

Analytical Fluid Dynamics

- Example: laminar pipe flow

Assumptions: Fully developed, Low $Re = \frac{\rho U D}{\mu} < 2000$

Approach: Simplify momentum equation, μ integrate, apply boundary conditions to determine integration constants and use energy equation to calculate head loss

$$\cancel{\frac{Du}{Dt}} = -\frac{\partial p}{\partial x} + \mu \left[\cancel{\frac{\partial^2 u}{\partial x^2}} + \frac{\partial^2 u}{\partial y^2} \right] + \cancel{g_x}$$

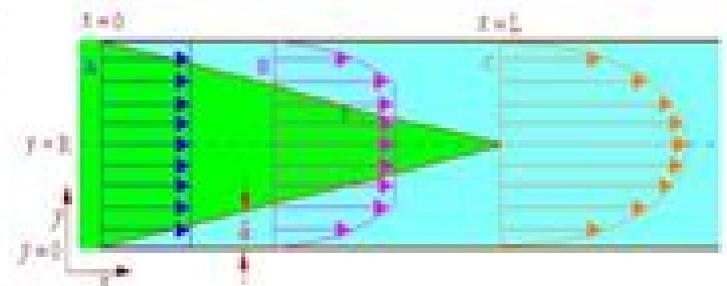
Exact solution :

$$u(r) = \frac{1}{4\mu} \left(-\frac{\partial p}{\partial x} \right) (R^2 - r^2)$$

Friction factor: $f = \frac{8\tau_w}{\rho \bar{V}^2} = \frac{8\mu \left. \frac{du}{dy} \right|_y}{\rho \bar{V}^2} = \frac{64}{Re}$

Head loss: $\frac{p_1}{\gamma} + z_1 = \frac{p_2}{\gamma} + z_2 + h_f \quad h_f = f \frac{L V^2}{D 2g} = \frac{32\mu L V}{\gamma D^2}$

Schematic



δ = Boundary layer thickness
 R = Radius of pipe
 L = Transition length
 v = Velocity

■ Potential flow region
■ Boundary layer flow

Development of boundary-layer flow in pipe

Analytical Fluid Dynamics

George Emanuel



Analytical Fluid Dynamics:

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potential fluid flows boundary layer problems aerodynamics gas dynamics compressible fluid flow and stability instability inspired by the lectures and problems given by Professors Su and Maxey of Brown University *An Introduction to Fluid Dynamics* Stanley Middleman,1998 This comprehensive text links abstract mathematics to engineering applications in order to provide a clear and thorough exploration of fluid dynamics Focus is on the development of mathematical models of physical phenomena and the wide range of technologies available to students Filled with examples and problems inspired by real engineering applications this resource will not only teach but motivate students to further emerge themselves in the field

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