ME614 Fall 2017 - Homework 4

Final Project

(Due December 16, 2018)

Please submit your homework on Blackboard in the form of a (1) report in PDF (keep file size smaller than 5MB) and (2) a working code, zipped in one file. The submitted code needs to run and create all (and possibly only) the plots you are including in your report. The use of LaTeX for your report is strongly recommended (but not required) and you can start with a template from http://www.latextemplates.com/. Discussions and sharing of ideas are encouraged but individually prepared submissions (codes, figures, written reports, etc.) are required. Due to the sensitivity of some numerical results to the specific coding choices, and sometimes even hardware, it is easy for the instructor to flag homeworks as suspicious. A plagiarism detection algorithm will be run against all codes submitted. Do NOT include in your submisison any files that are not required (e.g. the syllabus, zip files with python libraries, other PDFs, sample python sessions etc).
Points will be deducted from late submissions at a rate of 20% of the overall homework value per day late. Homeworks are due at 11:59 PM of the due date.

Preface: Pick **one** of the following problems as your final project. Your report should be in a form of a brief paper with approximately the following break down: Introduction/Motivation (0.5 page), Problem Description/Methodology (1-2 pages), Validation/Results (3-4 pages), Discussion/Comments (0.5 page). Keep it short and to the point. Most importantly, show that your code works correctly for the specific problem of choice and that you have acquired a basic physical understanding of the fluid mechanics being simulated.

Lid-driven cavity

Perform lid-driven cavity simulations showing quantitative matching with the numerical simulations of Ghia, et al. (1982) and/or Botella & Peyret (1998) for a low and a high Reynolds number.

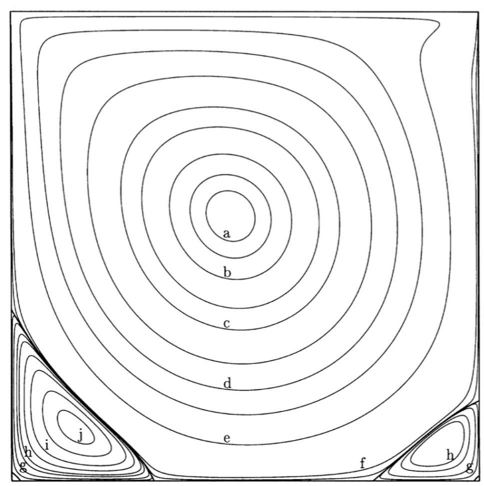
[85%]

Complete HW3, Problem (b) if you have not achieved second-order convergence on the full viscous solution with RK2.

[+15% bonus]

Compute the streamfunction Ψ and show quantitative comparison with published data.

[15%]



On the right streamlines for lid-driven cavity problem at $Re = 1000$ from Botella & Peyret (1998).

Developing Boundary Layer

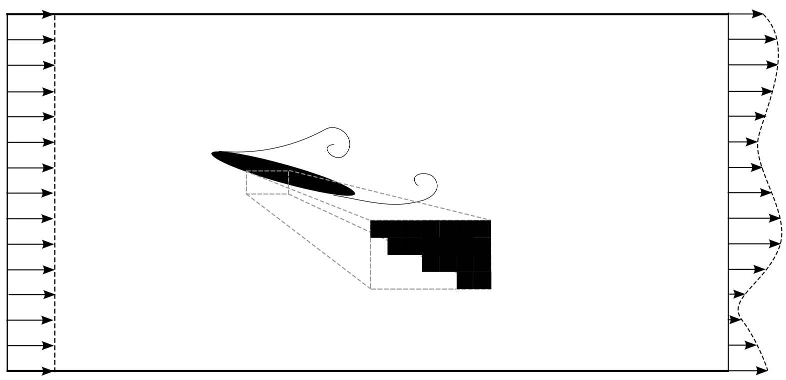
Perform a numerical simulation of a zero-pressure-gradient (ZPG) laminar boundary layer with plug inflow from the left and outflow boundary conditions based on Orlanski (1976) on the right. Validate against the Blasius solution obtained by numerically integration (along y) of the solution in self-similar form.

