INTEGRAL FLUCTUATIONS THEOREM FOR HIGHEST REYNOLDS

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We report on hot wire measurements (200 μm long Wollaston hotwire, diameter 1.3 μm) in the **S**uperfluid **H**elium high **Re**ynold number von **K**arman flow **(SHREK)** experiment. We used liquid helium in its classical phase (above 2.2 K) as working fluid in a large vessel (cylindrical tank 0.78 m in diameter and a height of 1.16 m). The fluid is mechanically stirred by two coaxial impellers, each 0.72 m in diameter located at both ends at 0.7 m distance (see Figure 1 in [4]). In the SHREK experiment, it is possible to control separately each of the bladed disks inside the cell, which allows to study either co-rotating or counter rotating flows by driving the impellers in the same or opposite direction or with possibly different impeller speeds. The low-temperature and large size forced von Karman liquid helium flow allows measurements at very high Re-number ($R_\lambda > 10000$ based on Taylor microscale and rms velocity) [4].

In this contribution we present an extensive statistical study of hot wire measurements in order to investigate one-point- and two-point-statistics (in terms of stationarity, higher order statistic, length scale, structure function and spectra). The data acquisition comprises 4.1×10^9 samples at a sampling frequency of 50 kHz for different conditions of the von Karman cell (different large scale inertial forcing at different Reynolds numbers). The high quality and large amount of data enables us to apply a multi-scale characterization based on the Markov property of the turbulent cascade. In this investigation, the turbulent cascade is taken as a stochastic process described by a Fokker-Planck equation and its Kramers-Moyal coefficients [1, 3, 6]. Moreover, the corresponding stochastic process can be interpreted as an analogue of a non-equilibrium thermodynamic process [5]. In particular, this advanced stochastic analysis allows to apply concepts of stochastic thermodynamics to turbulent flows [2]. Stochastic thermodynamics focuses on the description of distributions of thermodynamic variables like heat, work and entropy. Within stochastic thermodynamics, the **Integral Fluctuation Theorem** (IFT) [5] is a relation which expresses the balance between the relative frequency of entropy-consuming as compared to entropy-producing trajectories associated with the stochastic evolution of velocity increments along the eddy hierarchy.

In this presentation, we will show that the IFT as a generalisation of the second law of non-equilibrium thermodynamics of nanoscopic nonequilibrium systems, holds for turbulent flows at a macroscopic scale approaching the highest Reynolds numbers achievable in laboratory conditions in the SHREK experiment. Furthermore, using single trajectories of the cascade process, we will put the rare occurring entropy consuming (corresponding to intermittent bursts) and the frequently occurring entropy producing trajectories in relation to turbulent structures when evolving from the integral to the Taylor microscale.

The presentation will provide an enhanced insight in the complexity and the dynamics which drive the turbulent cascade in turbulent flows approaching the highest Reynolds numbers achievable in laboratory conditions, as the combination of Fokker-Planck description of velocity increments and concepts from stochastic thermodynamics allow a new approach to characterize the turbulent cascade process.

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