Turbulent Channel Flow – Statistical Quantities Near the Wall:

Profiles of the mean velocity, viscous stress, and Reynolds stress in a turbulent channel flow are included on D2L at the link:

28 – Turbulent Channel Flow – Statistical Quantities Near the Wall → Plots.pdf

These were obtained from direct numerical simulations at $Re = 5,600$ and $Re = 13,750$ by Kim, Moin, and Moser in 1987. Note immediately that the viscous stress dominates the Reynolds stress near the wall. In fact, at the wall, the Reynolds stress is zero due to boundary conditions, and the wall shear stress is entirely due to viscous contributions:

$$\tau_w \equiv \mu \left.\frac{d\bar{u}}{dy}\right|_{y=0}$$

This is in contrast to free shear flows where viscous stresses are everywhere negligible compared with the Reynolds stresses at high Reynolds number. In addition, the velocity profile near the wall depends upon the Reynolds number in contrast with free shear flows.

Evidently, the viscosity ν and wall shear stress τ_w are important parameters near the wall. From these parameters, we may define the viscous scales that are the appropriate velocity and length scales near the wall:

Friction Velocity: $$u_\tau \equiv \sqrt{\frac{\tau_w}{\rho}}$$

Viscous Lengthscale: $$\delta_\nu \equiv \nu\sqrt{\frac{\rho}{\tau_w}} = \frac{\nu}{u_\tau}$$

Note the time scale associated with the above is $\nu/u_\tau^2 = \mu/\tau_w$, which is the natural time scale associated with the viscosity and wall shear stress.

The Reynolds number based on the viscous scales $u_\tau \delta_\nu/\nu$ is identically unity, implying that viscosity is indeed important for such scales. The friction Reynolds number is defined as:

$$Re_\tau \equiv \frac{u_\tau \delta}{\nu} = \frac{\delta}{\delta_\nu}$$

and it is exactly the ratio of the half channel height and the viscous length scale.

The distance from the wall may be measured in viscous lengths – or wall units – and this is denoted by:

$$y^+ \equiv \frac{y}{\delta_\nu} = \frac{u_\tau y}{\nu}$$

Note that y^+ acts as a local Reynolds number. Indeed, the magnitude of y^+ measures the relative importance of viscous and turbulent processes. In the PDF file Plots.pdf, profiles of the viscous and Reynolds stress are also provided as plotted against y^+. Note that the profiles for $Re = 5,600$ and $Re = 13,750$ nearly collapse onto the same curve when plotted against y^+. Moreover, note that the viscosity is important only sufficiently near the wall. In fact, we define different regions of the near-wall flow based on y^+:

Viscous Wall Region: $(y^+ < 50)$ Region where viscous effects are important.

Outer Layer: $(y^+ > 50)$ Region where direct effect of viscosity is negligible.