XXI ICTAM, 15–21 August 2004, Warsaw, Poland

STUDY OF THE TURBULENT ENERGY SPECTRUM BUILD UP IN AN EXPERIMENTAL VORTEX BURST

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Summary We present an experiment where a stretched vortex is experiencing quasi-periodical turbulent bursts inside a laminar environment. We characterize the vortex bursts by hot film measurements. It is shown that the turbulent bursts are responsible for the build up of a Kolmogorov $k^{-5/3}$ energy spectrum over one decade. The build up of this turbulent spectrum with time is investigated and compared with the Lundgren mechanism for the energy transfer towards small scales [1].

INTRODUCTION

In 1982 Lundgren has proposed a model of turbulent fine scales in the form of a stretched spiral vortex. The main result of this model is that the time averaged spectrum of the structure shows a Kolmogorov $k^{-5/3}$ fall off. The Lundgren's mechanism for the built up of the energy cascade has initiated a field of research whose results show nice predictions for turbulent flows. However, experimental evidences validating this model are still lacking. In our experiment we investigate the energy cascade build up resulting of a vortex burst. We show some common features with the Lundgren mechanism for the energy cascade [2].

EXPERIMENTAL SET UP

A stretched vortex is generated in a low velocity hydrodynamic channel. A small step added to a laminar boundary layer profile in the bottom wall produces the initial vorticity that is strongly enhanced by the stretching produced by sucking the flow through slots on each lateral wall (Fig.1). Varying the experimental parameters make two regimes occur: in the first one, the vortex is stable (Fig.2 a,b), in the second one the vortex is experiencing periodical bursts (Fig.2 c,d). The flow is characterized by the following experimental values: $Re = 4000, R = 3$cm (lateral extension of the burst), a=[1-10 s^{-1}] (stretching)

AN EXPERIMENTAL VORTEX WITH A TURBULENT BEHAVIOR, COMPARISON WITH THE LUNDGREN VORTEX

We focused on the second regime, where we characterize the vortex evolution via hot film and PIV measurements. The hot film probe is set parallel to the z axis and measure $U = \sqrt{u_r^2 + u_\theta^2}$. A typical signal obtained from hot film measurements shows the quasi-periodical character of the bursts (Fig3). Each cycle is composed of two parts: a laminar part, for which the vortex is still coherent, showing a smooth increase of the velocity, and a turbulent part associated to the vortex burst, showing rapid fluctuations of the velocity.

Using an appropriate rescaling of the hot film data and a local Taylor hypothesis to obtain spatial scales, we compute the velocity spectra of the turbulent parts. When the spectrum is calculated over the whole lifetime of the burst, a turbulent behavior with Kolmogorov $k^{-5/3}$ spectrum is obtained near the place where the vortex explodes (Fig.4). An inertial range is found between $k_m = 0.2$ cm^{-1} and $k_M = 2$ cm $^{-1}$. The estimation of the inertial range of a Lundgren vortex for our experimental values of a, Re, R gives $k_m \simeq 0.3$ cm^{-1} and 10 cm^{-1} $\leq k_M \leq$ 34 cm^{-1} that reasonably compare with experimental inertial range.

Instantaneously a spiral vortex give a $k^{-\sigma}$ energy spectrum, where σ is dependant on the flow field characteristics. It is one remarkable property of the Lundgren vortex that the time averaging over the lifetime of the vortex always results in the $k^{-5/3}$ spectrum, independently of the spiral structure considered. To better understand the energy cascade build up and to go further in the comparison with the Lundgren model, we focus on the temporal evolution of the velocity spectra during the vortex burst. In order to observe an evolution in the spectra slopes, we compute the spectra over small windows $(t, t + \Delta t)$ within the turbulent parts, so that each spectrum gives a quasi-instantaneous picture of the vortex bust energy distribution among scales at different times. We find that the slope of the spectra is time dependant and varies between a value close to -1 at the beginning of the burst to a value close to -2 at the end of the burst (Fig5). However spectrum built over the whole burst lifetime results in the $k^{-5/3}$ spectrum, as it is the case for the Lundgren vortex.

