# Low temperature gaseous helium and very high turbulence experiments

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**Low temperature gaseous helium and very high turbulence experiments**

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Cryogenic gaseous helium gives access to extreme turbulent experimental conditions. The very high cooling helium flow rates available at CERN have been used to reach Reynolds numbers up to $Re \sim 10^7$ in a round jet experiment. First results are discussed.

Turbulence is a highly challenging problem both for fundamental understanding and industrial applications. Present capabilities of the most powerful computer simulations remain far away from common situations, and experimental data are needed to test the validity of theoretical predictions. Large air wind tunnels ($\geq 20$ m), for example, have been used for many years; however in such large experiments the $Re$ hydrodynamic parameter cannot vary on a wide range.

The physical idea is to understand how the energy injected at the large scale $L$ of the flow cascades down through the inertial scales to the smallest scale $\eta$ where it is dissipated by viscosity. In air this behavior is investigated in large systems : $L$ is in the range of several meters and $\eta$ is in the millimetric or submillimetric range.

Turbulence studies in gaseous helium at cryogenic temperatures have been achieved in the last twenty years and have opened a very attractive way to vary $Re$ on several orders of magnitude in a single geometry and reach very high $Re$ values. They take advantage of the very low kinematic viscosity $\nu$ of gaseous helium ($\nu = 7\times10^{-8}$ m$^2$/s at 4.2 K and 1 bar, 230 times lower than air in STP conditions). In a typical ($\phi = 10$ cm) laboratory jet experiment, $Re = VL/\nu$ ($V$ is the mean velocity and $L$ the width of the jet) may easily vary over three orders of magnitude by varying pressure and flow rate [1].

A large experiment with low temperature helium flow rates is today available at CERN, in the framework of the Large Hadron Collider development. We use a large scale refrigerator producing 6 kW at 4.5 K, with flow rates from 20 g/s up to 300 g/s [2]. A specific 6 m long $\phi$ 22 cm transfer line, with concentric tubes, feeds the experiment. The inner tube drives liquid and gaseous helium out of the refrigerator; the mixture is turned to gas at controlled temperature by a powerful heater (up to 10 kW) before entering a specific flow meter, a honeycomb and finally the $\phi$ = 25 mm nozzle. The round jet develops inside the 2.5 m high experimental chamber. The investigation of the expected micrometric dissipative $\eta$ scale requires an original 5 µm superconducting anemometer [3], located axially 1.25 m down the nozzle : it gives access to the velocity measurements. The helium flows back to the refrigerator through the transfer line outer tube.

The grid at the nozzle entrance is a honeycomb, $\phi$ 240 mm and 20 mm thickness, with hexagons of 4 mm side dimension. The nozzle diameter has been determined to maintain the flow velocity significantly lower than the sound velocity : at 300 g/s the output velocity is half the sound velocity. The nozzle height is 280 mm. The surface contraction factor in the nozzle is 92. Thus the flow in the experimental chamber is independent from the incoming flow characteristics as confirmed by first tests with water: they showed that the outgoing flow from the nozzle is laminar for several cm and is aligned with the nozzle axis before turning to the turbulent state. At the level of the detectors the flow diameter is about 40–50 cm. The mean temperature is 4.8 K.

Special care has been taken to avoid spurious heat leaks in order to limit the temperature difference $\Delta T$ between the incoming and outgoing He in the experimental chamber. For heat leaks ranging around 30 W, $\Delta T$, including the temperature fluctuations of the flow induced by the turbulent regime, does not exceed 100 mK at a 50 g/s flow rate. With such a low $\Delta T$, the outgoing He feeds directly the last stage of the liquefier and the He flow is in constant average temperature conditions.

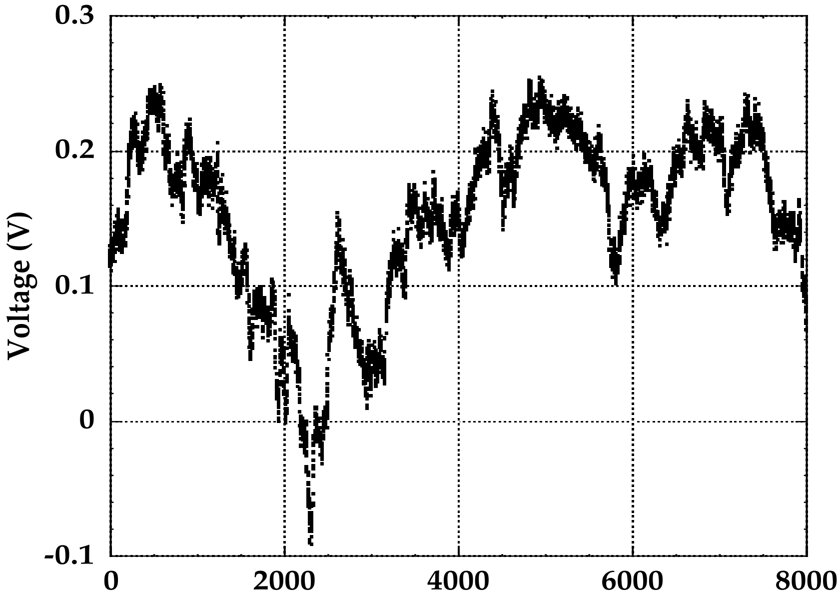


Figure 1 Voltage data at a sampling frequency of 312 kHz ($Re = 3{\times}10^6$) extracted from a full $10^8$ data record

