Case BL2:
Shock Wave / Laminar Boundary Layer Interaction

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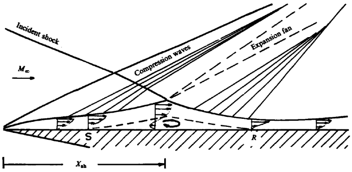
Test-case description

Incident oblique shock wave impinging a laminar boundary layer

- Objectives:
  - Test shock capturing capabilities of high-order methods
  - Test ability to converge to steady state
  - Outputs: drag, separation / reattachment points, recirculation zone, wall data (pressure, skin friction)



[Degrez et al., J. Fluid Mech., 177 (1987)]

Test-case description

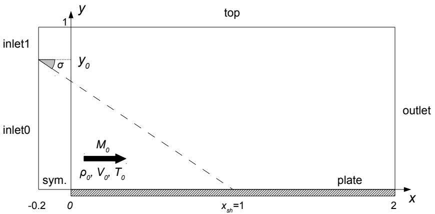
Incident oblique shock wave impinging a laminar boundary layer

- Flow conditions:
  - Angle between shock and plate: $\sigma = 30.8^\circ$
  - 2D steady laminar supersonic flow ($M_0 = 2.15$)
  - Navier-Stokes eq.
  - Reynolds number (freestream quantities, abscissa of impingement of the inviscid shock with the plate):

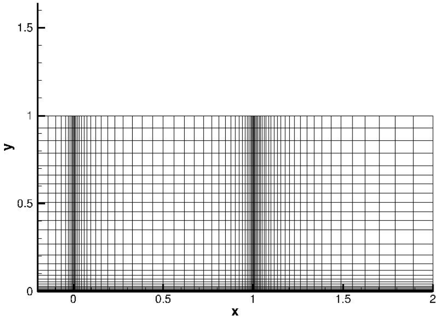
$$Re = \frac{\rho_0 V_0 x_{sh}}{\mu(T_0)} = 10^5$$

- Boundary conditions:
  - walls: no-slip adiabatic condition
  - supersonic inlet and outlet conditions
  - inlet conditions satisfy Rankine-Hugoniot relations through the shock
  - top: non-reflecting condition
- Closure laws:
  - ideal gas law with $\gamma = 1.4$
  - Sutherland's law
  - Fourrier's law with $Pr = 0.72$

Geometry of the domain and provided meshes



(a)



(b) mesh 1

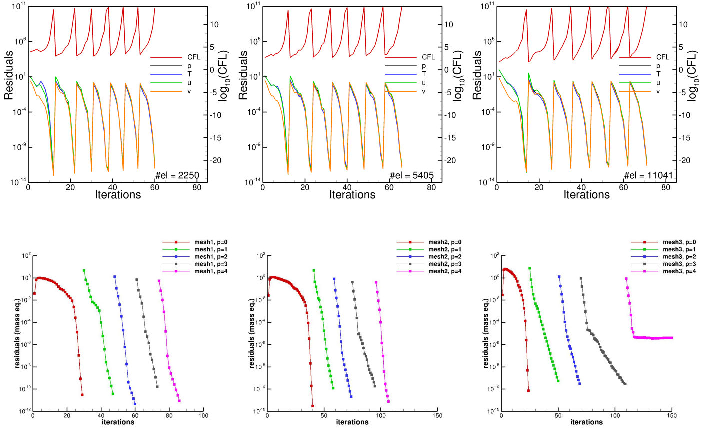
Series of 5 Cartesian meshes (from 2, 250 to 59, 262 quads)

Participants

- University of Bergamo:
  - primitive variables with log(p) and log(T)
  - DG orthogonal modal basis (polynomial degree $1 \leq p \leq 6$)
  - inviscid fluxes: Godunov method
  - viscous fluxes: BR2 method
  - no shock-capturing
  - backward-Euler time integration (GMRES linear solver, ILU0 and Additive Schwarz)
  - pseudo-transient continuation strategy
  - runs performed on 1 to 16 cores (TauBench $\simeq$ 10.4)
- Onera:
  - conservative variables
  - DG orthogonal modal basis (polynomial degree $1 \leq p \leq 4$)
  - inviscid fluxes: local Lax-Friedrichs flux
  - viscous fluxes: BR2 method
  - no shock-capturing
  - backward-Euler time integration (rGMRES linear solver, ILU0)
  - pseudo-transient continuation strategy
  - runs performed on 4 to 36 cores (TauBench $\simeq$ 7.4)

Convergence histories (residuals vs. iterations)

