The effects of porous walls on transitional and turbulent channel flows

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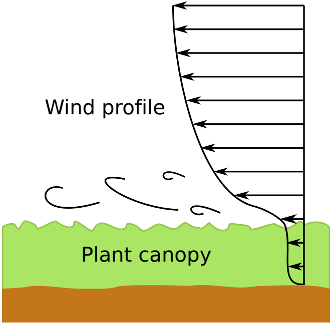
Why porous walls?

Flow over porous media are common:

- Water-immersed surfaces
- Biologic surfaces (blood vessels, vascular protheses)
- Atmospheric boundary layer over plant canopies
- Aeronautics



STATE OF THE ART

STABILITY: POROUS WALLS ARE DE-STABILIZING

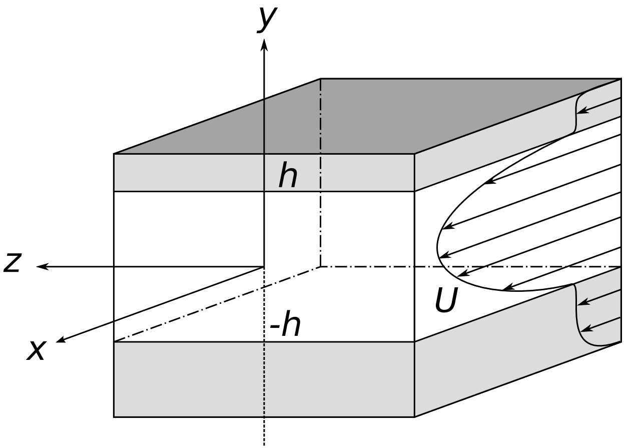
- Critical linear Reynolds number decreases by 90%
- Sparrow (JAM 1973), Tilton & Cortelezzi (JFM 2008)

TURBULENT FLOWS

- Porous layer is neglected and represented via a wall boundary condition
- Very simple porous material are considered
- Present approach: solve VANS equations

Problem setup

Two boundary layers across every porous layer



Model of the porous medium

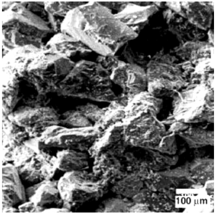
Porosity ε

- Volume fraction of the fluid phase
- $\varepsilon = V_{fluid}/V_{total}$, $0 \leq \varepsilon \leq 1$

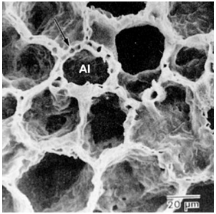
Permeability K [m^2]

- The ease of fluid flow through the medium
- Non-dimensional permeability $\sigma = \sqrt{K}/h$, $\sigma \geq 0$

Sandstone



Alveoli in the lungs



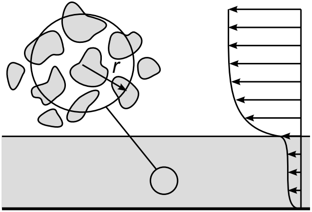
The Volume-Averaged Navier–Stokes equations

VANS: Whitaker, 1996

Simplified VANS: linear!

$$\nabla \cdot \langle \mathbf{u} \rangle = 0$$

$$\frac{\partial \langle \mathbf{u} \rangle}{\partial t} = -\frac{1}{\rho}\nabla \langle p \rangle + \nu \nabla^2 \langle \mathbf{u} \rangle - \frac{\nu}{K}\varepsilon \langle \mathbf{u} \rangle$$



$\langle \mathbf{u} \rangle$ and $\langle p \rangle$ are continuous functions

- Homogeneous porosity
- Isotropic porosity
- Inertial effects negligible

The interface condition

Ochoa-Tapia and Whitaker, IJHMT 1995

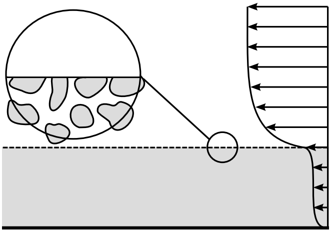
Continuity

$$\mathbf{u} = \langle \mathbf{u} \rangle, \; p = \langle p \rangle$$

Stress jump conditions

$$\frac{1}{\varepsilon}\frac{\partial \langle u \rangle}{\partial y} - \frac{\partial u}{\partial y} = \pm \frac{\tau}{\sqrt{K}} u$$

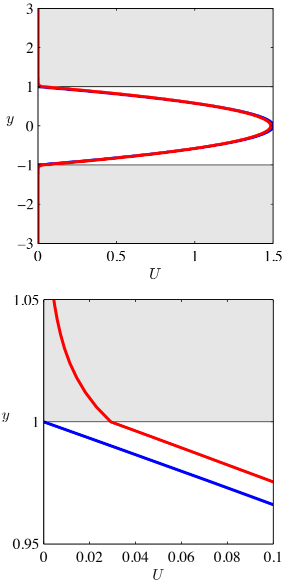
$$\frac{1}{\varepsilon}\frac{\partial \langle w \rangle}{\partial y} - \frac{\partial w}{\partial y} = \pm \frac{\tau}{\sqrt{K}} w$$



