MN61111 Theory of Turbulence

Term Project #2

Due: July 10, 2022.

Turbulent flow field data

- The velocity data (file name: "INS3D_Vel_xxxxxx.dat") are obtained from direct numerical simulation of fully developed turbulent channel flow. The data file includes the dimensionless streamwise, wall-normal, and spanwise velocity (U/U_{CL}, V/U_{CL} and W/U_{CL}) where U_{CL} denotes the centerline laminar velocity.
- Grid points: 256×192×256 in the streamwise (x), wall-normal (y), and spanwise directions (z), respectively (uniform grid in x & z, and non-uniform grid in y).
- Domain size: $4\pi h \times 2h \times 2\pi h$, where h is the channel half-height.
- Reynolds number based on U_{CL}: $Re = \dfrac{U_{CL}h}{\nu} = 4200$
- Boundary conditions: Periodic condition in x & z and no-slip condition on the wall.

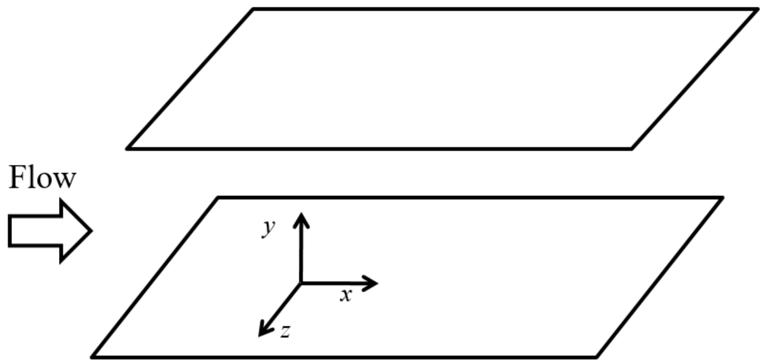

Figure 1 Coordinate system in channel.

- You can find a total of 41 velocity data which are measured at 41 different times.
- Each velocity data includes the following information

1~3 column: I, J, K (indices in x, y, and z directions)

4~6 column: U/U_{CL}, V/U_{CL}, W/U_{CL} (dimensionless velocities in x, y, and z directions)

- The grid data (file name: "Grid_x.data", "Grid_y.data", "Grid_z.data") includes the information about the physical locations with the corresponding index.

1 column: I, J, or K

2 column: x/h, y/h, or z/h

MN61111 Theory of Turbulence

Term Project #2

Due: July 10, 2022.

Use any programming language that you are familiar with, obtain the following quantities, plot the graph and compare your results with the work of Kim, Moin & Moser (1987 Journal of Fluid Mechanics 177, hereafter KMM).

Provide your discussions with the results in terms of what you've learned in this course.

1. Plot the streamwise, wall-normal, spanwise velocity contours in the x–z plane and the y–z plane. Choose any position and time.

2. Compute the friction Reynolds number (Re_τ), displacement thickness (δ^*/h), momentum thickness (θ/h) and shape factor ($H = \delta^*/\theta$). Compare your results with Table 1 in KMM.

3. Plot the mean velocity profile and root-mean-square velocity fluctuations in wall units. Compare your results with figure 5 and 6 in KMM.

4. Plot the wall-normal profiles of the total shear stress, viscous shear stress and Reynolds shear stress. Compare your results with figure 10 of KMM.

5. Plot the joint probability density function of u^+ and v^+ at $y^+ = 5$, 20, 100 and 180. Compare your results with figure 21 of KMM.

6. Using the velocity field data (INS3D_Vel_000001.dat), plot the streamwise velocity fluctuations signals with respect to x/h at $y^+ = 5$ and 150.

7. Plot the streamwise and spanwise autocorrelation functions $R_{11}(r_x/h)$ and $R_{11}(r_z/h)$ at a given wall-normal location ($y_{ref}^+ = 5$ and 150). Compare your results with figure 2 of KMM. Compute the Taylor micro length scale.

$$R_{11}(r_x) = \frac{\left\langle u(x + r_x, y_{ref}, z)u(x, y_{ref}, z)\right\rangle}{\left\langle u^2(y_{ref})\right\rangle}$$

$$R_{11}(r_z) = \frac{\left\langle u(x, y_{ref}, z + r_z)u(x, y_{ref}, z)\right\rangle}{\left\langle u^2(y_{ref})\right\rangle}$$

8. Compute the one-dimensional energy spectra of streamwise, wall-normal, and spanwise velocity at $y^+ = 5$ and 150. Compare your results with figure 3 of KMM. Explain your results in terms of Kolmogorov's theory.