Origin of Levitation Force in Horizontal Core Annular Flows

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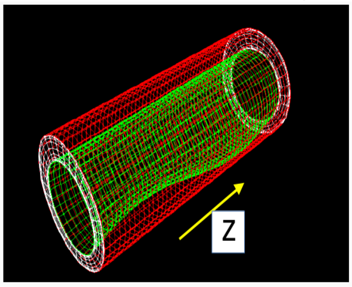
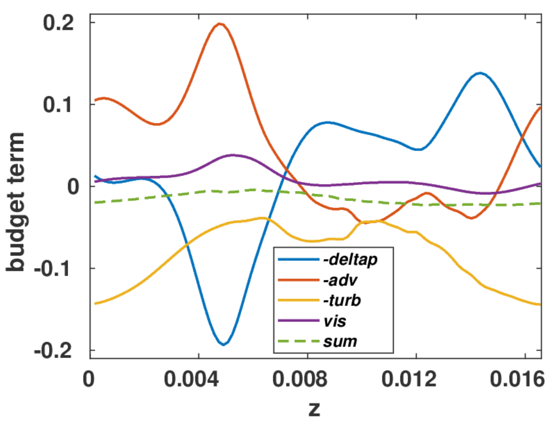
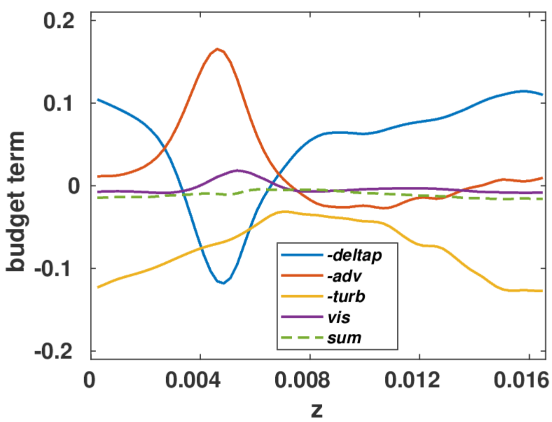
Core Annular Flows (CAFs) in pipelines consist of a high-viscosity liquid in the core region being lubricated by low-viscosity liquid injected in the annular region. The low-viscosity annular fluid can dramatically reduce the pressure drop required to pump the high-viscosity core liquid. In horizontal pipelines, even in the presence of density difference between the core and annular liquids, it is possible to achieve CAF via balance between levitation force and buoyancy. In this work, we perform numerical simulations of only annular flow within the CAF using OpenFOAM, in which the core velocity as well as the shape of the core-annular interface wave is fixed. The wavelength and amplitude of the wavy interface as well as the average eccentricity of the core, is prescribed. The ratio of bulk velocity of annulus and core is kept constant at 0.7, and the Reynolds number of the annular flow is kept in the inertial range. Several simulations are performed, in which the flow-rate of the annular fluid is systematically increased. The coefficient of lift acting on the core is found to change sign from negative to positive values with increasing flow rate, especially when the interfacial waves are prescribed on the thicker side of the annulus. A momentum budget analysis along the azimuthal direction shows that the gap-averaged pressure difference between the top and bottom of the core is balanced by advection and turbulent stresses, with very small contribution from viscous stresses. The change in sign of lift coefficient of the core can be attributed to the changes in distribution of advection force along the pipe. Interestingly, the turbulent stress always contributes to the positive lift force. The trends in advection and turbulent force distributions are attributed to specific flow structures in the annulus. Results from this work yield insights into how the wavelength and amplitude of the interface, as well as the average eccentricity of the core, give rise to levitation force, thereby sustaining horizontal CAF.



(a) Flow domain

Domain details	:	Pipe radius: 0.0075 m, core radius: 0.0054 m, length of pipe: 0.0375 m.
Wave details	:	Eccentricity: 0.00063 m, amplitude of wave: 0.000819 m.
Flow details	:	Viscosity of annulus: 10^{-6} cSt.
Velocity of core	:	0.32 m/s (Positive levitation), 0.45 m/s (Negative levitation).





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(b) Negative Lift (c) Positive Lift

Figure 1: (a) Schematic showing flow geometry with core (green) and pipe (red) surface. An axial velocity is imposed at the core surface and an axial flow rate is imposed in the annulus. Budgets for average azimuthal momentum budget, integrated between the top and bottom of annulus for cases with (b) negative and levitation (c) positive levitation acting on the core. The budget terms are: pressure difference (-deltap), advection (-adv), turbulence (-turb), viscosity (-vis) and residual (sum).