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FLOW CONTROL USING SURFACE VIBRATIONS

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Abstract

Resistance reduction effects induced by surface vibrations in the form of travelling waves in pressure-gradient-driven channel flows have been investigated. A spectrally accurate algorithm, incorporating the Immersed Boundary Conditions (IBC) method, was developed for this analysis. The algorithm is based on the combination of Fourier expansions in the streamwise direction and Chebyshev polynomials in the normal direction. The study is focused on laminar flows and sinusoidal waves characterized by wave number, phase speed, and amplitude. The effectiveness of the surface vibrations was assessed by measuring the pressure gradient correction needed to sustain the same flow rate as in the absence of vibrations. Although the flow response to these waves varies with Reynolds number, upstream-propagating waves consistently increase flow resistance. At low Reynolds numbers, downstream-propagating waves reduce resistance, thereby attenuating pressure losses. However, the flow response becomes more complex at higher Reynolds numbers, and the waves must be sufficiently fast to reduce pressure losses in these flows. It has been found that simultaneous imposition of vibration waves on both channel walls enhances the impact of these waves. The magnitude of this improvement depends on the relative phase of the waves, with out-of-phase waves leading to the most significant reduction in pressure losses, nearly doubling effectiveness compared to channels with a single vibrating wall. The results indicate that in certain conditions, surface vibrations can generate ample propulsive forces to completely overcome resistance and pump fluid in the wave direction, eliminating the need for an external pressure gradient. These findings highlight the potential of surface vibrations as an effective flow control mechanism, with implications for reducing energy consumption in fluid transport systems.