

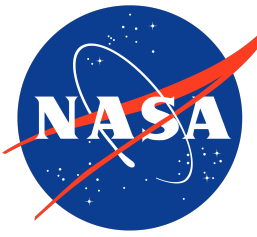
Toward an Automated Unstructured-Grid Adaptation Workflow with VULCAN-CFD

Matthew O'Connell, Jeffery White, Kyle B. Thompson

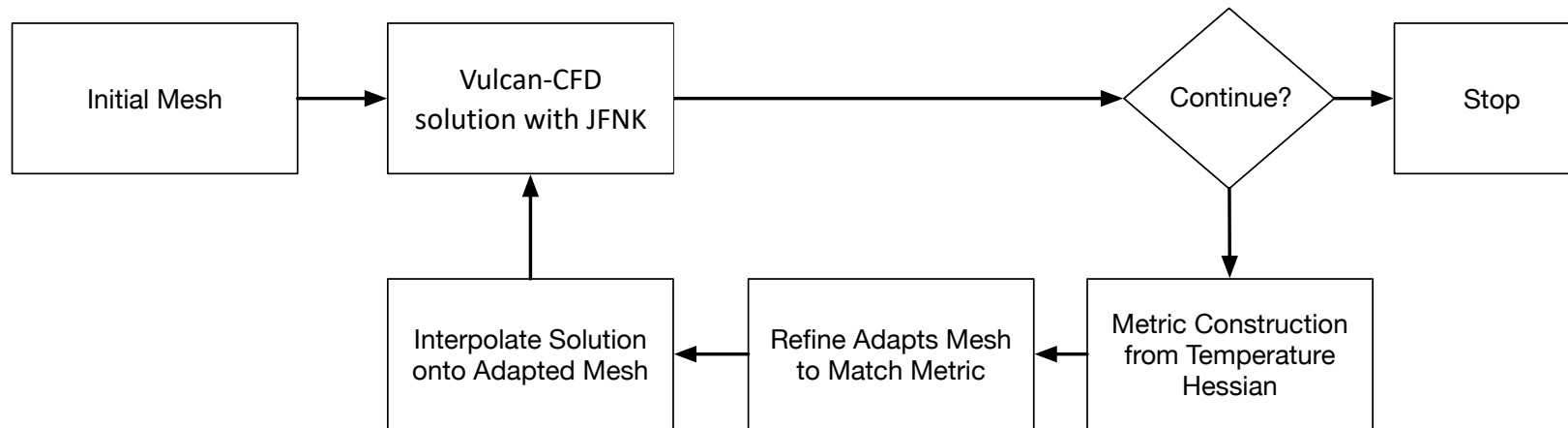
NASA Langley Research Center

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Goal: Automatic CFD solutions for hypersonics

