Hypersonic Flow Computations On Unstructured Meshes

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Session: Applied Computational Aero

Time: wed afternoon

Mention: colleagues

- Ram Prabhu for running codes
- Bill Scallion & Matt Rhode for UPWT data

Background

- Rapid, accurate aerodynamic screening capability is needed:
  - aerodynamic performance coefficients
  - pressure loads for preliminary structural analysis
  - general flow features, for example, shock location
- Unstructured grids offer flexible and rapid grid generation
- Historically, unstructured Euler schemes are not robust hypersonically

Outline

- Computational algorithm
- Comparisons to other codes and experiment
- Use as a screening tool
- Concluding remarks

- details are in the paper for the algorithm
- screening tools are talked about throughout

FELISA System

- Unstructured mesh generation
- 'Standard' Euler flow solver, for subsonic $\Rightarrow$ low supersonic
- Hypersonic Euler flow solver, FELISA_HYP
  - perfect gas
  - equilibrium air
  - CF_4
- Parallel versions of flow solvers

- for parallel: work on IBM sP2, J90, workstation clusters.
- not used for the calculations in the paper

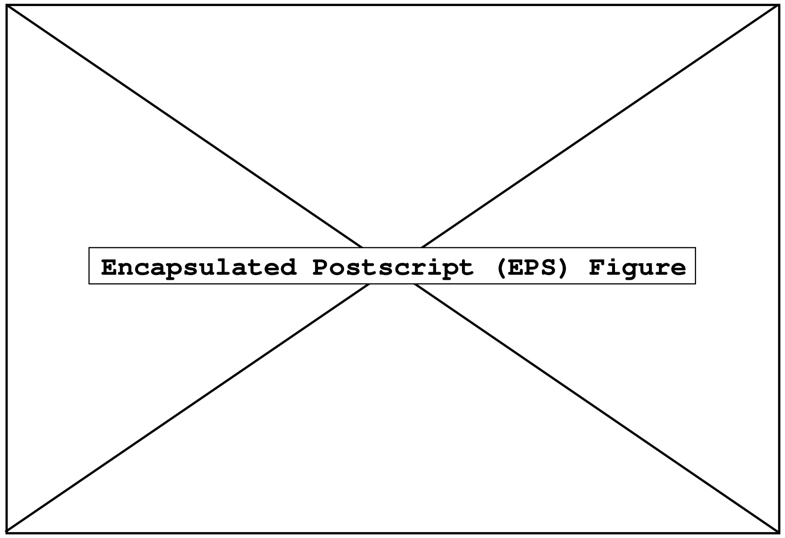
Unstructured Inviscid Hypersonic Flow Solver (FELISA_HYP)

- Euler equations
- Finite volume formulation
- Edge data structure
- Hänel flux vector splitting
- MUSCL reconstruction
- Explicit time stepping

Time Stepping

- check to ensure monotonicity
- eliminate limit cycle behavior

Edge Data Structure



- control volumes are tetrahedra surrounding each node
- fluxes computed across outer faces of control volume
- flux computations grouped by edge

Old Edge Data Structure notes. . .

- edge il is used in all of the figures. . .

