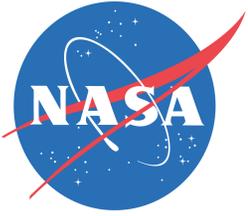# Overset Techniques for Hypersonic Multibody Configurations with the DPLR Solver

Andrew J. Hyatt, Dinesh Prabhu
ERC Inc.

David A. Boger
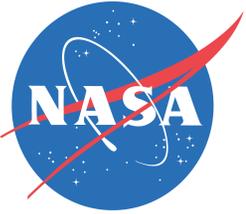Penn State Applied Research Laboratory

10th Symposium on Overset Composite Grids and Solution Technology
Moffett Field, CA

September 22, 2010

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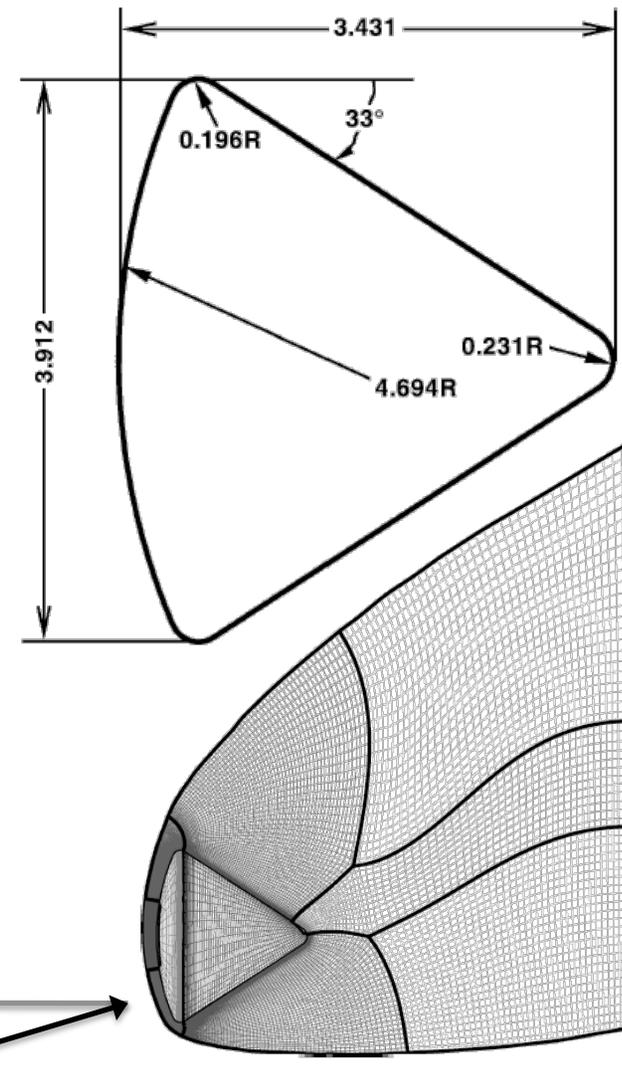
Wright, M., Prabhu, D., and Martinez, E., "Analysis of Apollo Command Module Afterbody Heating Part I: AS-202", Journal of Thermophysics and Heat Transfer, Vol. 20, No. 1, 2006
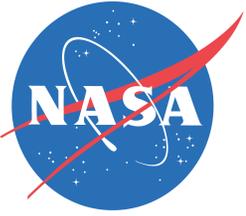
Background

- 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
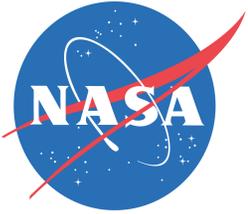
Geometry and Configuration

Configuration A

250 (mm)

30 (mm)
20 (mm)
60 (mm)

460 (mm)

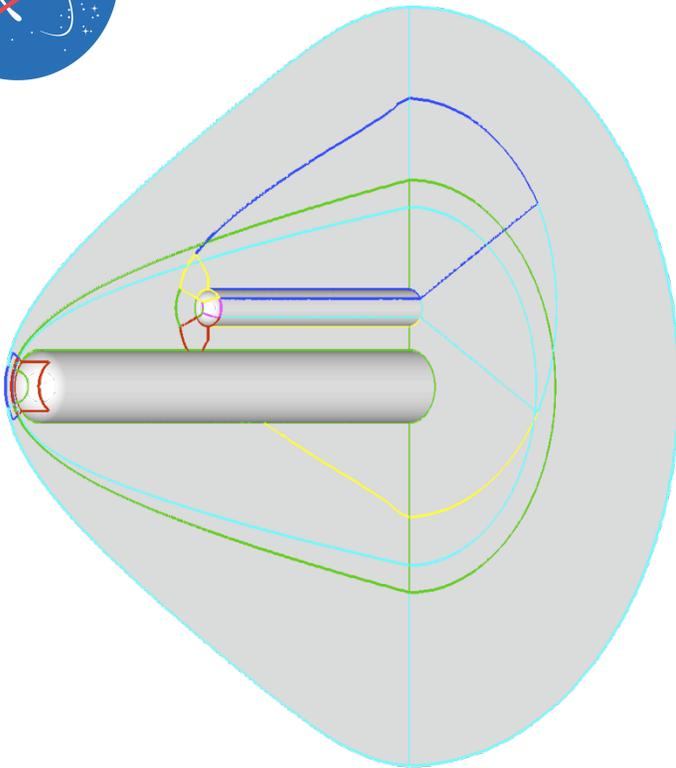**Configuration B**

10°

Configuration C

15°
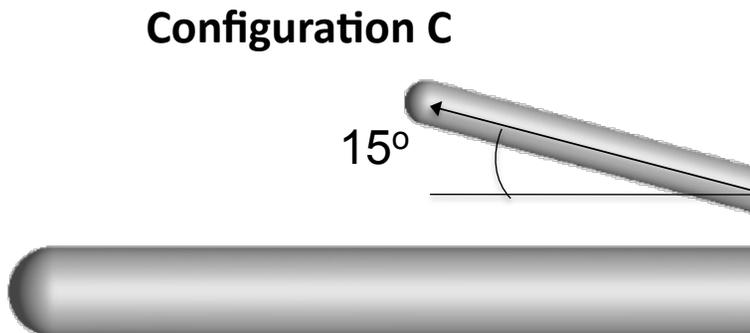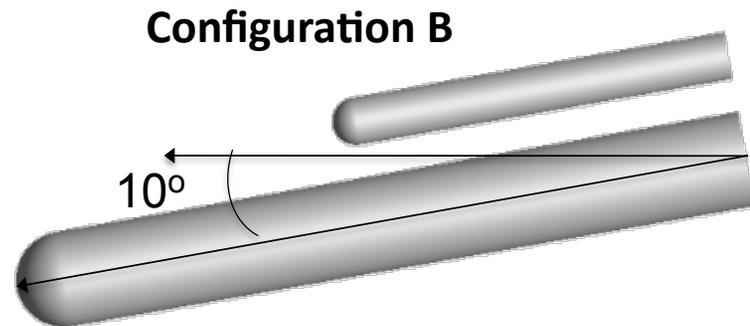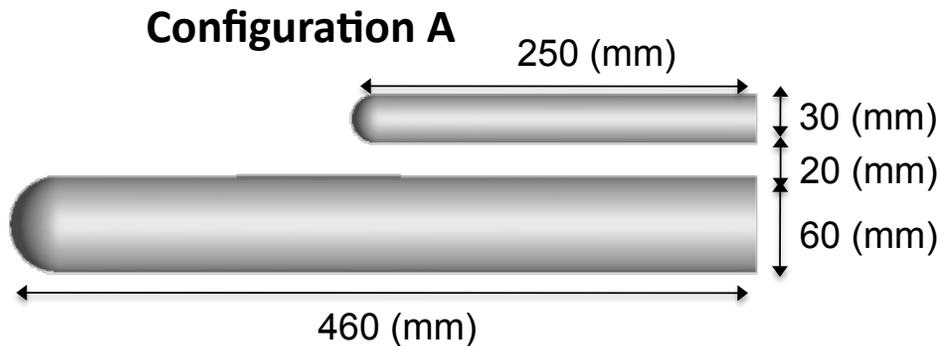
- The geometry considered is from the previous study by Yamamoto et al. (AIAA-2002-0217)

