HOT-WIRE MEASUREMENTS IN A LIQUID ^{4}HE TURBULENT INERTIAL JET: INTERMITTENCY IN HE II

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Abstract We present a comparative study of hot wire measurements in liquid helium at temperatures above and below superfluid transition. We focus on the Flatness of the signal increments in order to evidence the intermittency features.

INTRODUCTION

At temperatures below $T_\lambda \simeq 2.17\,\mathrm{K}$ the hydrodynamic behavior of the liquid helium, He II, is described by the two-fluid model: a normal component, that behaves like a Navier-Stokes fluid, with finite viscosity coexists with a superfluid inviscid component [12]. The vorticity of the latter is quantized, which results in discrete vortex filaments arranged in tangles with a complex topology. The relative motion of these tangles with respect to the normal fluid introduces a mutual friction force that couples the two components. Many questions arise about the effects of these quantum restrictions on the energy dissipation process and on the statistical properties of a turbulent flow of He II within the framework of the classic K-41 phenomenology. Previous results obtained in inertially forced liquid He flows [8, 9] above and below T_λ show a behavior compatible with the $k^{-5/3}$ Kolmogorov scaling over one decade of inertial range (the probe spatial resolution is the limiting factor). More recently the third-order structure functions of the velocity increments were measured [10] to verify the validity of the $4/5$ law in a stationary turbulent flow down to $1.56\,\mathrm{K}$. In the present paper we focus our attention on the flatness of the signal increments obtained from hot wire measurements in He I and He II.

EXPERIMENTAL SETUP

Cryogenic wind tunnel

The experimental facility consists of a cryogenic pressurized closed loop facility that uses liquid Helium at temperatures from $4.2\,\mathrm{K}$ down to $1.7\,\mathrm{K}$ at a constant pressure ($\simeq 3\times10^5$ Pa) to generate an axi-symmetric round jet turbulent flow [4]. An inertial forcing is achieved by means of a centrifugal pump and the jet develops from a $D = 5\,\mathrm{mm}$ in diameter nozzle inside a cylindrical chamber. The temperature of the working fluid is controlled by imposing the saturation vapor pressure of an external liquid He cooling bath in which the entire closed loop is immersed. A vacuum pump and a throttling valve are used to tune the temperature of the cooling bath. The facility can sustain a steady flow with a Re_λ number, based on the Taylor length scale, the normal component viscosity and the total density $\rho = \rho_s + \rho_n$, that ranges from 400 up to 2600 at $2.3\,\mathrm{K}$.

Hot-wire anemometry at low temperature

The well mastered hot-wire anemometry technique has been adapted according to the materials physical properties change that occurs at low temperatures (see e.g. [6, 1]). We developed a cryogenic hot-wire based on a metallic Pt-Rh wire with a diameter d_w from $1.3\,\mu\mathrm{m}$ to $0.6\,\mu\mathrm{m}$ and an aspect ratio of $\simeq 300$. The probe was installed on the jet axis at $x/D = 60$ downstream and operated at constant temperature using a DISA-55M01 bridge. Signals were acquired over 2000 integral time scales and the signal time-space conversion was performed by means of a usual Taylor hypothesis ($r = \langle U\rangle t$): either local in He I ([7]) or global in He II (more details can be found in [5]).

RESULTS

For the first time, hot-wire measurements were performed both in He I and He II in the same experimental facility. In He I, we have check that global and local quantities such as integral length scale, fluctuation ratio and intermittency exponents conform with previous results in similar geometries ([13, 5]). In He II, the behavior of the hot wire is very different due to the very efficient thermal transport: the usual King's calibration law is no longer observed so that our first approach has been to analyze raw voltage signals. This choice is supported by the fact that according to previous studies ([8, 9]), the observation of power laws and their exponent (e.g. in the signal power spectral density, PSD hereafter) is expected to be weakly sensitive to the calibration law.

Accordingly, the PSD of the voltage signal follows a $f^{-5/3}$ power law up to the maximum currently resolved frequencies (about 1 kHz). This result shows that no difference can be found at large scale in second order statistics and this is the reason why we decided to study higher order statistics. The flatness of the voltage increments $\delta_r E = E(x+r) - E(x)$

in He II and of the longitudinal velocity increments $\delta_r u = u(x+r) - u(x)$ in He I are presented in figure Fig. 1 as a function of the separation length scale r normalized by the longitudinal integral length scale $L_{uu} \simeq 15\,\mathrm{mm}$ at $2.3\,\mathrm{K}$ and $1.89\,\mathrm{K}$:

$$F_E(r) = \langle(\delta_r E)^4\rangle / \langle(\delta_r E)^2\rangle^2 \tag{1}$$

$$F_u(r) = \langle(\delta_r u)^4\rangle / \langle(\delta_r u)^2\rangle^2 \tag{2}$$

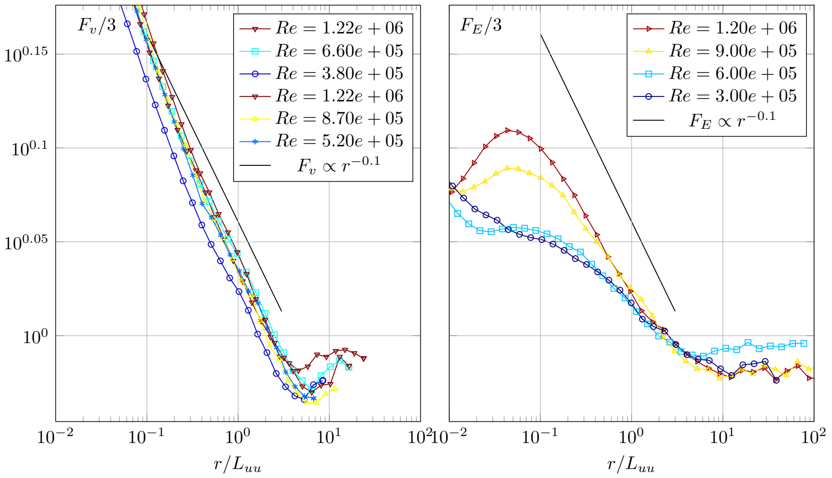

Figure 1. Comparative analysis of the skewness and flatness coefficient of the velocity in He I at $2.3\,\mathrm{K}$ (left) and of the voltage in He II at $1.89\,\mathrm{K}$ (right).

The analysis of the fourth order statistics of the velocity increments in He II reveals a sub-gaussian behavior as usually observed at large scale, i.e. $r/L_{uu} \gtrsim 10$. In the inertial range, down to $r/L_{uu} \approx 10^{-1}$, the flatness displays a power law behavior with an exponent -0.1. The same exponent is obtained in both phases. This latter result confirms that intermittency correction with respect to K-41[2], are not affected by the nature of the dissipation mechanism, at least in the upper end of the inertial range.

At smaller scale, but well above the inter-vortex spacing, some authors (see e.g. [11, 3]) claim the existence of a mesoscale where equipartition of the energy should replace the K-41 statistics. With a few improvements in the signal to noise ratio and the manufacturing of our sensor, those scales should be accessible with our current setup.

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