The anemometer operation and the data acquisition procedure will be presented elsewhere [3]. On Figure 1, the sampling of 8000 voltage data points among a $10^8$ data file at $Re = 3{\times}10^6$ is shown . As typical in turbulence rather quiet periods are interrupted by sudden bursts. The calibration procedure [3] relies on the gaussian distribution of the spatial velocity and uses an improved Taylor frozen turbulence hypothesis [1]; also special care was taken to remove the noise at "low" flow rates and high frequency parasitic peaks.

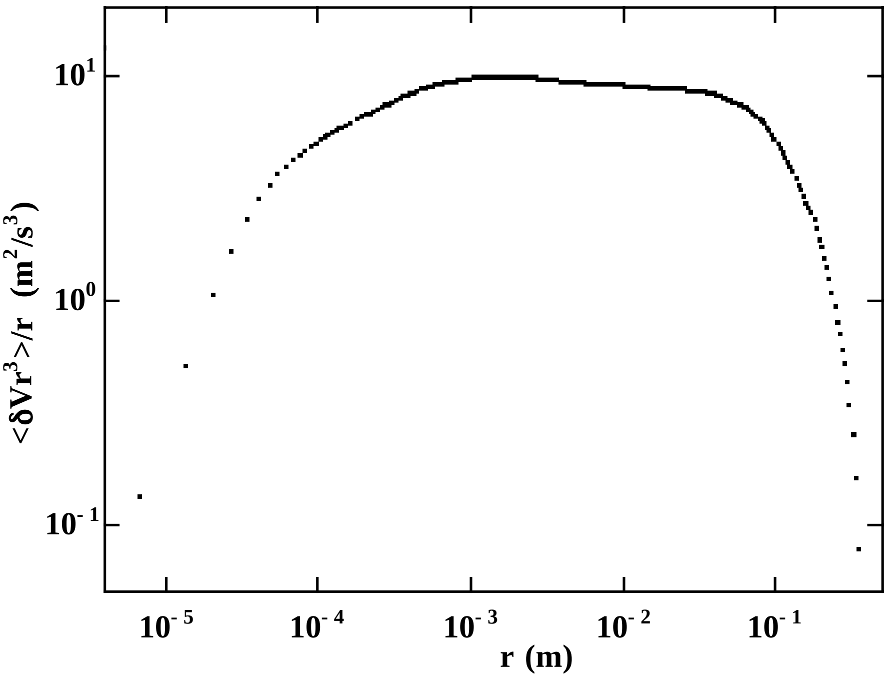


Figure 2 Third moment of the velocity fluctuations divided by $r$ vs $r$ at $Re = 10^7$

It is expected from the Kolmogorov theory [4] that for inertial scales between $L$ and $\eta$, $\langle \delta V_r^{\,3} \rangle / r$ should be constant and equal to $-(4/5)\,\langle \varepsilon \rangle$ where $\langle \varepsilon \rangle$ is the mean energy transfer rate between the various flow scales. This behavior is roughly followed: an example is given on Figure 2 at $Re = 10^7$ from 0.5 mm up to 5 cm. The sharp decrease above 10 cm is characteristic of scales close to $L$. For the lowest scales the behavior is governed, at low $Re$, by the viscous process and, at large $Re$, by the anemometer characteristic detection size.