- Flow Conditions
  - Test gas was air
  - **Mach = 9.56**

- Modeling Assumptions
  - Laminar
  - Perfect Air ($\gamma = 1.4$)
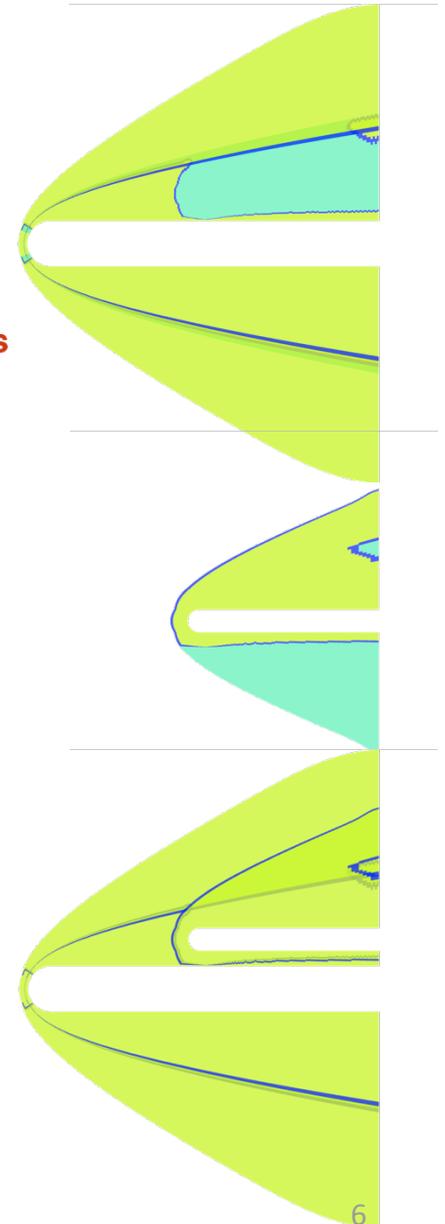 - Park 90 5-species Air
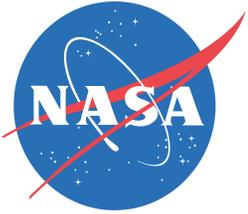
Overset Grid Topology

Configuration A

Field Cells
Out Cells
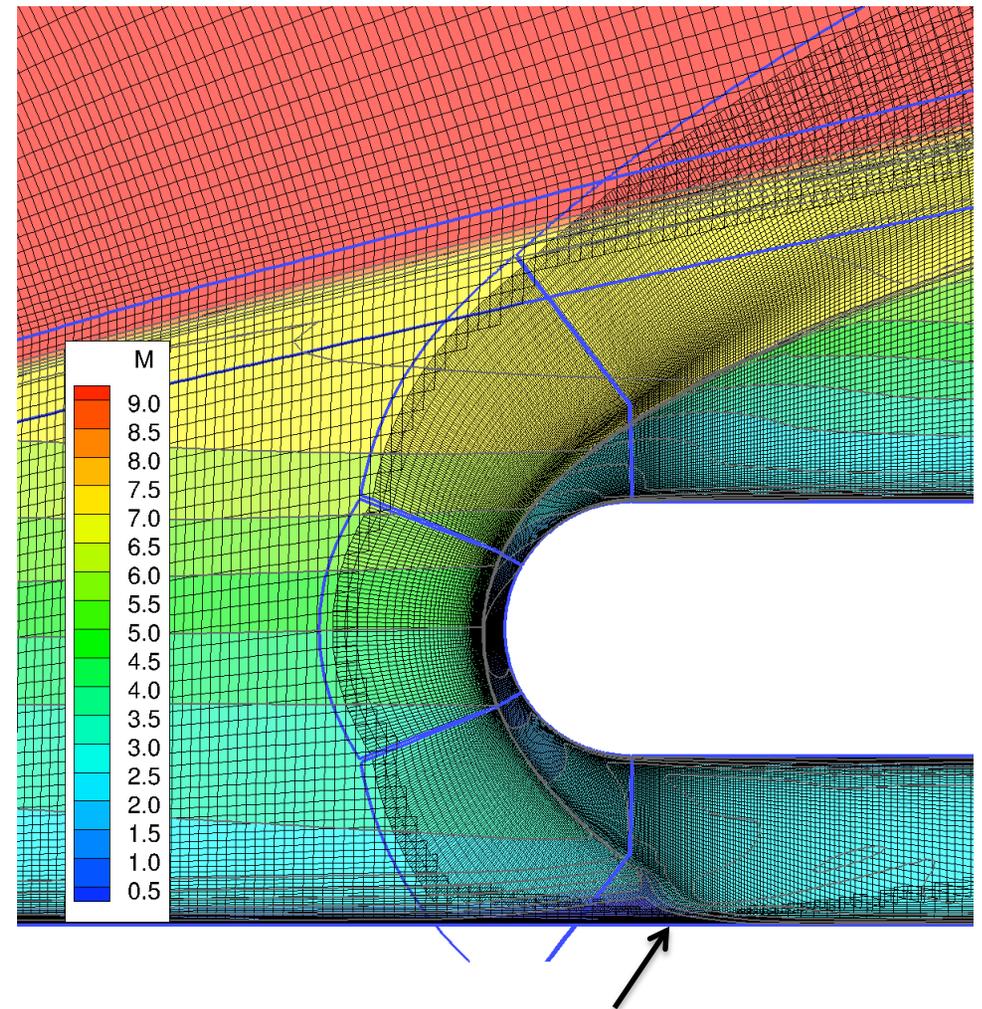**Fringe Cells**
Orphan Cells

- 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
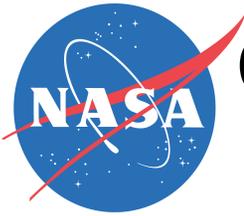
Overset Boundary Between Bodies

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
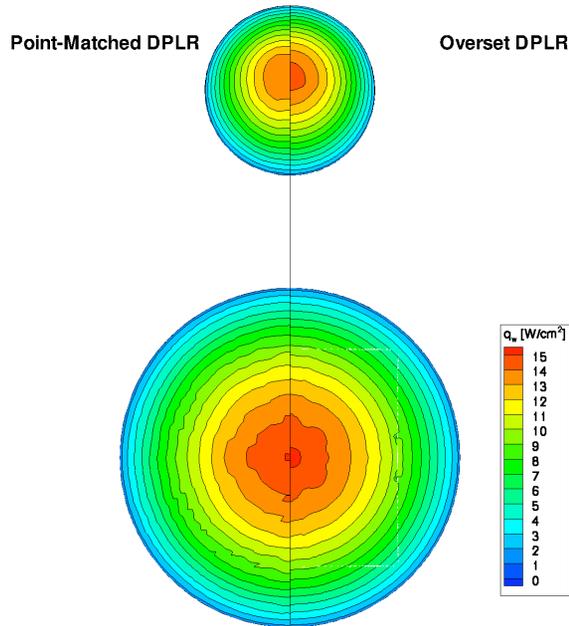
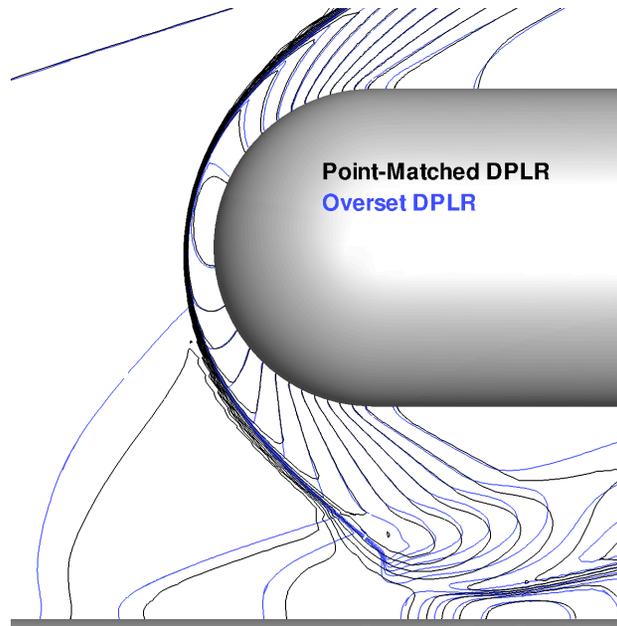- Shock / Boundary Layer Interaction

Shock / Boundary Layer Interaction

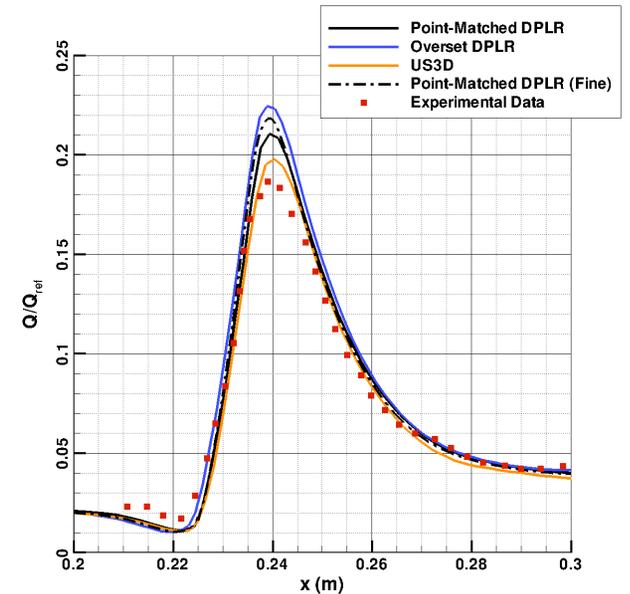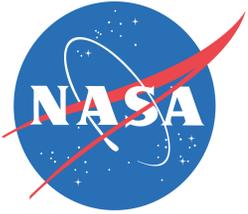# Overset Evaluation

Configuration A

Heat Flux Contours

Point-Matched DPLR   Overset DPLR

q_w [W/cm^2]
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

Contour Lines of Pressure

Point-Matched DPLR
Overset DPLR

Shock Impingement Heating

- Point-Matched DPLR
- Overset DPLR
- US3D
- Point-Matched DPLR (Fine)
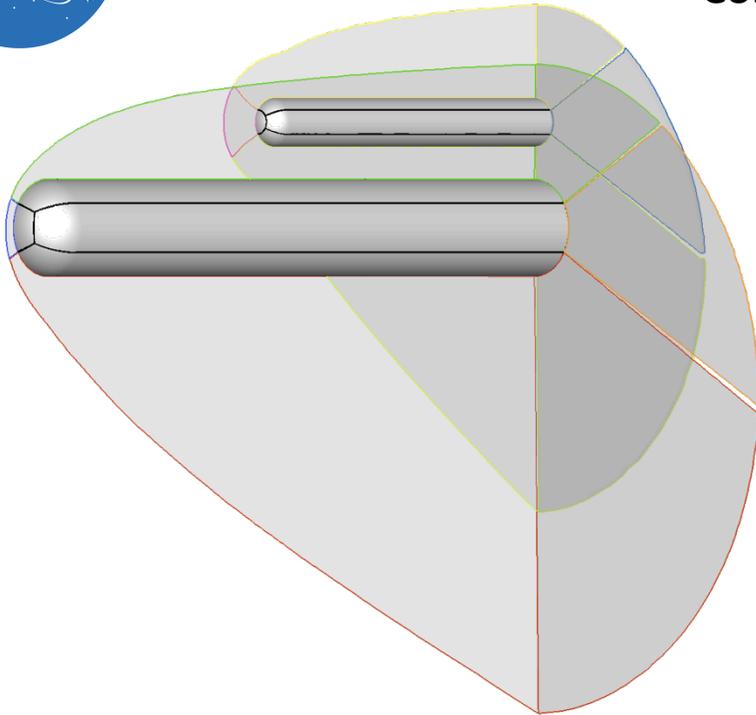- Experimental Data

Q/Q_{ref}

x (m)

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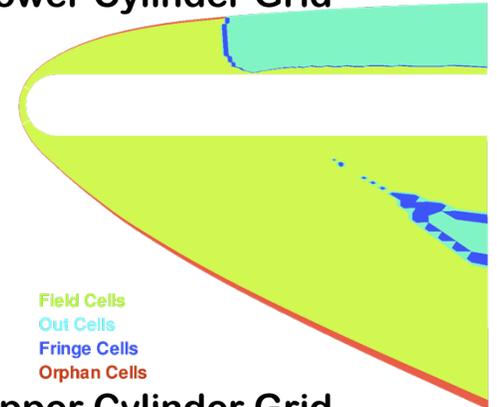- Excellent agreement in shock impingement heating level
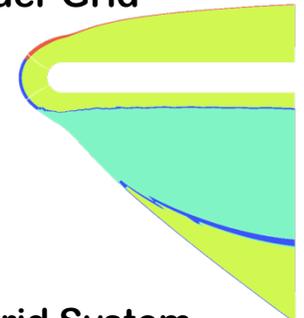
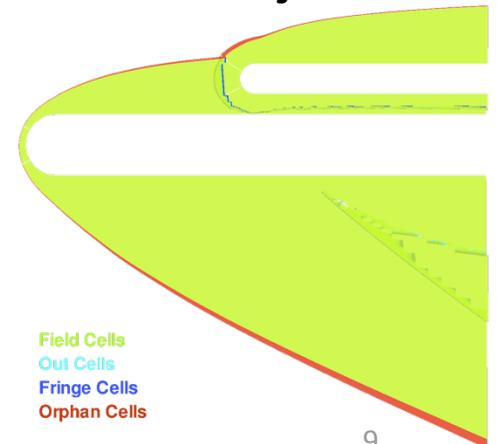# Overset Grid Topology

