

The JHU Tubulence Database Cluster

Turbulent Channel Flow Data Set

The turbulent channel flow database is produced from a direct numerical simulation (DNS) of wall bounded flow with periodic boundary conditions in the longitudinal and transverse directions and no-slip conditions at the top and bottom walls. In the simulation, the Navier-Stokes equations are solved using a wall-normal, velocity-vorticity formulation [1]. Solutions to the governing equations are provided using a collocation method which is comprised of Fourier spectral method for the longitudinal and transverse directions and seventh-order Basis splines (B-splines) in the wall normal direction. Dealiasing is performed using the 3/2-rule [3]. Temporal integration is performed using a low-storage, third-order Runge-Kutta method. The flow is driven using a constant mean pressure gradient forcing term.

The simulation was performed using the petascale DNS channel flow code (ESDNS) developed at the University of Texas at Austin by Prof. Robert Moser's research group [2]. In the wall-normal, velocity-vorticity formulation the pressure is eliminated from the governing equations. In order to obtain the pressure field for the database, we subsequently implemented, in ESDNS, the pressure solver which solves the pressure Poisson equation with the Neumann boundary conditions at the top and bottom walls. This calculation is performed independantly from the velocity field solution.

The simulation was performed for approximately 1/2 of a flow through time (another 1/2 flow through time will be added in the future). The 3 component velocity vector and pressure fields were stored every 5 time steps resulting 2000 frames of data. Information regarding the simulation setup and resulting statistical quantities are listed below.

Note that the averaging operation for mean and other statistitcal quantities is applied in time and over x - z planes.

Simulation parameters

- Domain Length: $L_x \times L_y \times L_z = 8\pi h \times 2h \times 3\pi h$ where h is the half-channel height
- Grid: $N_x \times N_y \times N_z = 2048 \times 512 \times 1536$ (wavemodes); $3072 \times 512 \times 2304$ (collocation points); data is stored at the wavemode resolution
- Viscosity: $\nu = 5 \times 10^{-5}$ (non-dimensional)
- Mean pressure gradient: $dP/dx = 0.0025$ (non-dimensional)
- DNS Time step: $\Delta t = 0.0013$ (non-dimensional)
- Database time step: $\delta t = 0.0065$ (non-dimensional)
- Time stored: $t = [0, 12.993]$

Flow statistics averaged over $t = [0, 12.993]$

- Bulk velocity: $U = 0.99992$
- Centerline velocity: $U_c = 1.13195$
- Friction velocity: $U_\tau = 4.99857 \times 10^{-2}$

- Viscous length scale: $\delta_\nu = 1.00029 \times 10^{-3}$
- Reynolds number: $Re = 3.99970 \times 10^4$
- Centerline Reynolds number: $Re_c = 2.26391 \times 10^4$
- Friction Reynolds number: $Re_\tau = 9.99713 \times 10^2$

Grid spacing in viscous units

- x direction: $\Delta x^+ = 12.2683$
- y direction at first point: $\Delta y_1^+ = 1.65259 \times 10^{-2}$
- y direction at center: $\Delta y_c^+ = 6.15728$
- z direction: $\Delta z^+ = 6.13416$

In the following figures several quantities from the simulation are shown. Shown in Figure 1 is the computed friction Reynolds for the time interval in the database. In Figure 2 the mean velocity is shown along with the theoretical U^+ profiles in the viscous sublayer and log-layer. The viscous and turbulent stresses, Reynolds stress, mean pressure, and velocity–pressure covariances are shown in Figures 3–6. In the remaining plots, the power spectral densities of velocity and pressure are shown for various y^+ stations along the x direction in Figure 7 and along the z direction in Figure 8.

