PMRF Review I

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Problem and motivation

- Numerical simulation of hypersonic shock-boundary layer interactions (SBLIs)

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- Ubiquitous presence in hypersonic cruise vehicles and missiles
  - Outer body
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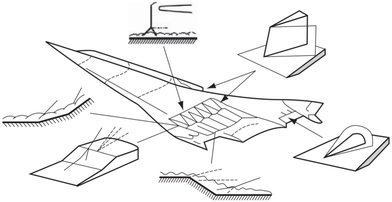

Babinsky & Harvey [1]

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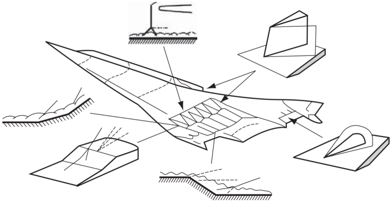

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- Ubiquitous presence in hypersonic cruise vehicles and missiles
  - Outer body
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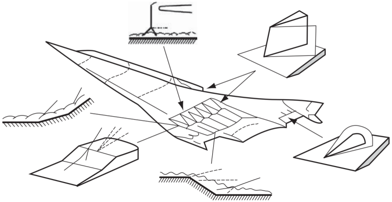
- Prediction and control of SBLI critical for design
- Challenges for computations
  1. Extremely localised peak in heat transfer
  2. Unsteadiness/sustained oscillations
  3. Strong viscous inviscid coupling



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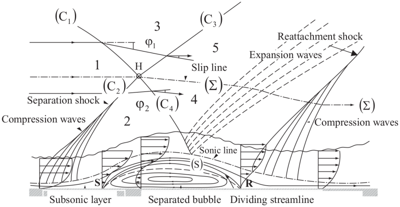

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Current status and issues

- Current capabilities of CFD solutions (Knight *et al.* [2], Gaitonde [3], and Knight *et al.* [4])
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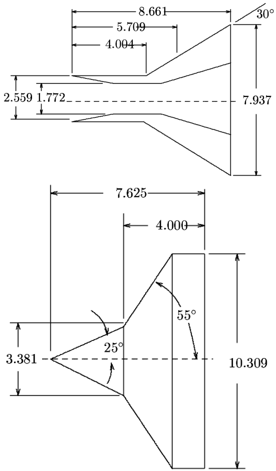
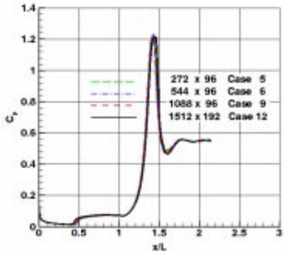
- Sensitivity to computational choices: an issue for simulations
- Specific case: hypersonic laminar perfect gas SBLI
- Blind validation study by Harvey *et al.* [5]
  - Experiments
    - Axisymmetric geometries: cylinder/flare and double cone
    - With N_2 at LENS shock tunnels, CUBRC
  - Navier-Stokes simulations by 4 participants
  - Experimental results declared only after participants gave simulation results



Knight [6]

Sensitivity of simulations to grid and numerical scheme



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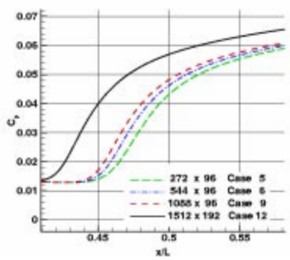
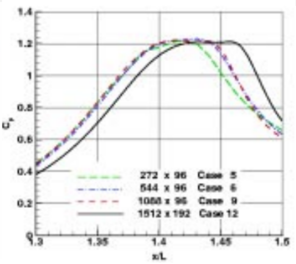


(b) Zoomed at separation point of (a)



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- Gnoffo [7]
  - Cylinder flare run 8 ($M_\infty = 11.5$, $T_\infty = 132.8\,\mathrm{K}$, $\mathrm{Re} = 359\,600\,\mathrm{m}^{-1}$): stalled convergence on finest grid

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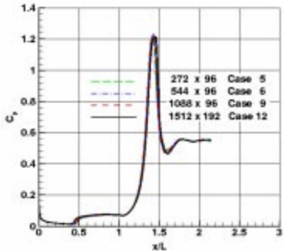

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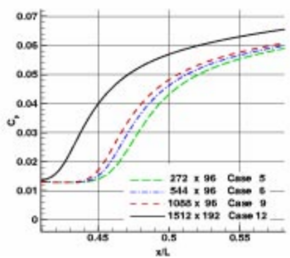

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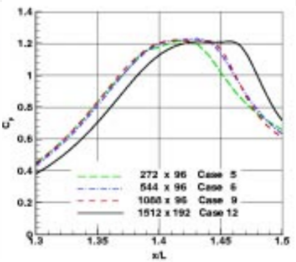

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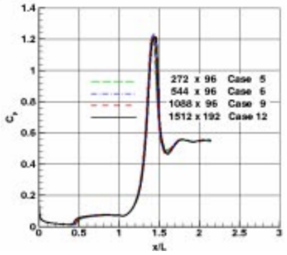

