Specifying Basic Inflow and Outflow Boundary Conditions in STAR-CCM+

ME 448/548 Notes

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BC Overview

Physical boundary conditions for isothermal flow are

1. Walls (solid and porous)
2. Inlets
3. Outlets
4. Symmetry
5. Far field

These boundary conditions can be implemented in STAR-CCM+.

In this slide deck we focus on simple inflow and outflow boundary conditions.

Wall Boundaries

- Solid walls are impermeable and have no-slip
  - ▷ Impermeable means there is no normal velocity component
  - ▷ No-slip means that fluid adjacent to the wall moves with the wall
    - ⋆ Zero velocity if wall is stationary
    - ⋆ Wall velocity if wall is moving
- By default all boundaries of a region are walls in a StarCCM+ model
- A porous wall allows for a normal velocity component

Inlet/Outlet Combinations for Incompressible Flow

Allowable Combinations for One Inlet and One Outlet

Inlet	Outlet
Case 1: Prescribed Velocity	Standard outlet (recommended) or Gage pressure relative to ambient
Case 2: Prescribed Flow Rate	Standard outlet (recommended) or Gage pressure relative to ambient
Case 3: Prescribed Gage Pressure	Standard outlet (recommended) or Prescribed Gage Pressure or Fixed Mass flow rate or Velocity (directed outward)

A Note on Specifying Pressures

- For incompressible flow, the absolute level of pressure does not matter.
  - ▷ Fluid density depends on absolute pressure
  - ▷ Momentum transport is determined by pressure gradients, not pressure level
- When simulating incompressible flow with CFD, always work in gage units.
  - ▷ Fluid density depends on absolute pressure and is constant.
  - ▷ Working in gage units reduces roundoff and catastrophic cancellation errors
- When simulating compressible flow with STAR-CCM+, use *Total Pressure* boundary conditions.

Boundary conditions for flow through a Pipe (1)

Case 1a: Combination of prescribed inlet velocity and standard outlet

User prescribes the normal
inlet velocity component

$$\dot{m} = \rho V A$$

where V is uniform over
the inlet face.

Standard outlet

The “Normal” component specification guarantees that the velocity of magnitude V is oriented inward. The solution gives the pressure distribution over the inlet.

At the outlet, the velocity magnitude and pressure vary over the outlet surface. The outlet mass flow rate matches the inlet mass flow rate for incompressible flow.

Option: The inlet velocity can be specified as three vector components. This gives the possibility of imposing a velocity vector that is not normal to the domain boundary. The inlet flow rate is only determined by the normal component.

Boundary conditions for flow through a Pipe (2)

Case 1b: Combination of prescribed inlet velocity and prescribed pressure at the outlet

User prescribes the normal
inlet velocity component

$$\dot{m} = \rho V A$$

where V is uniform over
the inlet face.

Outlet: Pressure p_{out} is
uniform over the outlet.

The "Normal" component specification guarantees that the velocity of magnitude V is oriented inward. The solution gives the pressure distribution over the inlet.

The prescribed pressure uniform over the outlet.

The velocity magnitude varies over the outlet surface. The outlet mass flow rate matches the inlet mass flow rate for incompressible flow.

Boundary conditions for flow through a Pipe (3)

Case 2: Combination of prescribed mass flow rate and standard outlet

Specify $\dot{m}$ and V is computed from

$$V = \frac{Q}{A} = \frac{\rho \dot{m}}{A}$$

V is applied to surfaces of cells on inlet boundary.

Standard outlet

STAR-CCM+ figures out the direction of V that is oriented inward. The solution gives the pressure distribution over the inlet.

At the outlet, the velocity magnitude and pressure vary over the outlet surface. The outlet mass flow rate matches the inlet mass flow rate for incompressible flow.

Question: For unsteady incompressible flow, does the inlet flow rate match the outlet flow rate?

Boundary conditions for flow through a Pipe (4)

Case 3: Combination of prescribed pressure at the inlet, and prescribed pressure at the outlet

Pressure p_{in} is uniform
over the inlet face.

Pressure p_{out} is uniform
over the outlet face.

Mass flow rate is determined as part of the solution.

Velocity is not uniform over the inlet or the outlet.

Warning: Empirical testing shows that using and overall Δp obtained from Case 1 or Case 2 boundary conditions results in higher flow rates than when the Case 1 or Case 2 boundary conditions are used.
An example follows.