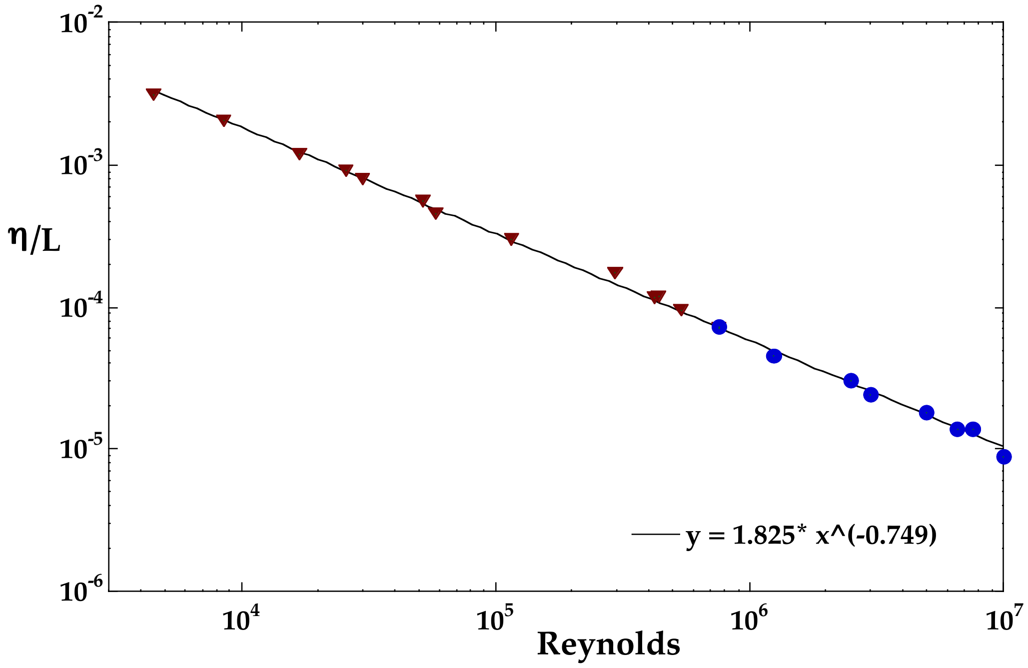


Figure 3 Kolmogorov dissipative length scale vs *Re*. The line is a best $Re^{-3/4}$ fit over the data at CERN (full circles) and former Grenoble data (triangles, Ref. [5])

From the plateau it is possible to extract a typical dissipative Kolmogorov length value: $\eta^4 = \nu^3/\langle\varepsilon\rangle$. For increasing *Re* ($7.10^5$ to $10^7$), $\eta$ decreases from 20 down to 3 µm. We present on Figure 3 the $\eta/L$ dependence with *Re* in the present and former [5] measurements. They nicely follow on more than three orders of magnitude the expected $Re^{-3/4}$ relation predicted by Kolmogorov; they are in excellent agreement with each other.

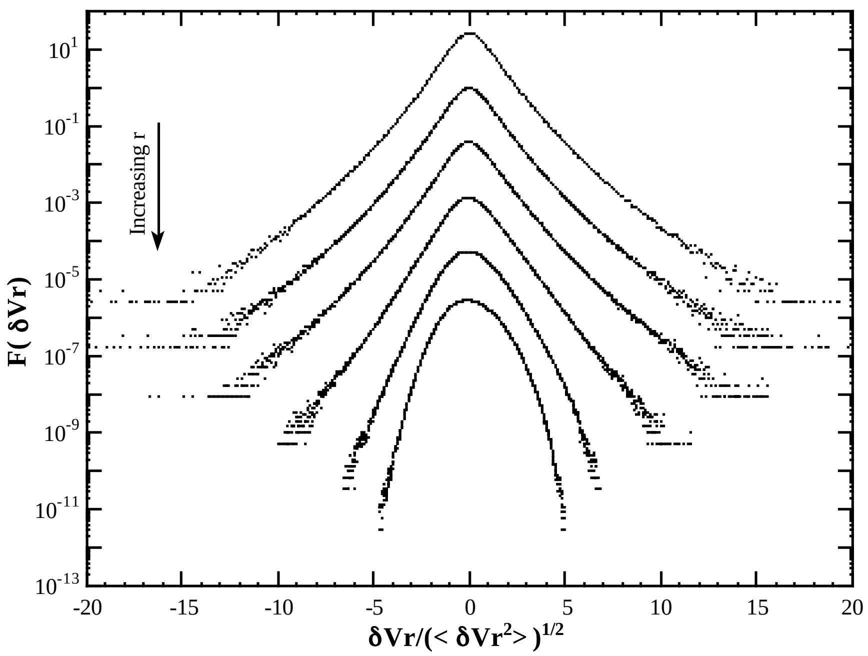


Figure 4 Normalized histograms of the velocity fluctuations $\delta V_r$ for $Re = 10^7$ ($r$ = 7, 21, 98 µm, 1, 12, 93 mm). Each histogram is shifted for clarity.

Further analysis relies on the velocity increments : $\delta V_r = V(x+r) - V(x)$ at scale r, to investigate the intermittency process. On Figure 4, the normalized $\delta V_r$ histograms are presented for several values of $r$ ($Re = 10^7$). At large $r$ the parabolic shape is characteristic of a gaussian behavior. However when $r$ decreases the more and more peaked central part and the reinforced wings are typical of intermittency processes.

Other statistical analysis are presently under progress in order to compare the data with the theoretical infinite Reynolds predictions.

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