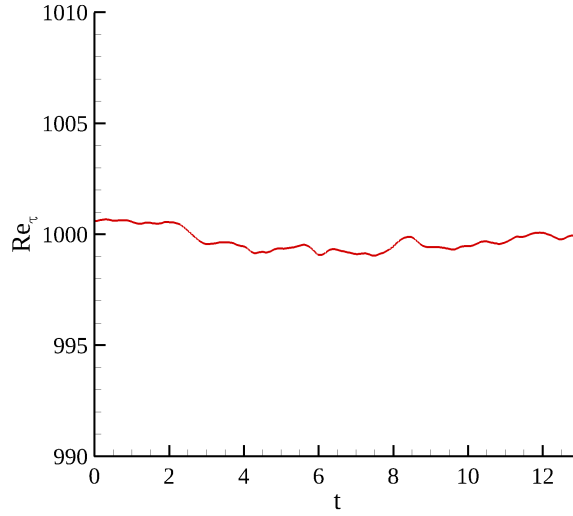


Figure 1: Friction Reynolds number during channel flow simulation

References

- [1] J. Kim, P. Moin, and R. Moser. Turbulence statistics in fully developed channel flow at low reynolds number. *J. Fluid Mech.*, 177:133–166, 1987.

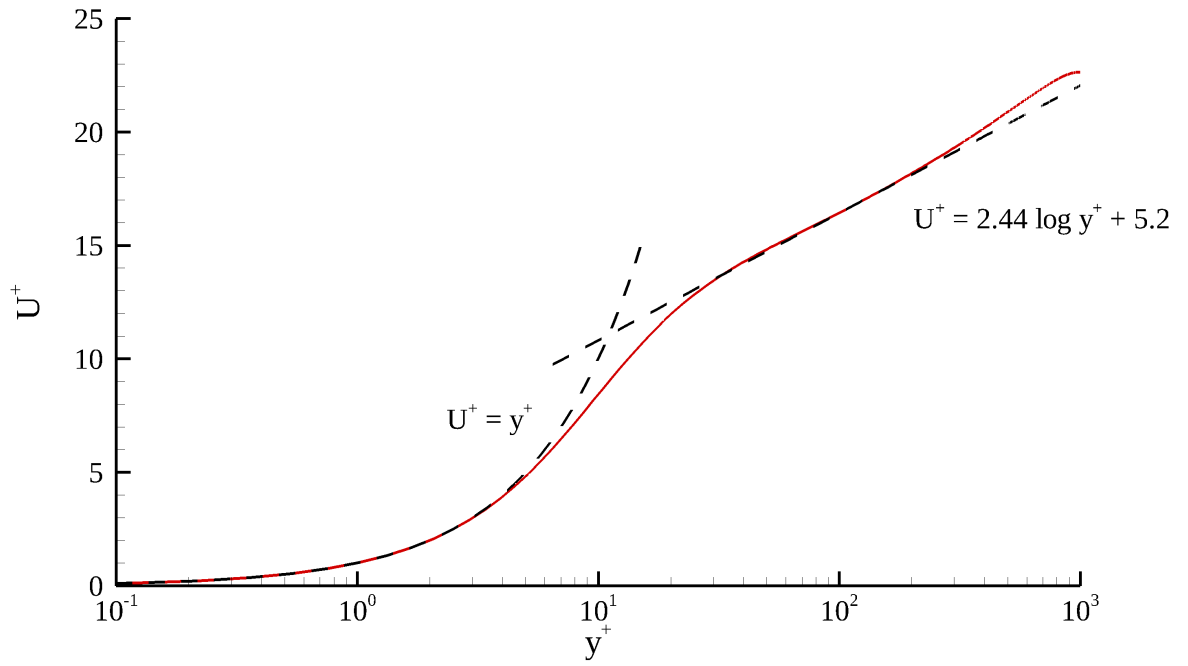


Figure 2: Mean velocity profile in viscous units

- [2] M. Lee, N. Malaya, and R. D. Moser. Petascale direct numerical simulation of turbulent channel flow on up to 786k cores. Supercomputing (SC13), 2013.
- [3] S. A. Orszag. On the elimination of aliasing in finite-difference schemes by filtering high-wavenumber components. *J. Atmos. Sci.*, 28:1074–1074, 1971.