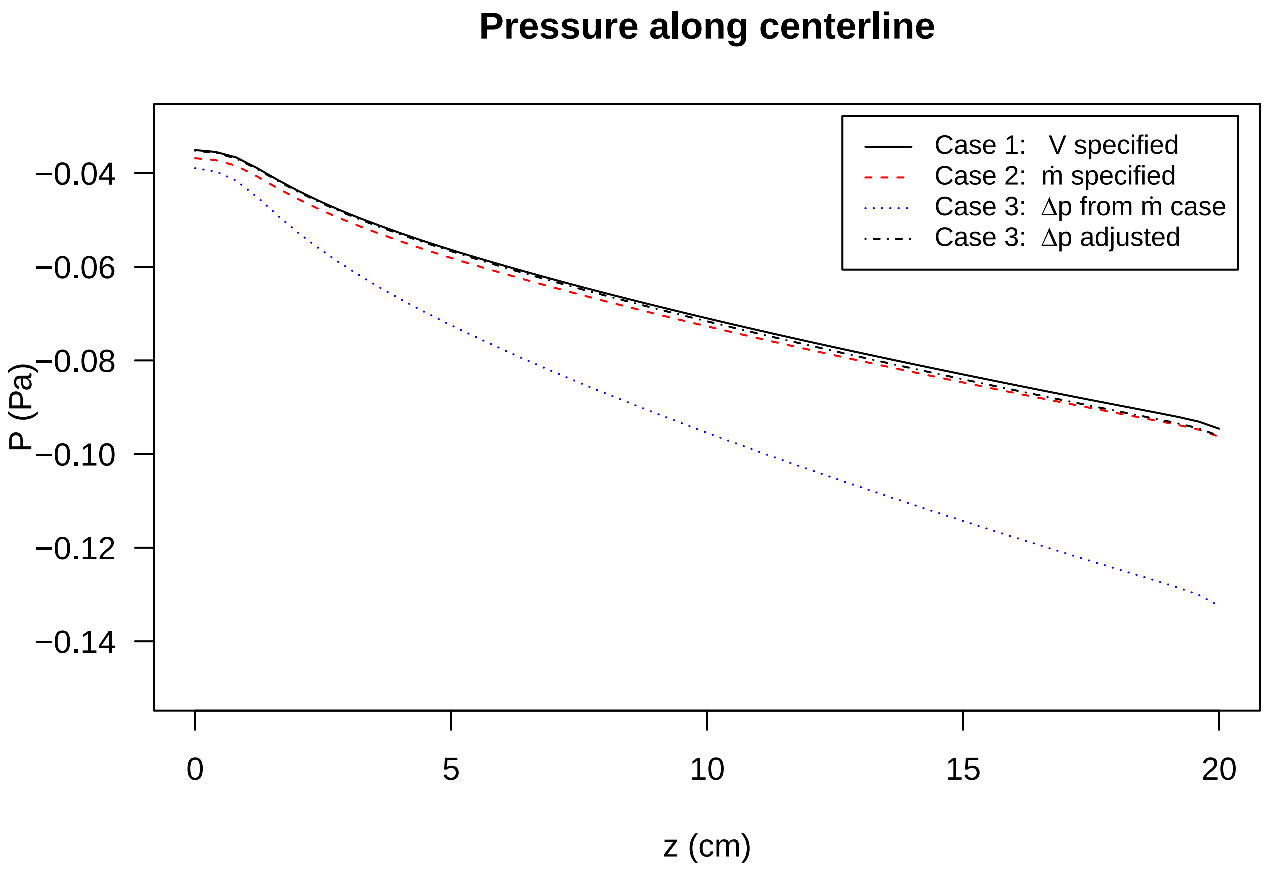
Effect of Boundary conditions for flow through a Pipe (1)

