Applied and Computational Mathematics Seminar

Title: Flows Over Patterned Topographies: theoretical and computational studies

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Abstract: Topographical textures or surface corrugations are often employed in the discipline of microfluidics to achieve objectives such as mixing, modulation of wetting and frictional properties, and separations. Outside microfluidics, such textures form the basis of drag-reducing riblets engineered to turbulent flows and are natural features of fractured rocks carrying oil or water in geological formations. Motivated by such applications, macroscopic characterization of creeping Newtonian flows establishing wetted contact with topographies is undertaken theoretically, using the effective slip length tensor as a metric for unconfined flows and the hydraulic permeability tensor as a metric for confined flows. First, for sinusoidally corrugated no-slip surfaces in shear flow, analytical models usable over a significantly wider amplitude range than those available from the literature are developed, taking advantage of symbolic computations, numerical-graphical convergence studies with Domb-Sykes plots, and series-improvement techniques like Euler and Shanks transformation and Padé approximants. Next, confined pressure-driven flows are studied using a grid-free semi-analytical approach based on spectral analysis. This method has a faster (exponential) decay of errors compared to discretization-based methods such as finitedifferences and finite elements and is also easily reducible to new and known analytical forms in various disparate limits. The final contribution of this work is a spectral-asymptotic approach to model confined flows over complex topographies specifiable by an arbitrary continuous function. Using a novel decomposition of the channel height effects into exponentially and algebraically decaying components, a simple surface-metrology-dependent relationship, which connects the eigenvalues of the effective permeability tensor, is obtained. Representative topographies assessed numerically include the infinitely-differentiable topography of a phase-modulated sinusoid with multiple local extrema and zero-crossings and the nondifferentiable triangular-wave topography. Corners in triangular patterns and cusps in scalloped patterns are not found to be an impediment to meaningful and numerically accurate asymptotic predictions, contradicting an earlier suggestion from the literature. Several distinct applications of the theory to the friction-reduction and shear-stability performance of the recently developed lubricant impregnated patterned surfaces and scalloped and trapezoidal drag-reduction riblets are discussed, with comparison to experimental data from the literature for the last application