Flexible fiber in turbulent flows

Gautier Verhille and Patrice Le Gal

IRPHE-UMR 7342, Aix-Marseille Universitée, CNRS, École Centrale Marseille,

Keywords: Lagrangian turbulence, Flexibility, Polymer.

Presenting author email: gautier.verhille@irphe.univ-mrs.fr

For the first time, an analogy between a flexible fiber in a turbulent flow and a polymer submitted to thermal fluctuation is drawn.This analogy is verified experimentally and will allow to improve the modeling of deformable particles in turbulent flow and to study with a new sight dynamical problems in polymer theory.

Transition from rigid to flexible regime

We studied in a von Kármán flow the conformation statistics of a flexible fiber in a turbulent flow. For a given filament, if turbulent fluctuations are strong enough, the fiber starts to wriggle. A systematic study has been done changing the fiber length L, its diameter d and its Young modulus E, and the fluid viscosity μ to characterize this transition. As it is usually done in polymer theory, we focused on the evolution of the end-to-end vector.

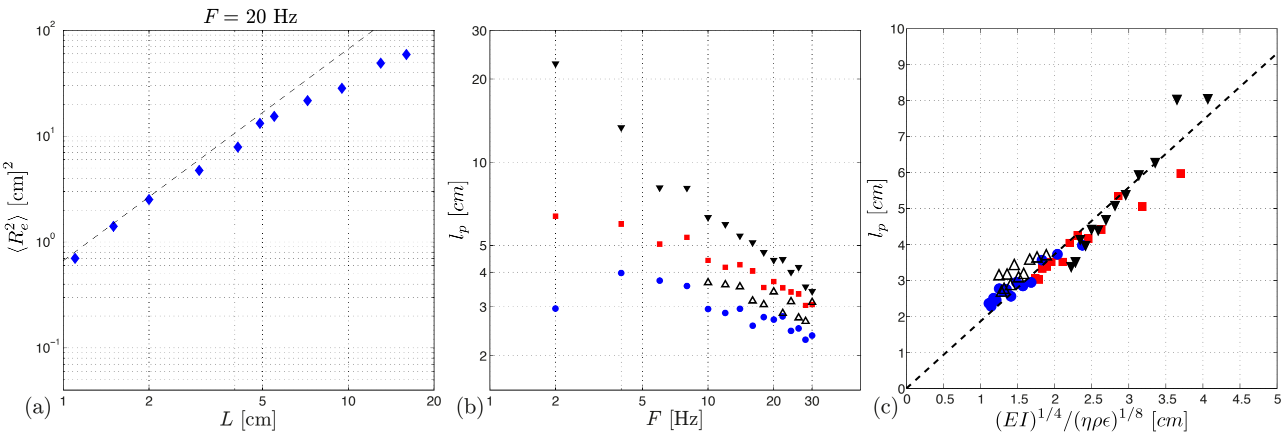

Figure 1: (a) Evolution of $\langle R_e^2 \rangle$ as a function of the fiber length L (type I) at $F = 20$ Hz. Dashed and solid lines represent the prediction for rigid fibers and the fit from the wormlike chain model respectively. (b) Evolution of the persistence length l_p as a function of the rotation frequency. c) Evolution of the experimental persistence length l_p as a function of the characteristic length l_p^P for $F \geqslant 4$ Hz. Dashed line is a guideline with a slope of 1.9. F ■ and • silicone fiber with $d = 1$ mm and d=0.6 mm, ▼ and △ nylon fiber in water and Ucon+water mixture.

We observed that the transition is well described by the worm-like chain polymer theory: $\langle R_e^2 \rangle = 2L\ell_p - 2\ell_p^2(1 - \exp(-L/\ell_p)$ [1], where ℓ_p is the persistence length and is here an adjustable parameter. To describe the evolution of this length, we propose a model based on the balance of the injected power in the turbulent cascade ε and the elastic power needed to bend the fiber [2]. This balance defines a typical length $\ell = (EI)^{1/4}/(\mu\rho\varepsilon)^{1/8}$ proportional to the persistence length ℓ_p, *cf.* figure (c).

This work has been carried out in the framework of the Labex MEC Project (No. ANR-10-LABX-0092) and of the A*MIDEX Project (No. ANR-11-IDEX-0001-02), funded by the ÒInvestissements dÕAvenirÓ French Government program managed by the French National Research Agency (ANR).

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