46115 - Turbulence Modeling (2024)

Assignment 1 – deadline 18-10/2024

RANS modeling of fully developed turbulent channel flows (FDTCF)

On week 2, we started working on the discretization and solution of the fully developed 1D laminar flow (Poiseuille flow). In this assignment, you will be asked to extend the work and solve equations for the same 1D flow but at turbulent Reynolds numbers.

You recall from the class that turbulent boundary layers (among other features) exhibit sharper gradients near the walls. This calls for grid refinement in such regions and solving for such high Reynolds number flows requires either high fidelity direct numerical simulations (DNS) or turbulence modeling.

A fully developed channel flow corresponds to an infinitely long channel as shown in Figure 1 where the flow (the boundary layer) has already developed therefore will *no longer* depend on the x-coordinate. To account for infinitely long channel, one uses cyclic boundary conditions (i.e., the flow from outlet is recycled at the inlet while the simulation goes on and on) in numerical codes. As you probably recall from the class, due to symmetry, one can just simulate the lower half of the flow from y=0 to y=H.

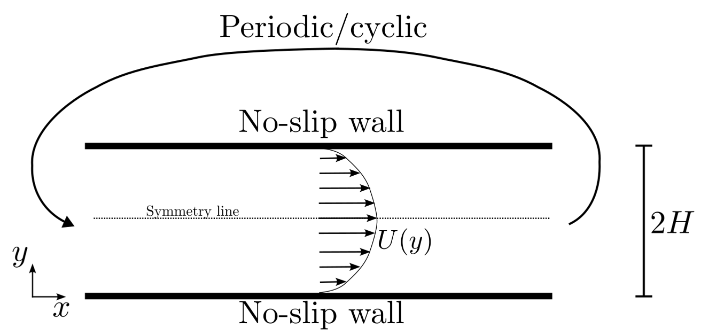


Figure 1. Schematics of a fully developed channel flow. H is the half-channel width.

1. For laminar 1D channel flow, you derived an analytical relation between dP/dx, u, H and rho by simplifying the full Navier-Stokes equations. Now for the turbulent 1D fully developed channel flow, derive an analytical relation between dP/dx, u_tau, H and rho. How does it look compared to the formula for laminar 1D channel flow? *Hint: The derivation is similar to the derivation of the 1D case, but now you have to start from the RANS U-momentum equation.*

2. Write a 1D solver (explain the assumptions you have made) for turbulent channel flow by implementing
   a. Prandtl's algebraic model, and

$u_\tau = \sqrt{\frac{\tau}{\rho}}$

b. k-epsilon model,

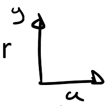
to close the RANS equations (you can start from the code developed for your 1D laminar solver). Simulate flows at Re_tau = 180, 395 and 590 and compare with DNS data (U, k and Reynolds stresses) from Kim et al. (1987) and Moser at al. (1999). Note that in order to be able to “compare”, it is important that you plot your results *on top of* DNS data (and using the same plot/axes style) and NOT separately.

c. Plot velocity and the relevant terms of the Reynolds stress tensor according to how they are plotted in the references and argue why is it better to plot the velocity profile in semi-log format.

d. Run cases both with and without the damping function and explain the role of the damping function in predicting the flow more accurately

e. How is the k-epsilon model different than the Prandtl model in implementation and results?

3. Compare the velocity profiles between the turbulent (assignment 1) and laminar (exercise 2) cases by plotting them in the same figure and analyzing the results.



not log-log

4. Conclude your report by writing a one-paragraph conclusion and addressing:
   a. The key differences between the 3 turbulent flow cases above in terms of the resulting velocity and Reynolds stress profiles, grid requirements, numerics and other complications.
   b. The importance of adding the van Driest damping function

Reference:

Kim, J., Moin, P. and Moser, R., 1987. Turbulence statistics in fully developed channel _ow at low Reynolds number. Journal of fluid mechanics, 177, pp.133-166.

Moser, R., Kim, J. and Moin, P., 1999. Direct numerical simulation of turbulent channel flow up to Retau=590. Physics of Fluids

DNS data available at: https://turbulence.oden.utexas.edu/MKM_1999.html

Appendix

Report preparation:

Write a 5-10 page report about your findings and address the questions above by answering each clearly and in the same order as asked. Your suctions (answers) could e.g. look like:

> 1 Derivation of models
>
> …
>
> 2.b k-e model derivation for the 1D FD channel flow
>
> …
>
> 2.d The effect of damping function
>
> *Some text, explanation, derivation … then some results*
>
> *…*
>
> *4 Conclusion*

To save time, please do not repeat what can be found in textbooks or lecture notes unless explicitly asked for. Append your code to the report (do not attach a separate file) and submit only one pdf file (report + code) on DTU Learn.

Note 1: please send only one report per group.

Note 2: use of AI: This is a hands-on turbulence modeling learning experience, and we need to learn coding the models among other things. Please note that while you are welcome (*no penalties*) to use ChatGPT/AI for inspiration, proofreading the report (for clearer communication) or for possible physical and theoretical insights (*with caution though!*), it is only the code that you (the team) has prepared that received a grade and not the AI/friends/ex-TM-students' codes.

If used, remember to add this acknowledgement section in your report:

> ***Acknowledgements***
>
> *In preparation of this report, AI/ChatGPT is used for …". (you can extend this section as you wish).*

Note 3: individual contributions: Please include the following in your report:

> ***Contributions:***
>
> *Name Last Name s12345: coding part X, ideation, writing the …, approximate percentage contribution: X% (be as specific as you want)*
>
> *Name Last Name s12345: coding, ideation of question X, running …, approximate percentage contribution: X% (be as specific as you want)*
>
> *Name Last Name s12345: coding, ideation, implementing X …, approximate percentage contribution: X% (be as specific as you want)*