[100%]

Estimate the skin friction by closing the integral momentum budgets and compensate for confinement effects as done in Piomelli & Scalo (2010) to enforce true ZPG conditions $U_\infty(x) = \text{const.}$

[+5% bonus]

Flow Around Confined Obstacle



Unsteady flow around an obstacle. Inset figure shows a zero-order reconstruction of the obstacles's edge.

Perform numerical simulation of a flow around an obstacle with a shape of your choice. Use slip-walls for the upper and lower boundaries, outflow boundary conditions based on Orlanski (1976) and plug flow for the inlet. Test a low and a high Reynolds number case (yielding, respectively, a steady and an unsteady flow).

[100%]

Draw the drag and lift coefficient curves as a function of the Reynolds number (based on the characteristic obstacle size, D) for a given blockage ratio h/D, where h is the total vertical domain height, by closing the integral momentum budgets.

[+5% bonus]

Pseudo-Spectral 2D Simulations

Perform doubly-periodic numerical simulation of the decaying Taylor-Green green vortex with the pseudo-spectral method explained in section 6.4.2. – *The evolution of Fourier modes* – in Pope (2000).

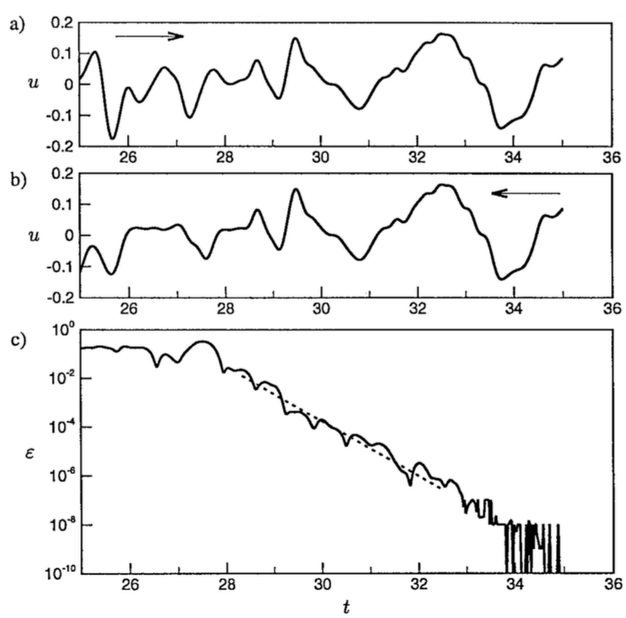
[100%]

Investigate the physical properties of the same flow under the effects of shell linear forcing as done in Rosales & Meneveau (2005).

[+5% bonus]

Discrete Energy Conservation

Implement the fully discrete-energy-conserving scheme by Ham, et al. (2002) for the two-dimensional Euler equations proving temporal reversibility of the time advancement scheme, for example, by reproducing the figure below taken from the paper.



(a) Time trace of velocity at one point in the inviscid periodic box simulation, (b) velocity calculated at the same point by time-reverse simulation, (c) difference: $\epsilon = \sqrt{\Delta u^2 + \Delta v^2 + \Delta w^2}$

[110%]

References

O. Botella & R. Peyret (1998). 'Benchmark Spectral Results on the Lid-Driven Cavity Flow'. *Computer & Fluids* **27**(4):421 – 433.

U. Ghia, et al. (1982). 'High-Re Solutions for Incompressible Flow Using the Navier-Stokes Equations and a Multigrid Method'. *J. Comput. Phys.* **48**:387–411.

F. Ham, et al. (2002). 'A fully conservative second-order finite difference scheme for incompressible flow on nonuniform grids'. *J. Comput. Physics* **177**(1):117–133.

I. Orlanski (1976). *Journal of Computational Physics* **21**:251 – 269.

U. Piomelli & C. Scalo (2010). 'Subgrid-scale modelling in relaminarizing flows'. *Fluid Dynamics Research* **42**(4):045510.

S. Pope (2000). *Turbulent flows*. Cambridge University Press.

C. Rosales & C. Meneveau (2005). 'Linear forcing in numerical simulations of isotropic turbulence: Physical space implementations and convergence properties'. *Physics of Fluids (1994-present)* **17**(9).