Graphs, AI/ML and Adaptivity-based Meshing for Accurate Prediction of Surface Heating in Hypersonic Flow Problems

Aiden Woodruff[1], Sharat Val[1], Mikiel Gica[2], M Arshad Zahangir Chowdhury[2] and Onkar Sahni[2]

[1]Department of Computer Science and
[2]Department of Mechanical, Aerospace, and Nuclear Engineering &
Scientific Computation Research Center
Rensselaer Polytechnic Institute, Troy, NY

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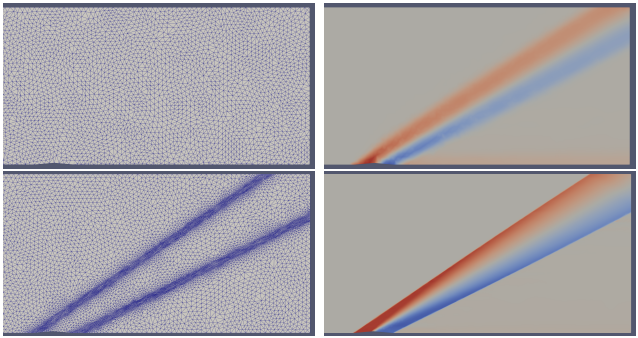
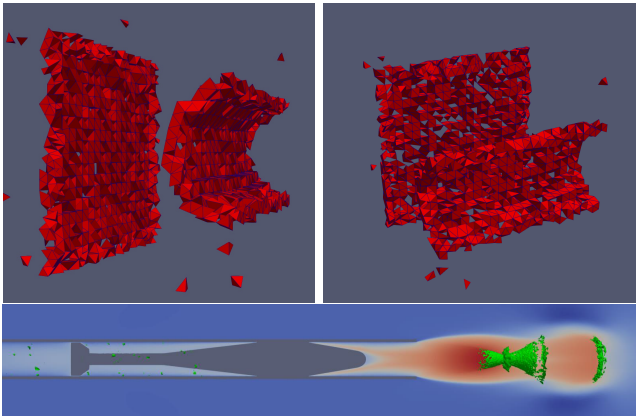
Overall Motivation

- Meshing for solution features (e.g., shocks) improves simulation accuracy
- Information on solution features is required



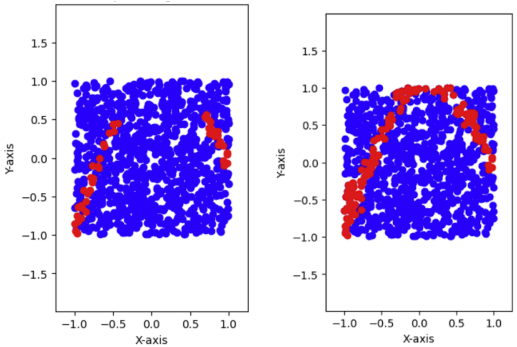
Graph-based Defragmentation Motivation

- Current detectors/sensors produce noisy and fragmented surfaces
- A “cleaner” shock data is needed to adapt the mesh



AI/ML Motivation

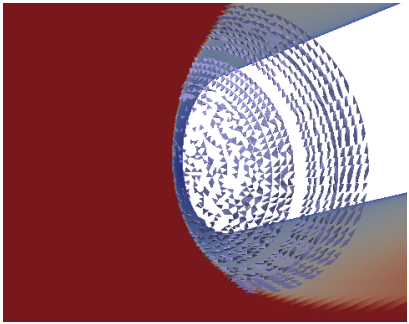
- Use AI/ML to assist with robustness
- Fill in sparse data and/or larger gaps



List of Cases

- First Hypersonic International Flight Research Experimentation (HIFiRE-I): near-nose blunt/bow shock
- Diamond airfoil: external shocks (inviscid)
- Wedge duct: internal shocks (inviscid)
- Crew exploration vehicle (CEV): bow shock (viscous)

