PRESSURE BASED INCOMPRESSIBLE SOLVER IN SU2

SU2 Developers meet 2019 | Koodly Ravishankara, A. (Akshay)

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- Incompressible flow equations
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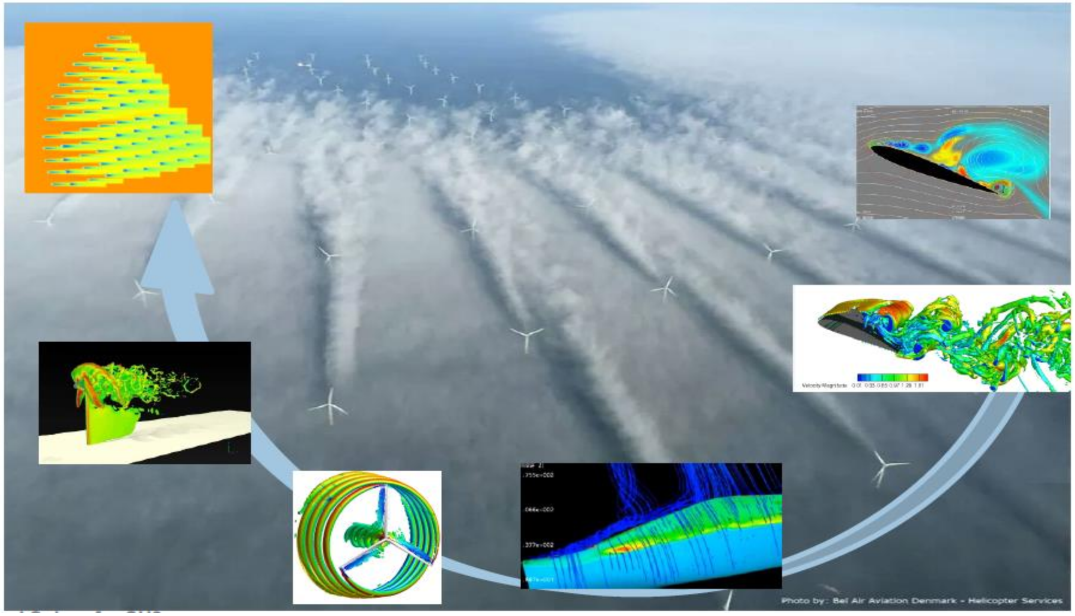
WIND ENERGY AT ECN PART OF TNO

- Research on many topics of **renewable energy technologies –** Wind energy, Solar energy, Biomass, etc.
- Wind energy unit mainly focused on **low-fidelity tools** that are tailor made for wind energy applications (about 50 researchers on various topics)
- **SU2** is our first serious attempt to include **CFD** in our research/design tool chain



INCOMPRESSIBLE FLOW METHODS

- Main difficulty – Pressure velocity coupling.
- *Compressible flows* – Solve for density in the continuity equation and use equation of state for pressure.
- *Incompressible flows* – Continuity equation reduces to divergence condition and no governing equation for pressure.
- **Density based methods**
  - Introduce artificial compressibility to mimic compressible flows – Artificial compressibility methods.
  - Alternatively, solve continuity equation and use pre-conditioning to overcome the stiffness of the system.

PRESSURE BASED METHODS

Pressure based methods

- Derive an equation for pressure based on discrete mass conservation or the continuity equation.
- Many variations – SIMPLE family of algorithms or pressure projection methods etc.
- SIMPLE algorithms – A predictor and corrector approach to resolve the pressure-velocity coupling in a segregated manner.

Advantages

- More suitable for very low Mach number flows.
- Ensures better mass conservation.
- Faster solution possible.

PRESSURE BASED METHOD IN SU2

Momentum equation:

$$\boldsymbol{A_{ij}} \Delta U_j^* = R(U_i^n) - F_i^p$$

$$\boldsymbol{A}_{ij} = \left(\frac{|\Omega|}{\Delta t} \delta_{ij} + \frac{\partial R_i}{\partial U_j} \right), R(U) = F^v - F^c$$

Pressure correction equation:

$$-\sum_f \rho \frac{|\Omega|}{diag(\boldsymbol{A})} . (\nabla P_f'). \overrightarrow{n_f} = -\sum_f \dot{m}_f^*$$

Mass flux on the RHS found using:

$$\sum_f \dot{m}_f^* = \sum_f \rho \vec{U}_f^* . \vec{n}_f$$

Face velocity found using momentum interpolation (Rhie-Chow) technique

$$U_f^* = \overline{U_f^*} - \frac{|\Omega|}{diag(\boldsymbol{A})} (\nabla P_f - \overline{\nabla P_f})$$

IMPLEMENTATION DETAILS

- Upwind discretization (with MUSCL reconstruction)
- Boundary conditions available – Velocity inlet, Pressure outlet, Wall, Inviscid wall, Freestream, Symmetry (from the recent pull request by @TobiKattmann)
- Single core support no MPI yet.
- Steady state solutions.
- Local time stepping.

IMPLEMENTATION DETAILS

- Available on the main repo in the ‘feature_Pressure_based’ branch (updated with develop regularly).
- New config option –
  KIND_INCOMP_SYSTEM = (DENSITY_BASED, PRESSURE_BASED)
- Use existing driver structure routines.
- Defined a new iteration class for the predictor corrector algorithm.
- Adding new multigrid cycle to accommodate the predictor-corrector loop.
- New set of files for solver, numerics and variable classes.
  (_direct_mean_PBinc.cpp). Poisson solver classes still remain.

TEST CASES

1. Channel flow ($Re = 400$)
2. Laminar flow over a flat plate ($Re = 4 \times 10^5$)
3. Laminar flow over a cylinder ($Re = 40$ and $Re = 100$)
4. Laminar flow over a backward facing step ($Re = 800$)

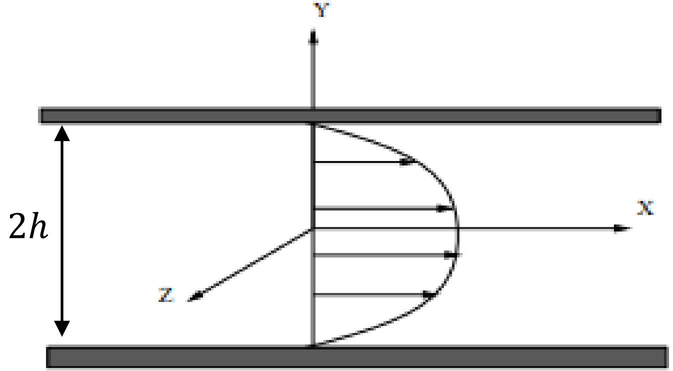
CHANNEL FLOW

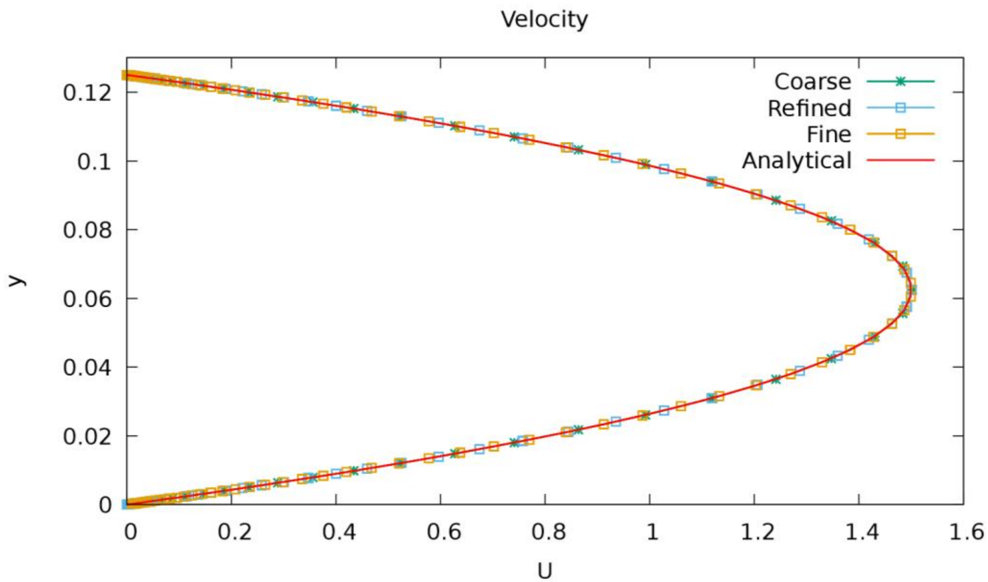
- Fully developed channel at $Re = 400$

- Velocity profile given by

$$u(y) = \frac{P}{2\mu}(h^2 - y^2)$$
$$v = 0$$

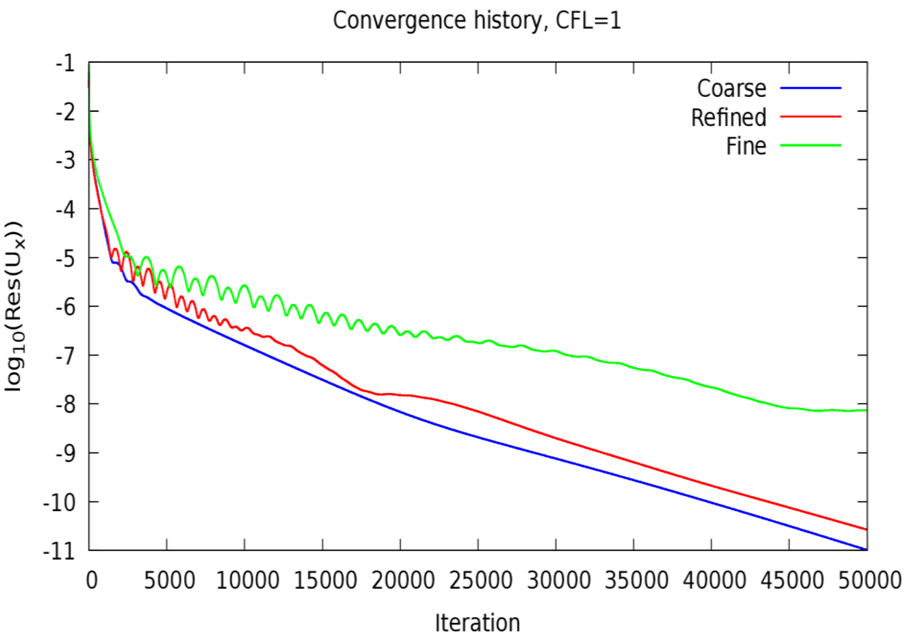
- $h = 0.0625$

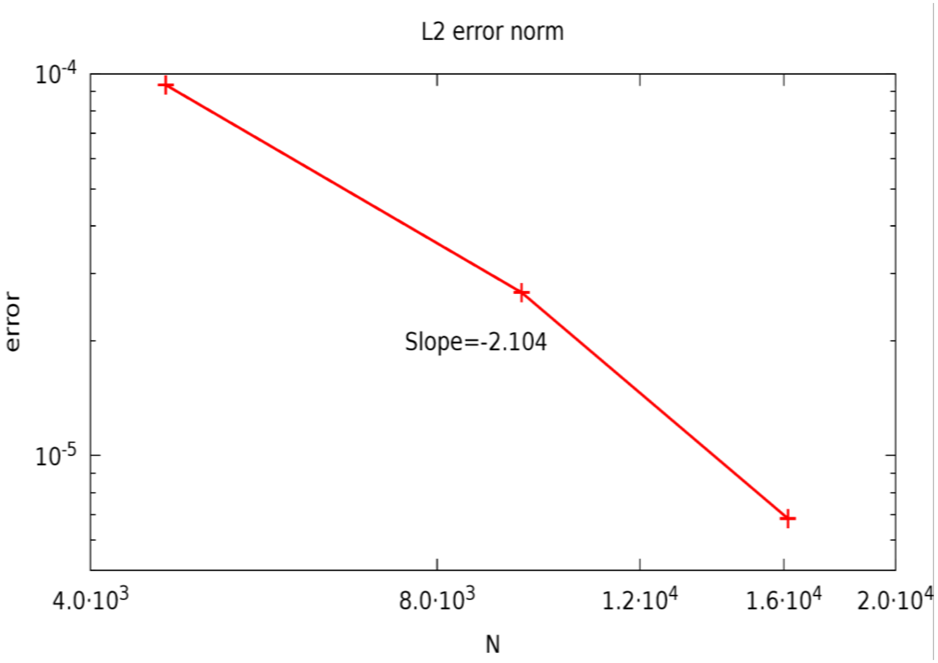




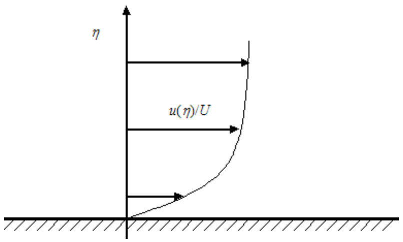
CHANNEL FLOW

- 3 different grid resolutions
- Order of accuracy based on the grid refinement study ~ 2





LAMINAR FLAT PLATE



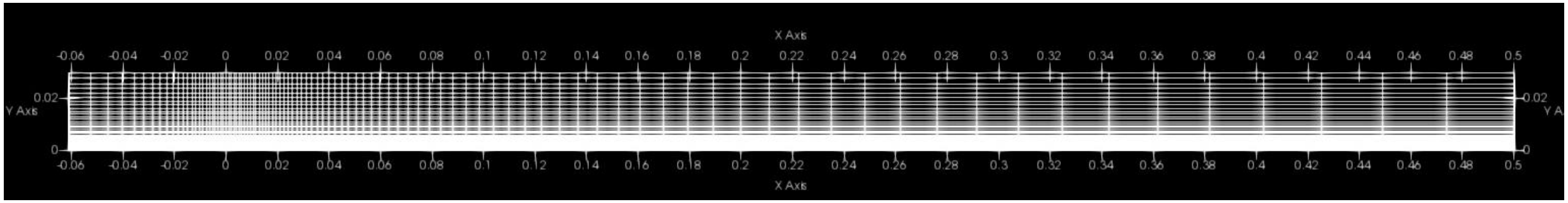
- Steady laminar boundary layer at $Re = 4.0 \times 10^5$
- Blasius equation – Assume zero pressure gradient and uniform outer flow. Define a scaled wall normal distance, η, and stream function ψ.
- Based on the boundary layer equations, an ODE can be formed for the stream function which is solved numerically to obtain self similar solutions for the flow.

$$\eta = y\sqrt{\frac{U}{2\nu x}} \qquad \psi = \sqrt{2\nu U x} f(\eta) \qquad f''' + ff' = 0$$

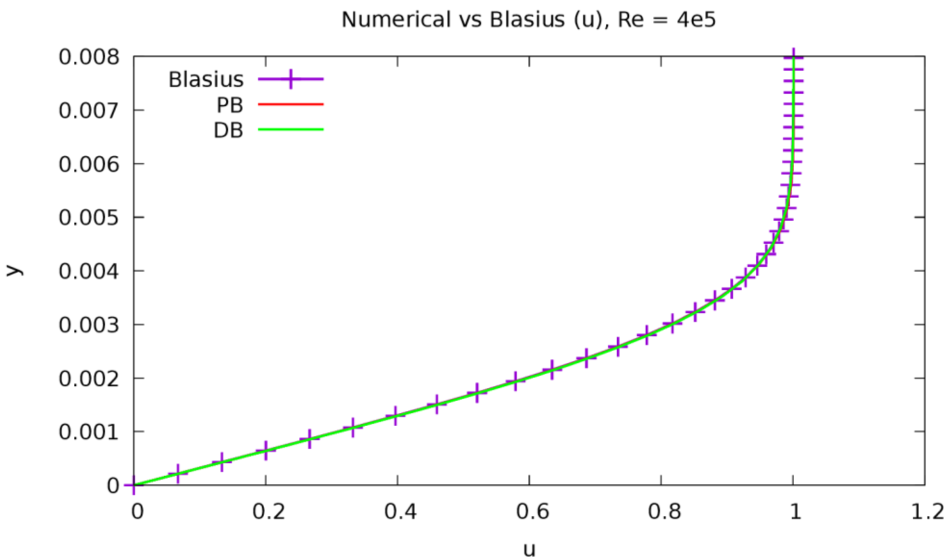
LAMINAR FLAT PLATE

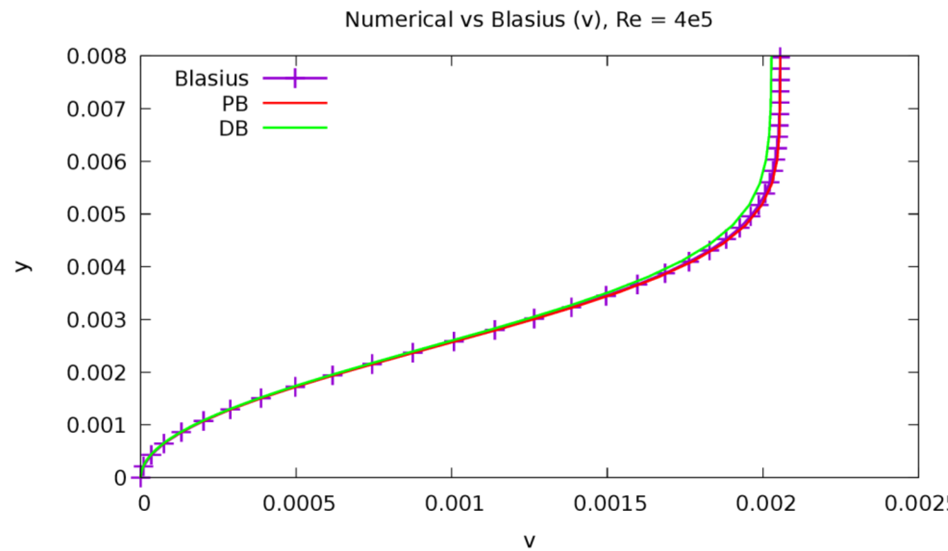
- Solve the Blasius equations using the shooting method.
- Compare numerical and Blasius solutions for velocity components at $x = 0.45$ and skin friction, c_f, along the length of the flat plate.

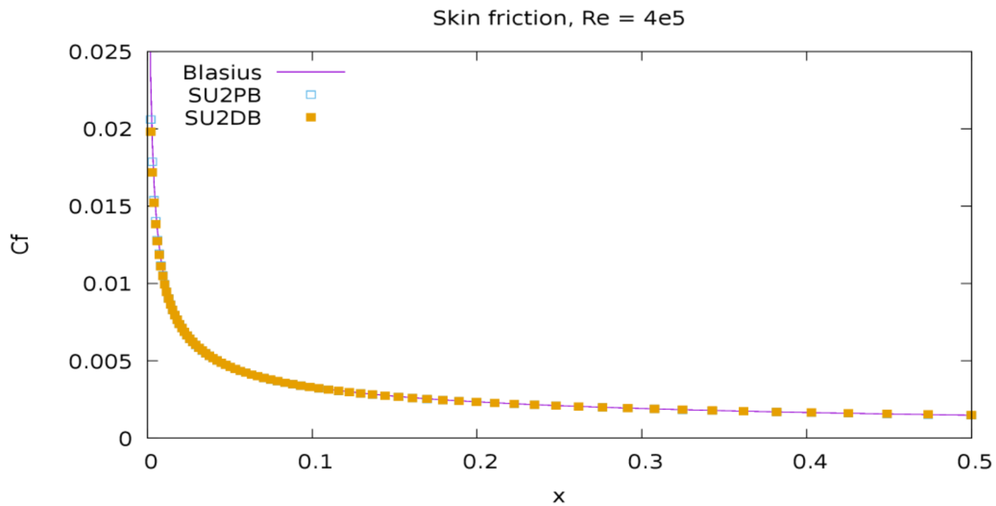
$$u(x,y) = Uf'(\eta) \qquad v(x,y) = \sqrt{\frac{U\nu}{2x}}\left[\eta f'(\eta) - f(\eta)\right] \qquad c_f = \frac{0.664}{\sqrt{Re_x}}$$



LAMINAR FLAT PLATE

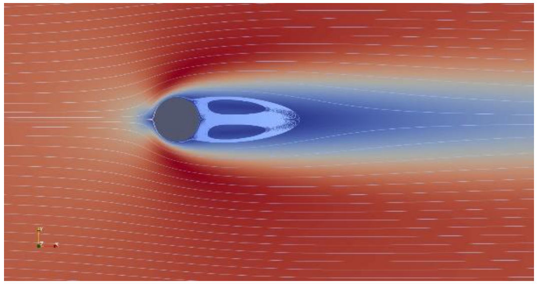


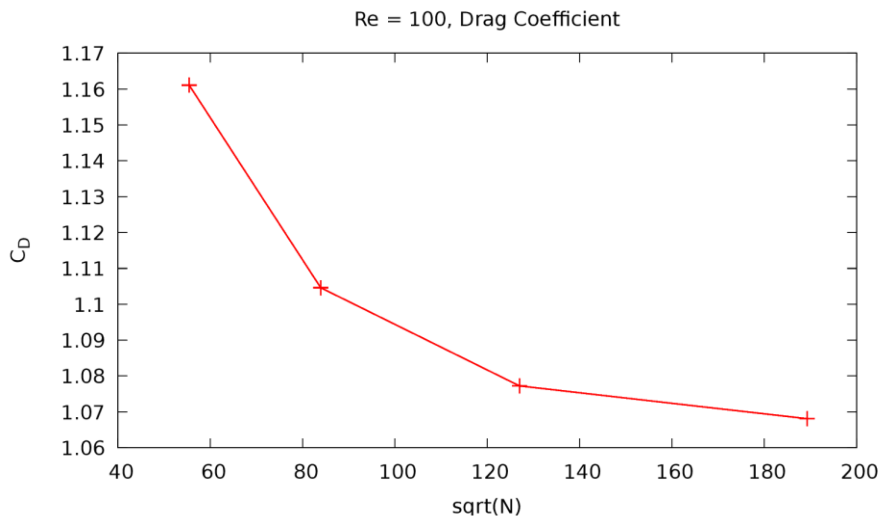


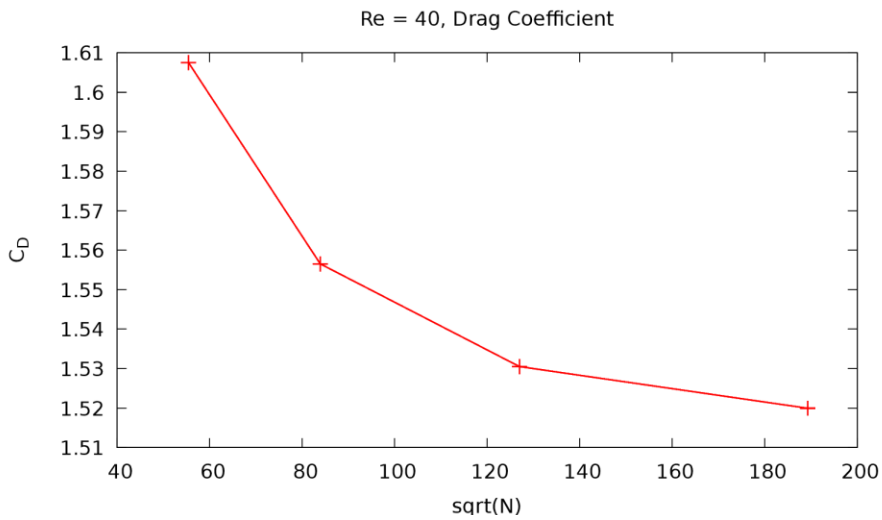


LAMINAR FLOW OVER A CYLINDER

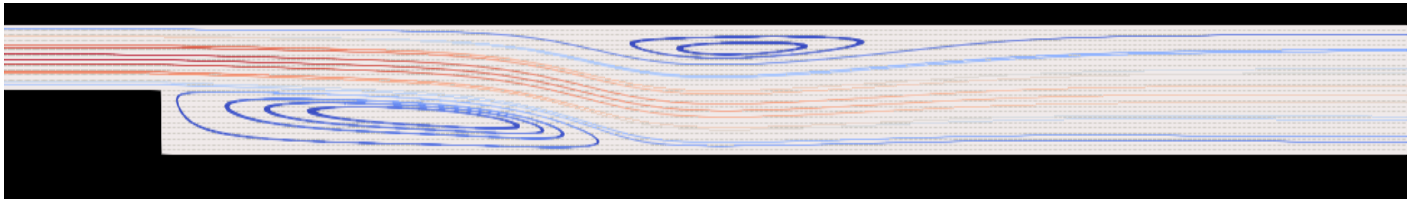
- Steady separated flow around a cylinder
- $Re = 40 \text{ and } Re = 100$
- Compare drag for different grid resolutions.