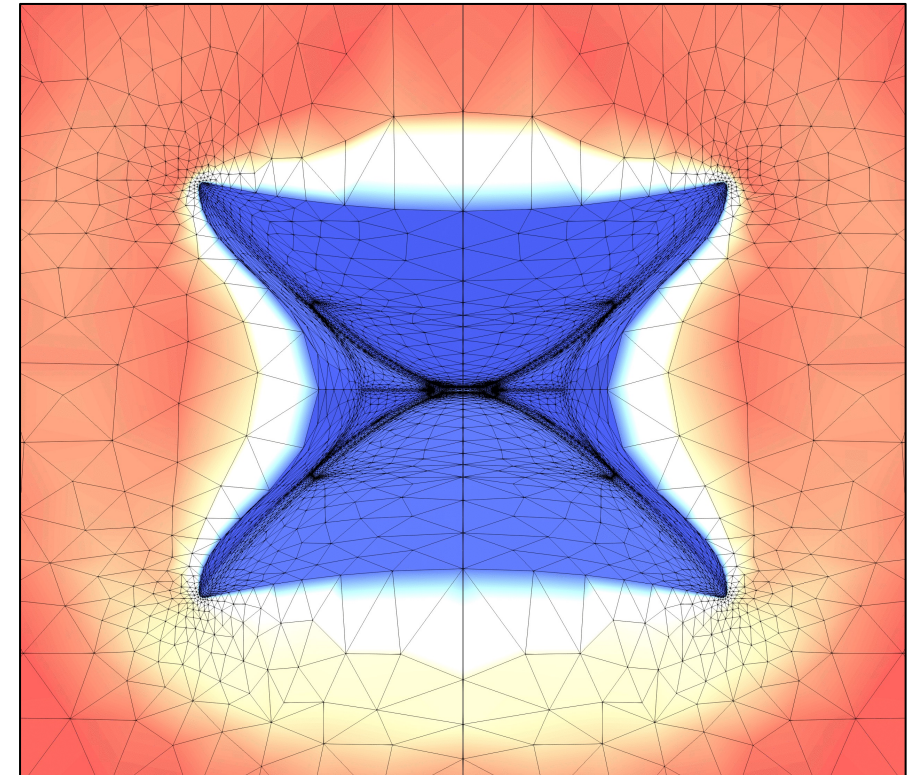


- Start with geometry. (EGADS)
- Automatically generate an unstructured grid. (Tetgen + *refine*)
- Automatically obtain a flow solution. (VULCAN-CFD)
- Estimate interpolation error via Hessian reconstruction of a sensor field (Mach number, or static temperature).
- Adapt to control interpolation error. (*refine*)
- Automatically obtain a new flow solution (VULCAN-CFD).
- Repeat.

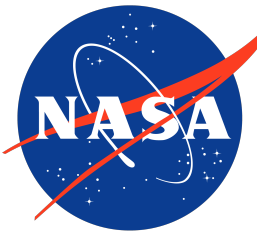


Adaptation begs for automation

- With an unstructured adaptation workflow the solver will be asked to solve an order of magnitude more grids than “bespoke” grid workflow.
- Cost of human-in-the-loop decisions are on a per-grid basis.
 - CFL schedule
 - Limiter freezing schedule
- Recent experience has shown that highly adapted anisotropic grids are challenging to solve.
- Increased solver robustness and automation is highly desired.



BOLT outflow plane (see paper)



Increasing VULCAN-CFD automation with Jacobian-Free Newton-Krylov (JFNK)

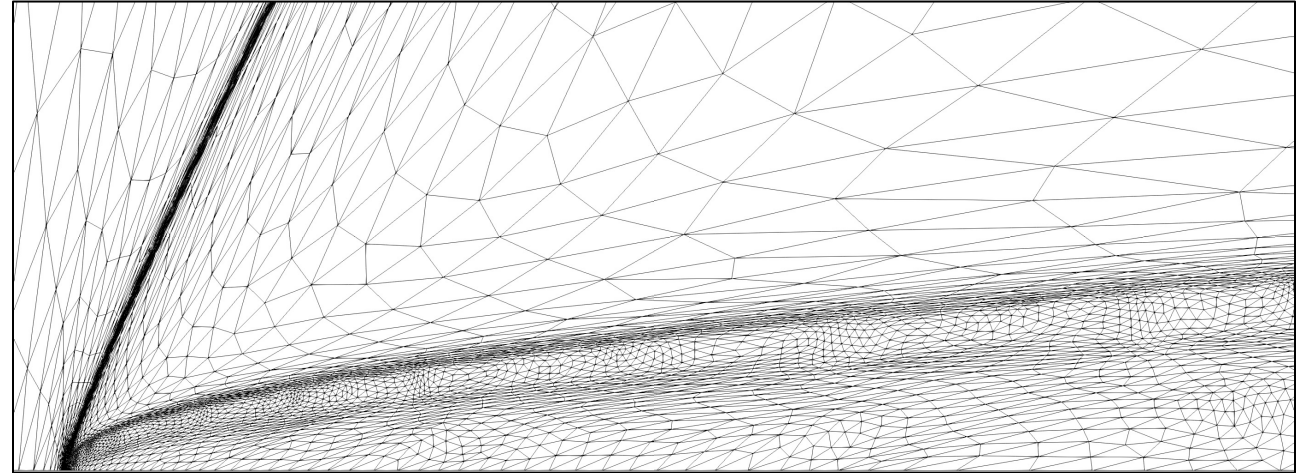
- Integrated a JFNK scheme into VULCAN-CFD using Enigma + PETSc.
- Existing first-order Jacobians (hand coded or automatic differentiated) are used as a preconditioner.
- Matrix-free GMRES is used to solve the linearized problem with the influence of accurate Jacobians via Frechet derivatives.
- Additional robustness and automation from:
 - A nonlinear line search
 - An automated CFL controller (details in the paper)
 - A checkpoint / recovery process that can recover from unexpectedly poor steps (e.g., NaN in boundary conditions).



2D flat plate Mach 6.0 Re 26.4 million

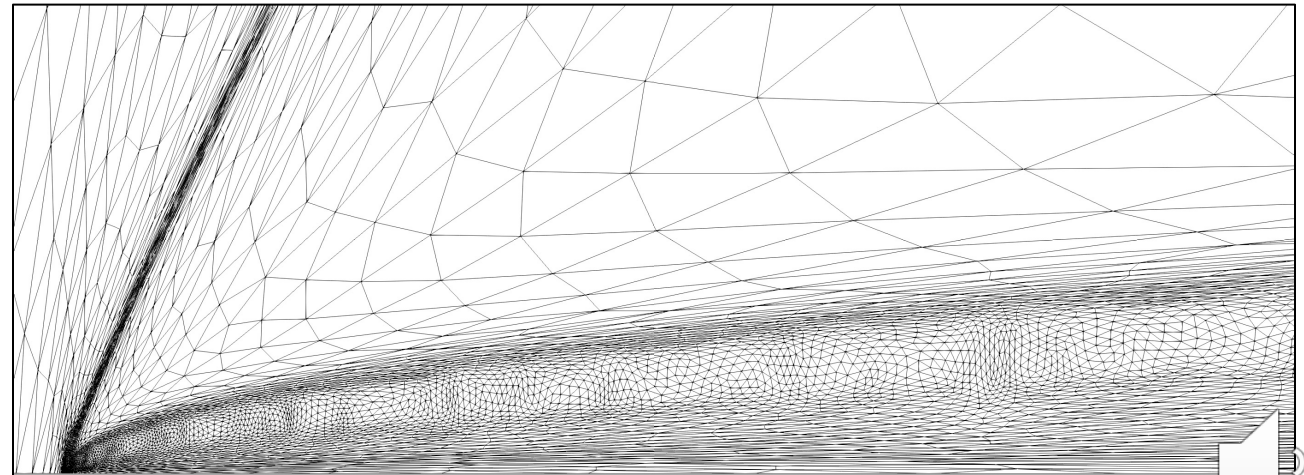
- Hot isothermal wall temperature 335.83 K.
- Inflow static temperature 63.01K.
- Mach sensor very sensitive to the oblique shock.
- Static temperature sensor captures the shock but also the boundary layer.
- Final grids consist of 170k triangles.

10x



Final mesh with Mach number as sensor

10x

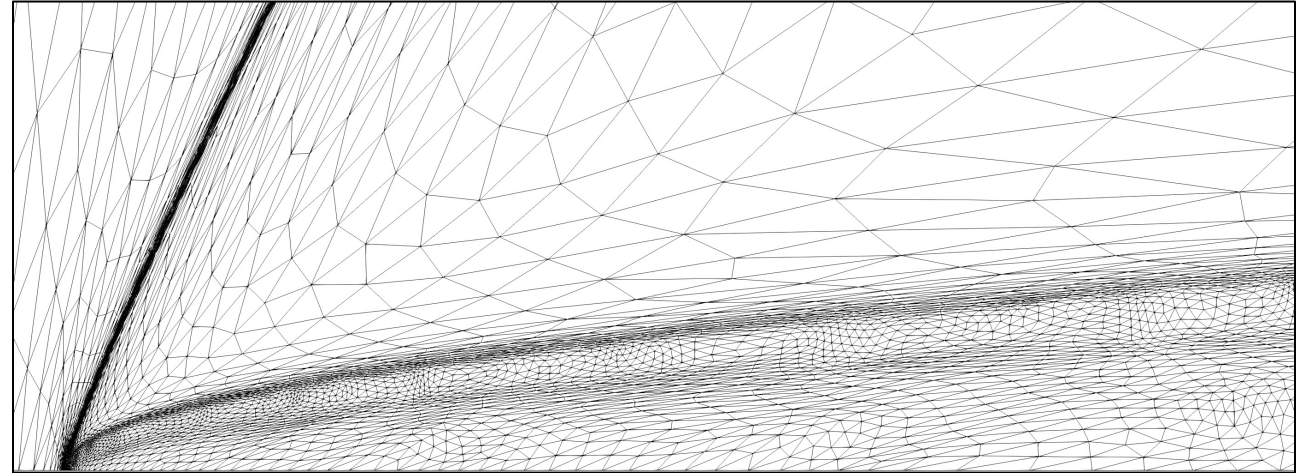


Final mesh with static temperature as sensor

2D flat plate Mach 6.0 Re 26.4 million

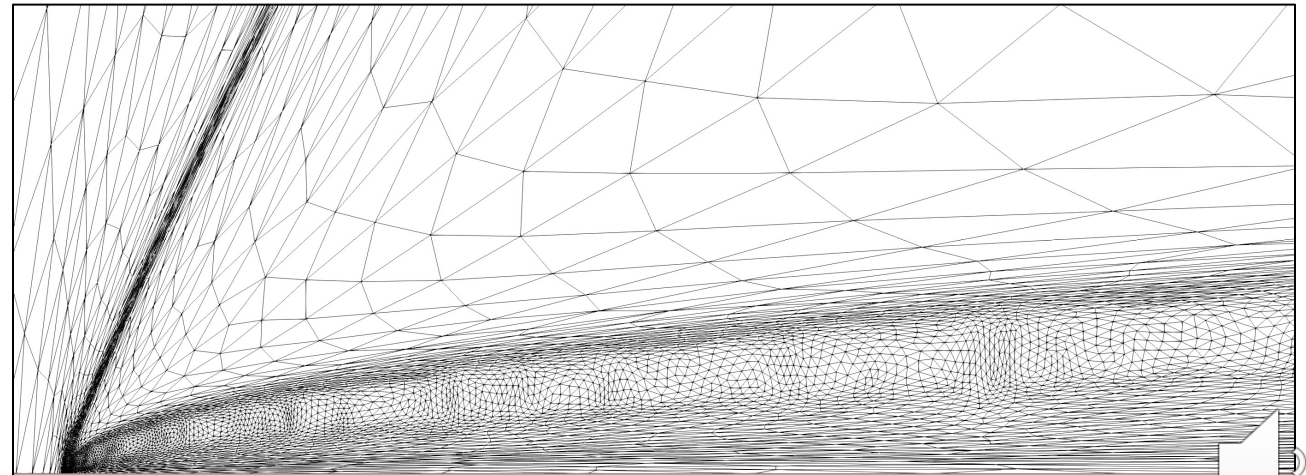
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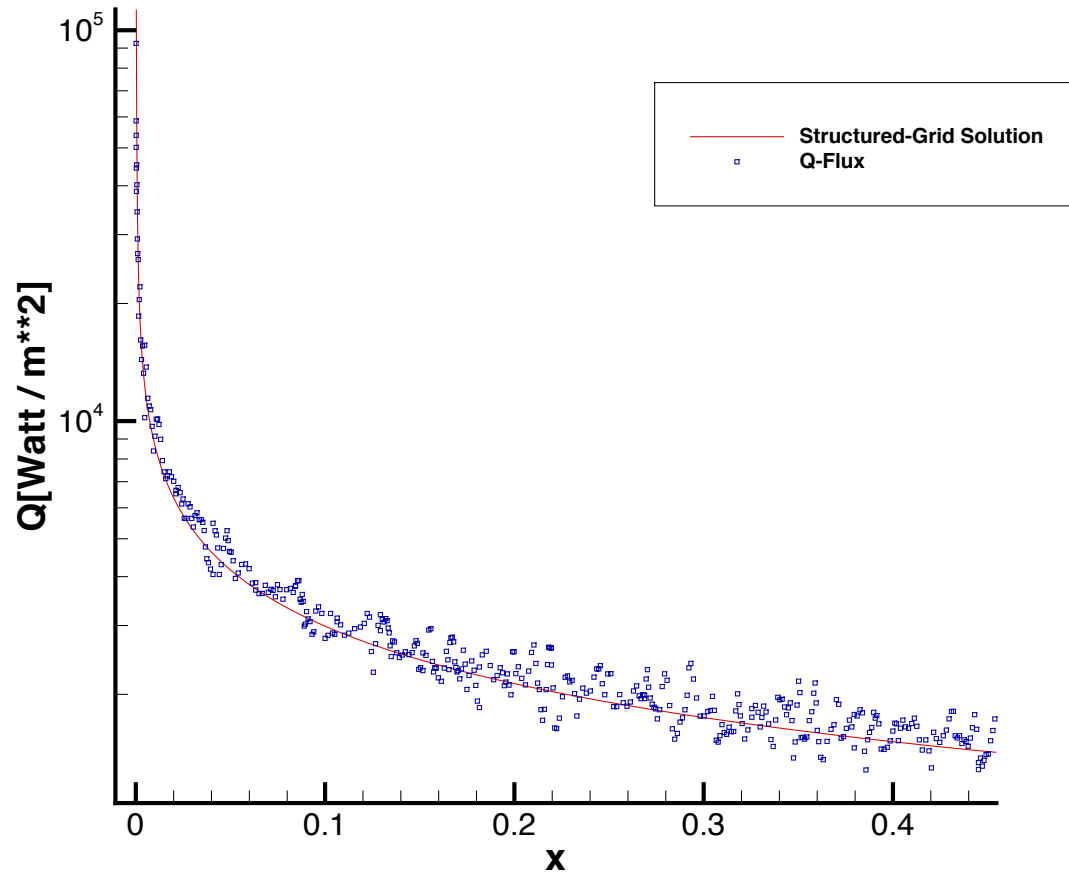
10x



