Development of Discontinuous Galerkin simulation Framework for Hypersonic Shock-Boundary Layer Interaction

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Teaching information

Year	Semester	Internal (IITB)	External (VJTI, Mumbai)
2018	Autumn	Engineering Drawing	
2019	Spring	Engineering Drawing	
	Autumn	Engineering Drawing	
2020	Spring	Applied Thermodynamics	
	Autumn	Thermodynamics	
2021	Spring	Applied Thermodynamics	Advanced Fluid Dynamics
	Autumn	Thermodynamics	Computational Fluid Dynamics

Hypersonic CFD: conclusions based on FV numerical simulations [CMT09; Kni+12; Can15; Gai15; Kni+17]

- Issues
  - Grid generation for complex geometries
  - Heat transfer sensitivity to modelling, grid and numerical details
- Needs
  - Solution uncertainty quantification (wrt model parameters) and improved physical models
  - Adaptive, mixed element techniques (a)
  - Schemes capable of subcell resolution (b)
  - Accurate low dissipation methods for turbulent simulations (c)
  - Efficient parallel computation algorithms (d)

Features of DG method [HW07; CKS12]

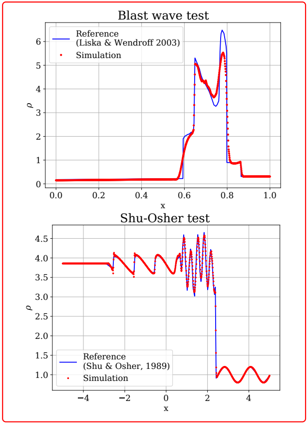
- Arbitrarily high order of accuracy (c)
- Cell-local interpolation, compact stencil (b) (d)
- Works with unstructured, 3d, curved and mixed element meshes (a)
- Extremely suitable for hp adaptive techniques (a)
- Highly suitable for high performance computing (d)

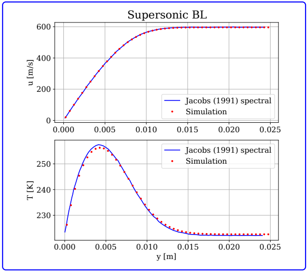
Ref.	Discretization	Geometry	Flow regime	Polynomial order N
[LD09]	Conservative residual distribution PG	Sharp DC	Laminar NEQ	1
[KC10]	SUPG	HCEF, blunt DC	Laminar PrG	1
[GLD18]	Entropy residual distribution Galerkin	Sharp DC	Laminar NEQ	1
[Hol+18]	SUPG	Blunt DC	Laminar PrG	1
[Chi+19][1]	DG	Sharp DC	Laminar PrG	1-3

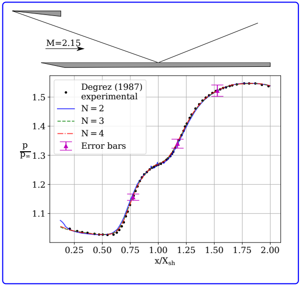
[1] Used polynomial order sequencing to obtain high order steady solution

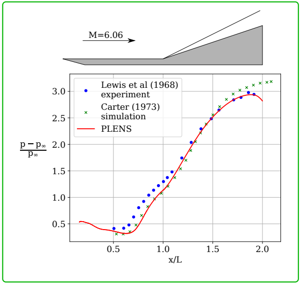
Proposed an extension to subcell limiter of [Hen+21] (red box)

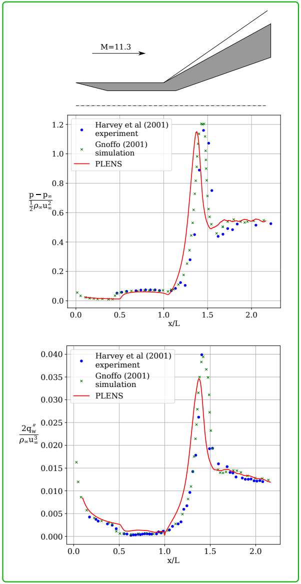
- Bassi-Rebay 1 extension to supersonic compressible Navier-Stokes equations [BR97] (blue box)
- Viscous residual blending for hypersonic flows (green box)







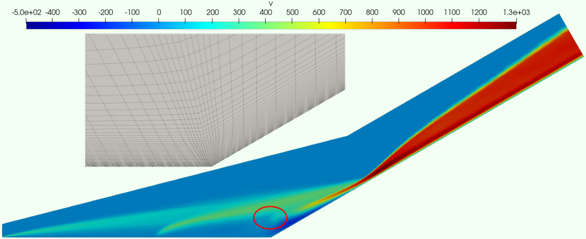




Comparison with FV simulation on unadaptive grid of equivalent resolution:

	x_{sep}/L	x_{att}/L
[Gno01]	0.52	1.31
PLENS	0.52	1.28

Discrepancy in post-corner solution $\leftrightarrow$ local time stepping algorithm



Reason: rapid change in cell size above the corner $\implies$ high variation in local time step $\implies$ delinking of solution above corner

Conclusion

- Proposed an extension of a subcell limiter for Euler equations to viscous hypersonic flows
- Stable and reasonably accurate simulations were performed for $M_\infty \geq 6$ with $N = 2$
  - $M_\infty = 11.3$ case: pre-corner solution OK, diffusion of local time step may give better post-corner results

Future work

1. Optimise: the current code implementation is slow
2. Validate the hypersonic extension on stronger cases (double cone geometry) with higher values of N
3. Extend to turbulent (RANS) solver [?]
4. Analysis of separation control technique(s) for scramjet intakes

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