Comparison of boundary conditions for laminar flow in a pipe

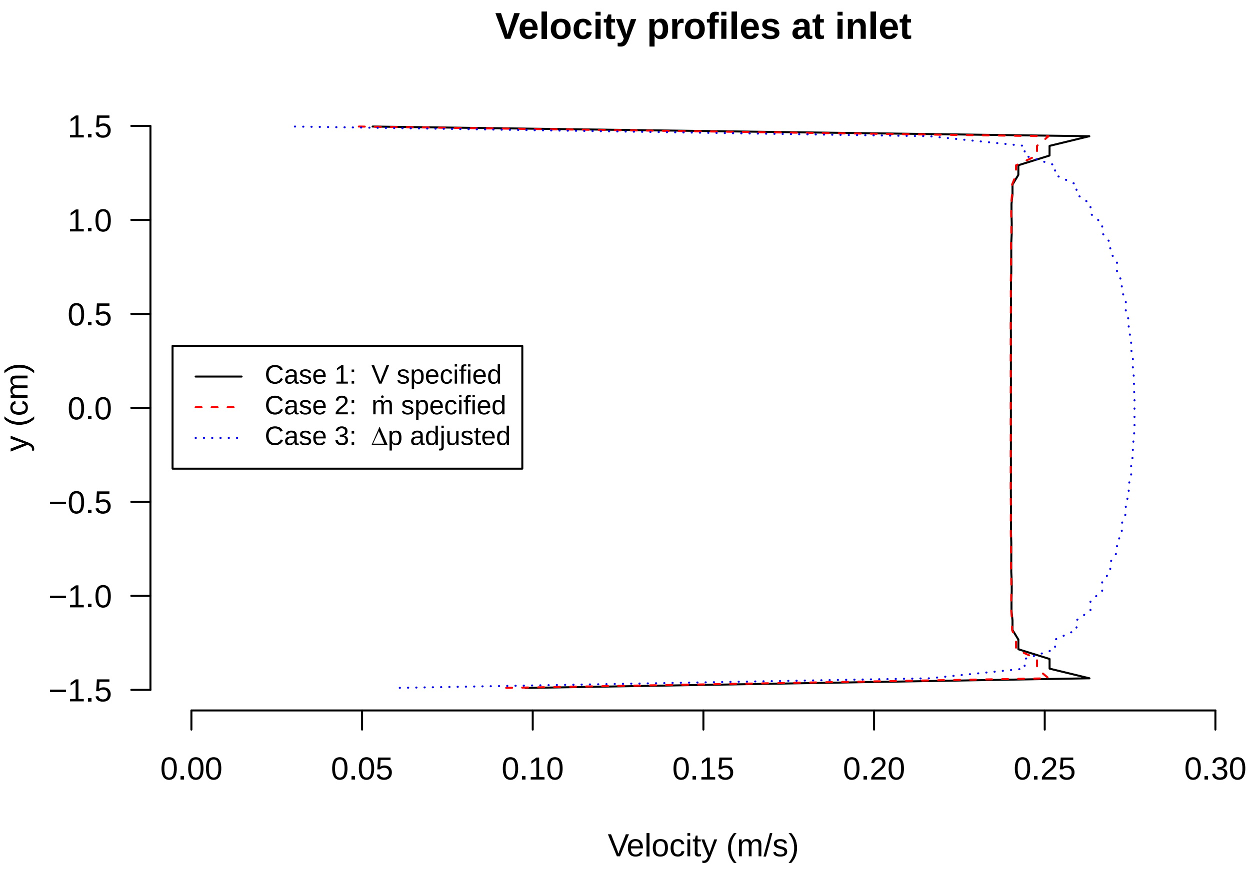
- STAR-CCM+ version 15.06 (2020.3)
- Full 3D simulation – do not exploit symmetry or use 2D
- Fluid is air
- $D = 3\,\text{cm}$, $L = 20\,\text{cm}$, $\text{Re}_D \approx 500$

	Inlet	Computed $\dot{m}$ (kg/s)	Computed Δp (Pa)
Case 1:	$V = 3$ m/s	2.006×10^{-4}	4.36×10^{-2}
Case 2:	$\dot{m} = 2.006 \times 10^{-4}$ kg/s	2.006×10^{-4}	4.36×10^{-2}
Case 3:	$p = 4.36 \times 10^{-2}$ Pa	2.873×10^{-4}	5.95×10^{-2}
Case 3:	$p = 2.00 \times 10^{-2}$ Pa	2.356×10^{-4}	4.68×10^{-2}
Case 3:	$p = 1.00 \times 10^{-2}$ Pa	2.100×10^{-4}	4.09×10^{-2}