Configuration B

Lower Cylinder Grid

Field Cells
Out Cells
Fringe Cells
Orphan Cells

Upper Cylinder Grid

Combined Grid System

Field Cells
Out Cells
Fringe Cells
Orphan Cells

- 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
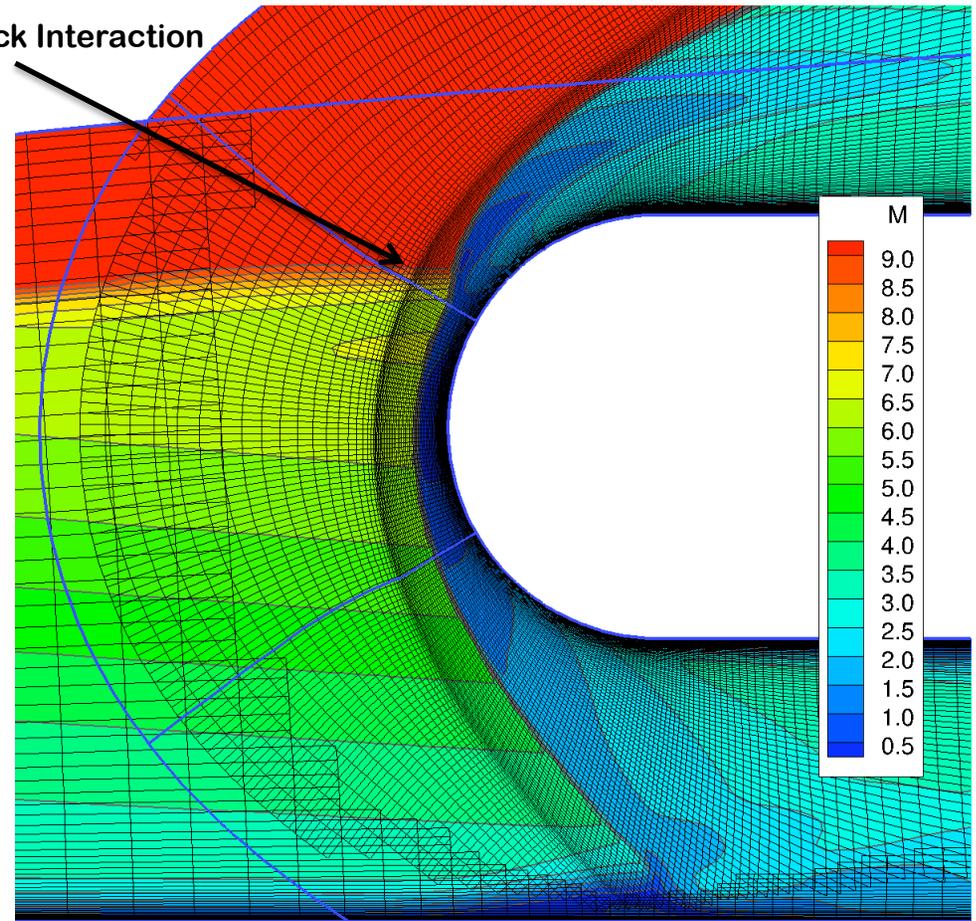- Orphan cells at outer boundary
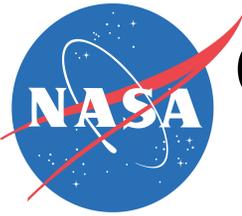
Overset Boundary Between Bodies

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
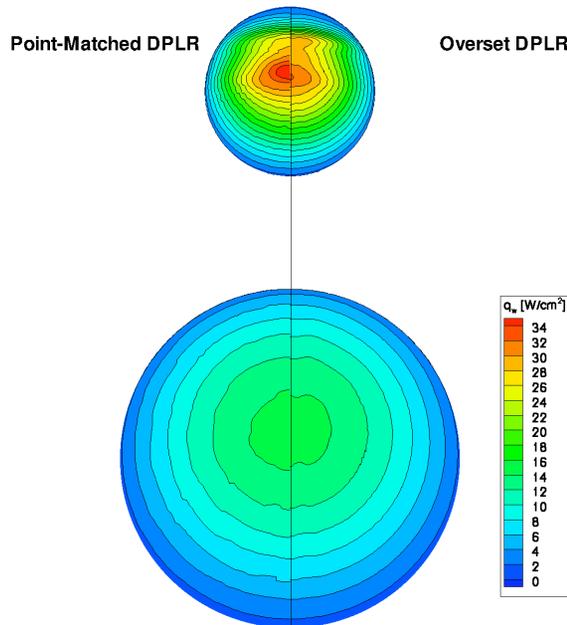- Shock / Shock Interaction

