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RESEARCH PAPER

The holy grail of microfluidics: sub-laminar drag by layout of periodically embedded microgrooves

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Abstract The sub-laminar drag effect of microgroove surfaces was studied numerically in a steady two-dimensional channel flow at subcritical Reynolds numbers. Considerations are restricted to grooves of a few viscous length scales in depth, which are assumed not to promote the laminar to turbulent transition process. It was found that the drag reduction effect is due to the layout of grooves with respect to the flow direction and contour geometry. Results of computations show that for grooves of curved contour placed normal to the flow direction, drag arising from viscous and pressure forces is modulated due to the functional dependence of forces on the surface area projected in the flow direction. Such a groove layout leads to a large skin-friction reduction, but a comparable increase in pressure drag results in sub-laminar drag if drag over flat surface is considered as a reference. For a curved groove contour, the drag reduction increases with increasing Reynolds number and reaches about 5 % at Reynolds numbers approaching critical.

Keywords Viscous drag reduction · Drag reduction surfaces · Flow control · Viscous flow · Wall-bounded flows

1 Introduction

In many technical applications, the viscous contribution to the total drag is predominant. For this reason, there is continuing interest in how it can be reduced rationally leading to beneficial outcomes to the economy and the environment. Several mechanisms were accidentally discovered which showed a remarkable ability to reduce viscous drag significantly, but almost exclusively in the turbulent flow regime and under very special circumstances. This situation prevented the wider spread of attractive discoveries in technical practice and is the major reason for continuing interest aiming at more unified solutions. Some of successful approaches include dilute addition of high polymers (Toms 1949), fiber suspensions (Metzner 1977), surfactant solutions (Zakin et al. 1998) and dispersed particles (Lumley 1977).

In searching for unified solutions capable of matching the demands of engineering, attempts were made to achieve viscous drag reduction by patterning solid boundaries (Hage 2005). Various forms of riblet configurations aligned in the flow direction were employed in turbulent wall-bounded flows (Walsh 1983), which, however, produced a disappointingly small net reduction of drag. Another more promising approach currently under consideration is based on micro-geometries which trap gas inside microgrooves, allowing liquid in the main stream to pass over part of the surface with slip at the boundary inducing a significant reduction of drag which was measured in both laminar and turbulent flow regimes up to 30 % (Jung and Bhushan 2010).

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