Overset Techniques for Hypersonic Multibody Configurations with the DPLR Solver

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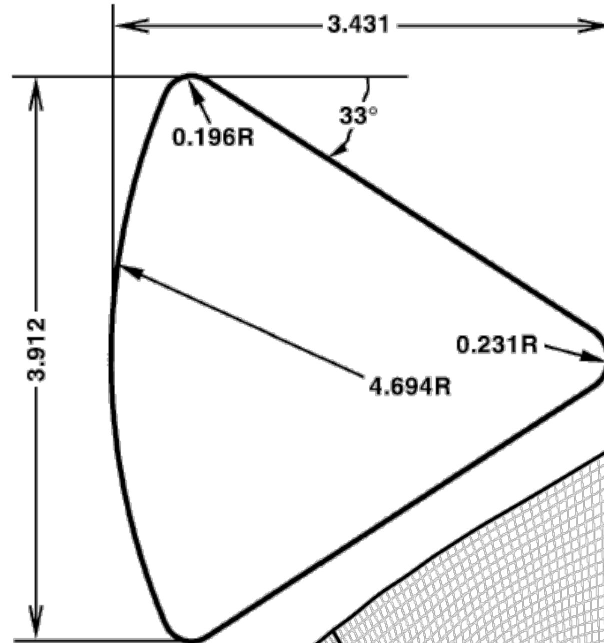
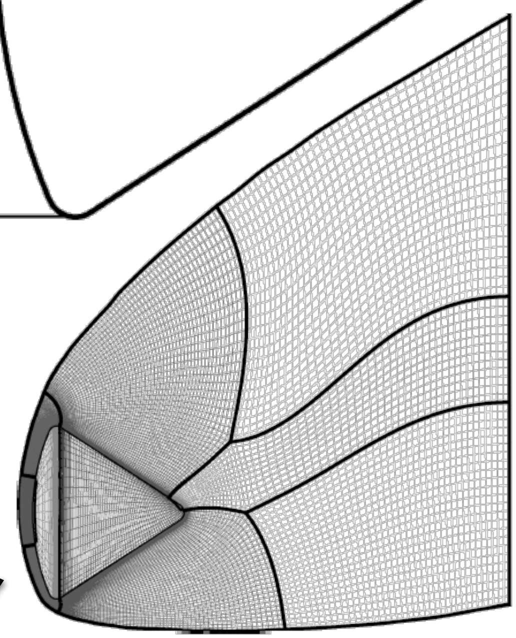
Outline

- Background
- Geometry / Flow Conditions
- Overset grid development process
- Results
- Conclusions

Background (DPLR)

- Data Parallel Line Relaxation (DPLR)
  - Three dimensional Navier-Stokes solver
  - Thermal and chemical non-equilibrium
  - Structured grids (block zonal)
- Standard grid development
  - **Primarily interested in accurate heat transfer for Thermal Protection System (TPS) sizing**
  - Simple geometry
    - Simple geometric shapes define body
    - Rotate about a singular axis
    - Replace topological singularity with a non-singular patch
  - Hyperbolically extruded grid is tailored to the shock as part of the solution process
    - Built in grid tailoring routine within DPLR



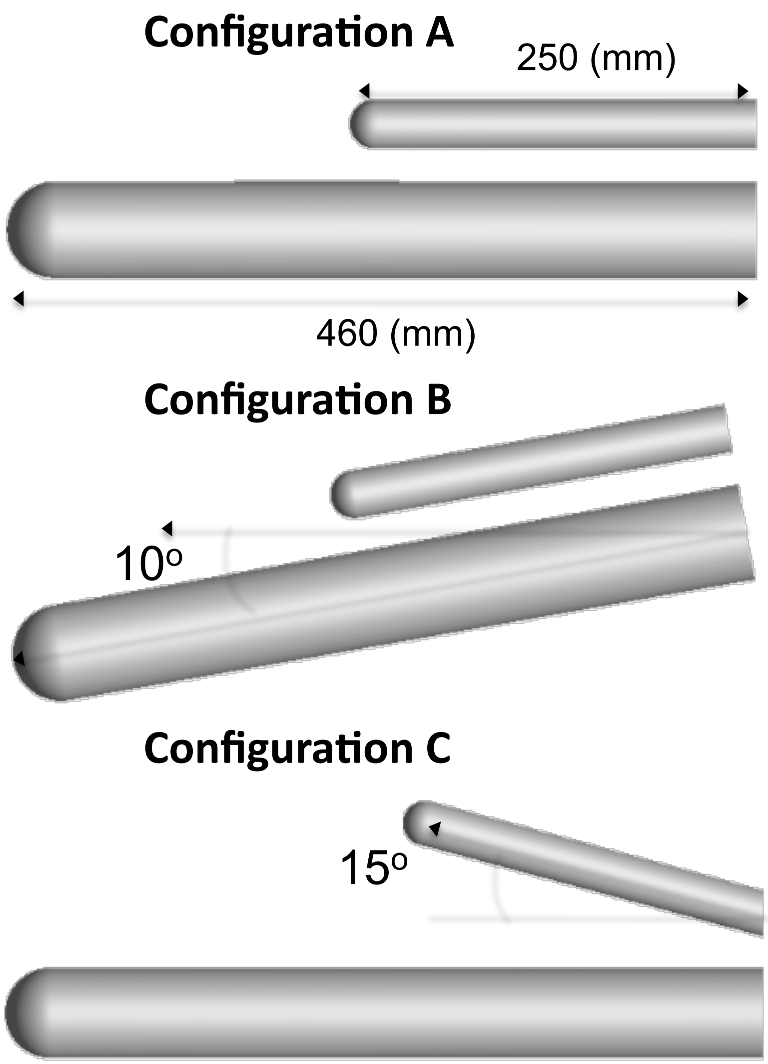


Wright, M., Prabhu, D., and Martinez, E., “Analysis of Apollo Command Module Afterbody Heating Part I: AS-202”, Journal of Thermophysics and Heat Transfer, Vol. 20, No. 1, 2006

Background

- In 2007 the overset capability was added to DPLR
  - DiRTlib (Noack – AIAA-2005-5116)
- Two Stage To Orbit (TSTO) investigation made a perfect test case for the “new” overset capability
  - Complicated geometry (winglets, engine inlet)
  - Scramjet (Tip-to-Tail analysis)
  - Stage separation
- Simplified TSTO geometry utilized as a proof of concept
  - Overset capability was evaluated by comparing to point-matched grid solutions which have been the standard with DPLR

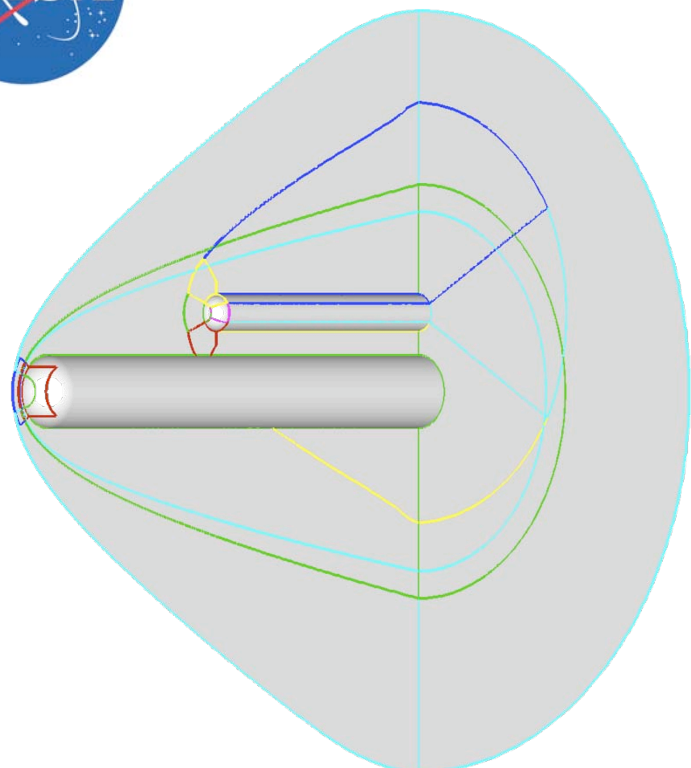
Geometry and Configuration

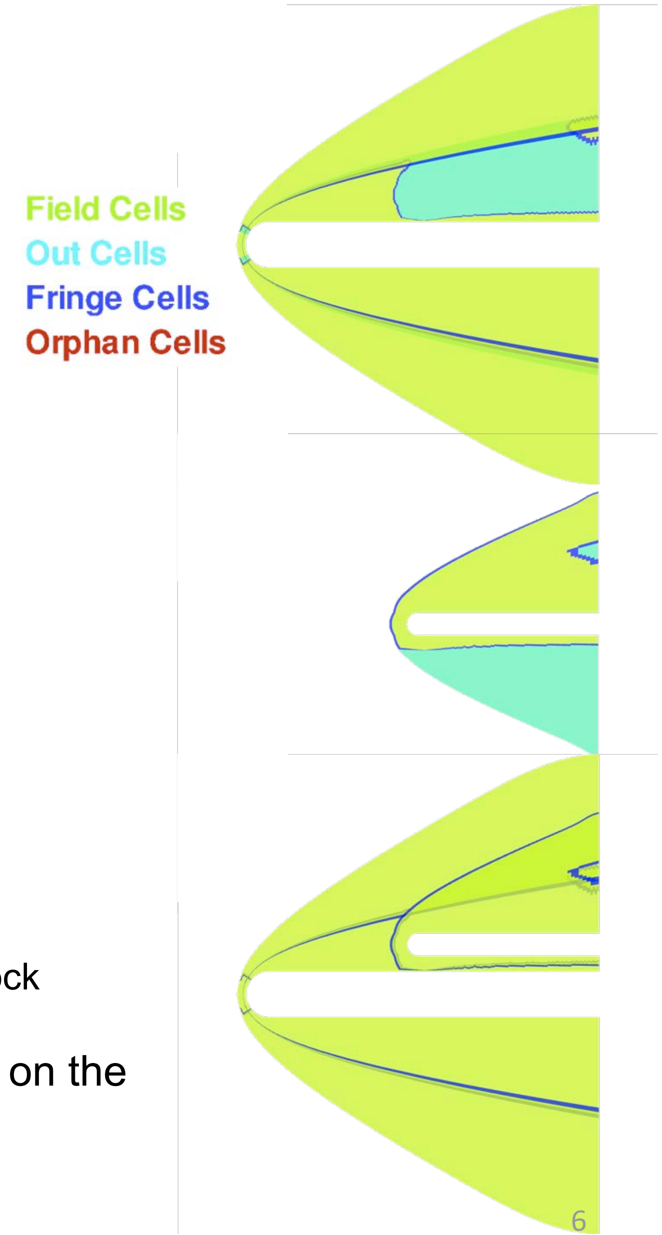


- The geometry considered is from the previous study by Yamamoto et al. (AIAA-2002-0217)
- Flow Conditions
  - Test gas was air
  - **Mach = 9.56**
- Modeling Assumptions
  - Laminar
  - Perfect Air ($\gamma = 1.4$)
  - Park 90 5-species Air

Overset Grid Topology

Configuration A



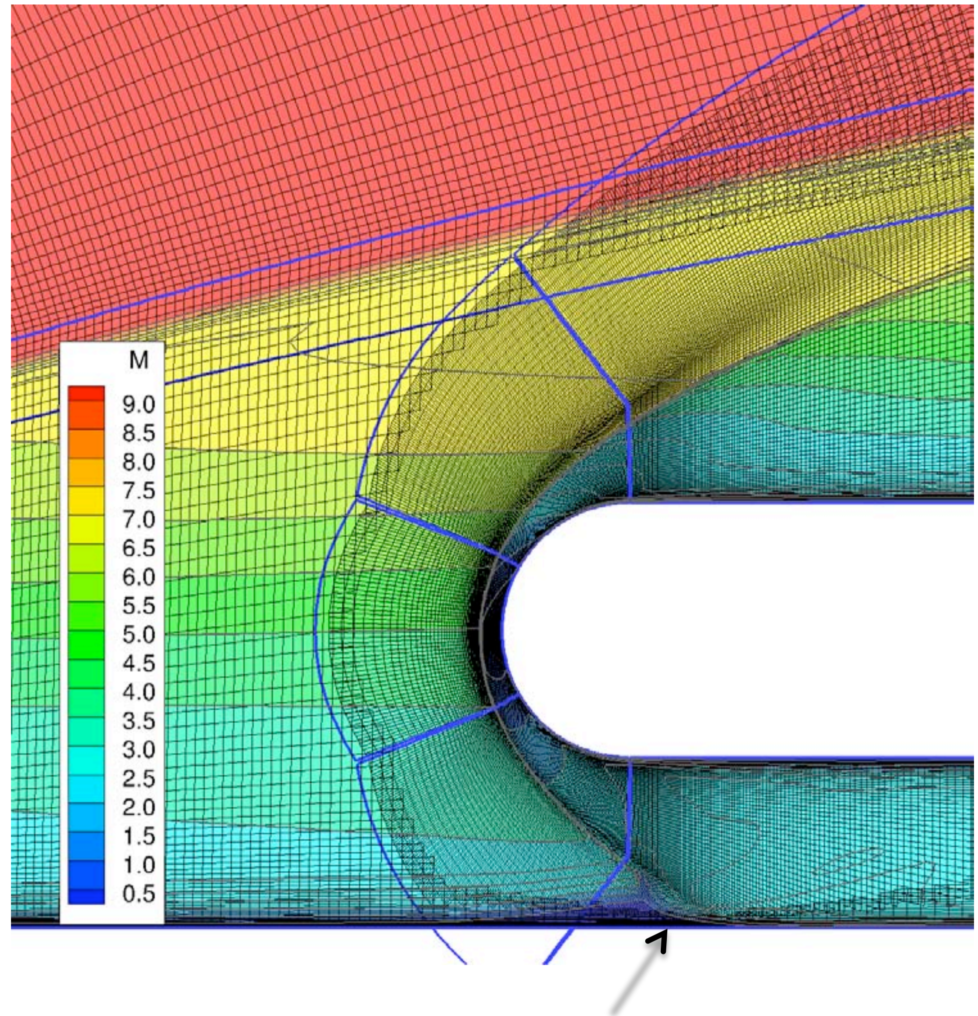


- Independently shock tailored grid for each cylinder
- Extra overlap region
  - Help match cell sizes at overset boundaries
  - Push the overset boundary out from the discontinuity at the shock
  - Fully contains the overset boundaries
- Overset nose patch used to remove the topology singularity on the lower cylinder
- No orphans at the outer boundary

Overset Boundary Between Bodies

Configuration A

- Shock tailored grid
  - Lower cylinder tailored grid
  - Upper cylinder tailored grid
  - Location of the upper cylinder shock
  - Overset boundary outside of the upper cylinder shock
- Shock / Boundary Layer Interaction

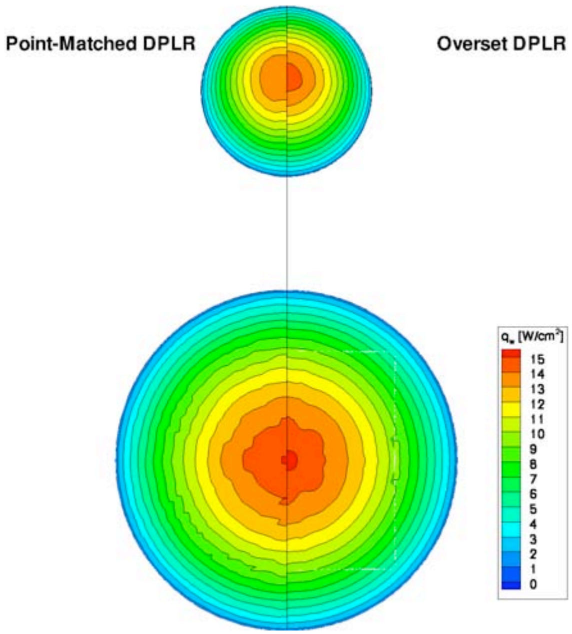


Shock / Boundary Layer Interaction

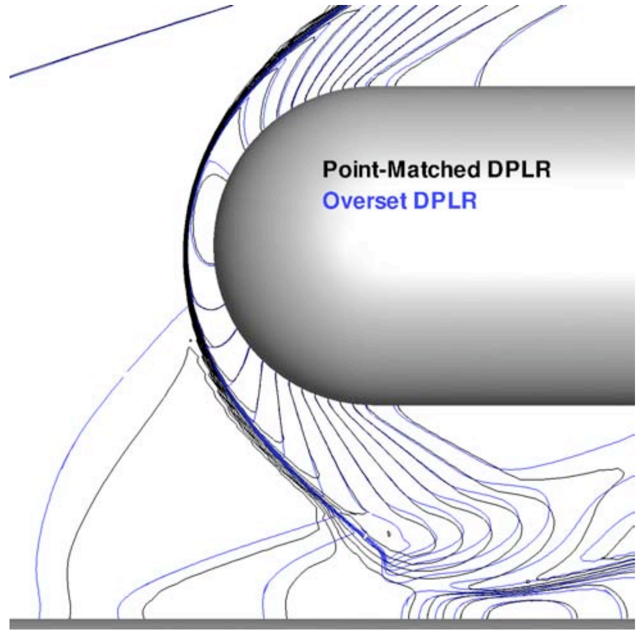
Overset Evaluation

Configuration A

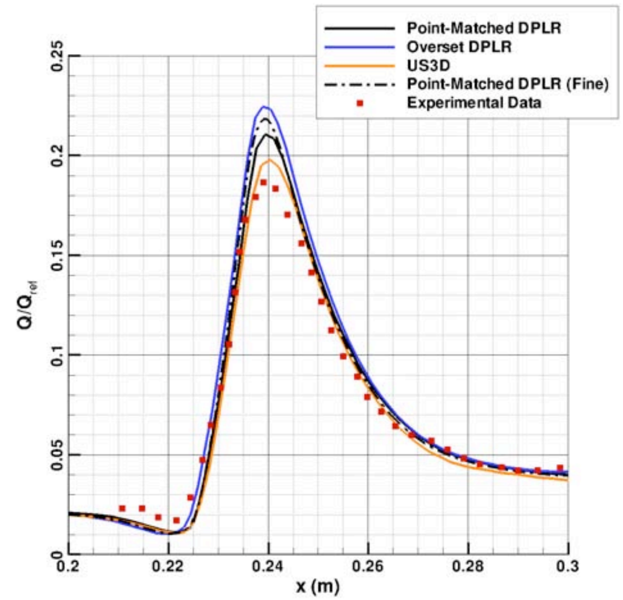
Heat Flux Contours



Contour Lines of Pressure

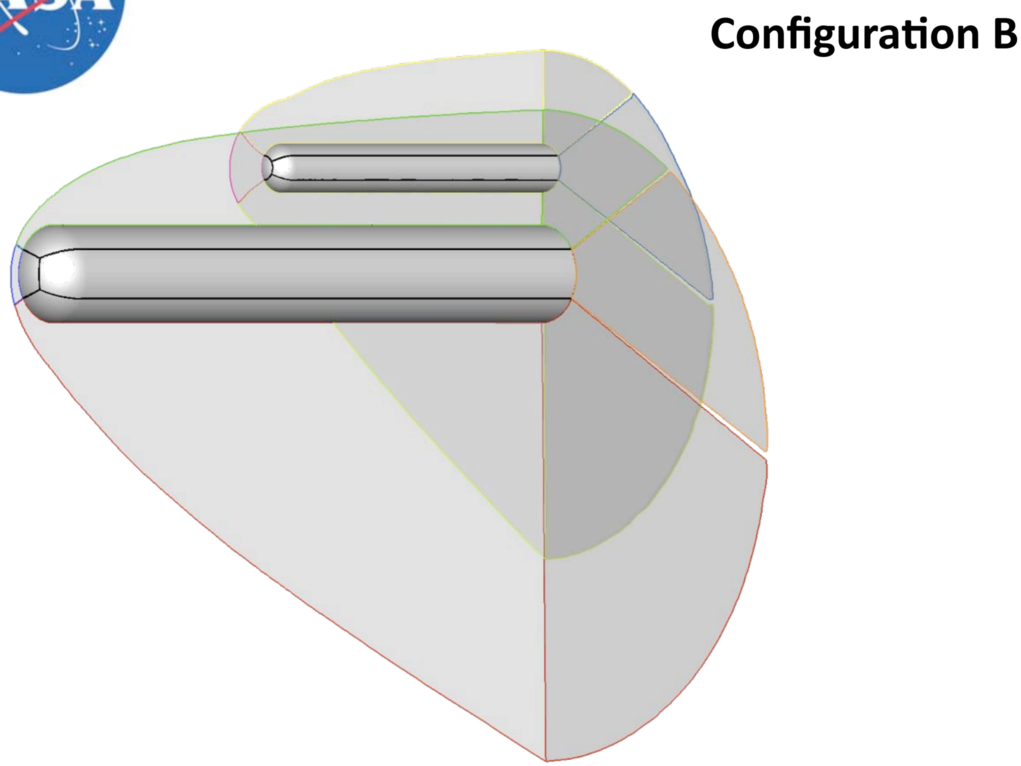


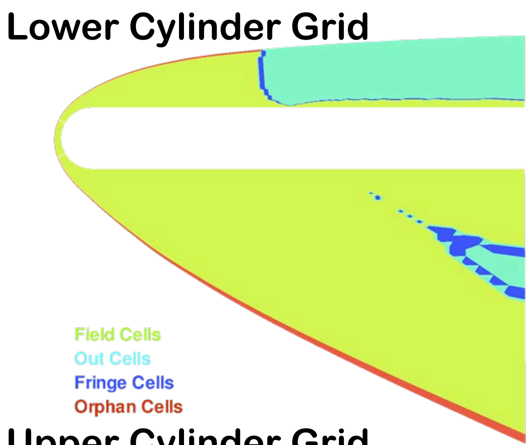
Shock Impingement Heating

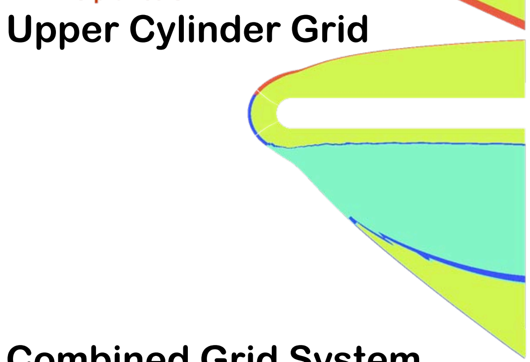


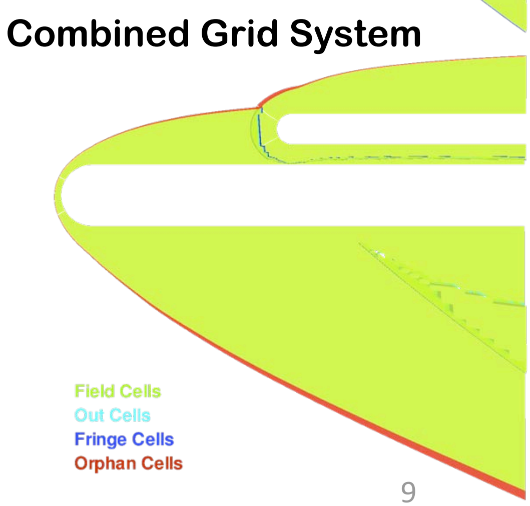
- Excellent agreement in heat flux contours
- Contour lines of pressure appear slightly more diffuse in point-matched solution
- Excellent agreement in shock impingement heating level

Overset Grid Topology







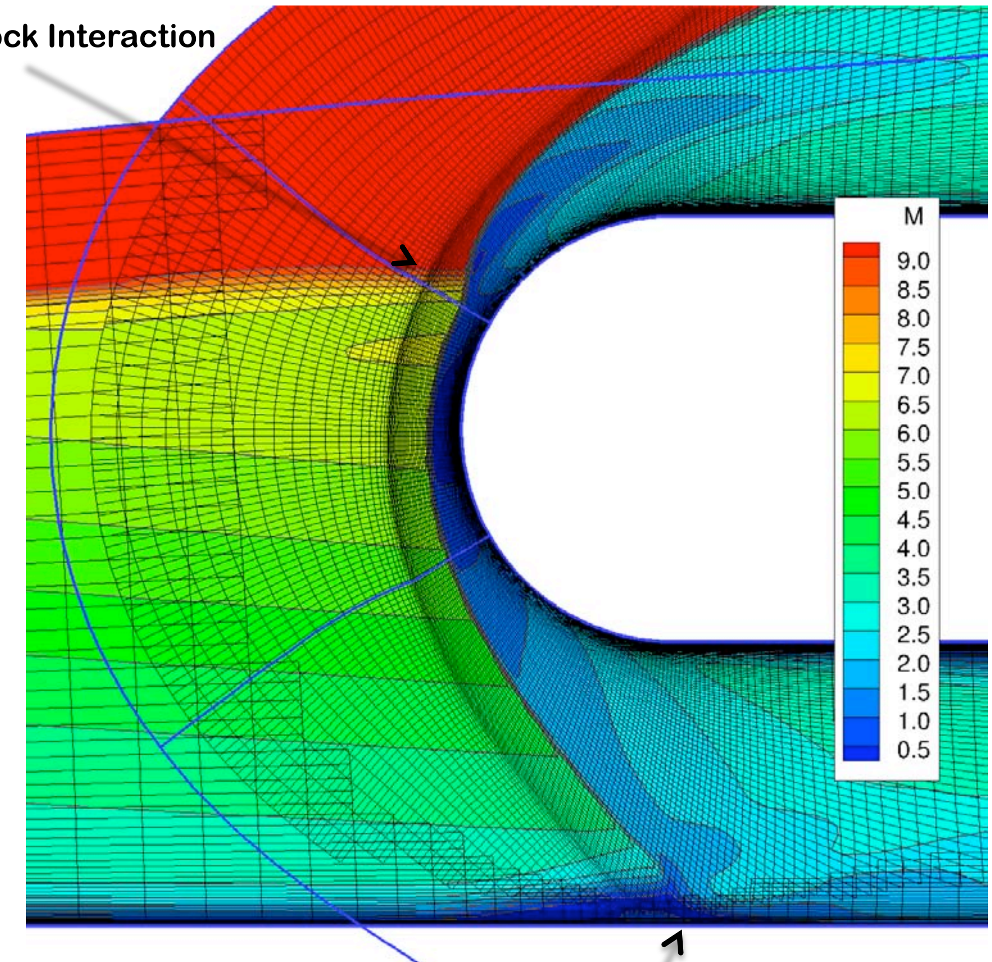


- Independently shock tailored grid for each cylinder
- Extra overlap region (upper cylinder only)
  - Help match cell sizes at overset boundaries
  - Push the overset boundary out from the discontinuity at the shock
- Orphan cells at outer boundary

Overset Boundary Between Bodies

Configuration B

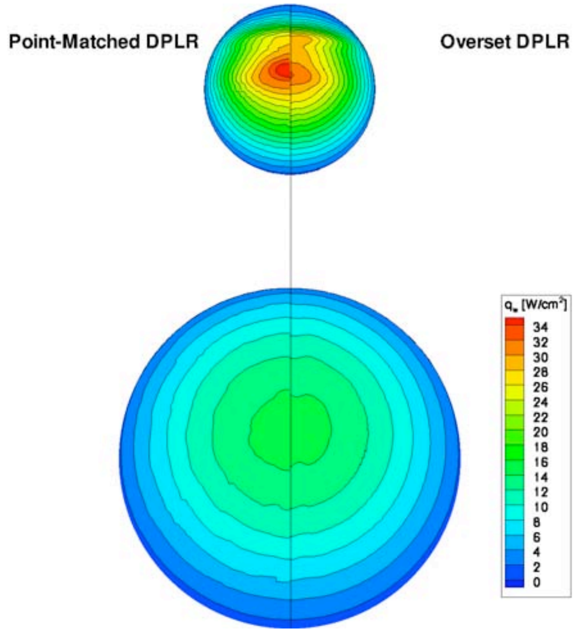
- Shock tailored grid
  - Lower cylinder tailored grid
  - Upper cylinder tailored grid
  - Location of the upper cylinder shock
  - Overset boundary outside of the upper cylinder shock
- Shock / Boundary Layer Interaction
- Shock / Shock Interaction