HIFiRE-I: Detected Shock Elements

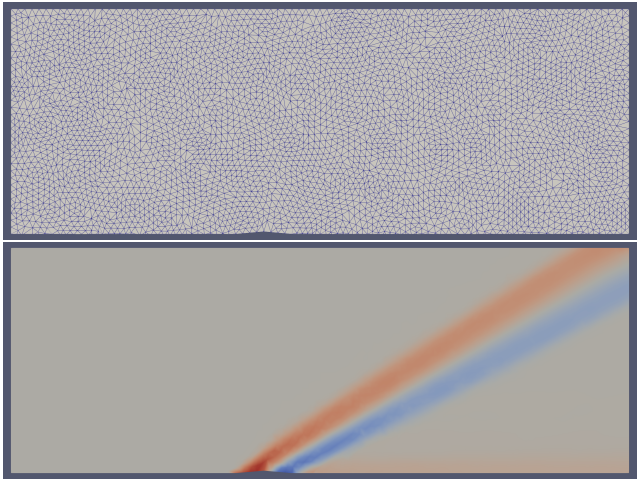


HIFiRE-I case: near-nose shock elements on coarse (initial) mesh

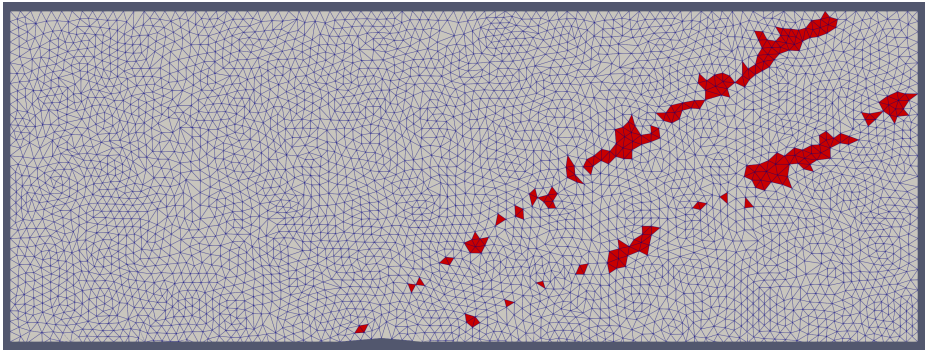
HIFiRE-I: Before and After Defragmentation

Shock elements for the HIFiRE-I case on coarse mesh: original detection (left) and after defragmentation (right)