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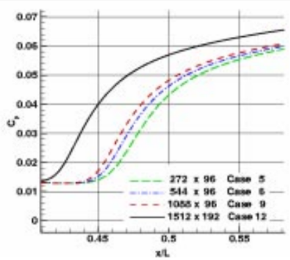

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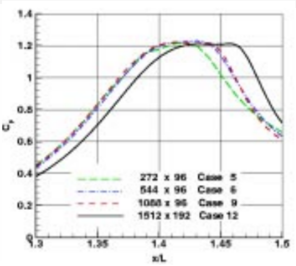

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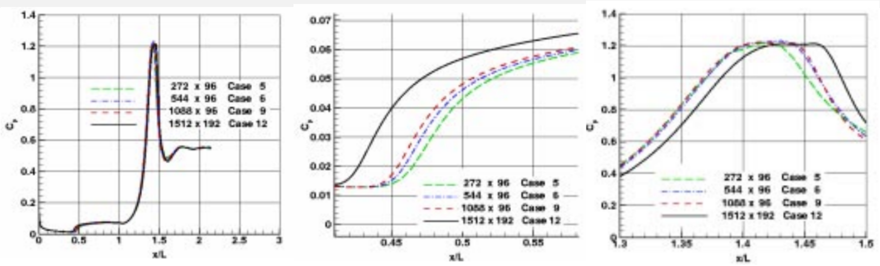

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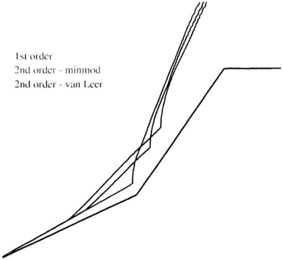

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- Scope of current work: 2 & 3

Research topic and present status

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- Work done (current review period)
  1. Developed pens2D: a code for Parallel Explicit Navier-Stokes simulations of 2D compressible flows using the deal.II finite element library [10, 11, 12]
     1. Inviscid fluxes: RKDG method [13] and HLLC Riemann solver [14]
     2. Viscous fluxes: auxiliary variable approach [15]
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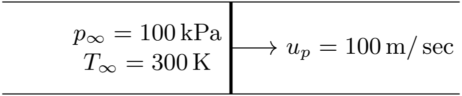
  2. Tested the solver (currently in debugging phase) with
     1. 1D inviscid expansion and subsonic flow over flat plate (without limiter)
     2. 5 shock tube tests from Toro [14]

3rd order results will be shown

Tests without limiter



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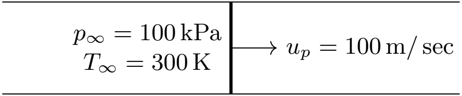

- Exact solution at $0.1\,\mathrm{sec}$ used as IC

Tests without limiter

$p_\infty = 100\,\mathrm{kPa}$
$T_\infty = 300\,\mathrm{K}$

$\longrightarrow u_p = 100\,\mathrm{m/sec}$

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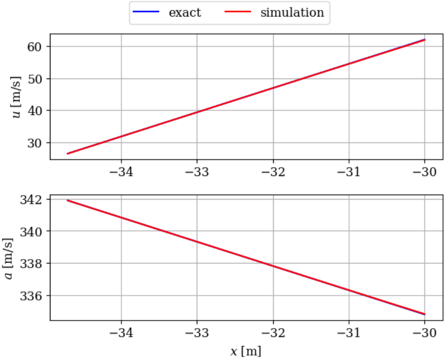

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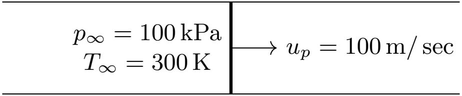

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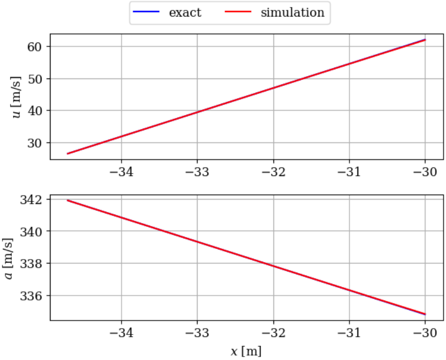

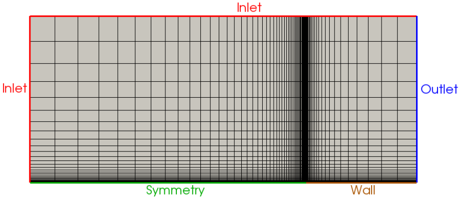

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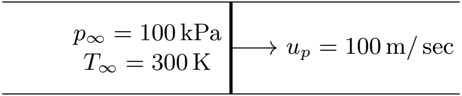

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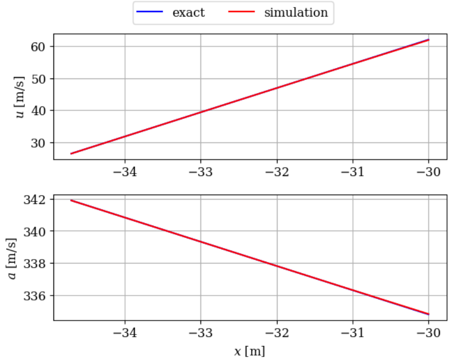

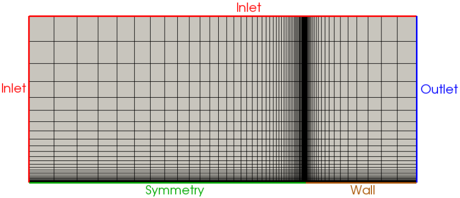

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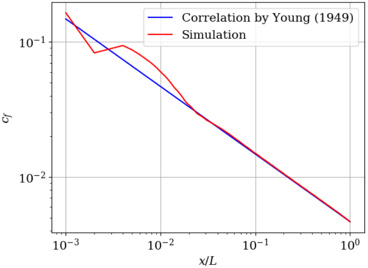

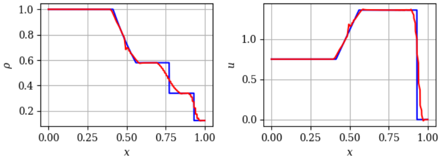

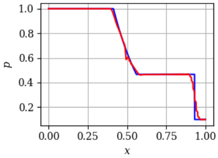

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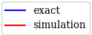

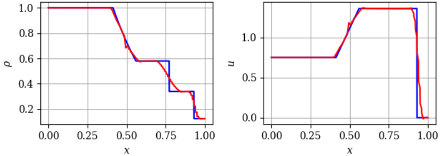

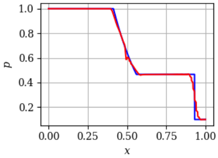

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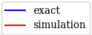

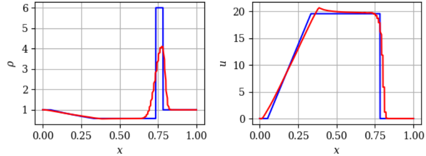

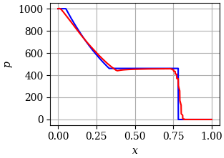

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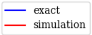

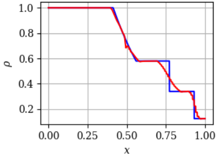

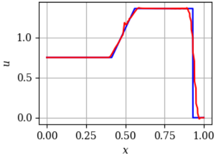

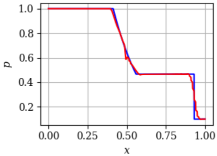

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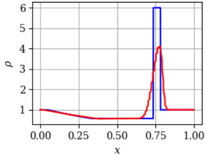

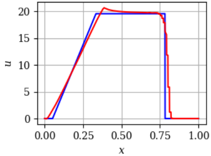

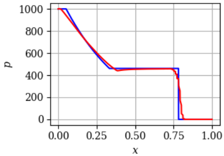

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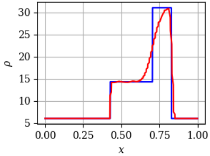

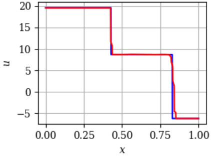

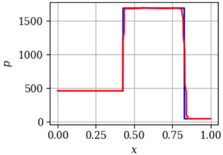

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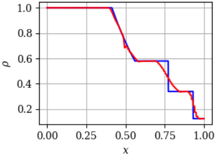

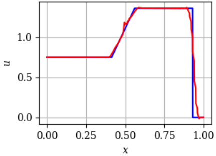

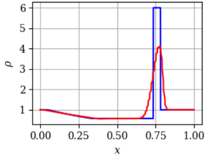

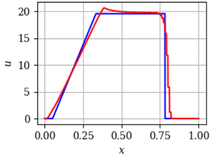

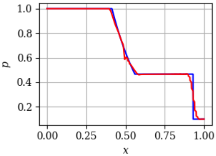

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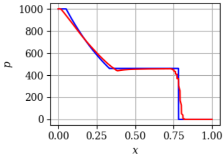

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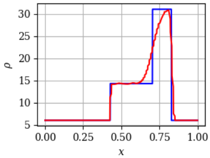
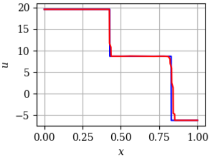
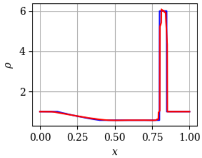
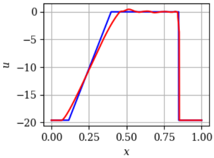
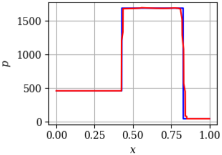
exact
simulation





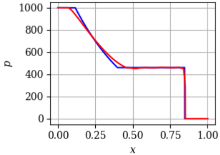






Test 4

exact
simulation



Test 5

exact
simulation

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  3. Numerical dispersion of strong expansion waves (tests 3 & 5) - High order interpolation
- Bugs in limiter implementation
  1. Test 1: glitch in sonic point, not observed with 1st order solution [14]
  2. Test 2: positivity limiter supposed to prevent crash

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- Plan for next review period: 1 and parts 1 & 2 of 2

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