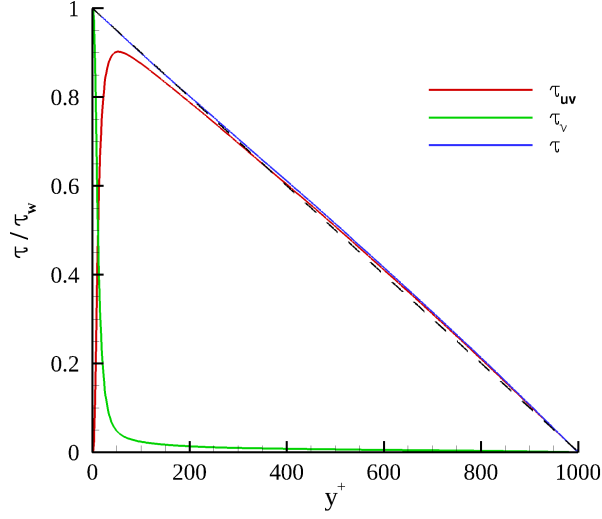


Figure 3: Mean viscous, turbulent, and total stress normalized by the wall stress

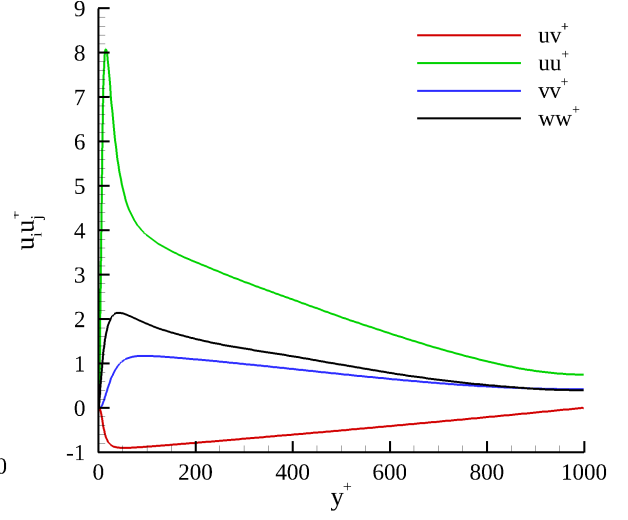


Figure 4: Velocity covariances in viscous units

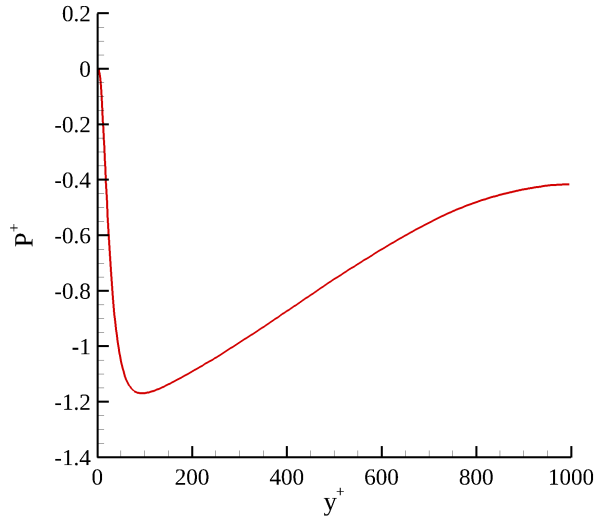