Diamond Airfoil: Coarse Mesh and Computed Result

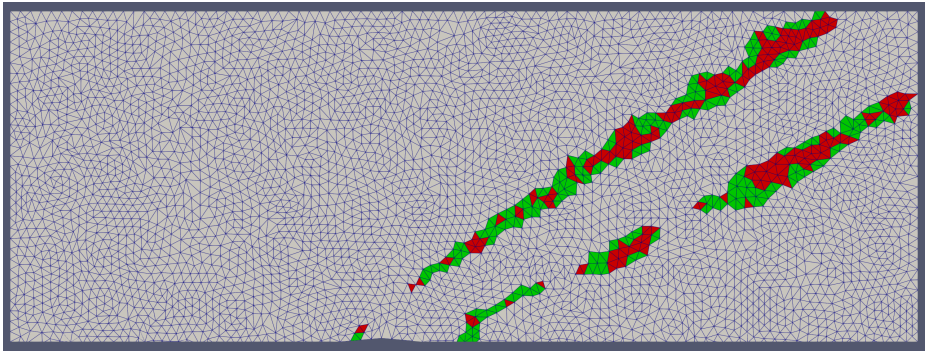


Diamond Airfoil: Detected Shock Elements



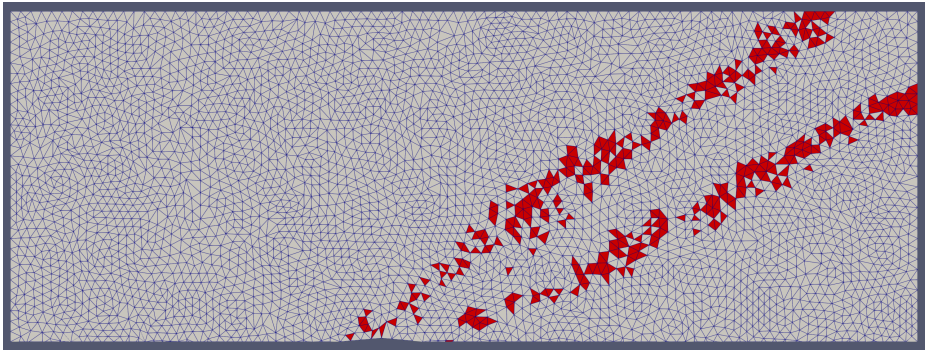
Originally detected shock elements (red) for diamond airfoil on coarse mesh

Diamond Airfoil: Defragmentation without ML



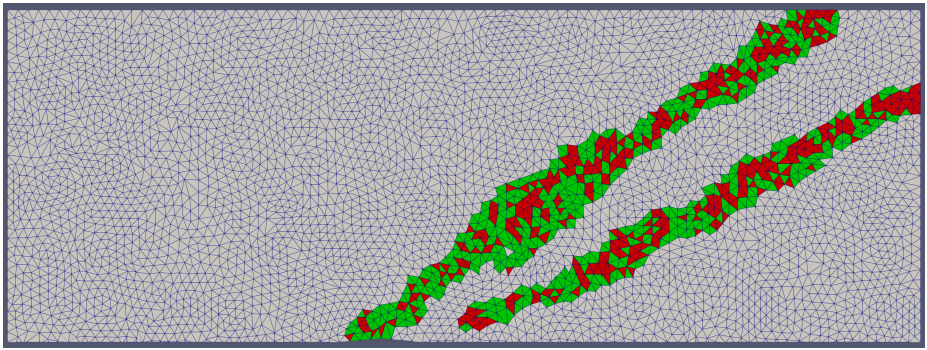
Originally detected (red) and after defragmentation (green) shock elements for diamond airfoil on coarse mesh

Diamond Airfoil: Detected Shock Elements with ML



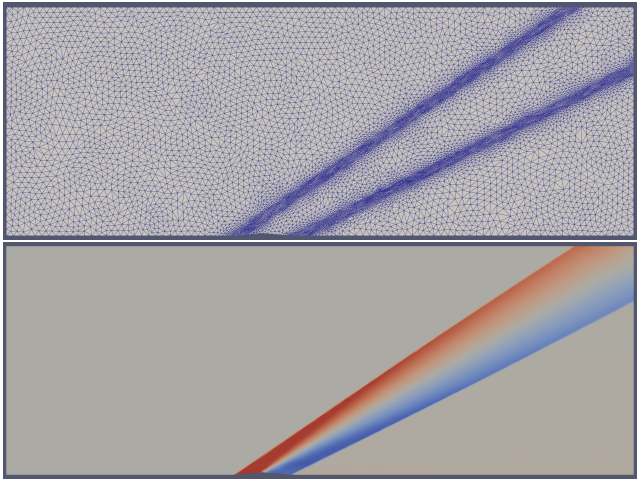
Post ML shock elements for diamond airfoil on coarse mesh

