22.315 - Homework 1

Name: Lorenzo Mazzocco
HW Partner: Witiwat Jiragoontansiri

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Code: StarCCM+

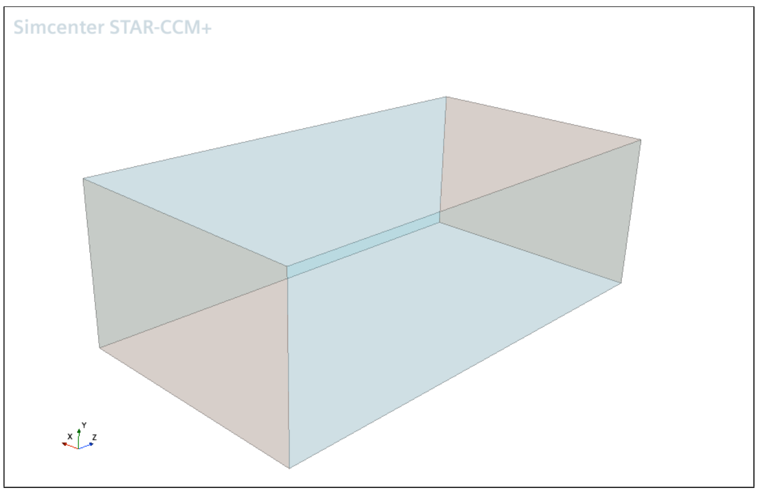
Contents

1. GEOMETRY

The geometry is a cuboid constructed from the origin of the coordinate system. It extends in the following directions:

- x: 3.2m so $x \in [0, 3.2]$
- y: 2.0m so $y \in [0, 2.0]$
- z: 6.0m so $z \in [0, 6.0]$

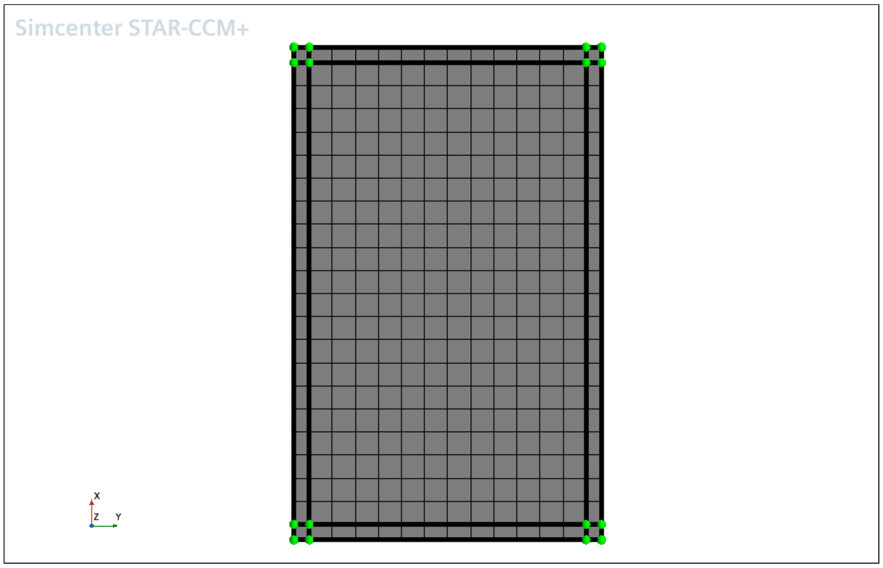
The following domain is obtained:



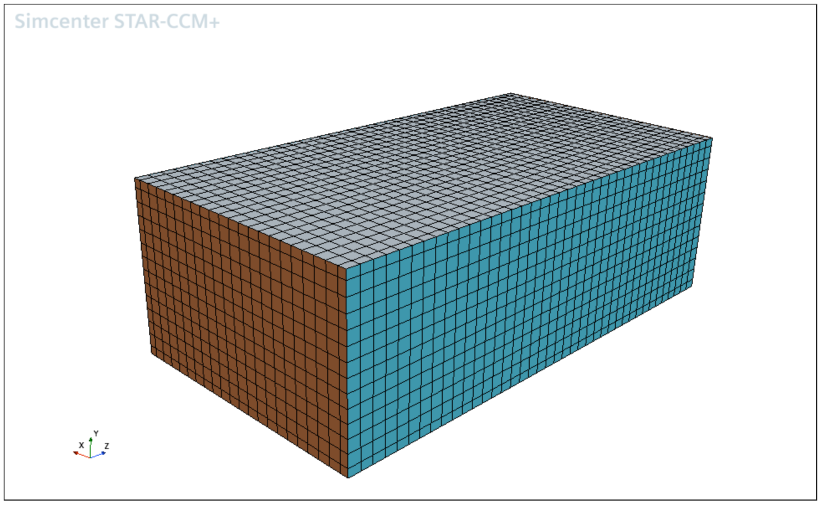
For the x-normal faces (left and right) a "Symmetric Plane" boundary condition was selected. For the y-normal faces (top and bottom) a "Wall" boundary condition was selected with no-slip condition by default. For the z-normal faces (inlet and outlet) a "Pressure Outlet" boundary condition was selected with absolute pressure for both surfaces set at 0 Pa. Then on the inlet and outlet faces a periodic interface was created of the type "Fully-Developed Interface Boundary" with a pressure jump of $\Delta p = 2.535MPa$.

2. MESHING

A **Directed Mesh** was used with source surface the inlet and target surface the outlet. Patches of 15 cm were used and 1 layer of 10 cm next to top, bottom, left and right surfaces:



Then a Volume Distribution with 40 layers (corresponding to a size of 0.15 cm) was specified and the 2D mesh finally extended in 3D:

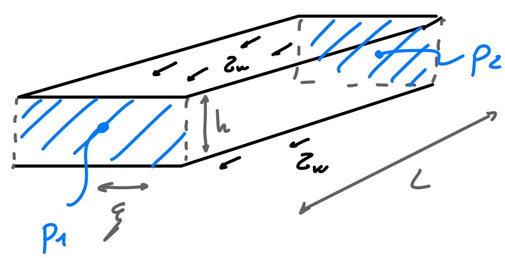


3. PHYSICS AND MODEL SETUP

For the sake of simplicity the following constant material parameters were chosen:

- **Density:** $\rho = 1$ kg/m^3
- **Dynamic Viscosity:** $\mu = 1 \; Pa \cdot s$

The only pressure drops in the system are frictional (given by the top and bottom walls). A simple free body diagram can give us the relationship between the pressure drop Δp and the wall shear stress τ_w:



Balancing the forces in the z direction:

$$\Delta p \cdot \xi \cdot h - 2 \cdot \tau_w \cdot L \cdot \xi = 0 \tag{1}$$

$$\Delta p \cdot h - 2 \cdot \tau_w \cdot L = 0 \tag{2}$$

$$\tau_w = \frac{\Delta p \cdot h}{2L} \tag{3}$$

Finally we can compute the pressure drop given Re_τ:

$$Re_\tau = \frac{\delta \cdot u_\tau}{\nu} \longrightarrow u_\tau = \frac{Re_\tau \cdot \nu}{\delta} \longrightarrow \frac{\tau_w}{\rho} = \frac{Re_\tau^2}{\delta^2} \cdot \frac{\mu^2}{\rho^2} \longrightarrow \tau_w = \frac{Re_\tau^2}{\delta^2} \cdot \frac{\mu^2}{\rho} \tag{4}$$

Substituting τ_w as a function of Δp:

$$\frac{\Delta p \cdot h}{2L} = \frac{Re_\tau^2}{\delta^2} \cdot \frac{\mu^2}{\rho} \longrightarrow \Delta p = \frac{Re_\tau^2}{\delta^2} \cdot \frac{2L\mu^2}{\rho h} \tag{5}$$