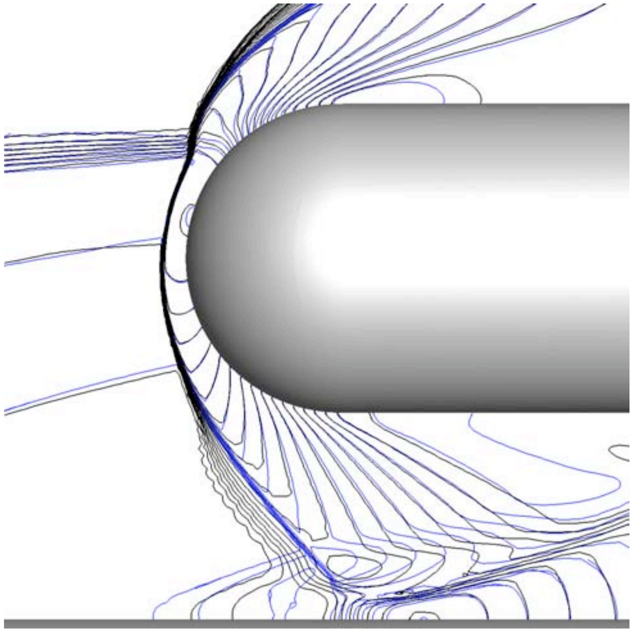
Overset Evaluation

Configuration B

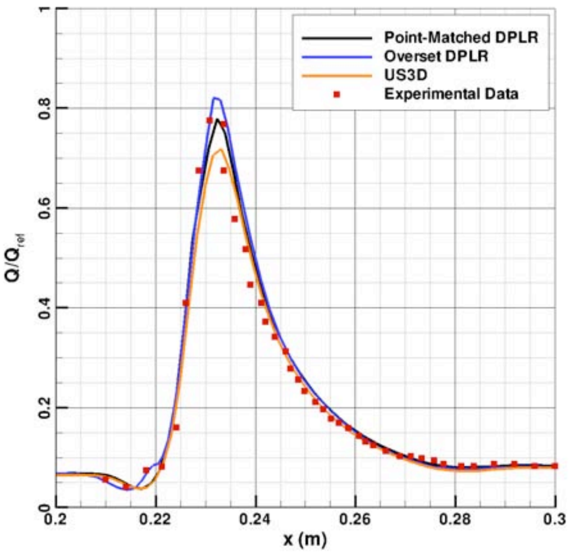
Heat Flux Contours



Contour Lines of Pressure

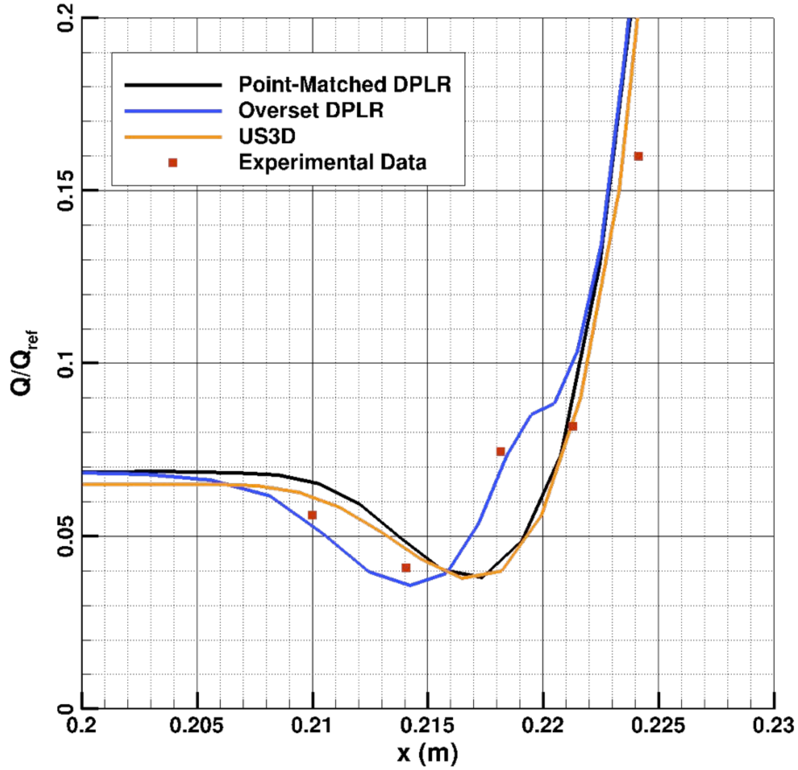


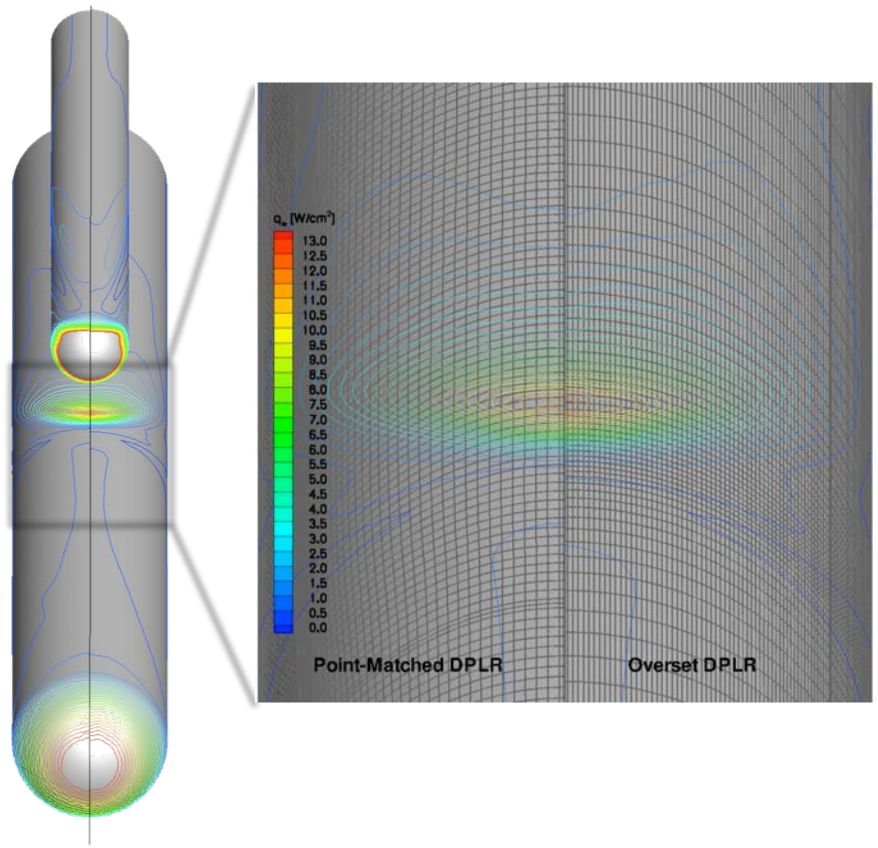
Shock Impingement Heating



- Differences in shock / shock interaction heat flux distribution
- Contour lines of pressure appear slightly more diffuse in point-matched solution
- Excellent agreement in shock impingement heating level

Advantage of Overset Grids

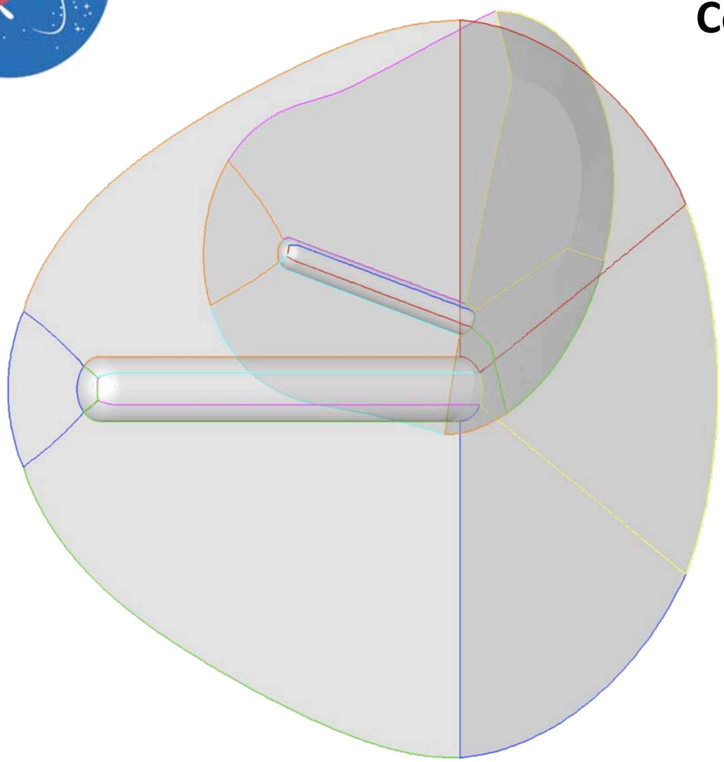


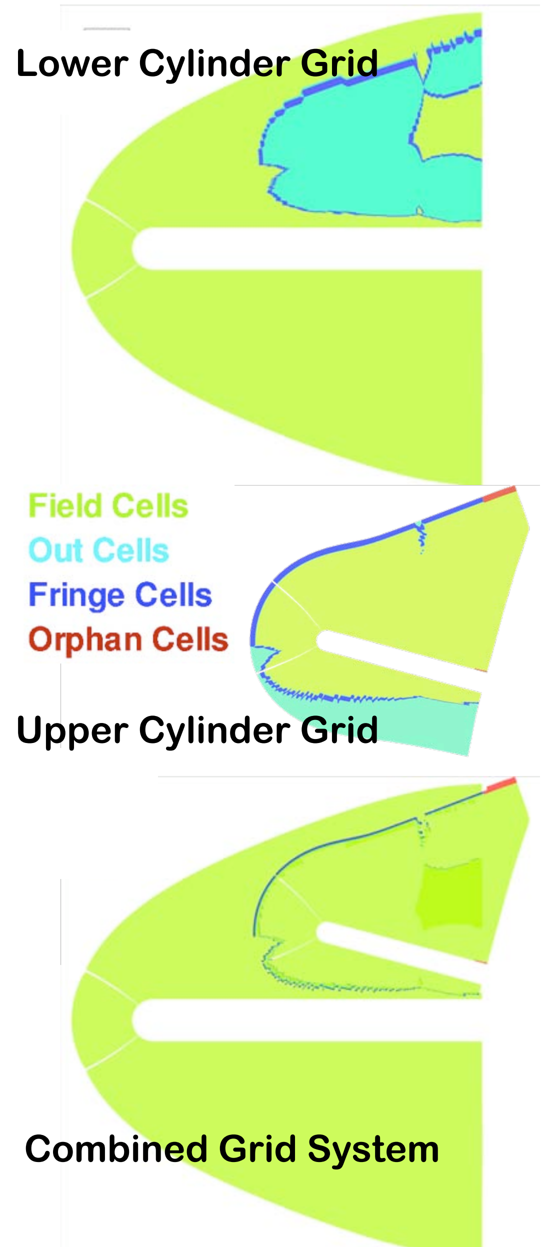


- Clustering of the grid to the shock / boundary layer interaction region

Overset Grid Topology

Configuration C



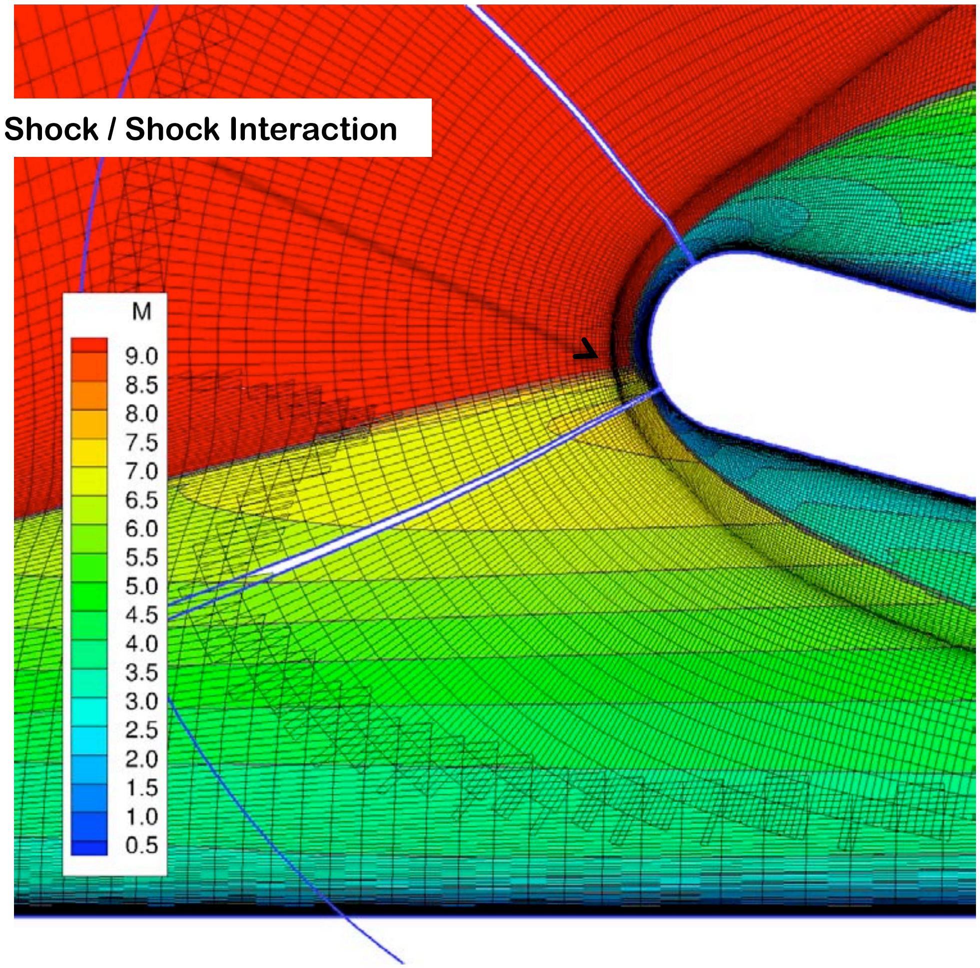


- Independently shock tailored grid for each cylinder
- Extra overlap region
  - Help match cell sizes at overset boundaries
  - Push the overset boundary out from the discontinuity at the shock
  - Fully contain the overset boundaries
- Orphans at the outer boundary near the end of the solution domain

