How polymers tweak the nonlinearity of turbulence to reduce drag

Wouter Bos*[1]

[1]Laboratoire de Mecanique des Fluides et d'Acoustique (LMFA) – CNRS : UMR5509, Ecole Centrale de Lyon, Université de Lyon – 36 Av Guy de Collongue 69134 ECULLY CEDEX, France

Résumé

In the 1940s B.A. Toms carried out experiments to assess the influence of small additions of polymer solution to water flow (1). He showed that the drag and thereby the energy needed to pump the water through the pipe was drastically reduced. A few parts per million of polymer can lead to a drag-reduction of up to 80% !

Since this discovery, now 80 years ago, an enormous amount of research has been devoted to the subject, without leading to a satisfactory theory. Indeed, the complexity of the problem comes from the fact that molecular dynamics (the polymers carried about by the fluid), lead to an important modfication of the macroscopic flow properties.

In the last 5 years we investigated a turbulent flow, where we artificially suppressed a part of the dynamics of the Navier-Stokes equations: we carried out numerical simulations where the stretching of vorticity was suppressed in a turbulent flow (2). This imaginary flow does not exist in nature, but can be studied by numerical experiments. This system turned out to show similarities with turbulent drag reduction by polymers.

Extending these ideas, we showed that we can adapt the ideas of Von Karman from the 1930s to describe turbulent pipe-flow to our new system (3). We show that the resulting prediction agrees with experimental observations of polymer-laden pipe flow. The proposed model: turbulence with reduced vortex stretching turns thus out to be the minimal description of the macroscopic dynamics of polymer laden flow. It thereby clarifies the 80 year old Toms riddle of drag-reduction (4).

(1) Toms, BA 1949 Proceedings of the 1st international congress on rheology. Vol. II, North Holland, Amsterdam. p. 135.
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(3) von Kármán, Th. 1930 Mechanische änlichkeit und turbulenz. Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse 1930, 58–76.
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*Intervenant