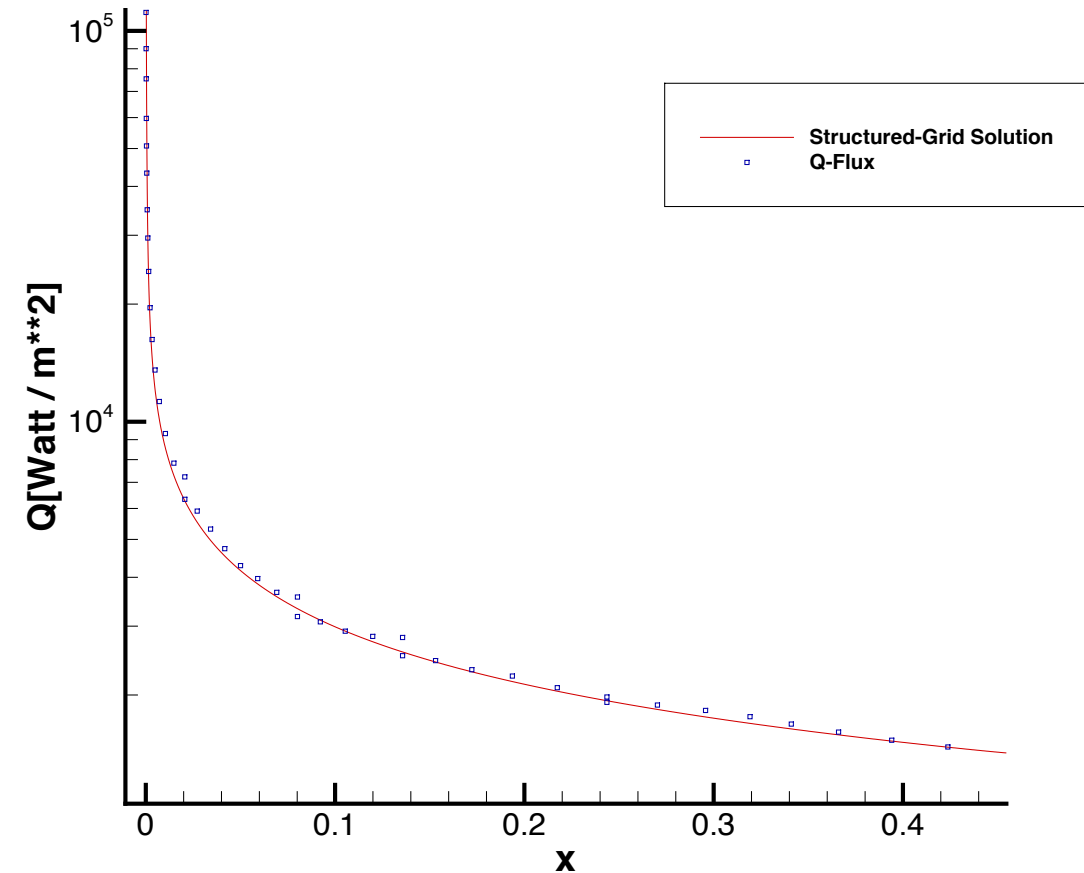
Final mesh with static temperature as sensor