Figure 5: Mean pressure profile in viscous units

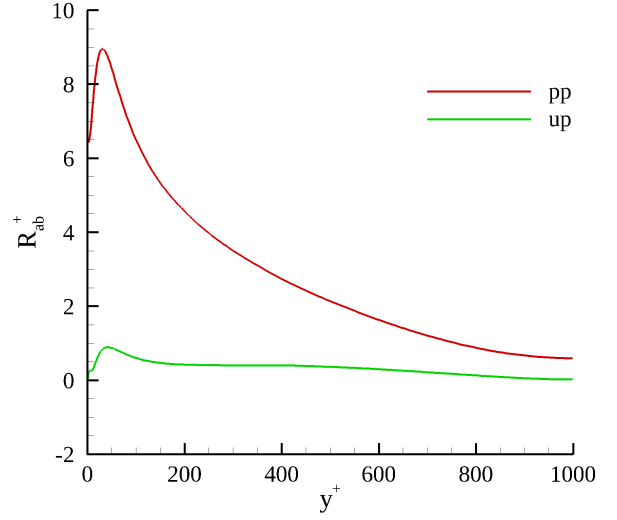


Figure 6: Pressure variance and pressure-velocity covariance in viscous units

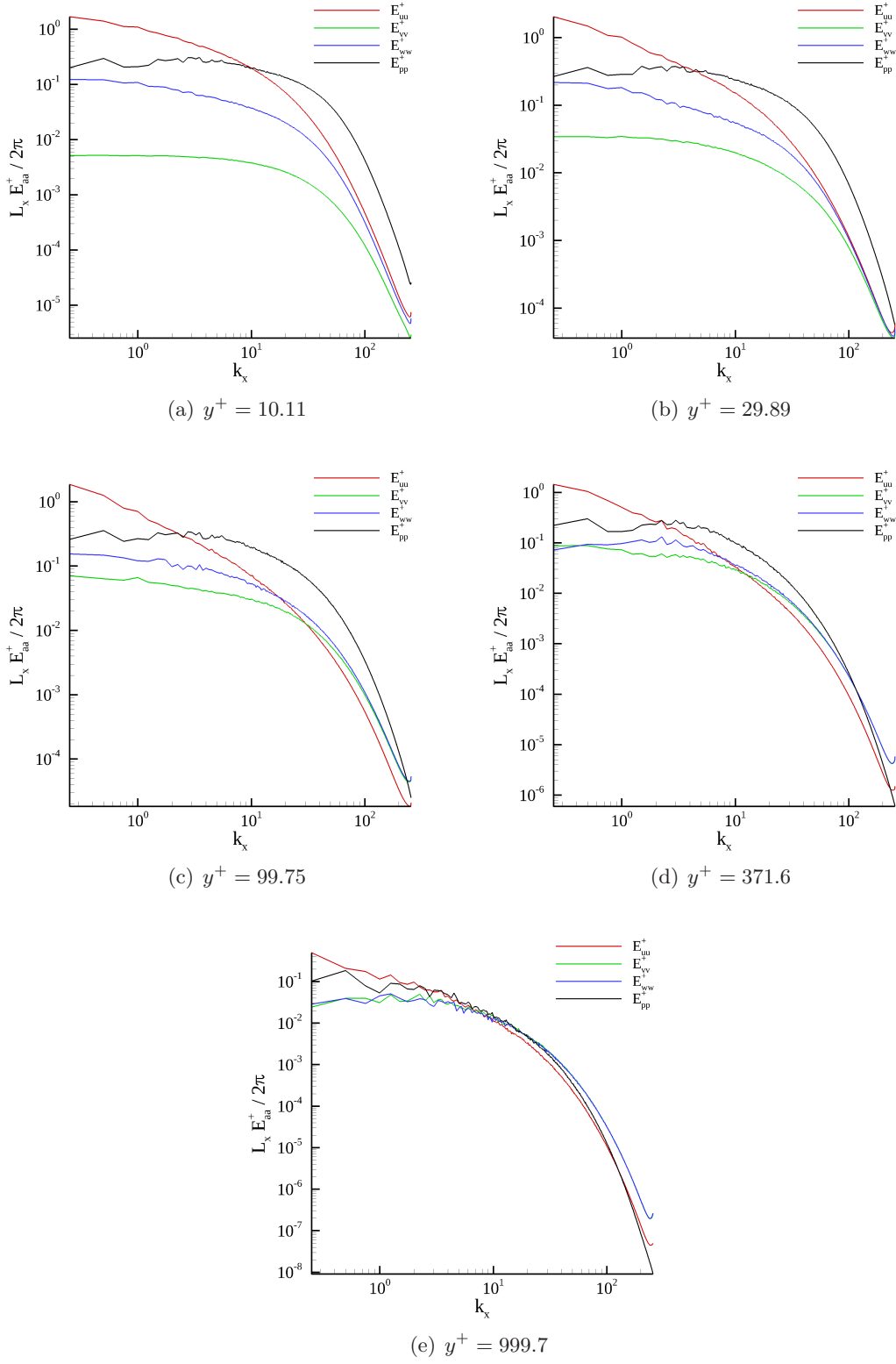


Figure 7: Power spectral densities at various y^+ locations along the x direction