Diamond Airfoil: Combination of ML and Defragmentation

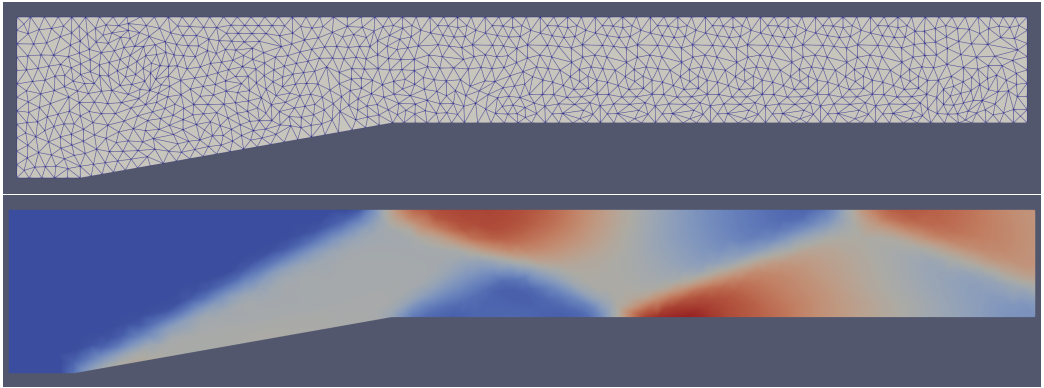


Post ML (red) and after defragmentation (green) shock elements for diamond airfoil on coarse mesh

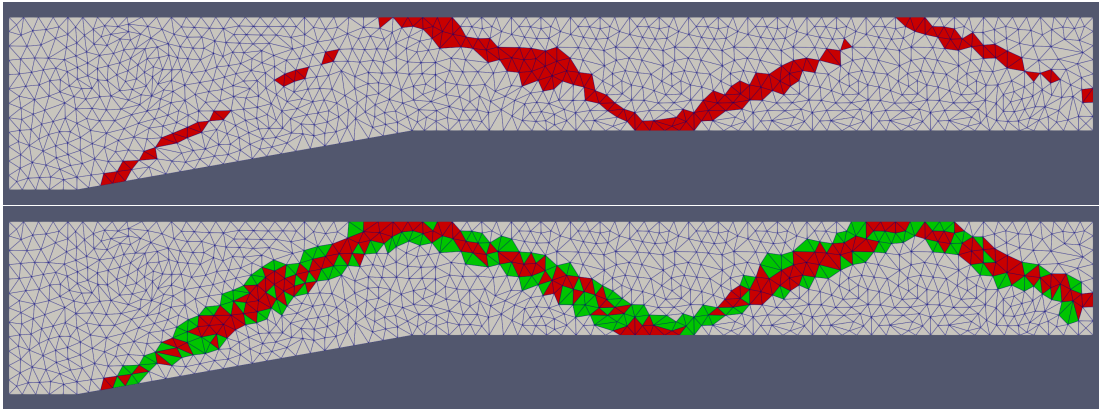
Diamond airfoil: Shock-adapted Mesh and Computed Result