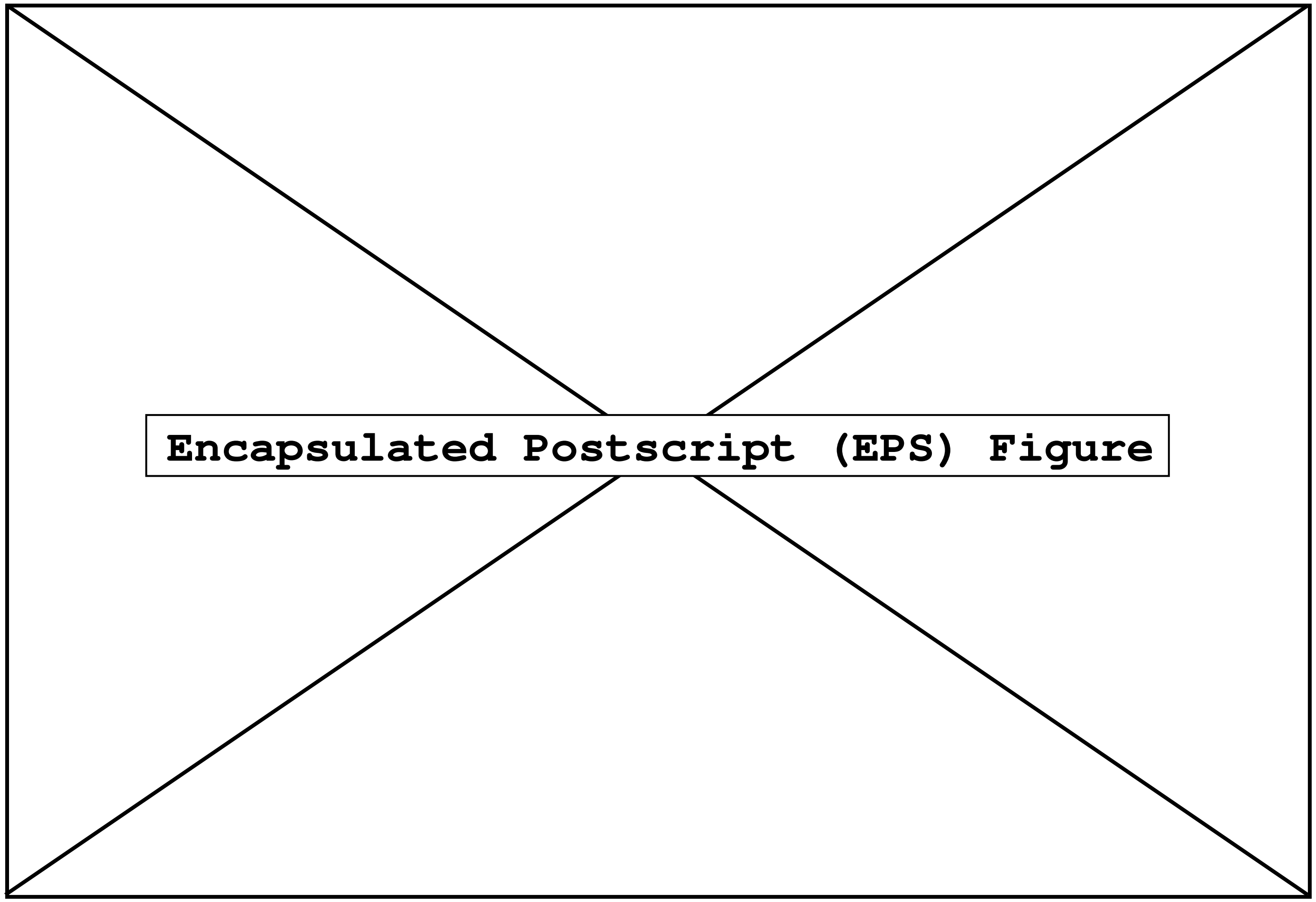
- fluxes computed across faces of tetrahedra
- control volume is tetrahedra
- nodal info for cells is stored

- fluxes computed across S^e for all edges of node i
- control volume surrounds node
- weights for S^e stored

Hänel Flux Vector Splitting

- Upwind formulation; allows for stable computations across strong shocks
- No 'free' parameters are required
- Allows for constant enthalpy solution where solution is fully converged

Gradient Reconstruction



Gradient Reconstruction notes

- compare to structured grid gradient calculation
- edge il is used in all of the figures...
- MUSCL reconstruction (Monotone Upwind Scheme Conservation Law)