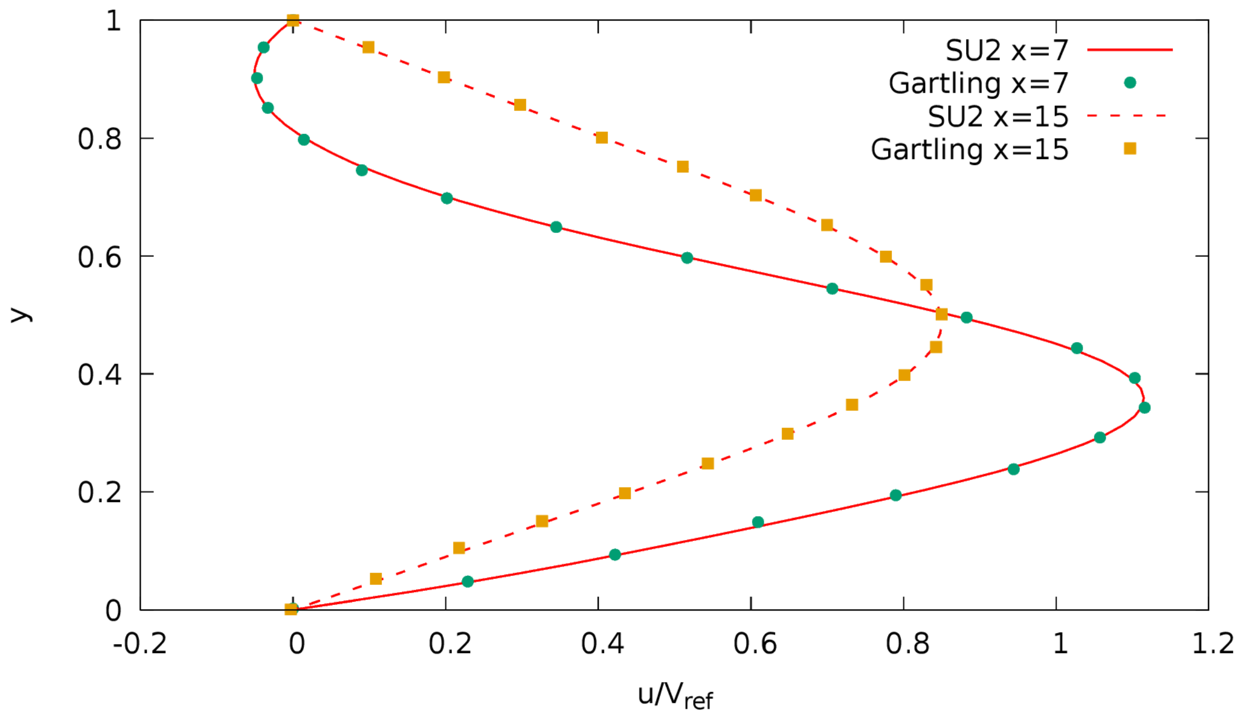


LAMINAR BACKWARD FACING STEP



- Flow past a backward facing step at $Re = 800$.
- Flow separates at the step and reattaches to the lower wall.
- At $Re = 800$, a secondary eddy is formed along the upper wall.
- Compare the numerical solution to Gartling, D. K. (1990), A test problem for outflow boundary conditions—flow over a backward-facing step. Int. J. Numer. Meth. Fluids, 11: 953-967.

LAMINAR BACKWARD FACING STEP



Reattachment length:

- Lower wall – $L_{lw} = 5.81$
- Upper wall – $L_{uw} = 5.69$

UPCOMING DEVELOPMENTS

- Multigrid method.
- RANS equations.
- MPI support.
- Unsteady problems.
- Periodic BCs, ALE formulation.

THANK YOU FOR YOUR ATTENTION

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