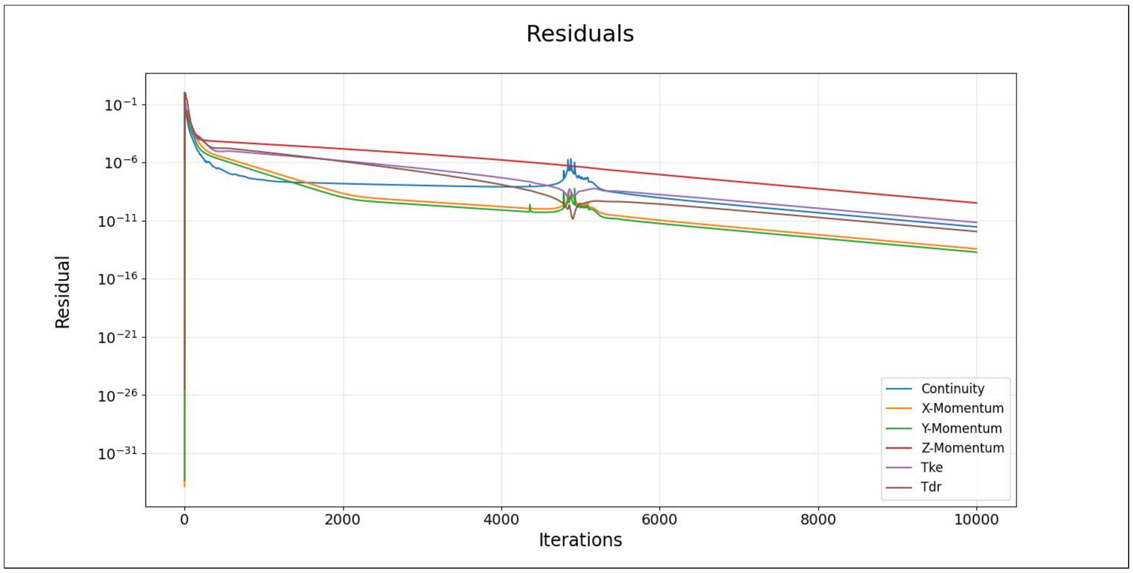
Knowing that by setup $\delta = \mu = \rho = 1$, $Re_\tau = 650$ and the geometric data one finds $\Delta p = 2.535$ MPa. This is the pressure difference value we will impose to the periodic interface.

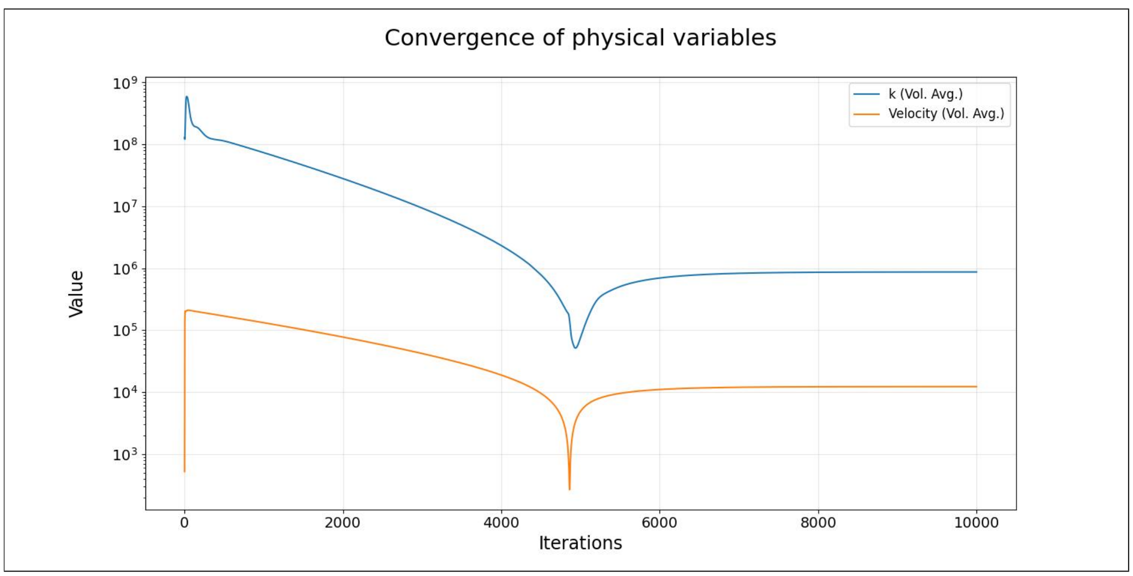
4. SOLVER AND CONVERGENCE

A steady state $k - \varepsilon$ solver was selected. The variables are all inizialized to zero. To check convergence on top of the residuals we monitor two physical quantities (volume averaged over the whole domain):

- velocity magnitude
- turbolent kinetic energy

After 10.000 iterations we stop the solver:



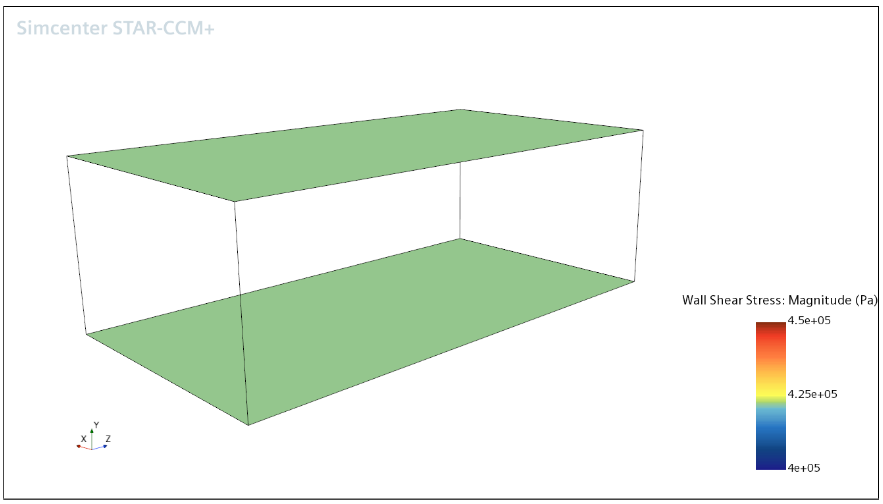


5. POSTPROCESSING AND DNS BENCHMARK

Data for the DNS benchmark is taken from the data provided in this file. The data from the simulation undergoes a first elaboration within StarCCM+ (user-defined field functions are plotted) and then data exported from plots is post-processed in a Jupyter Notebook.

5.1. Model Consistency

First of all I verified that the simulation results are coherent with the physical model imposed. I did so by extracting the wall shear stress. Using a simple scalar scene on the wall boundaries I obtained the following:



The distribution is for all practical purposes uniform (confirming again convergence). The values range from 422232 Pa to 422235 Pa.

From eq. (3) we know that the shear stress as a function of the pressure drop across the channel is:

$$\tau_w = \frac{\Delta p h}{2L} = 422500 Pa \tag{6}$$

We can attribute the discrepancy of about 270 Pa to numerical errors and accept that model consistency is verified.

5.2. Bulk Velocity U^+

Data for the DNS benchmark is taken from this report in section 1.5 (Flow conditions). We can compute the normalized bulk velocity using the values for Re_m and Re_τ provided for Case 5:

$$U^+_{DNS} = \frac{U_m}{u_\tau} = \frac{Re_m}{2Re_\tau} = 18.8877 \tag{7}$$

In StarCCM we can extract the bulk mean velocity creating an ad hoc scalar field function for the streamwise component of the velocity vector field and dividing it by u_τ. Then a simple report on the volume average of said function yields:

$$U^+_{RANS} = 18.83627 \tag{8}$$

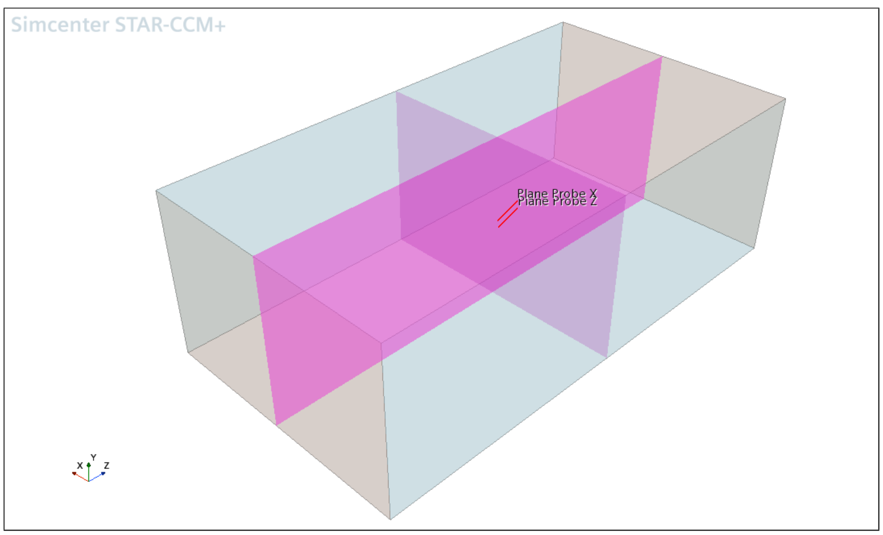
This corresponds to an error of 0.27%.

