Problem I (25 points)

(a) Nondimensionalize Navier-Stokes equation ($\rho \frac{D\vec{V}}{Dt} = -\nabla p + \mu \nabla^2 \vec{V}$) for an oscillatory flow with a high Reynolds number. Clearly list all typical scales you use and show all solution steps. **(8 points)**

(b) Explain the physical meaning of the dimensionless groups you obtain. **(5 points)**

(c) Nondimensionalize Navier-Stokes equation for a non-oscillatory, unsteady flow. Clearly list all typical scales you use and show all solution steps. **(7 points)**

(d) Use the non-dimensionalized equation to explain mathematically why the viscous term can't be dropped for solving the velocity field of a laminar high-Re# flow over a plate. **(5 points)**

Problem II (25 points)

Given:

A thin film of a Newtonian liquid flows over an inclined flat plate as shown.

Find:

(a) List your assumptions (3 points)
(b) Simplify the continuity equation as much as possible. (4 points)
(c) Simplify the x momentum equation. (5 points)
(d) What are the boundary conditions? (4 points)
(e) Find the velocity distribution in the liquid. (3 points)
(f) What is the maximum velocity? (3 points)
(g) What is the wall shear stress? (3 points)

Schematic: