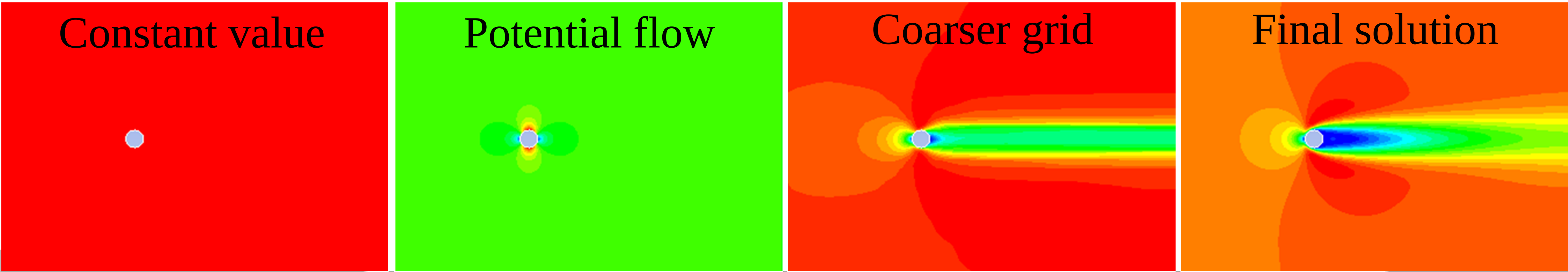
Boundary Conditions

Initial conditions

- Steady-state problem -> completely determined by BC
- Limit-cycle oscillation -> completely determined by BC
- Transient computation of an initial-value problem is dependent on the initial conditions
- Initial conditions may be important for the convergence to steady state
  - Set to constant value
  - Solve simplified equation (potential flow – ”hybrid”)
  - Solve on coarser grids (FMG = full multi-grid)



Boundary flow field

- Supersonic inflow
  - All information from boundary to interior
- Subsonic inflow
  - Most information from boundary to interior
  - pressure related information from interior to boundary.
- Subsonic outflow
  - Only pressure related information from boundary to interior
- Supersonic outflow
  - No information from boundary to interior

- Must be
  - Numerically stable
  - Well posed

Boundary influence

If interaction between the boundary and interior flow fields is a problem:

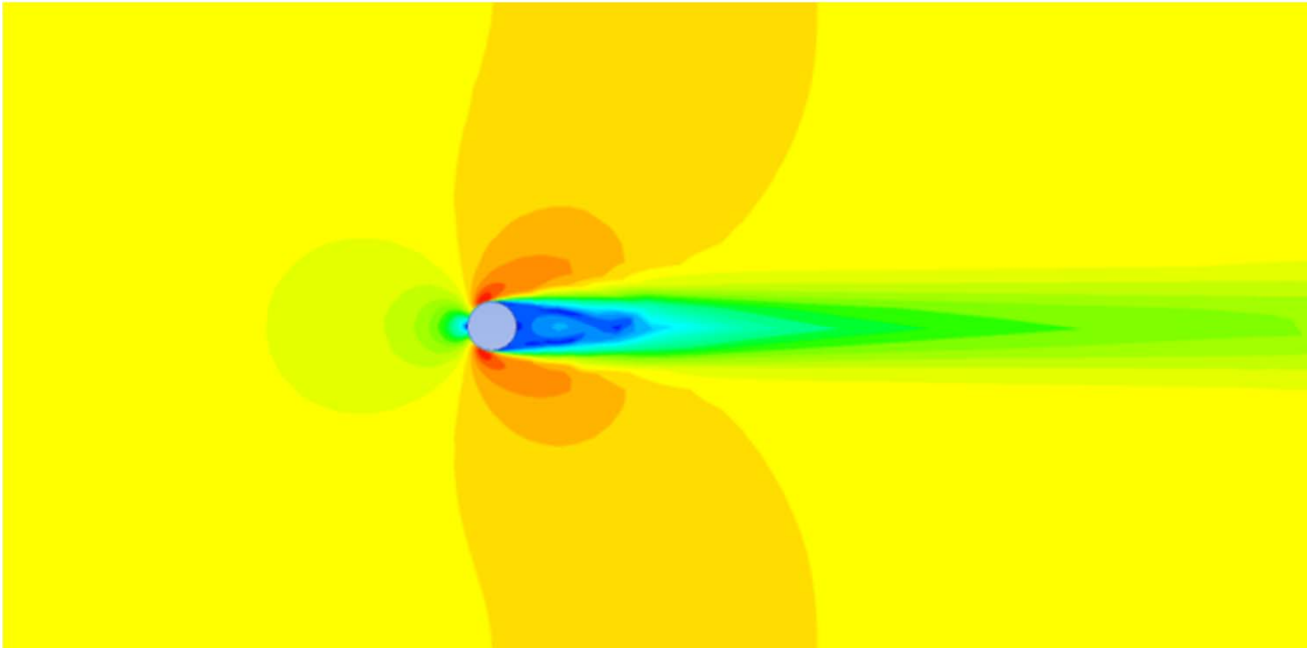
- Extend the boundaries for external flows
  - typically 10-50 times the size of the object
  - Less problem in 3D flows
- Include more of the true inflow/outflow geometries for internal flows
- Make empirical/mathematical corrections on the boundaries
- Warning for recirculation
  - Inflow at outflow boundaries, or
  - Outflow at inflow boundaries

- **Be aware of the problem!!!**

External flow B.C.

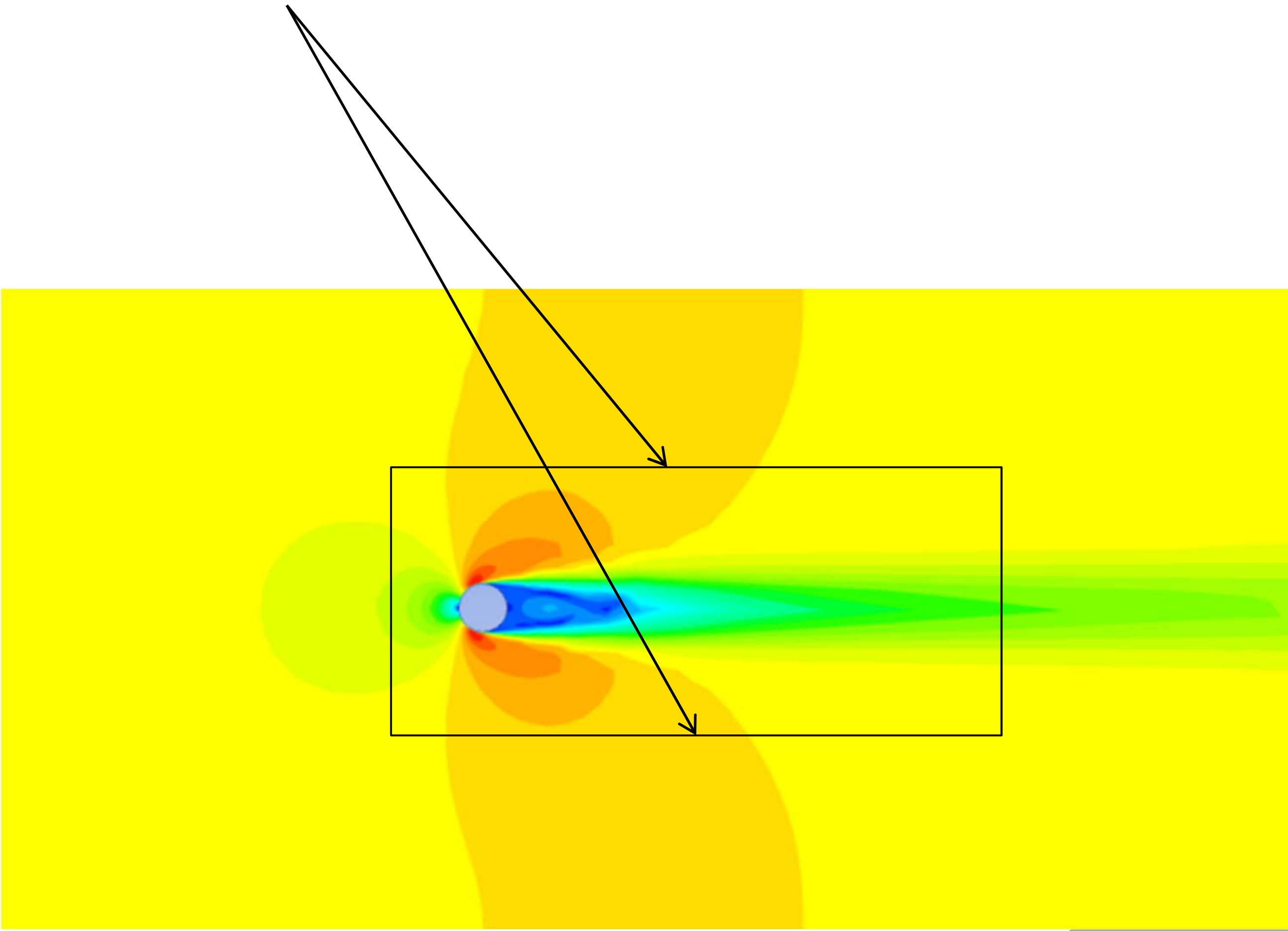
Example: Cylinder wake (picture, thanks to one of you)

- Real problem: one isolated cylinder in free air
- How to define the domain and boundary conditions?



External flow B.C.

As symmetry or periodic BCs

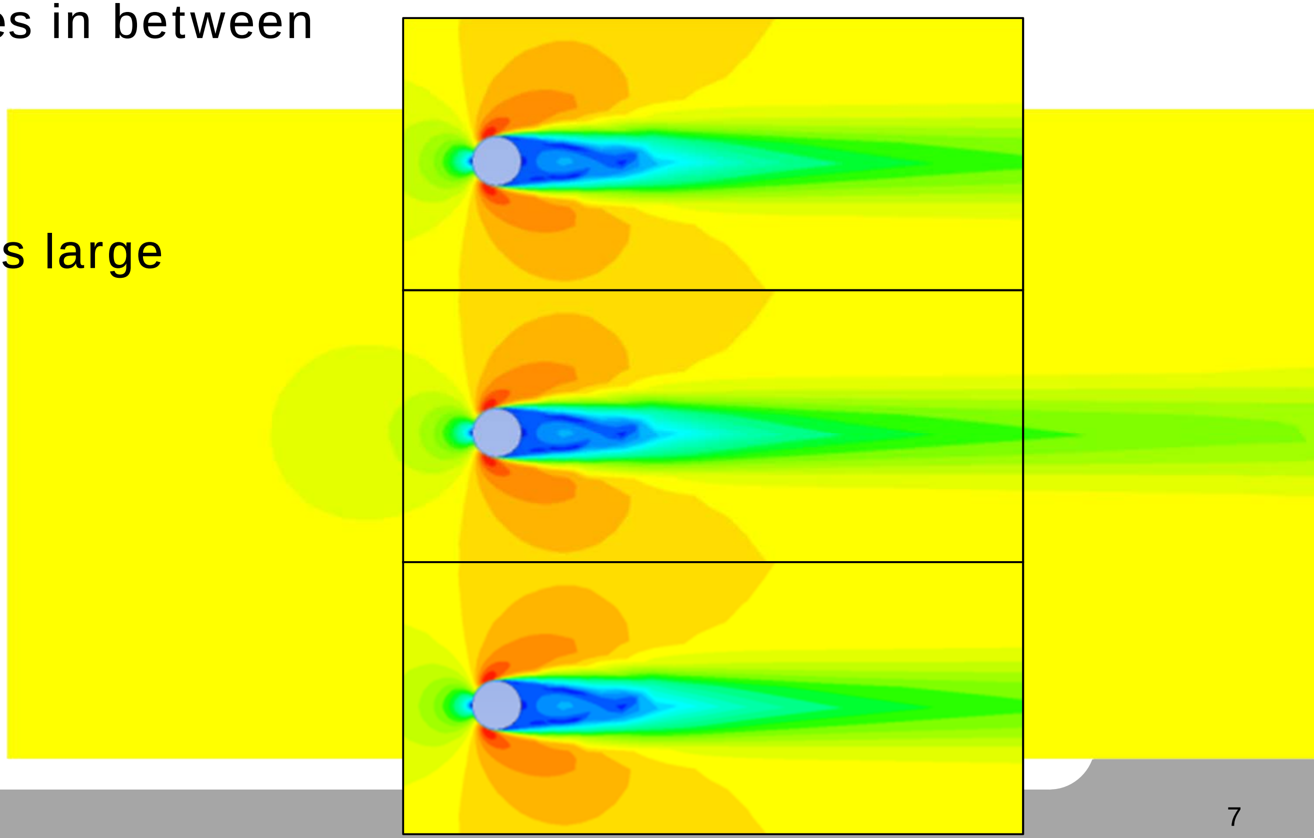


External flow B.C.

As symmetry or periodic BCs

- Corresponds to a row of cylinders
- Distance set by domain size
- Flow accelerates in between
- Higher forces

- OK if distance is large

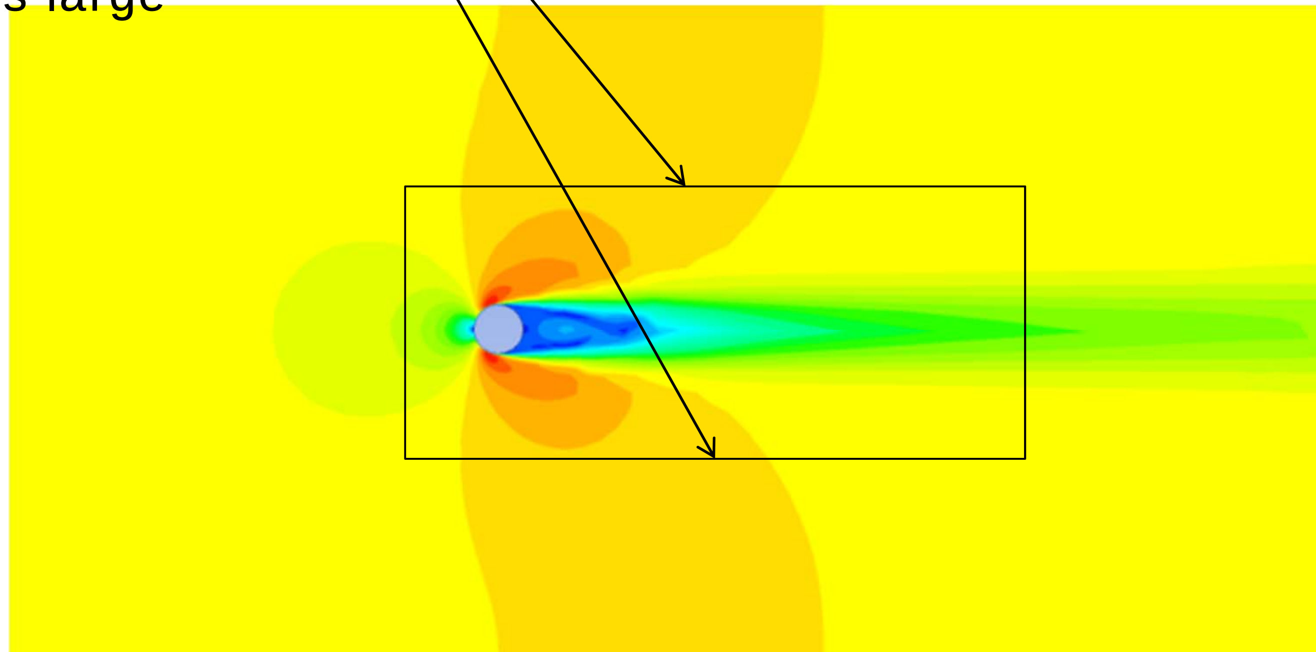


External flow B.C.

As pressure BCs (pressure outlet)

- Velocity and pressure not constant at the boundary
- Might be a local inflow – numerical instability?

- OK if distance is large

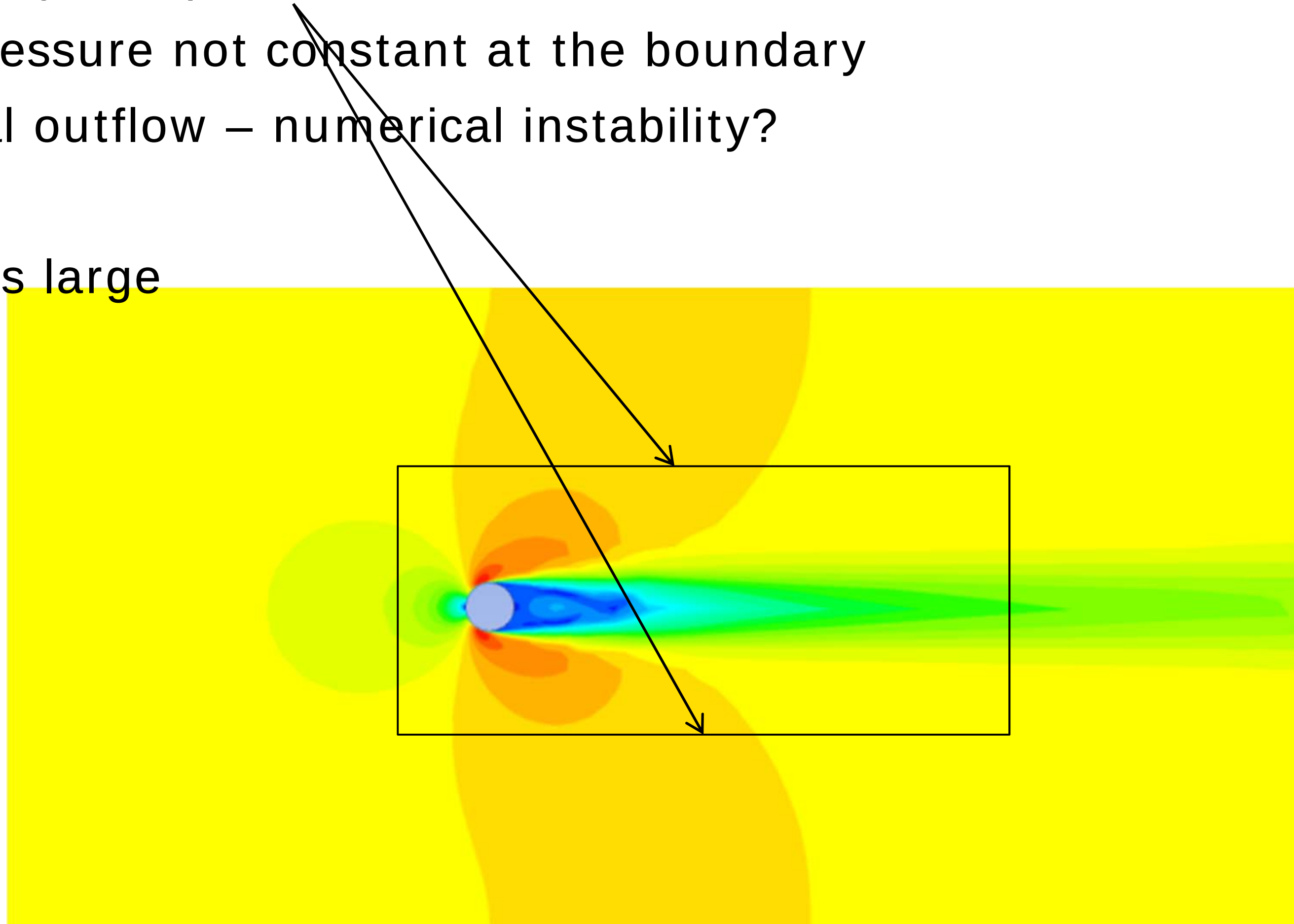


External flow B.C.

As inlet BCs (velocity inlet)

- Velocity and pressure not constant at the boundary
- Might be a local outflow – numerical instability?

- OK if distance is large

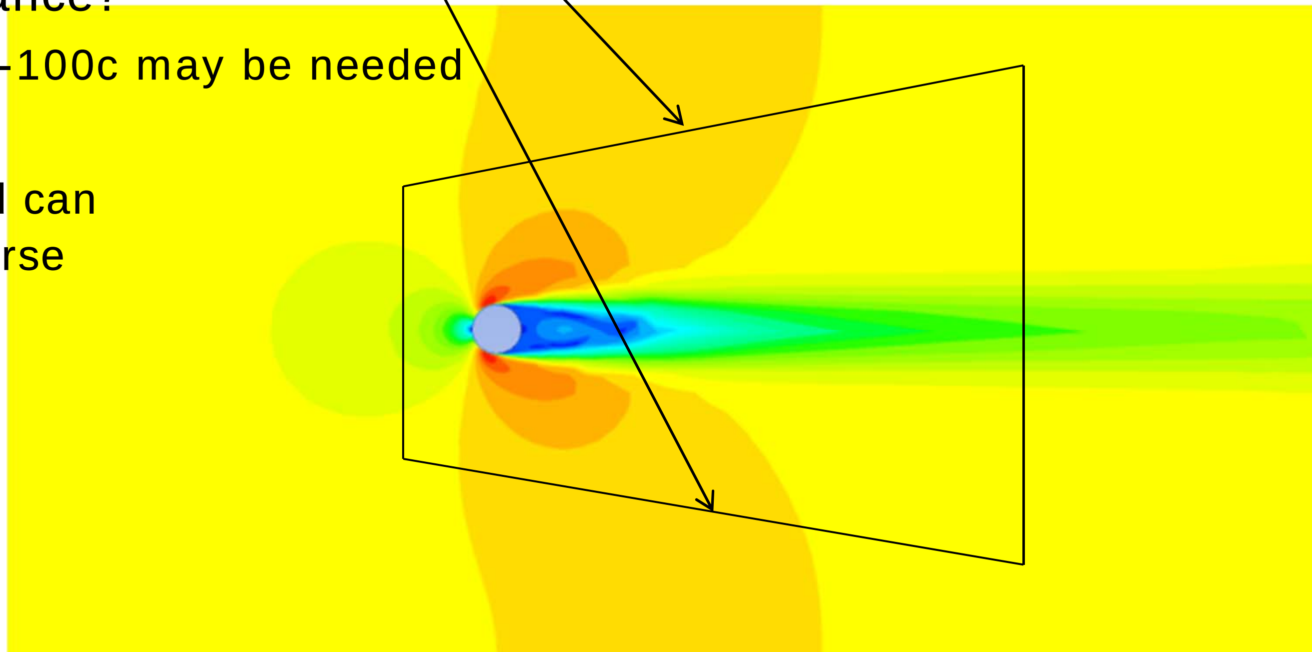


External flow B.C.

As inlet BCs (velocity inlet)

- Inflow everywhere – numerical stable

- Good alternative, if distance is large
- How large distance?
  - 2D wing: 20-100c may be needed
  - 3D: 10-20c
  - Far-field grid can be VERY coarse

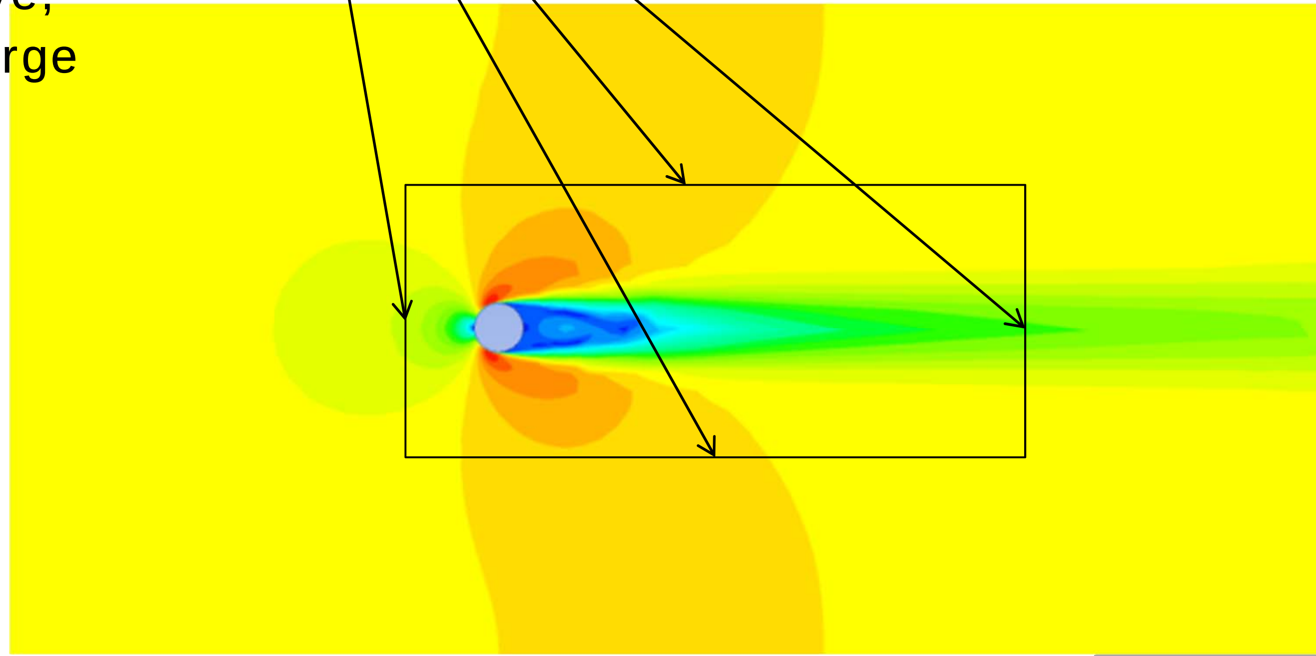


External flow B.C.

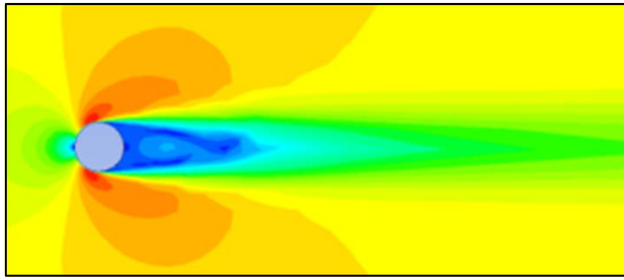
Far-field boundary condition (compressible flows only)

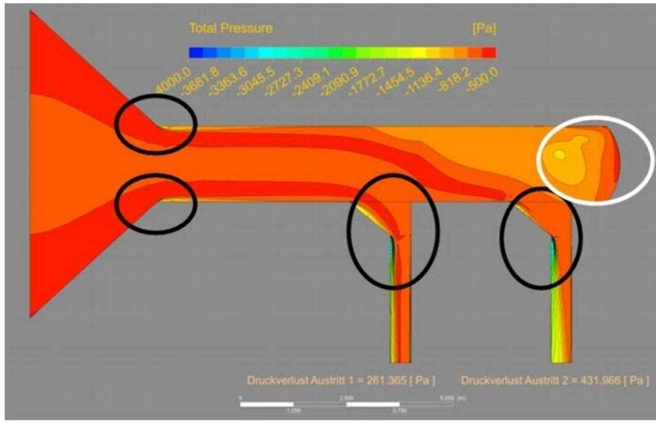
- Can handle both inflow and outflow
- Both sub- and supersonic flows

- Good alternative,
  if distance is large



Inflow B.C.





- Velocity inlet
  - External and internal flows
- Pressure inlet
  - Sets total (stagnation) condition at inflow
  - Internal flows
- Mass flow inlet
  - Sets mass flow rate over the inflow
  - Internal flows

Inflow conditions for turbulence

- At inflow boundaries the turbulence quantities must be prescribed for turbulent computations
- Inflow turbulence levels mostly not fully known
- Solution may be strongly dependent on the inflow turbulence levels, but mostly only minor dependencies
- Important to prescribe realistic values for solution accuracy and numerical stability

- If problems: move the inflow boundary sufficiently far from the region of interest.
- The turbulence levels at the inflow boundary are also applicable as initial conditions.

Turbulence level

- Turbulence level, Tu
  - Relation between rms of fluctuations and mean velocity
    $$u_{rms} = Tu\, U_\infty$$
  - Assuming isotropic turbulence, turbulence kinetic energy becomes
    $$K = \frac{3}{2}(Tu\, U_\infty)^2$$
  - Must be specified on inlet boundaries and for initial values
- Estimate Tu
  - $Tu < 0.3\%$ in external aerodynamic flows
  - $Tu \approx 1\%$ in wind tunnels
  - $Tu \approx 5-10\%$ in internal turbo machinery flows
  - $Tu < 2-3\%$ usually do not influence the mean flow field

Turbulence length scale

- Viscosity ratio $VR = \nu_T/\nu$
  - Often recommended to be $1-10$ in external flows
  - Results in length scale

$$L_T = \frac{K^{3/2}}{\varepsilon} = \frac{VR\,\nu}{C_\mu\sqrt{K}}, \qquad \nu_T = C_\mu \frac{\mathrm{K}^2}{\varepsilon}, \qquad \mathrm{C}_\mu = 0.09$$

  - Problem: L_T should not be Re dependent
  - For $K-\omega$ models: $\omega \equiv \varepsilon/C_\mu K$
- Turbulence length scale, L_T
  - Easier estimated than viscosity ratio
  - $L_T = 1-10\%$ of geometrical scales
- Turbulence advection length scale, L_A

$$L_A = \frac{KU_\infty}{\varepsilon} \approx \frac{L_T}{Tu}$$

  - The length scale on which free-stream turbulence reduces
  - Should not be much smaller than typical geometrical scales

Transition to turbulence

- The location of the transition point (or region)
  - Depends on surface roughness, free stream turbulence levels, noise, etc.
  - No general method to predict
  - Difficult to measure
- The flow may be dependent on the transition location
  - Try to get information from experiments
  - Try to estimate (specific empirical relations exist)
  - Compute the growth rate of disturbances (a subject as big as CFD)
  - Assume the flow fully turbulent (if transition is unimportant)
- Transition location prescribed in CFD by setting laminar or turbulent walls
  - Laminar: $Re < 10^3$
  - Turbulent: $Re > 10^6$