Overset Boundary Between Bodies

Configuration C

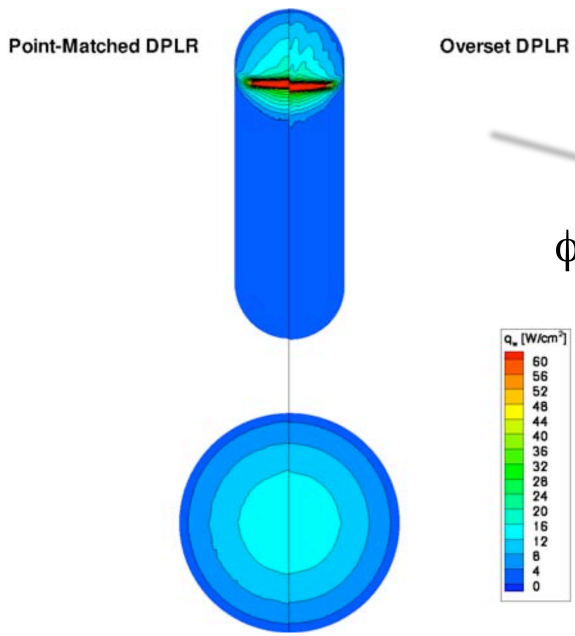
- Shock tailored grid
  - Lower cylinder tailored grid
  - Upper cylinder tailored grid
  - Location of the upper cylinder shock
  - Overset boundary outside of the upper cylinder shock
- Shock / Shock Interaction
  - Spreading of the shock through the overset boundary