References

[1] T. S. Lundgren, Phys. Fluids, **25**: 2193-2203 (1982).
[2] Y.Cuypers, A.Maurel, P.Petitjeans, Phys. Rev. Lett. **67**, 19, (2003)

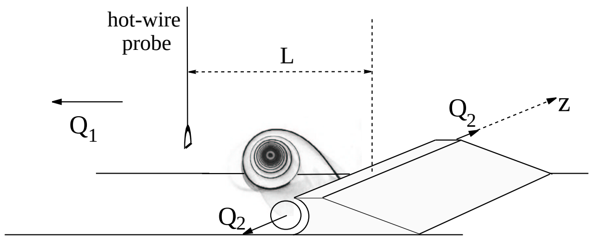

Figure 1. Experimental set-up.

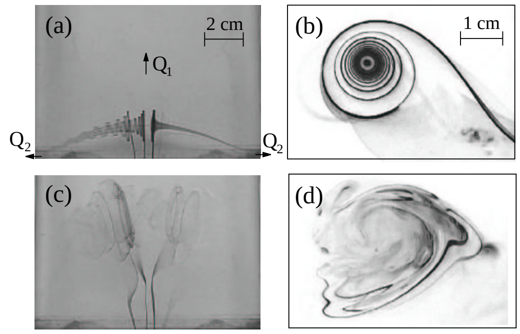

Figure 2. Sketch of the vortex cycle at $Q > Q_c$: (a-b) first stage of the cycle, the vortex is still coherent (a) side view and (b) top view; (c-d) second stage of the cycle, the vortex breaks into a turbulent burst (c) top view and (d) side view.

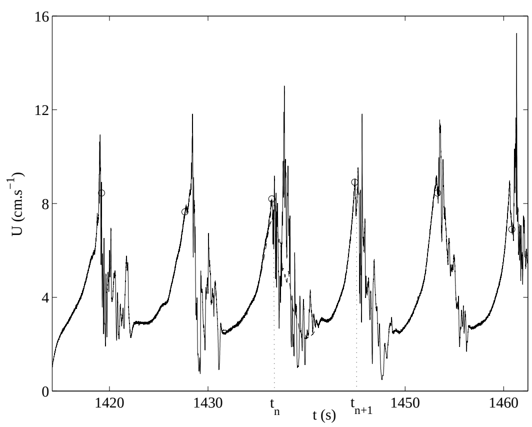

Figure 3. Close up of the temporal recording over several vortex cycles $U(t_a)$, $\circ$ indicates the times t_n at which the vortex breaks on each cycle;

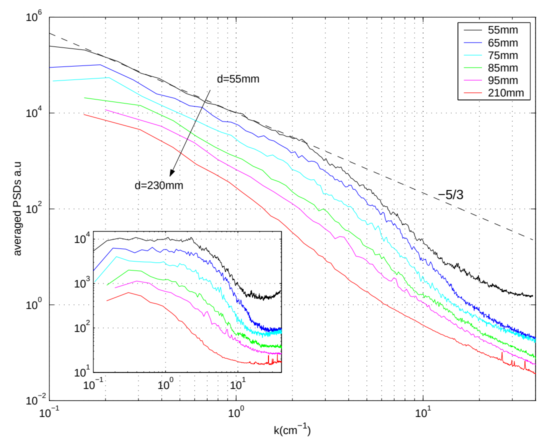

Figure 4. Experimental velocity PSD's averaged over the whole cycle for various distances d of the probe from the z-axis (d = 55, 65, 75, 85, 95, 135 and 230 mm). Subplot shows the compensated spectra $k^{5/3}E(k)$

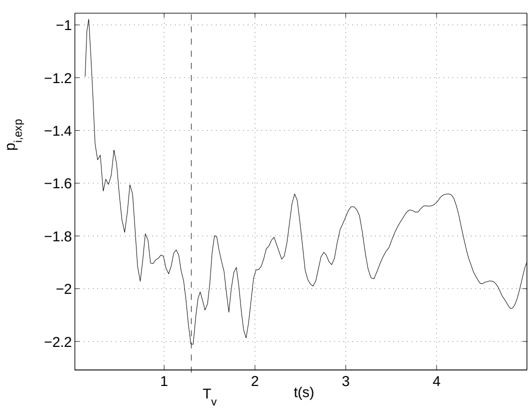

Figure 5. k-slope p of the quasi-instantaneous velocity PSDs as a function of time , T_v is the burst lifetime.