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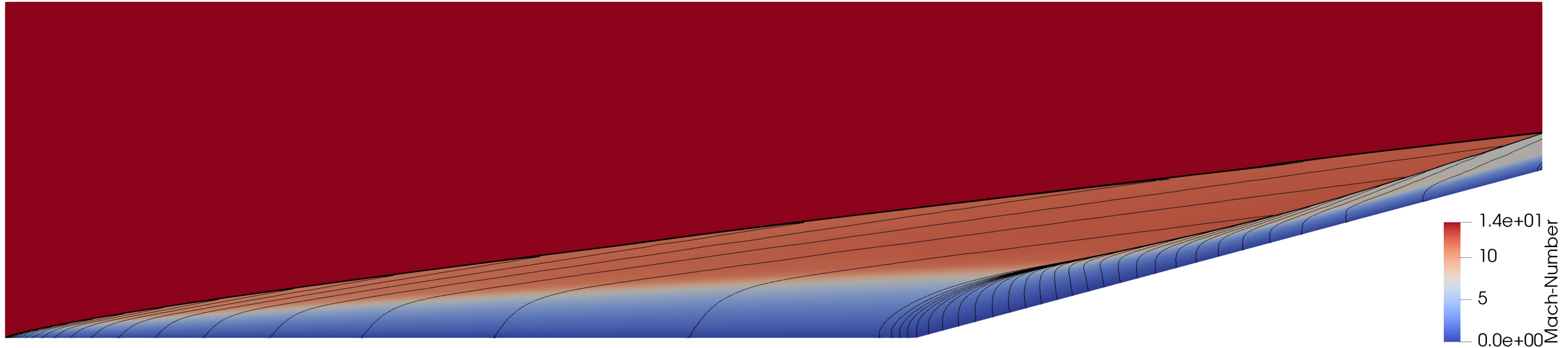