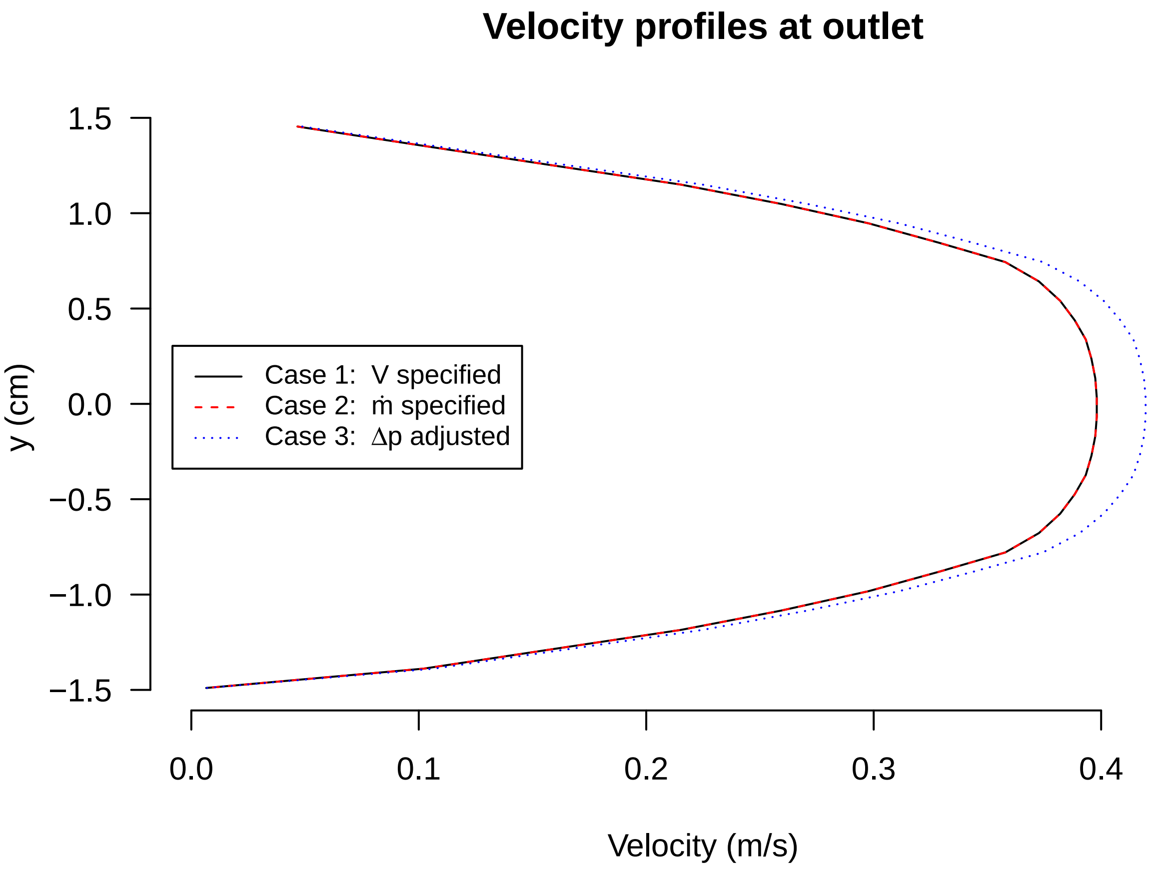
Effect of Boundary conditions for flow through a Pipe (2)



Effect of Boundary conditions for flow through a Pipe (3)



Effect of Boundary conditions for flow through a Pipe (4)



Recommendations for Simple Flows

- Recommend: use prescribed velocity or prescribed $\dot{m}$ at inlets
  - ▷ Small differences near the boundary of the inlet
  - ▷ Best practice is to move the inlet far enough upstream so the inlet conditions do not affect flow of interest inside the domain
- Recommend: use the standard "Outlet" boundary condition at the outet
- "Pressure Outlet" and "Outlet" appear to be equivalent when either velocity or $\dot{m}$ are prescribed at the inlet

Consideration for Non-Simple Flows

Non-simple boundary conditions at the inlet

- Prescribing tangential or swirl velocities at the inlet require "Velocity" inlet (check this, maybe $\dot{m}$, too)

- Specifying a non-uniform velocity profile is possible
  - ▷ Prescribe a function over the inlet
  - ▷ Use tabulated values from some another simulation or measurment