- The stress jump models the momentum transfer
- τ accounts for the surface manufacturing/machining

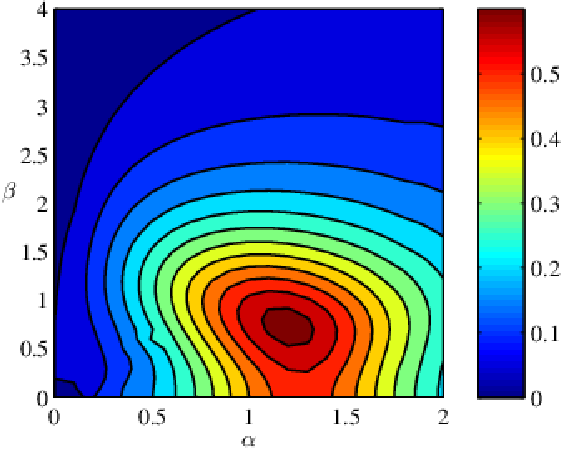
NON-MODAL STABILITY

- Analytical base flow
- Chebyshev discretization
- 7 parameters: Re, α, β, h_p, σ, ε, τ
- Adaptive algorithm, >4M cases



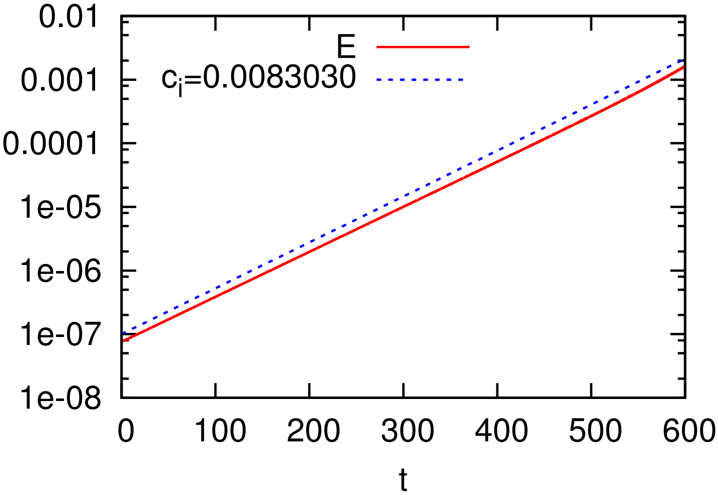
LARGEST FRACTIONAL CHANGE IN G_{max}

$Re = 500, h_p = 0.5, \sigma = 0.02, \varepsilon = 0.3, \tau = 0.5$



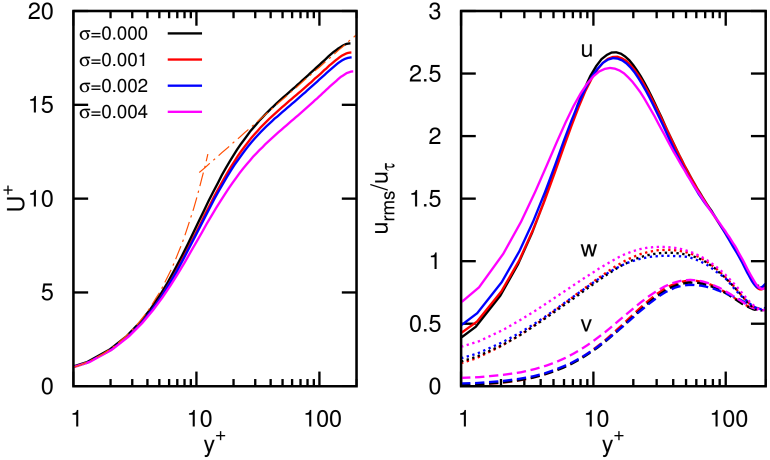
DNS solver: validation

$Re = 2800, \varepsilon = 0.6, \sigma = 0.004, \tau = 0, h_p = 1$

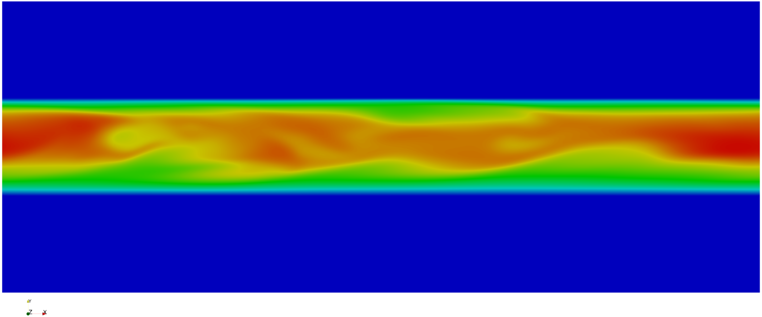


LIMIT OF SOLID WALL

$Re = 2800, \varepsilon = 0.6, \tau = 0, h_p = 0.1$



VERY LOW *Re*!



Conclusive remarks

- Non-modal stability
- Turbulent flow
- Ongoing work: control, drag reduction