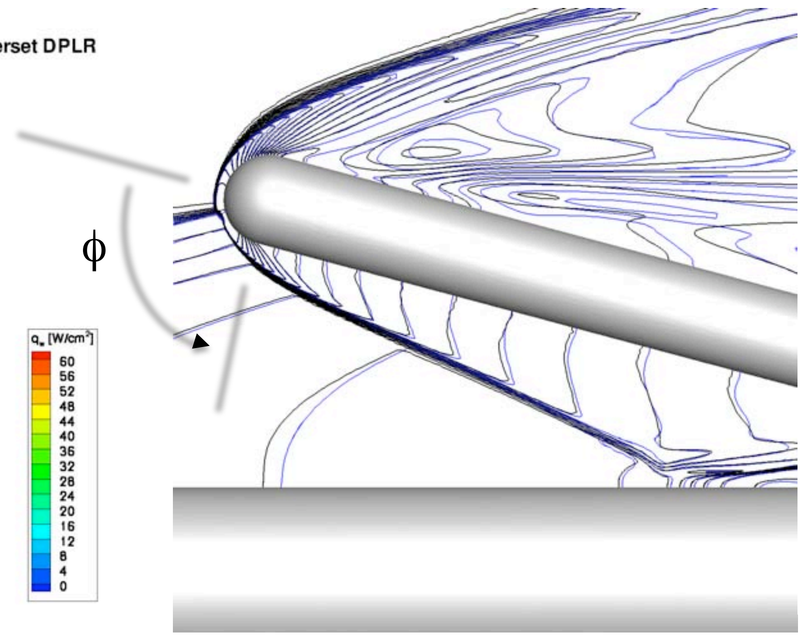
Overset Evaluation

Configuration C

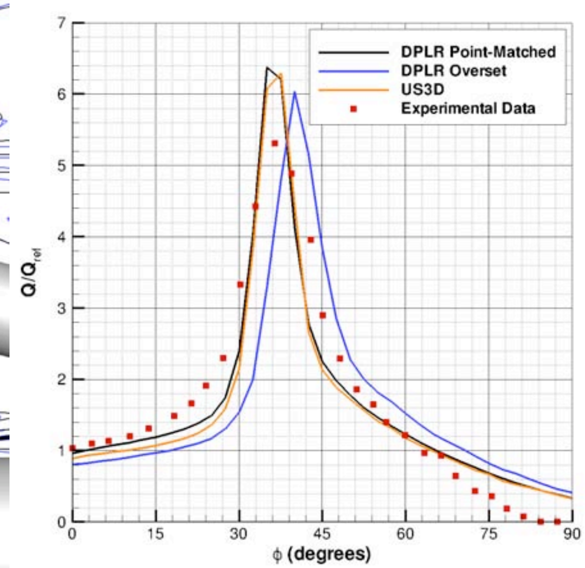
Heat Flux Contours



Contour Lines of Pressure



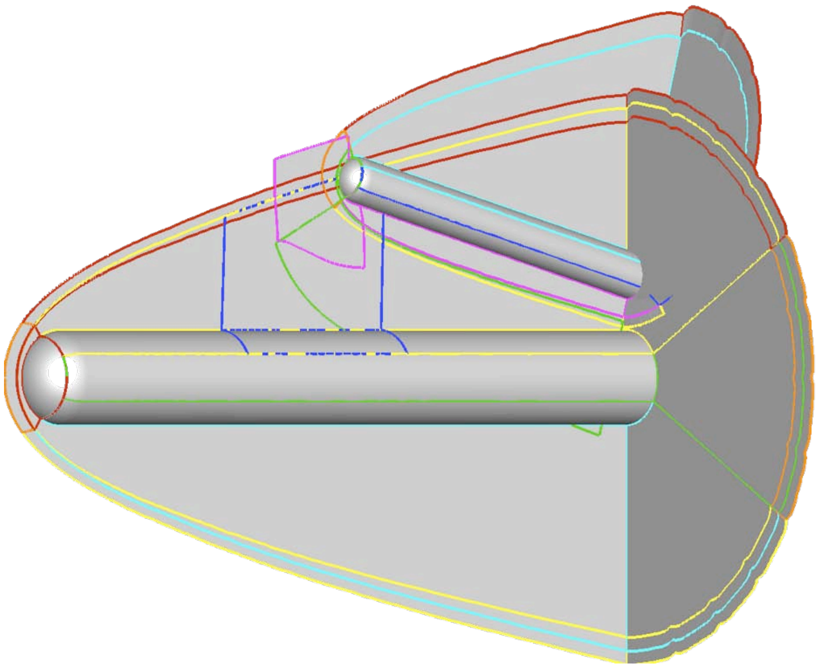
Shock Impingement Heating

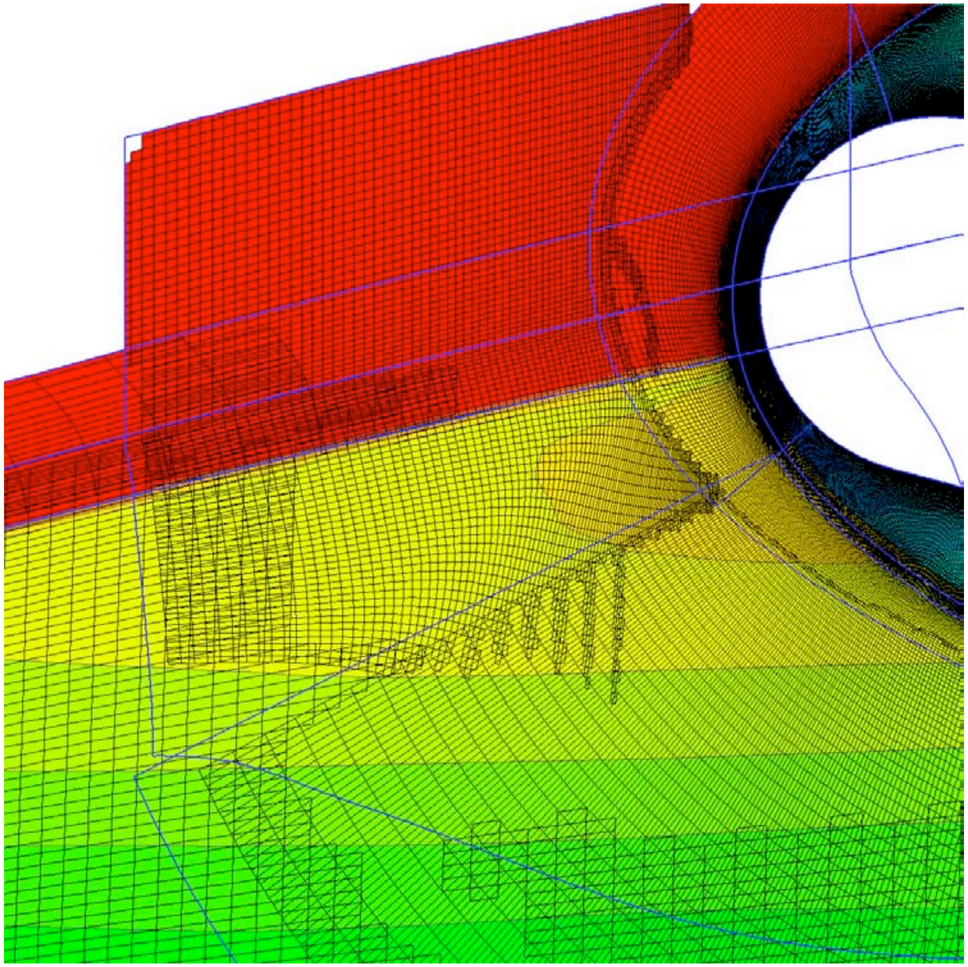


- Waviness in heat flux contours on the nose of the upper cylinder
- Offset in peak heating location in shock / shock interaction region
- Slight differences in the flow field at the shock / shock interaction region
- State as of AIAA Conference in June, follow on work included tracking down differences at the shock / shock interaction region

Overset Grid Topology (Updated)

Configuration C

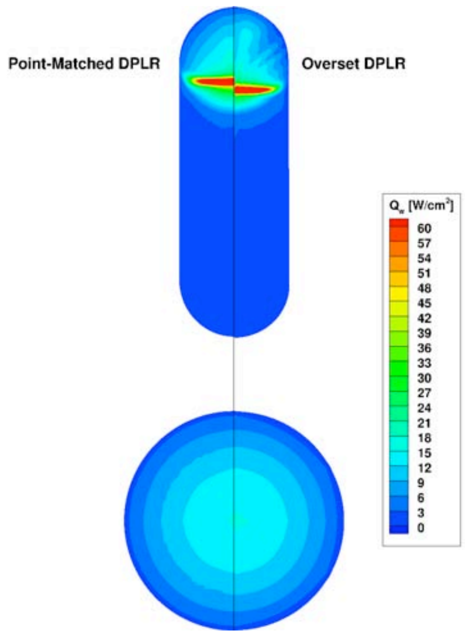




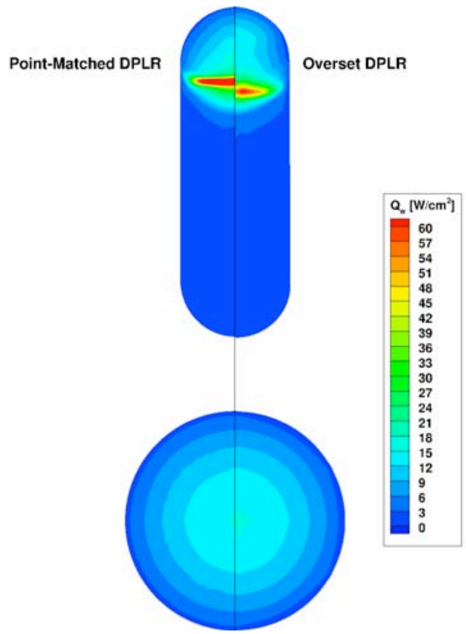
- Orphans on outer boundary
- Refinement grids in the shock / shock interaction region
- Designed for easy of use in grid convergence analysis

Overset Evaluation (Update)

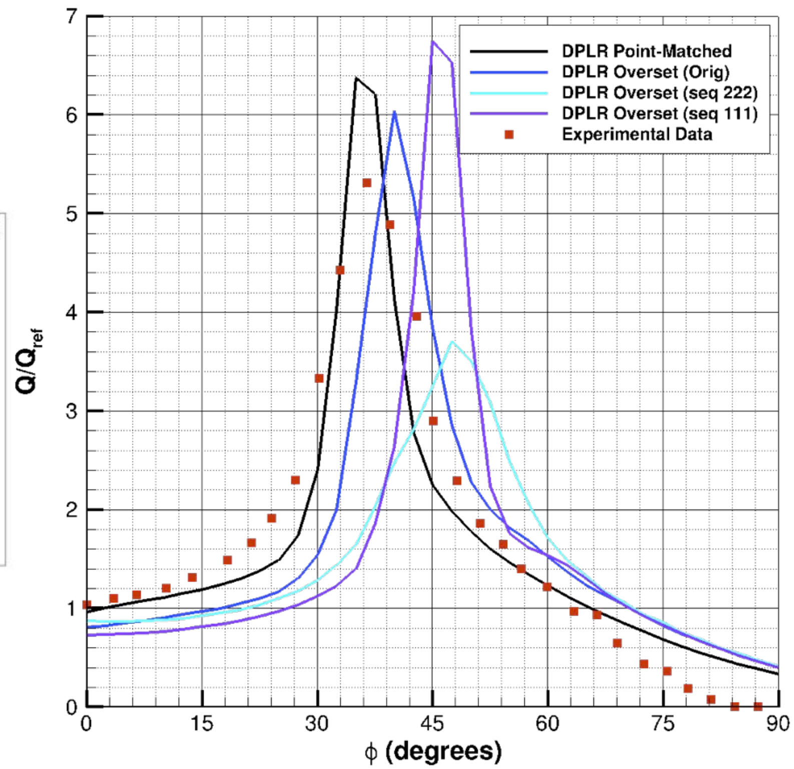
Configuration C



Finest Overset Grid



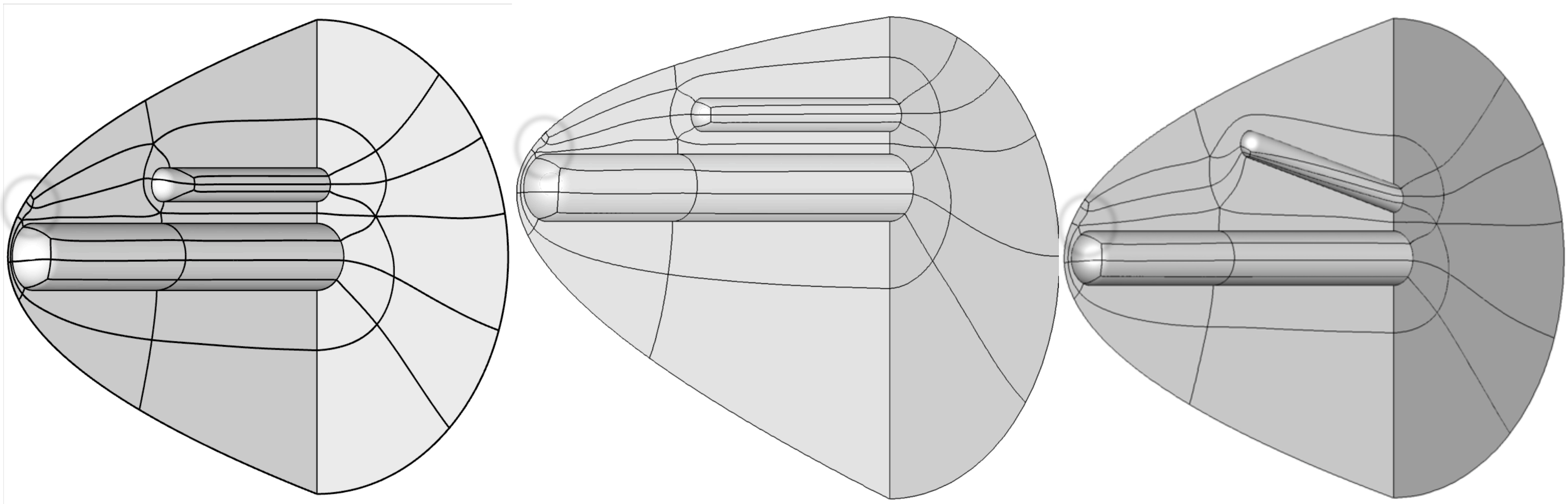
Sequenced Overset Grid



- Peak heating location is still offset in overset solution from the point-matched solution and the data
- Shock / shock interaction heating is very sensitive to grid resolution
- Peak heating location is the same at both grid resolutions