Wedge Duct: Coarse Mesh and Computed Result

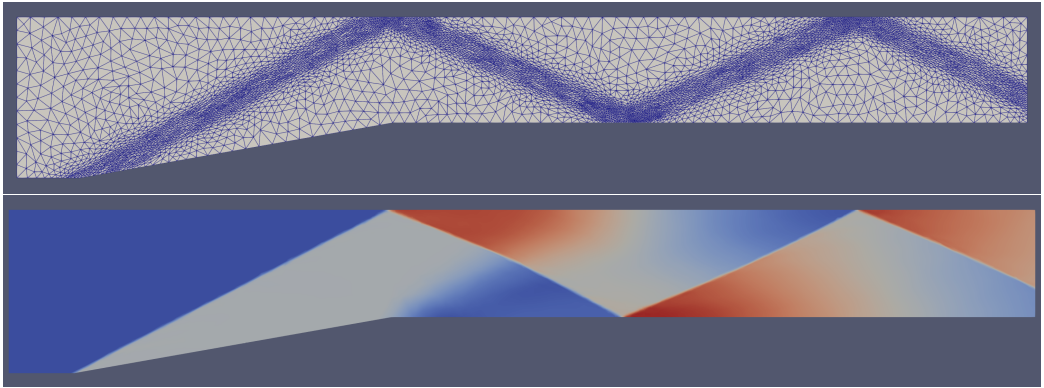


Wedge Duct: Detected Shock Elements



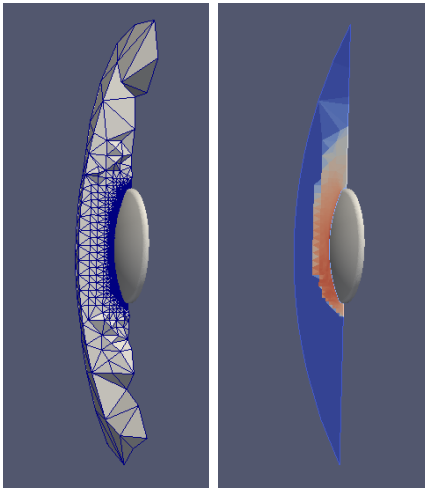
Originally detected (top) and after applying combination of ML and defragmentation (bottom) shock elements for wedge duct on coarse mesh

Wedge Duct: Shock-adapted Mesh and Computed Result



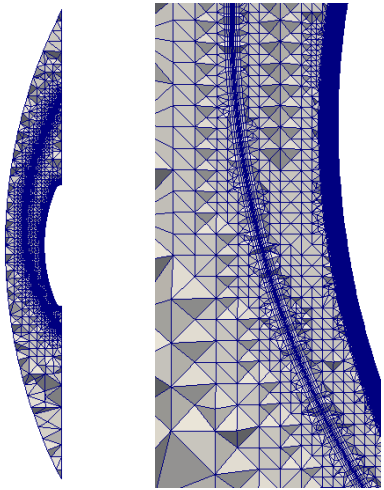
CEV: Coarse Mesh

Mesh (left) and temperature (right) for CEV case on coarse mesh

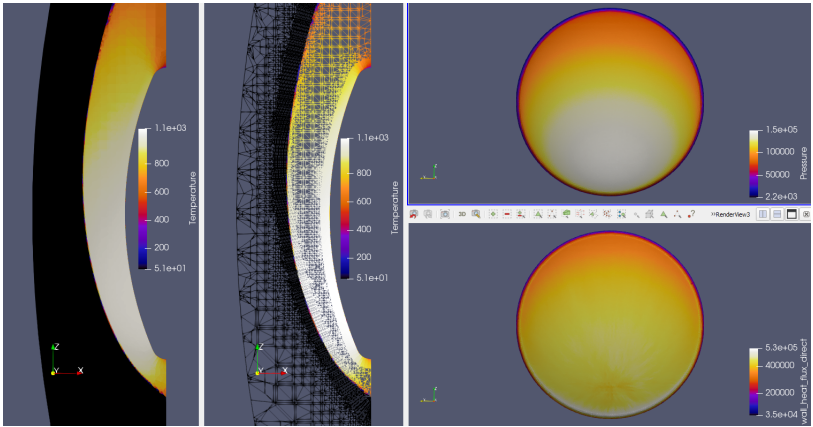


CEV: Shock-fitted Mesh

Shock-fitted mesh: full view (left) and zoomed view (right)



CEV: Shock-fitted Mesh and Computed Result



Solution for CEV on shock-fitted mesh

Closing Remarks and Acknowledgments

Summary:

- AI/ML is used to infer missing shock elements
- Graph-based defragmentation connects originally detected and ML-inferred shock elements
- Adaptive meshing informed by this shock detection/processing provides accurate predictions

Acknowledgments:

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References

More details can be found in the following conference papers:


Sahni, Onkar et al. (Jan. 3, 2025). "AI/ML-Assited Robust Shock Processing for CFD Applications". In: *AIAA SCITECH 2025 Forum*. AIAA SciTech Forum. American Institute of Aeronautics and Astronautics. DOI: 10.2514/6.2025-0699. URL: https://arc.aiaa.org/doi/10.2514/6.2025-0699.


Woodruff, Aiden and Onkar Sahni (Jan. 3, 2025). "Robust and Automatic Shock Detection and Processing in High-Speed Flow Simulations". In: *AIAA SCITECH 2025 Forum*. AIAA SciTech Forum. American Institute of Aeronautics and Astronautics. DOI: 10.2514/6.2025-0916. URL: https://arc.aiaa.org/doi/10.2514/6.2025-0916.