Inertial effects in flows generated by artificial cilia

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Inertialess, incompressible, Neo-Hookean solid with inertia can be of importance [2]. Recent experiments suggest that inertia is important in flows generated by artificial cilia. Consequently, for small, but realistic, Reynolds numbers the flow direction is changed due to inertial effects. This means that the flow direction can be controlled by varying the Reynolds number.

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.

The motion of fluid and solid is coupled by the condition that the fluid and solid velocities are equal at their interface.

\[ W = 3H \]

The fluid and solid domains, \( \Omega_t \) and \( \Omega_s \) respectively have the following properties:

- Inertial, incompressible, Newtonian fluid, with density \( \rho \) and viscosity \( \eta \).
- Inertialless, incompressible, Neo-Hookean solid with modulus \( G \).

The fluid and solid velocities are equal at their interface. 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].

Results

The paths followed by \( P \), 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 \( P \) 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.

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.