Point-Matched Grid Topology

Configuration A　　Configuration B　　Configuration C

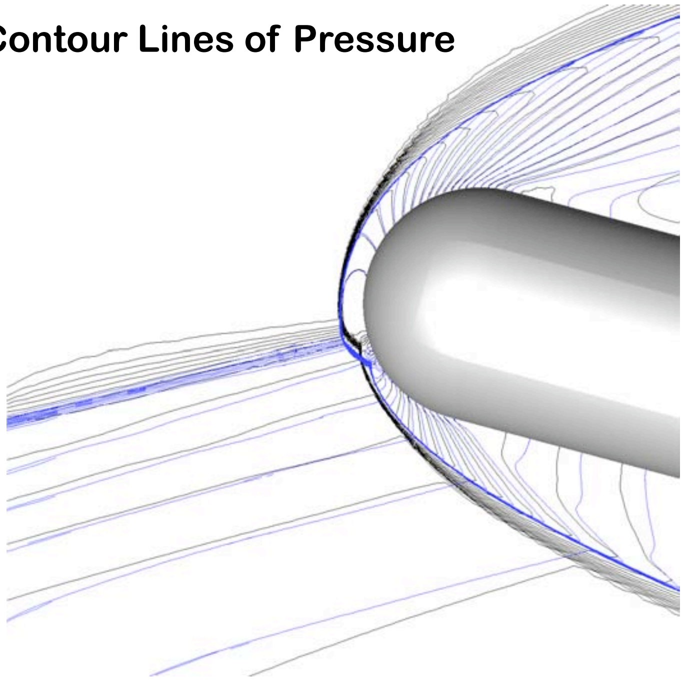


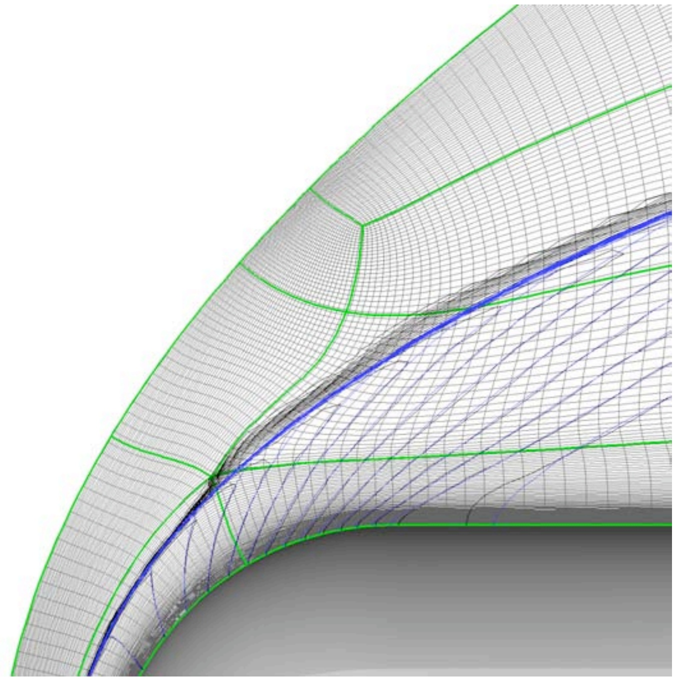
- Several topological singularities
- Topology required for this geometry made it impossible for the grid to remain aligned with the shocks

Evaluation of Point-Matched Solution

Configuration C

Contour Lines of Pressure



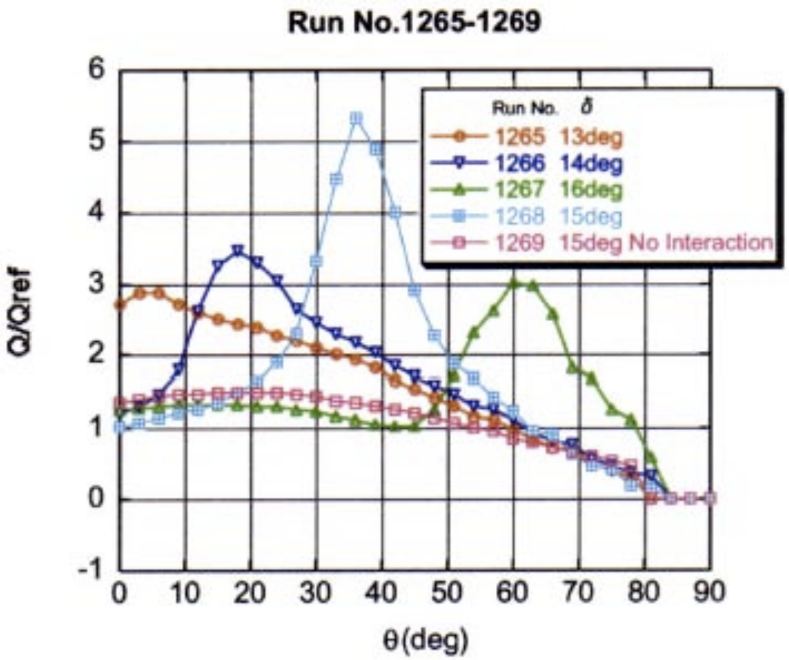


- Differences in upper cylinder shock location
- Point-matched solution lower cylinder shock appears more diffuse and further out from the body
- Possibly caused by the topology and grid alignment near the nose of the lower cylinder

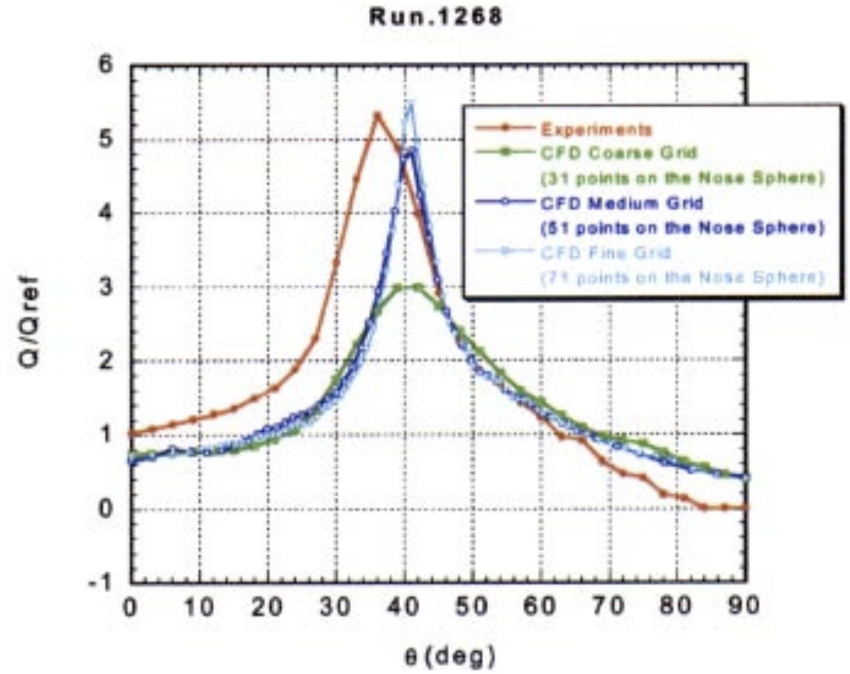
Evaluation of Test Data

Configuration C

Experimental Sensitivity



CFD Results of Yamamoto et al.



- 20-degree shift in peak heating location with 1-degree change in angle of attack of the upper cylinder
- CFD by Yamamoto et al. also showed a shift in peak heating location

Conclusions

- Overset grids show a number of advantages for multibody hypersonic configurations
  - Proper alignment of the grid to strong gradients and discontinuities is possible
  - Leads to more accurate prediction of peak heating locations and level
  - Possible to highly resolve regions of interest without propagating grid density into more benign regions
  - Simplified grid generation
- Disadvantages to using overset grids
  - Inertia of point-matched grids
  - Learning curve associated with generating the domain connectivity information

Acknowledgment

- Much of this work was performed under NASA contract NNA04BC25C to the ELORET Corporation
- The continuation of this work was performed under NASA contract NNA10DE12C to ERC Inc.
- Thanks to Ralph Noack for his continued help using SUGGAR and GVIZ
- Thanks to Mike Olsen for helpful discussions throughout this work