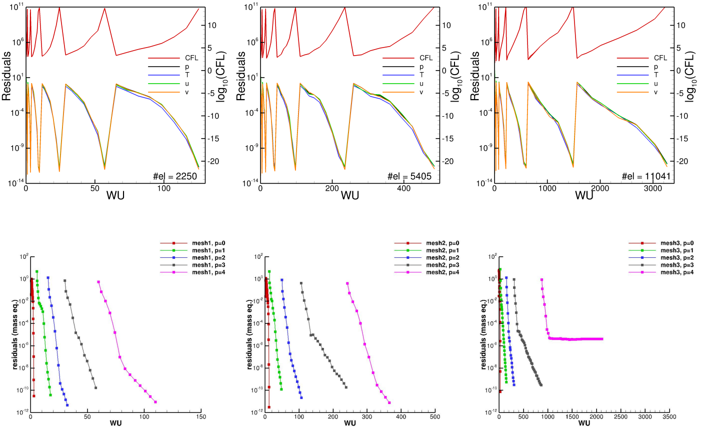
Univ. Bergamo (top) and Onera (bottom)



(a) $N = 2250$ (b) $N = 5405$ (c) $N = 11041$

Convergence histories (residuals vs. work units)

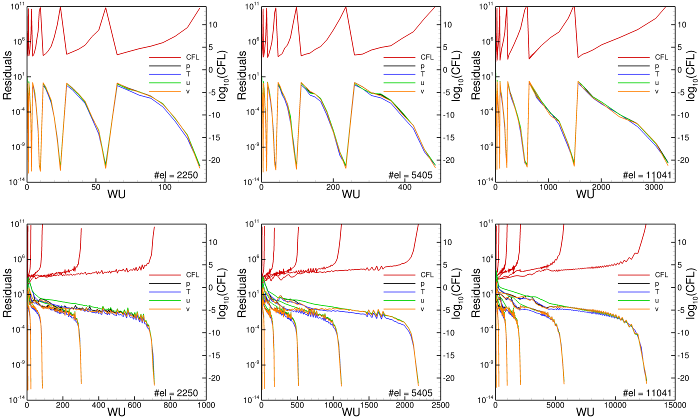
Univ. Bergamo (top) and Onera (bottom)



(a) $N = 2250$ (b) $N = 5405$ (c) $N = 11041$

Restarting computations (Univ. Bergamo)

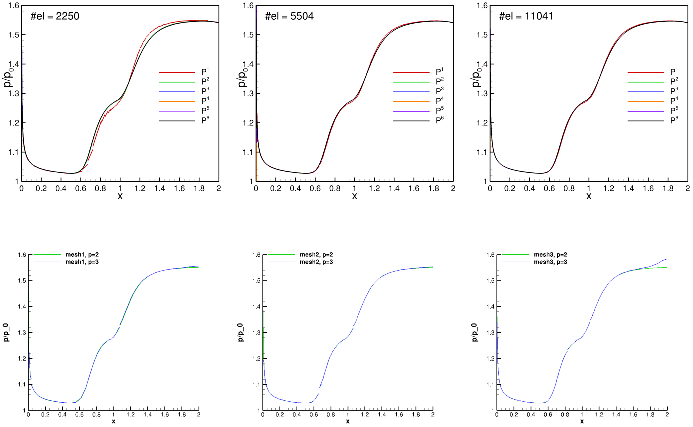
From: $p-1$ solution (top) / uniform solution (bottom)



(a) $N = 2250$ (b) $N = 5405$ (c) $N = 11041$

Pressure distributions at wall

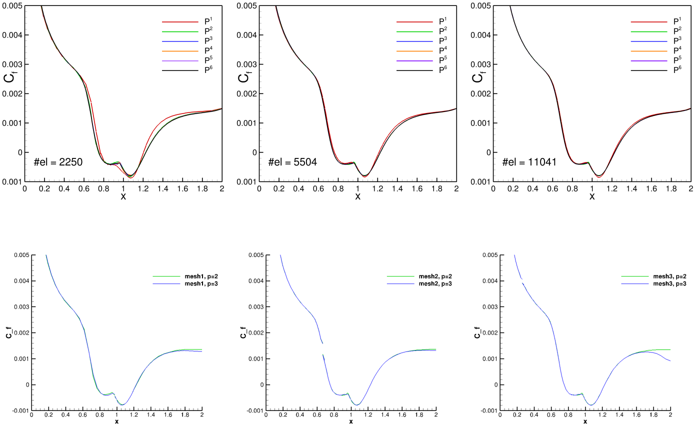
Univ. Bergamo (top) and Onera (bottom)



(a) $N = 2250$ (b) $N = 5405$ (c) $N = 11041$

Skin friction coefficient at wall

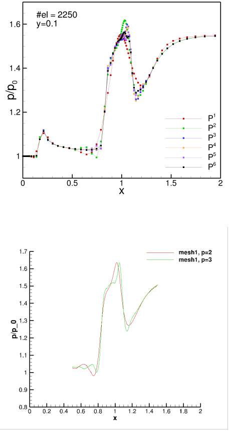
Univ. Bergamo (top) and Onera (bottom)