5.3. Turbolent Kinetic Energy k^+

First of all I created two user-defined scalar field functions according to their definition: $y+$ and $k+$.

To extract the data from the cells I used the combination of two planes:

- Plane X: defined by $z = 3$, spans in the x and y directions.
- Plane Z: defined by $x = 1.6$, spans in the z and y directions.

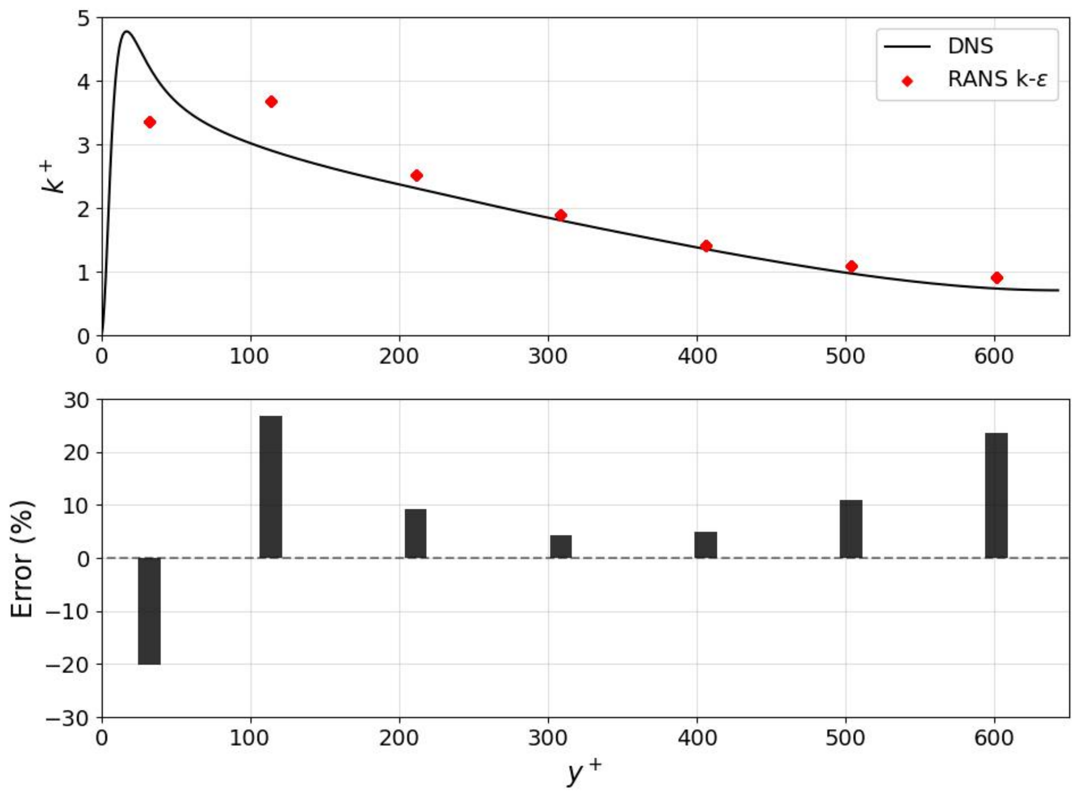


Using this method instead of a simple Line Probe (which would extract only 7 values) helped me verify the convergence of the solution which shouldn't show a dependence on the x or z positions. Indeed scattering all the points in a cartesian plot shows no dependence on those variables (we see 7 clusters of multiple, perfectly overlapping points).

To get the DNS turbolent kinetic energy I extracted the RMS values for all the velocity fluctuations (u,v,w). The RMS values can be found in the Turbolent Statistics - Rms section (4.1.2) under columns u_rms, v_rms, w_rms. To get the normalized turbolent kinetic energy one can just sum up the squares of the RMSs:

$$k^+ = \frac{1}{2}\left[u^2_{RMS} + v^2_{RMS} + w^2_{RMS}\right] \tag{9}$$

Plotting our results vs the DNS ones I obtained the following:



6. CHALLENGES

I only encountered two challenges while doing this PSET:

1. STARCCM+ would select a more sophisticated model than the wanted standard RANS $k - \varepsilon$, then finding the model settings in the main menu to verify that it was indeed the one I intended was not trivial to a new user like me

2. Initially it was challenging to understand the nomenclature and convention in the DNS data report