# Simulations of turbulent jets of viscoelastic fluids

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## Introduction

The addition of minute amounts of polymer macromolecules to a Newtonian liquid (e.g. a solution of 60 ppm polystyrene on tap water) can have dramatic consequences on fluid dynamics. Practical examples include the frictional drag reduction on turbulent pipe flow of the order of 80%, the dramatic enhancement of the cooling capacity of micro heat-exchangers for solar cell panels and the increase on the performance of firehoses for wildfire suppression. The physical mechanisms behind these particularly attractive phenomena are, however, still poorly understood. There is presently no theory able to describe the evolution of free turbulent flows with viscoelastic fluids and the influence of rheological parameters on quantities as basic as first and second order moments of the turbulent velocity field is unknown. We present results of the first Direct Numerical Simulations of turbulent viscoelastic jets and propose a theory which is able to describe their evolution. Comparisons between theoretical predictions and the numerical data are promising.

## Direct Numerical Simulations

The equations for conservation of mass, momentum and polymer stress (described by the Finitely Extensible Non-Linear Elastic constitutive model closed with Peterlin's approximation, see below) were numerically solved in a computational grid with 512x512x128 grid points, and marched on time with hundreds of thousands of time iterations. Simulations of the FENE-P fluid are one order of magnitude more expensive than for Newtonian fluids and these are the largest simulations of viscoelastic turbulent jets ever performed. The numerical method uses highly accurate pseudo-spectral/6th-order Compact finite differences schemes and the Kurganov-Tadmor method for the evolution equation of polymer stresses.

$$\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{u} = -\frac{1}{\rho}\nabla p + \nu^{[s]}\nabla^2\boldsymbol{u} + \frac{1}{\rho}\nabla\cdot\boldsymbol{\sigma}^{[p]}, \qquad \nabla\cdot\boldsymbol{u} = 0$$

$$\boldsymbol{\sigma}^{[p]} = \frac{\rho\nu^{[p]}}{\tau_p}[f(c_{kk})\boldsymbol{C} - \boldsymbol{I}], \qquad f(c_{kk}) = \frac{L^2-3}{L^2-c_{kk}}$$

$$\frac{\partial \boldsymbol{C}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{C} = \nabla\boldsymbol{u}^T\cdot\boldsymbol{C} + \boldsymbol{C}\cdot\nabla\boldsymbol{u} + \frac{1}{\tau_p}[f(C_{kk})\boldsymbol{C} - \boldsymbol{I}],$$

## Proposed Theory

The theoretical formulation is based on the assumptions of self-similarity of the mean flow and equilibrium between production of turbulent energy by the mean shear and dissipation of turbulent energy by the polymer molecules. It results that the viscoelastic jet spreads linearly with the distance from the nozzle while the jet mean velocity and polymer shear stress decay accordingly to -1/2 and -5/2 power laws, respectively.