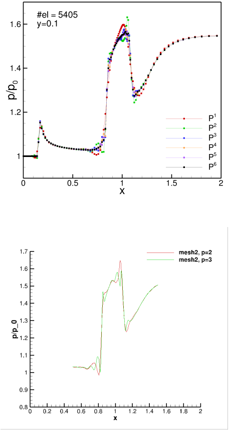
(a) $N = 2250$ (b) $N = 5405$ (c) $N = 11041$

Pressure distributions at $y = 0.1$

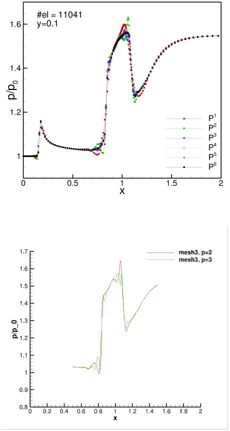
Univ. Bergamo (top) and Onera (bottom)



(a) $N = 2250$

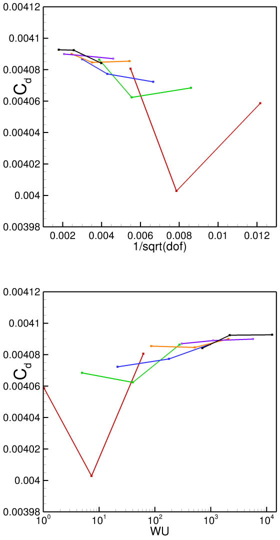


(b) $N = 5405$

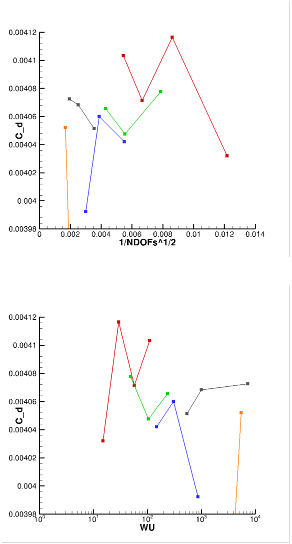


(c) $N = 11041$

Drag

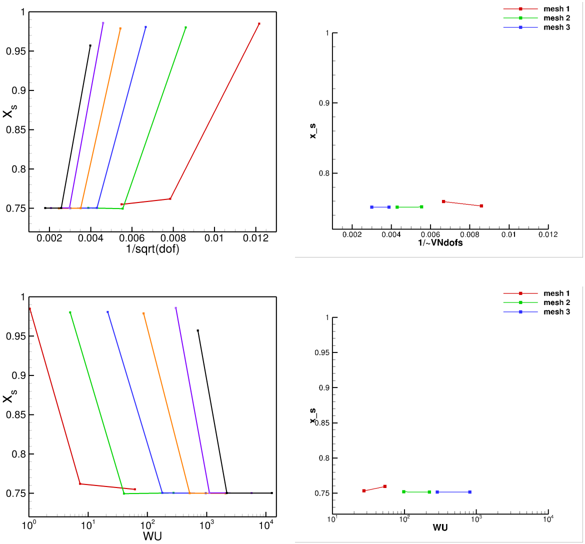


(a) Univ. Bergamo



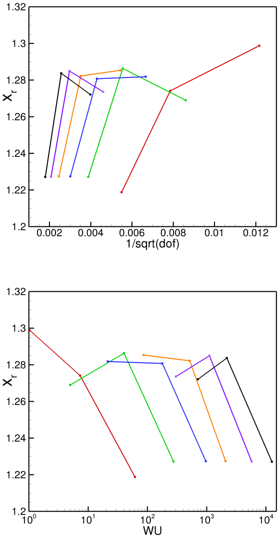
(b) Onera

Separation point

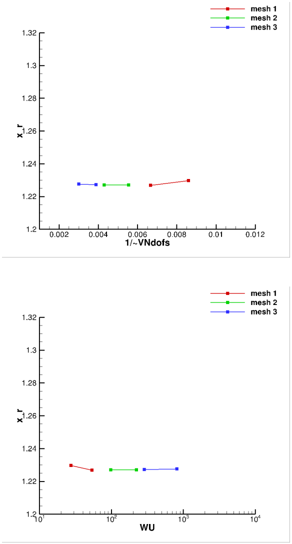


(a) Univ. Bergamo (b) Onera

Reattachment point



(a) Univ. Bergamo



(b) Onera

Conclusion

- Restarting from $p-1$ solution increases efficiency of the computations
- Comparable methods and results (except drag evaluation: Onera results altered by spurious oscillations at exit)
- Damping spurious oscillations across shock waves is important to restore flow physics
- Possible evolution of the test-case to 3D unsteady flow physics