Inertial effects in flows generated by artificial cilia

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Inertial Effects in Flows Generated by Artificial Cilia

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Introduction

The demand for fast, reliable and easy to use medical testing devices is growing rapidly. Lab-on-a-chip devices forfill these requirements and are therefore more and more used. The basic idea of a lab-on-a-chip is the incorporation of all manipulation and sensing components for a bodily fluid on a microchip. The transportation of fluid is necessary and due to the small lengthscales ($\mathcal{O}$(mm-μm)), new techniques are required. By mimicking nature, where small hairs (cilia) are used, this problem can be overcome [1]. These artificial cilia are to be powered by an external field. Although microfluidic flows are often treated inertialess, recent experiments suggest that inertia can be of importance [2].

Objective

Investigate the influence of inertial effects in a flow generated by an array of cilia.

Methods

The flow generated by an array of cilia in a channel will be modelled in a two dimensional framework. An infinite array of cilia is simulated, as depicted in Fig. 1, by applying periodic boundary conditions.

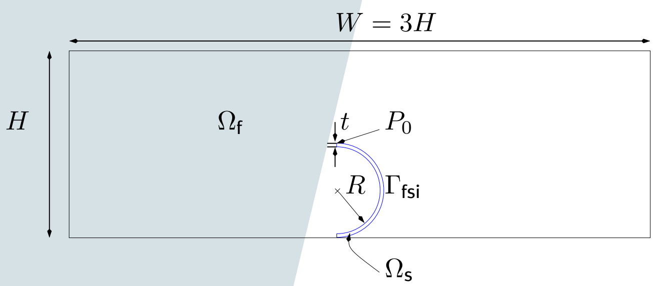

Fig. 1 *Schematic picture of the problem domain with $H = 100\mu$m, $R = 20\mu$m, $t = 1\mu$m.*

The fluid and solid domains, Ω_{f} and Ω_{s} respectively have the following properties:

- Inertial, incompressible, Newtonian fluid, with density ρ and viscosity η.
- Inertialess, incompressible, Neo-Hookean solid with modulus G.

The motion of fluid and solid is coupled by the condition that the fluid and solid velocities are equal at Γ_{fsi}, following van Loon *et al.* [3]. A downward pointing body force is applied on the solid until P_0 is almost in contact with the lower wall, after which the force is released. The governing dimensionless number is the Reynolds number (Re= $\frac{\rho U H}{\eta}$), where U is the typical velocity. For the simulations $U = 0.1$ m/s, $\eta = 1$ mPa s are used. By changing the density, Re is changed. A FEM (TFEM) is used for solving the set of equations.

Results

The paths followed by P_0 during one cycle are shown in Fig. 2 for two different Reynolds numbers. Both paths show an asymmetric motion of the cilium tip, and are similar. In Fig. 3 a typical flow field is shown.

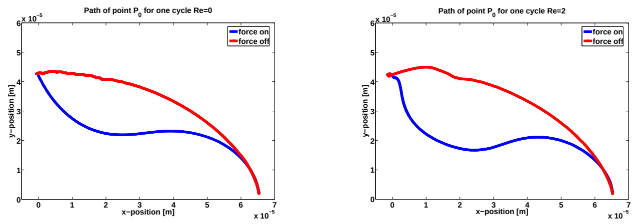

Fig. 2 *Paths of P_0 for Re$= 0$ (left) and Re$= 2$ (right).*

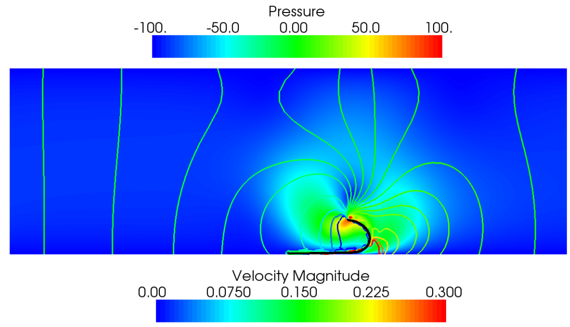

Fig. 3 *Characteristic flow field (Re=1) with pressure contours [Pa] and velocity magnitude [m/s].*

It is now possible to compute the net flow after one cycle for different Reynolds numbers, see Fig. 4.

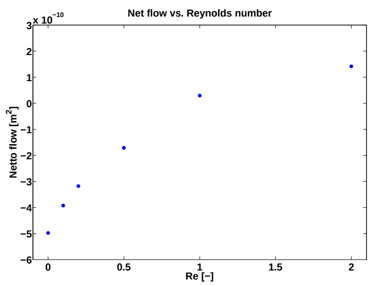

Fig. 4 *Net flow after one cycle for different Reynolds numbers.*

Due to the assymetric motion, a net flow is generated for all Reynolds numbers. For Re$= [1, 2]$ the flow direction is changed however. This means that the flow direction can be controlled by varying the Reynolds number.

Conclusions

The effect of inertia in flows generated by artificial cilia is investigated. For small, but realistic, Reynolds numbers the flow direction is changed due to inertial effects.

References:

[1] Khatavkar V. , Anderson P. D. , Toonder J. M. J. den, Meijer H. E. H. : *Active micromixer based on artificial cilia* (Phys. Fluids, 2007)
[2] Toonder J. M. J. den : *Personal communication* (2007)
[3] Loon R. van, Anderson P. D. , Vosse F. N. van de: *A fluid-solid interaction method with solid-rigid contactfor hart valve dynamics* (J. Comput. Phys., 2006)

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