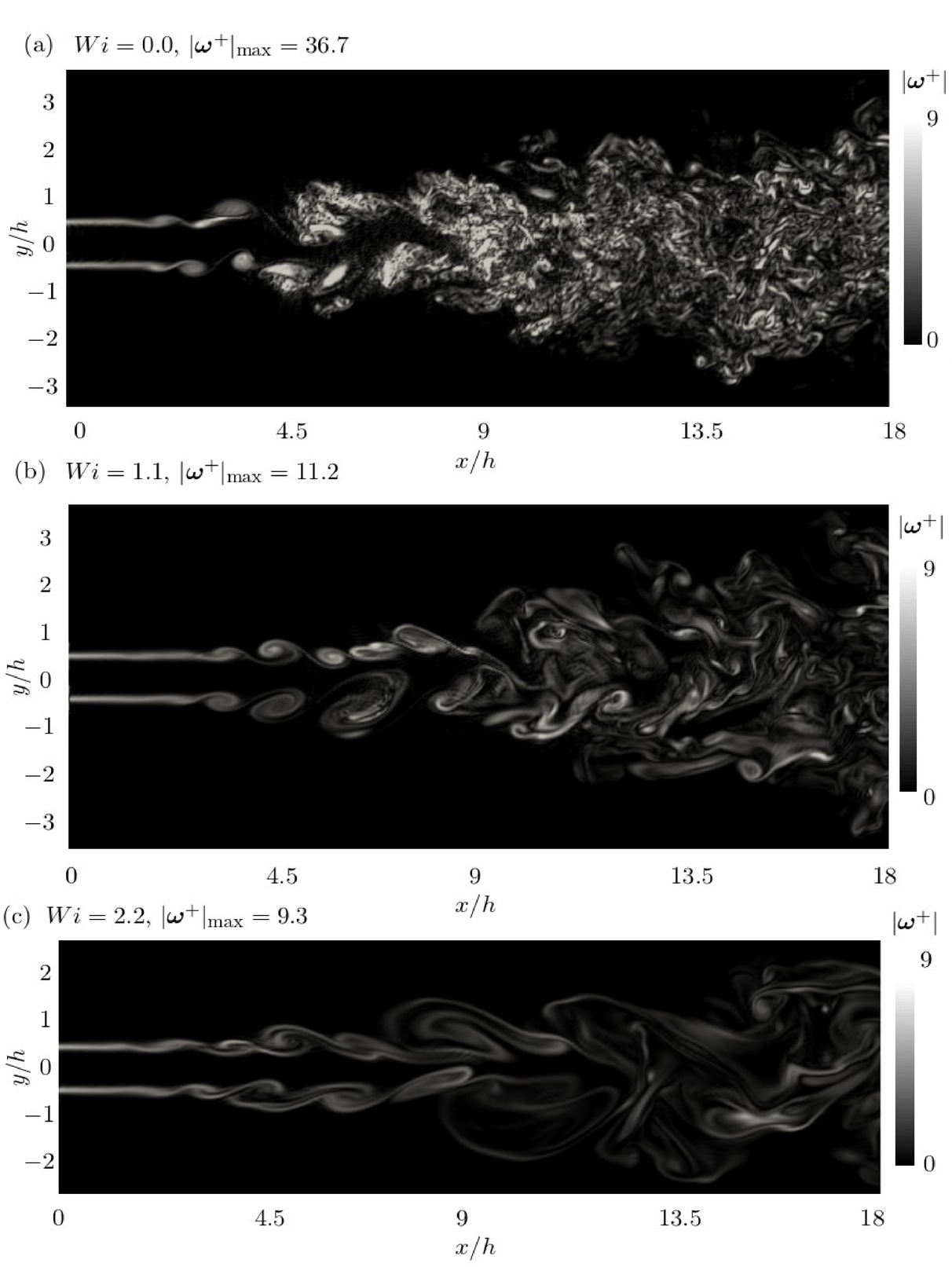


Fig 1: Contours of vorticity magnitude for Newtonian (a) and viscoelastic (b,c) jets.

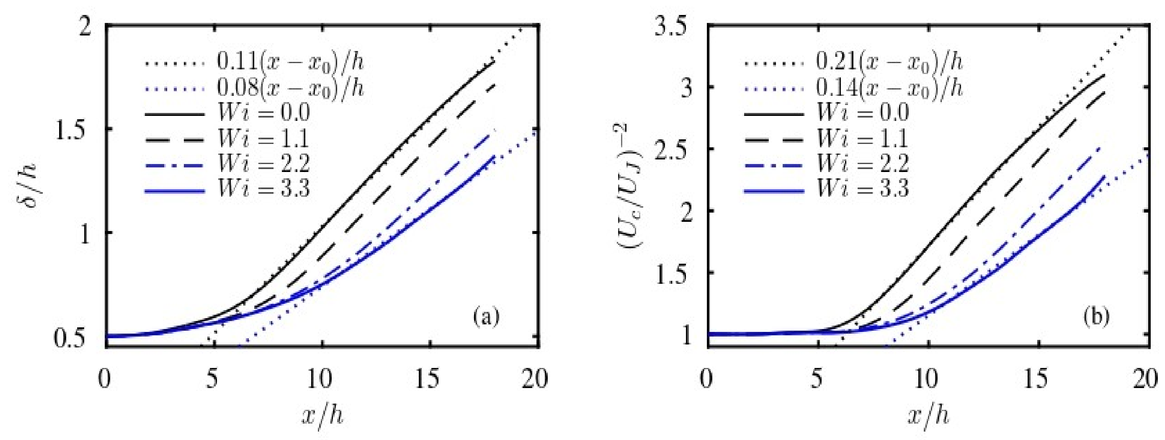


Fig 2: Evolution of the normalized jet width (a) and centreline velocity (b).

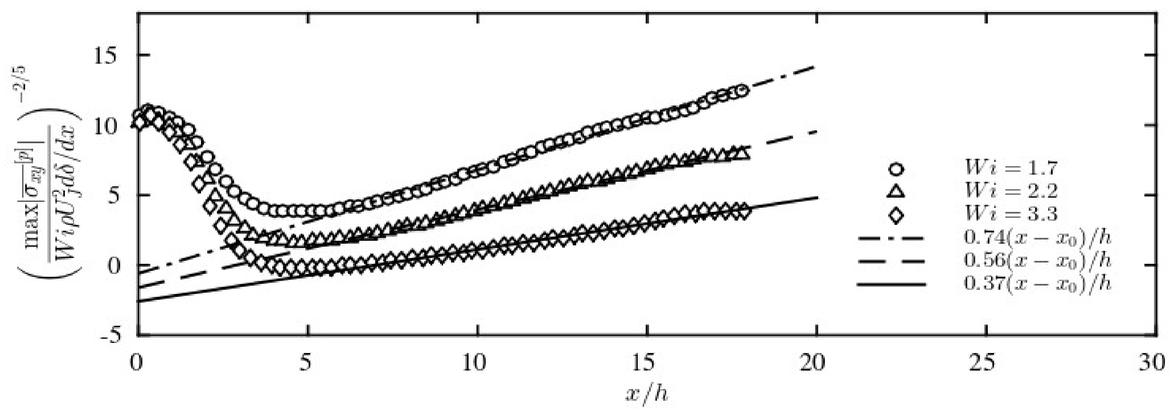


Fig 3 : Evolution of normalized maximum polymer shear stress.

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