OpenFOAM assignment 3

See due date on Canvas

COE 347

There is absolutely no tolerance for academic misconduct. All assigned material is to be prepared individually. Submissions that are up to 24 hours late will be accepted with 50% penalty. Work submitted later than 24 hours after the deadline will not be graded.

Submit your homework electronically as a PDF via Canvas by 11:59pm on the due date.

If you are submitting a scanned copy of your handwritten notes, rather than a typeset document, please take the time to reduce the file to a manageable size by adjusting the resolution.

1 Objectives

In this assignment, you will simulate the compressible, two-dimensional supersonic flow in a tunnel with a forward facing step. This test case is known as "The Mach 3 wind tunnel with a step". We shall describe the flow with the inviscid limit of the Navier-Stokes equations, i.e. the Euler equations. The configuration features supersonic and subsonic regions and you will utilize methods that are designed specifically to simulate shocks.

Because the flow features a normal shock on the leading step, you will be able to compare analytical solutions for the shock strength, stagnation pressure, and various other compressible flow parameters.

Similarly, extensive literature on this flow configuration exists, allowing for comparisons and guidance from previous work in terms of mesh resolution requirements.

You will also have the opportunity to execute the simulations "in parallel“, i.e. using multiple cores on one or more nodes.

2 Resources

You may find useful information from various resources

- Class notes on the forward facing step
- Three journal papers that show and discuss CFD solutions to this flow configuration are available on Canvas
  - Emery, An evaluation of several differencing methods for inviscid fluid flow problems, J. Comput. Phys., 2 (3) (1968), pp. 306-331
  - Woodward & Colella, The numerical simulation of two-dimensional fluid flow with strong shocks, J. Comput. Phys., 54 (1) (1984), pp. 115-173
  - Le Touze, Murrone, Guillard, Multislope MUSCL method for general unstructured meshes, J. Comput. Phys., 284 (2015), pp. 389-418
- Compressible flow book

3 Preliminaries

Download the archive "mach-3-tunnel-with-step.tar.gz" from Canvas. Copy the archive to TACC or any other system you will be using for the assignment. Unpack the archive. Read the README file for a description of the contents.

4 Governing equations

The governing equations for this problem are the two-dimensional Euler equations, complemented with the equation of state for an ideal gas with $\gamma = 1.4$.

In your report:

- Include working definitions of the local Mach number of the flow and the local sound speed. You will need those definitions when plotting quantities.
- Apply basic normal shock relations to estimate the pressure at the stagnation point on the surface of the step at $(x, y) = (0.6, 0)$ for free stream conditions of $M = 3$ and $p = 1$ Pa.

  For this part, you will need to use the normal shock table available on Canvas.

5 Generate a mesh

Starting from the templates provided with the archive, assemble a `blockMeshDict` and create a mesh.

In your report:

- Include a schematic of the vertices, blocks, edges, and all other details that would allow to reproduce the mesh.
- Attach (a) the blockMeshDict file you used for the mesh; (b) the outputs from blockMesh; and (c) from checkMesh.
- Include figures (e.g. from Paraview) that provide both an overview of the mesh and its details.

6 Convergence with `rhoCentralFoam`

Using the solver `rhoCentralFoam`, solve the problem for the following inlet conditions: $M = 3$, $p = 1$ Pa, $T = 1$ K, $\rho = \gamma$ kg/m^3 with $\gamma = 1.4$. Advance the solution up to $T = 4$ s.

Run the simulation with at least 2 levels of mesh refinement, compatibly with execution times and costs. Report the following quantities at these two levels and explore the grid convergence.
(**Hint**: Typically, grids with 50,000 to 100,000 grid points should suffice.)

In your report:

- Include figures (e.g. from Paraview) that provide an overview of solution. Make sure to include figures for: density ρ, x- and y- components of velocity u and v, velocity magnitude $|\mathbf{u}|$, pressure p, Mach number $M = |\mathbf{u}|/a$, sound speed a, temperature T and also the streamlines.
- In the form of $x - y$ plots, report the spatial distribution of the pressure at time $T = 4$ s on the top wall. You will need to modify the file `system/graph` by adding more segments that cut through the first cell next to walls as a function of either the x (horizontal surfaces) or y (vertical surfaces) coordinate.
- Comment on how the stagnation pressure at the foot of the step from the numerical solution compares to the analytical solution you found earlier for $M = 3$ and $p = 1$ Pa inlet stream.

7 Extra credit: Converge the solution with a faster solver

OpenFOAM makes available a second solver for compressible flows with shocks. The solver is `sonicFoam` and it is much faster than `rhoCentralFoam`.

In this last part of the assignment, you are to repeat Problem 7 above with the `sonicFoam` solver and conclude whether `sonicFoam` provides a more accurate solution than the one obtained in Problem 7 above or not?

In your report:

- Add some commentary on the accuracy/correctness of the `sonicFoam` solver compared to the `rhoCentralFoam` solver.