Final mesh with Mach number as sensor

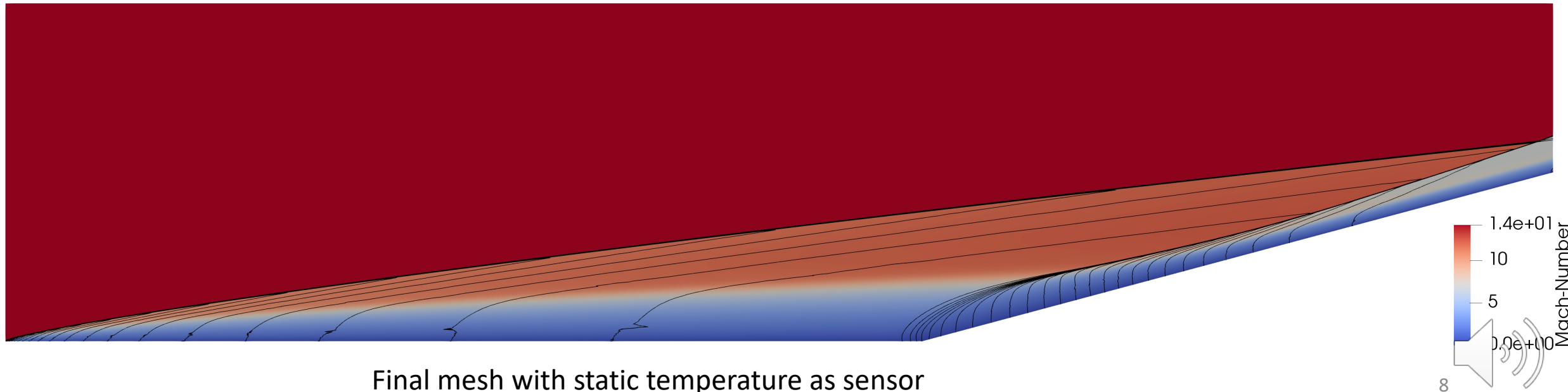


Final mesh with static temperature as sensor

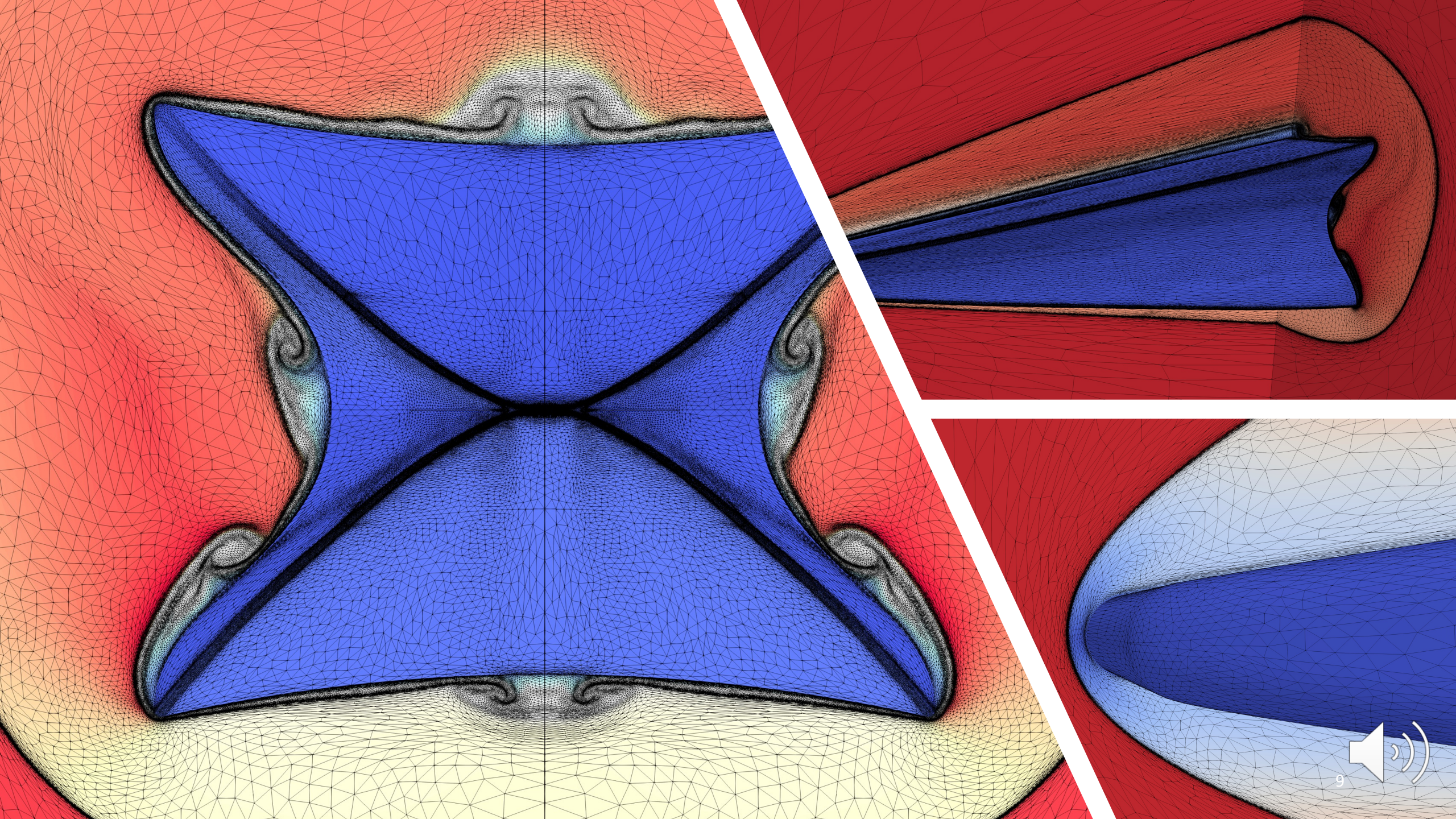
2D compression corner Mach 14.1 Re 0.104 million

