Turbulent coherent structures driven in parametrically excited surface ripples

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Abstract Spectral condensation in 2D turbulence is known to result in the generation of the system-size coherent vortices. The energy is supplied to the vortices via the inverse energy cascade from small–scale forcing. We report observation of large-scale coherent structures in quasi-2D turbulence driven by the parametrically excited Faraday ripples. The topology of the structures is very sensitive to boundary conditions. Single particle dispersion and formation of transport barriers is studied in such flows.

FARADAY RIPPLE DRIVEN SPECTRALLY CONDENSED TURBULENCE

It was found recently that the motion of floaters on the surface of parametrically excited surface ripples closely resembles fluid motion in 2D turbulence [1, 2]. The list of similarities includes the Kolmogorov-Kraichnan spectrum $E_k \sim k^{-5/3}$ in the inverse energy cascade range along with a linear positive 3rd order velocity structure function $S_{3l} = (3/2)\varepsilon r$, where ε is the energy dissipation rate and r is the separation distance [3]. It has been demonstrated that electromagnetically driven 2D turbulence in the layers of electrolytes can accumulate energy at the system size scale via the inverse energy cascade [4] which would lead to the generation of large vortex coherent across the boundary box. Here we show that the spectral condensation can also be achieved in the surface-ripple-driven turbulence. The forcing scale of turbulence is related to the Faraday wavelength, which is a length of a parametrically excited surface wave. In the range of frequencies corresponding to capillary waves (vertical vibration frequencies of $f_0 \geq 20$ Hz) at the liquid-air interface the Faraday wavelength is given by

$$\lambda_F = 2\pi^{1/3} (T/\rho)^{1/3} f_0^{-2/3} . \qquad (1)$$

Here T and ρ are the surface tension coefficient and density respectively. The forcing wave number in the ripple driven 2D turbulence k_f is approximately twice the Faraday wave number, $k_f \approx 4\pi/\lambda_F$. This opens a possibility to finely adjust turbulence forcing scale. It appears that the topology of spectrally condensed flow is sensitive to the ratio of the boundary size and the forcing scale, L/l_f. It is found that spectral condensates do not necessarily represent symmetric circular vortices, but can adopt different shapes, as illustrated in Fig. 1 and in Fig. 2(a). The kinetic energy spectrum however is not sensitive to the structure topology and in the inverse energy cascade range is given generally as $E_k \sim k^{-(3-4)}$, similarly to spectra found in electromagnetically driven turbulence [4]. Another advantage of the surface ripple method of turbulence/condensate generation is the broader range of available Reynolds numbers.

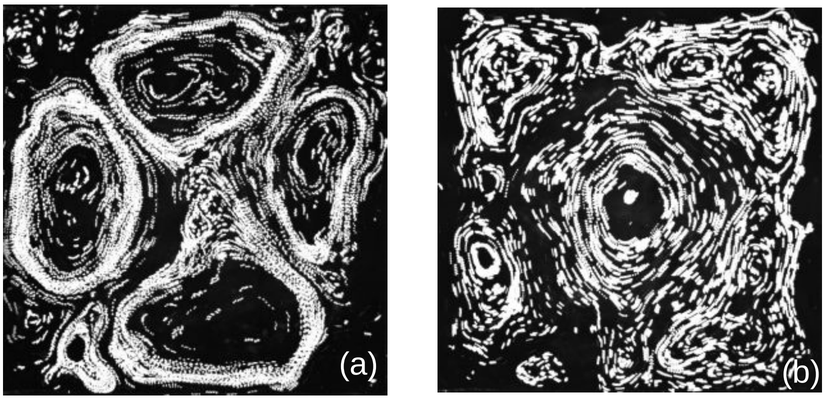

Figure 1. Coherent structures in bounded 2D turbulence produced in the Faraday ripples at the vertical vibration frequency of (a) $f_0 = 30$ Hz , and (b) $f_0 = 38$ Hz. Square boundary box size is $L = 110$ mm.

If the boundary size is large (L/l_f up to 100 was tested), coherent structures still form near the wall, such that turbulence is isolated from the wall by a chain of vortices. Bounded surface ripple driven turbulence thus appears a good test bed for studying coherent structures in turbulence.

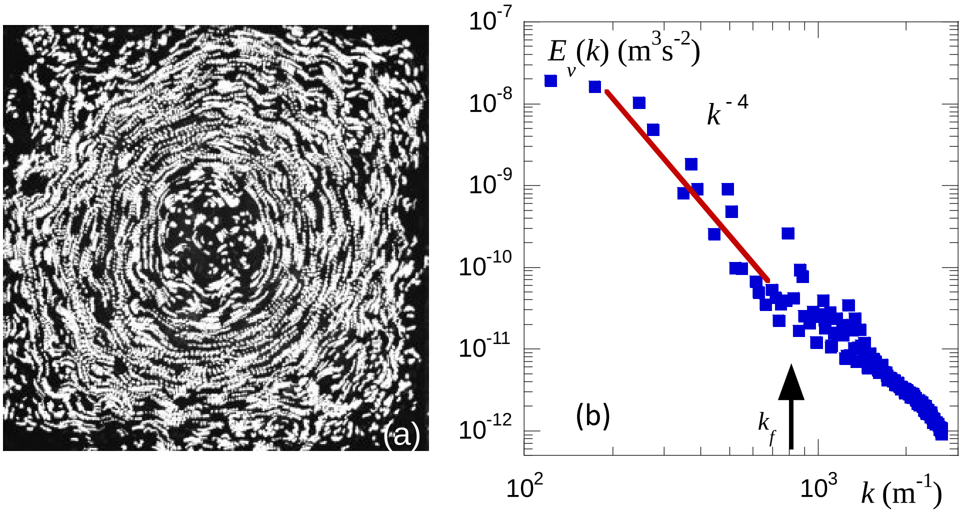

Figure 2. (a) Spectrally condensed vortex in bounded (L = 110 mm) 2D turbulence for the vertical vibration frequency of f_0 = 39.3 Hz. (b) Kinetic energy spectrum of the flow. k_f marks the forcing wave number.

LAGRANGIAN STATISTICS IN TURBULENCE WITH COHERENT STRUCTURES

Single particle dispersion has recently been studied in 2D turbulence where it has been shown that the diffusivity is given by the rms of velocity fluctuations and by the Lagrangian integral scale L_L : $D = \langle u \rangle_{rms} L_L$, where L_L can be determined from the spatial Lagrangian velocity correlation function $\rho(L) = \langle u[\vec{r}(r_0 + L)]u[\vec{r}(r_0)]\rangle / \langle u^2 \rangle$ [5]. Here we show that a similar relationship $D = \langle u \rangle_{rms} L_L$ holds in turbulence dominated by coherent structures. The diffusion coefficient is determined from the polynomial fit to the measured mean square displacement of tracer particle moving along the trajectory $\vec{r}(t)$ from its initial position $\vec{r}(0)$: $\langle \delta r^2 \rangle = At^2 + Bt$. The diffusivity is given by $D = B/2 \approx \langle u \rangle_{rms} L_L$. Such a relation is found to be valid for the displacements smaller than the coherent structure size L_c. Transport of tracers beyond this scale is restricted by the boundaries of Lagrangian coherent structures (LCS) determined by the minima of the finite-time Lyapunov exponents [6]. We present analysis of LCS in spectrally condensed turbulence. We also discuss the relation between Lagrangian velocity integral scale L_L and time T_L. We show that though in turbulence these quantities are related as $L_L = \langle u \rangle_{rms} T_L$, this relationship does not hold in the presence of coherent structures.

References

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