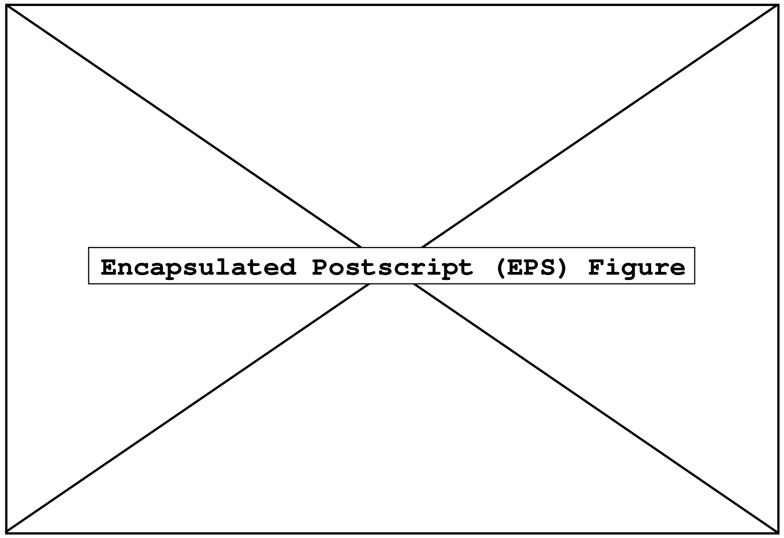
Recent Applications of the FELISA System

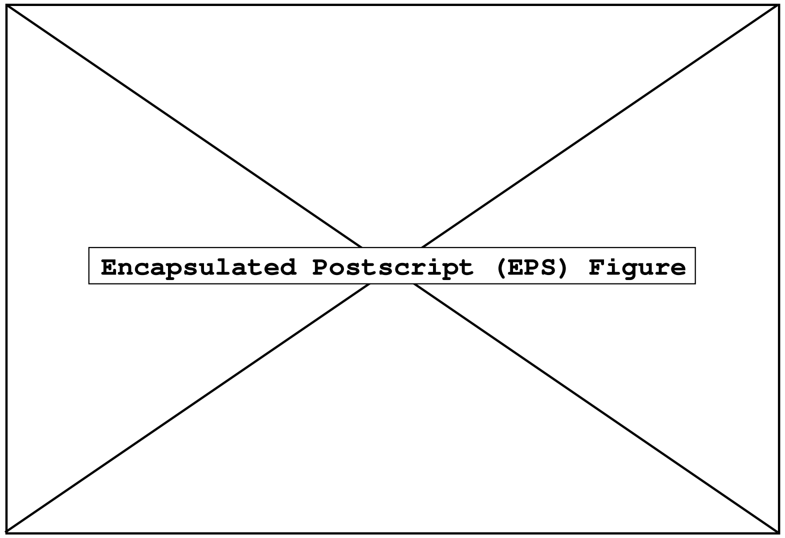
- Lockheed-Martin RLV/X-33 Phase I; aerodynamics
- Lockheed-Martin RLV/X-33 Phase II; Ascent shock interaction study; transonic aerodynamic screening
- McDonnell Douglas Phase I RLV/X-33; control surface loading (NASA CR 201606) and aerodynamics (subsonic $\Rightarrow$ hypersonic)
- OSC X-34, transonic screening, control surface loading

Code to Code Comparisons for Preliminary Lockheed–Martin X-33 Vehicle

- Codes:
  - FELISA_HYP: inviscid, unstructured mesh
  - LAURA: viscous, structured grid
  - DPLUR: inviscid, structured grid, parallel
- Flow feature, surface pressure comparisons:
  - $M_\infty = 9.8$, $\alpha = 40^\circ$
- Aerodynamic force and moment comparisons:
  - $M_\infty = 4.5$, experimental data from LaRC UPWT

X33 Configuration





Code to Code Comparisons for Preliminary Lockheed–Martin X-33 Vehicle

- mention code authors

Grid Generation Time Comparisons

- Initial geometry definition, surface and volume mesh generation for an X-33 configuration, first time $\|$ most recent:
  - FELISA: 1.5 weeks $\|$ 4 days
  - structured: 6 weeks $\|$ 3.5 weeks
- Case-specific grid generation: bow shock spacing: time consuming for FELISA, 1-2 days control surface deflections:
  - 1/2 day for unstructured
  - 1/2 week for LAURA

Grid Generation Time Comparisons

felisa: put together surfaces, intersection curves, topology

laura: build surface on cad

Concluding Remarks

- FELISA_HYP flow solver developed
- Applied FELISA System with FELISA_HYP to complex configurations
  - Comparable accuracy to structured grid solvers
  - Faster turn–around time than structured grid methods
- Significant impact on major NASA programs