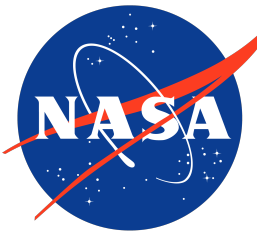


Final mesh with Mach number as sensor



Final mesh with static temperature as sensor

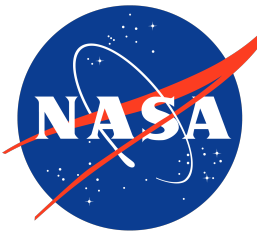




Summary

- Automatic hypersonic CFD solutions is the goal.
- Simplex unstructured mesh adaptation can now be preformed with VULCAN and *refine*.
- A new JFNK nonlinear solver has been integrated to VULCAN that improves automation.
- Mach number and static temperature were compared on example flows with hot isothermal walls.
- Mach number yielded smoother pressure contours, while static temperature produced more accurate wall heat flux.



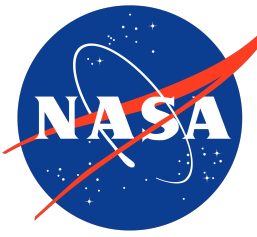


Future work

- Routinely obtaining deep nonlinear convergence is still a challenge, particularly at finer mesh resolutions.
 - JFNK works well on coarse meshes, but convergence degrades as the mesh is refined.
 - Convergence degradation is likely influenced by multiple causes:
 - Limiters
 - Boundary conditions
 - Nonlinear stiffness from shocks.
- Choice of sensor field.
 - Does static temperature continue to work well for cold isothermal walls?
 - How to handle adiabatic walls?
 - The pressure field is not well correlated with static temperature.
 - Metric intersection of multiple sensor fields could help address some of these challenges.

Thank you Mike Park, Hiro Nishikawa, and Rob Baurle for additional technical support and to the NASA Hypersonic Technology Project for funding this work.

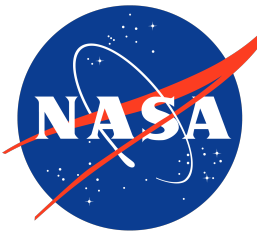




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Acknowledgements

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- We would like to thanks Mike Park, Hiro Nishikawa, and Rob Baurle for additional research and technical support.