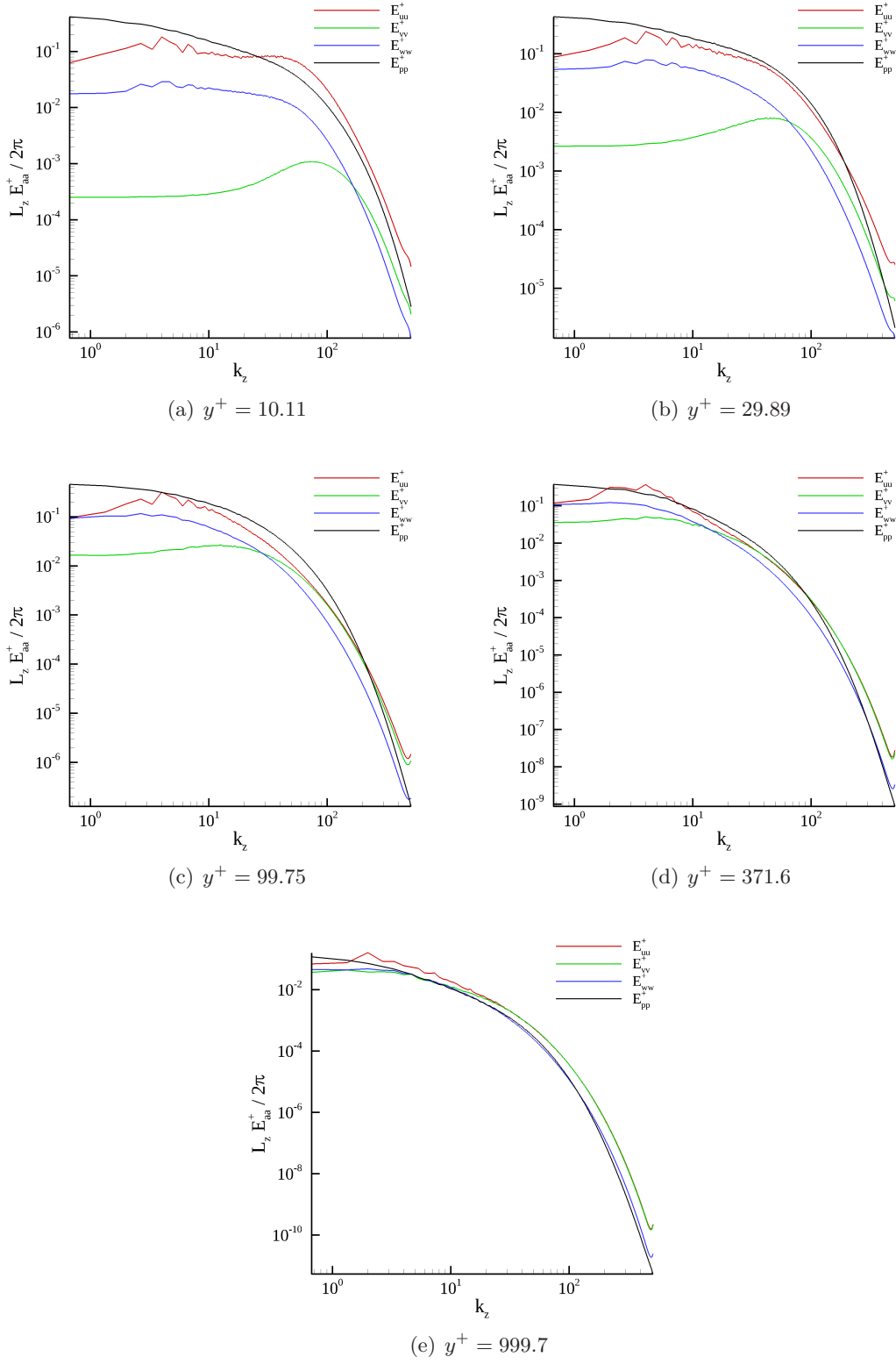


Figure 8: Power spectral densities at various y^+ locations along the z direction