used as a building block for the above multi-sensor one. The main theme of the present report is performing a number of experiments with single-sensor micro-probes of different lengths in a laboratory jet flow and comparison of experimental results obtained with such probes and the conventional hot-wire probe.

TECHNICAL ASPECTS AND RELATED

The probe. Except of miniaturization there are special requirements to the single sensing element in view of the goal to manufacture a multi-hot-sensor probe enabling access to all the components of the velocity gradient tensor. In particular, the single sensing element together with its supporting structure has to be compatible with the requirement in order to minimize not only the interference of its own supporting structure, but also of the neighboring sensing elements. Thus the outlay of the kind as shown at Figure 4 in [4] was not acceptable as not allowing to produce an array consisting of four single sensing elements which in turn would serve as building blocks for a probe consisting of five such arrays as, e.g., shown at Figure 1 in [3]. We followed the micro-fabrication process as reported in [1] with some essential modifications and improvements the main of which allowed to achieve a pure hanging sensor without any substrate, as in [4]. An example of such an element manufactured in this way is shown in Figure 1.

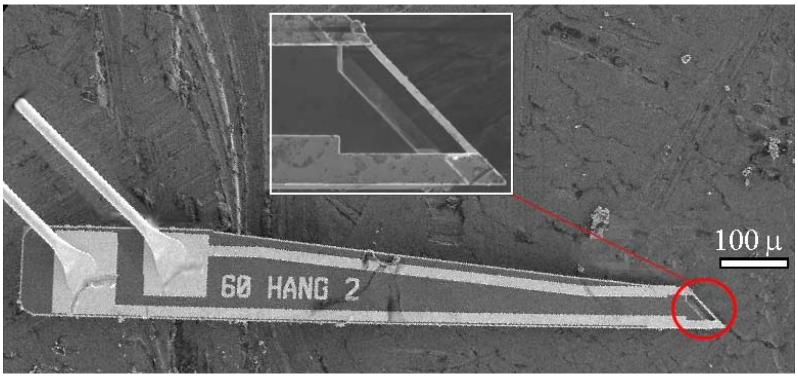

Figure 1. Microphotograph of a micro-hot-film sensor. Inset: close-up of the tip with the hanging sensing element.

The length L of the sensor of the probe element shown is 60 μ, its width is 2 μ and its thickness is 0.1 μ. It is a Nickel film oriented at 45˚ to the probe element axis. Experiments with such elements showed good reproducibility of results. The temporal response of the element with its anemometer channel was sufficient to ensure that no temporal filtering occurred in the frequency range more than 100 kHz. Therefore the only filtering introduced by such sensor was special averaging over its length. Comparison of results obtained with sensors of lengths from 20 to 100 μ showed that the effect of thermal conductivity to the sensor ends was negligible. Angular dependence of the sensor was a correct one.
Other experimental arrangements. The experiments were performed in a jet produced by the calibration unit (described in [4]) with outlet diameter D=2 cm. For calibration the probe was put in a potential core of the jet, for measurements – in a turbulent region at the distances from 15 to 25D from the nozzle. The signal from the anemometer was first low-pass filtered at 50 kHz and then sampled at 100 kHz.

EXPERIMENTS AND RESULTS

In Figure 2 we illustrate the performance of various probes at the level of the energy spectra of streamwise velocity component: microprobes of various dimensions (L=60 and 100 μ) and a usual hotwire (wire diameter 2.5 μ, L=600 μ).

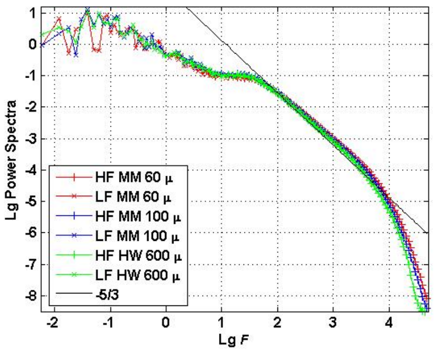

Figure 2. An example of wide-range velocity power spectra of streamwise velocity component of two micro-machined probes (MM) of two dimensions (L=60 and 100 μ) and a usual hotwire (HW, wire diameter 2.5 μ, L=600 μ) in the center of the cross-section of a turbulent round jet at x/D =20 and mean velocity $U \approx 10$ m/s. For the reason that will become clear from below the estimates of Re_λ are different for each probe: Re_λ=314 from MM 60 μ, Re_λ=437 from MM 100 μ, Re_λ=469 from HW 600 μ.

It is seen that all the probes perform almost identically as long as it goes about energy spectra. However, in order to observe the behavior of the sensors at small scales it is instructive and necessary to look at higher-order characteristics, e.g., the streamwise velocity derivative computed as the product of the velocity increment between two adjacent points and the sampling frequency 100 kHz. In Figure 3 we show the histograms of the velocity derivative and its square (proportional to the dissipation rate) for the probes as in Figure 2 and in addition a curve obtained as a running average of the 60 μ probe over time corresponding to the length of the hot-wire probe. Both curves are pretty close, which is an indication of strong spatial filtering of the hot-wire probe and consequently strong underestimate of the Taylor micro-scale, Re_λ, and the mean dissipation computed from isotropy, as seen from the Table 1 with some basic parameters of the same runs.

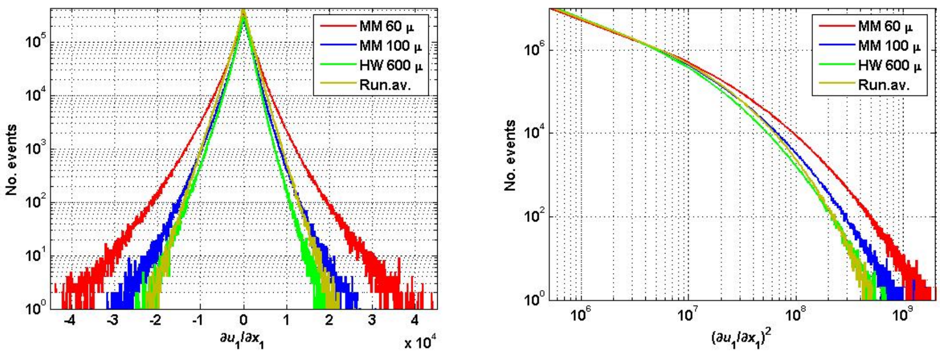

Figure 3. An example of histograms of the velocity derivative (left) and its square (right) for the probes as in Figure 2.

Table I. Some basic parameters of the runs.

Sensor	$\langle u \rangle$, m/s	RMS u, m/s	$\langle(\partial u/\partial x)^2\rangle \cdot 10^{-6}$, s^{-2}	$\langle\varepsilon\rangle \cdot 10^{-3}$, m^{2}s^{-3}	η, mm	λ, mm	Re_λ
MM 60 μ	9.9	3.7	8.8	2.0	0.036	1.26	314
MM 100 μ	10.9	3.8	5.1	1.1	0.042	1.71	437
HW 600 μ	10.4	3.7	3.7	0.8	0.045	1.91	469
Running average	9.9	3.7	4.7	1.1	0.042	1.72	425

References

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