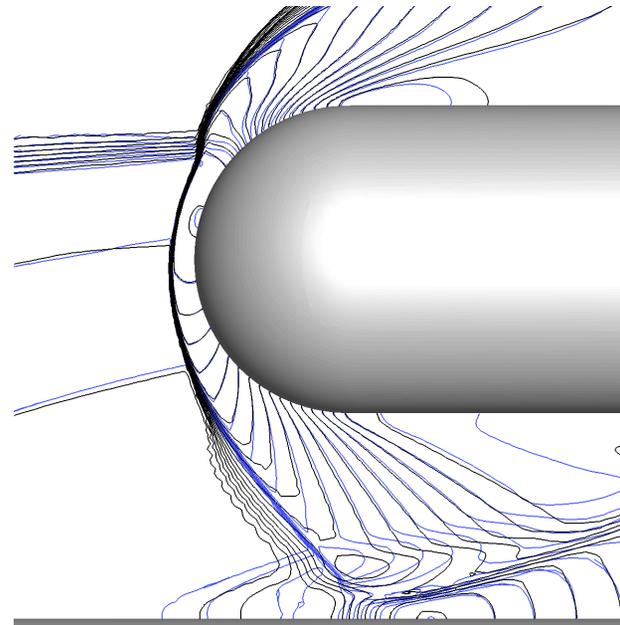Shock / Shock Interaction

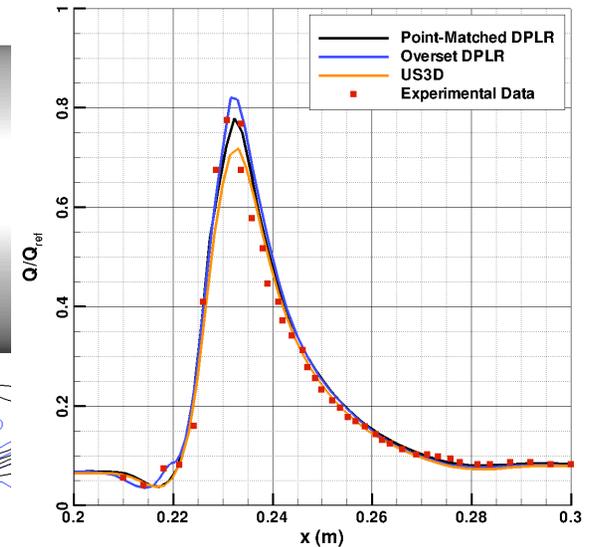Shock / Boundary Layer Interaction

Overset Evaluation

Configuration B
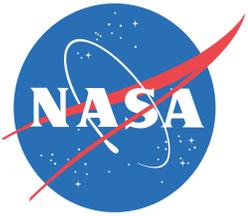
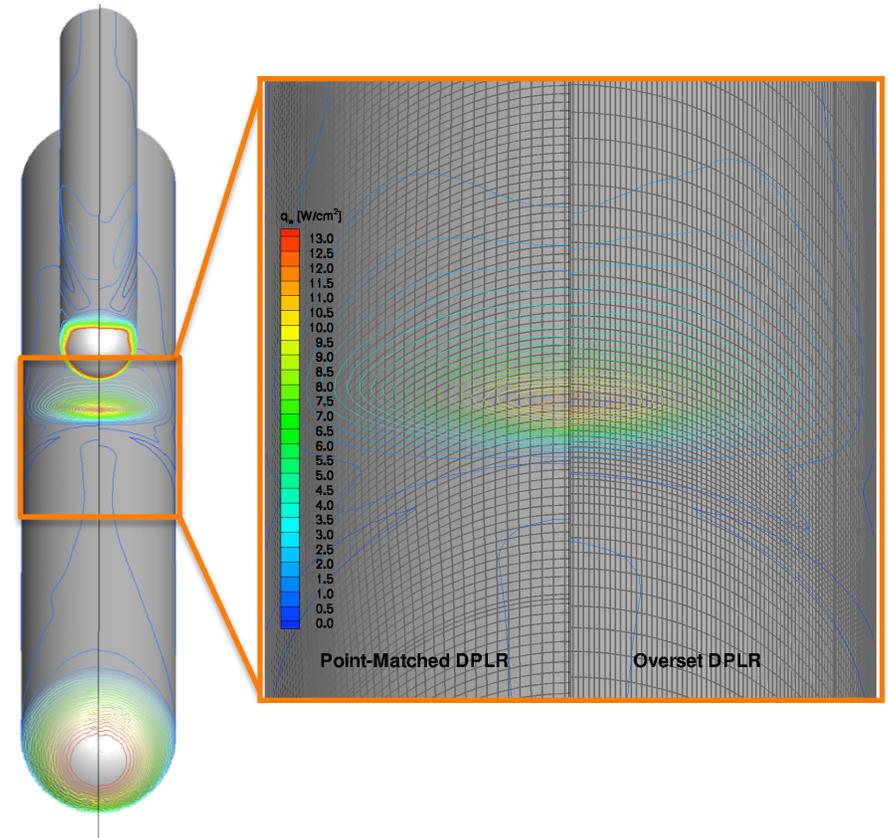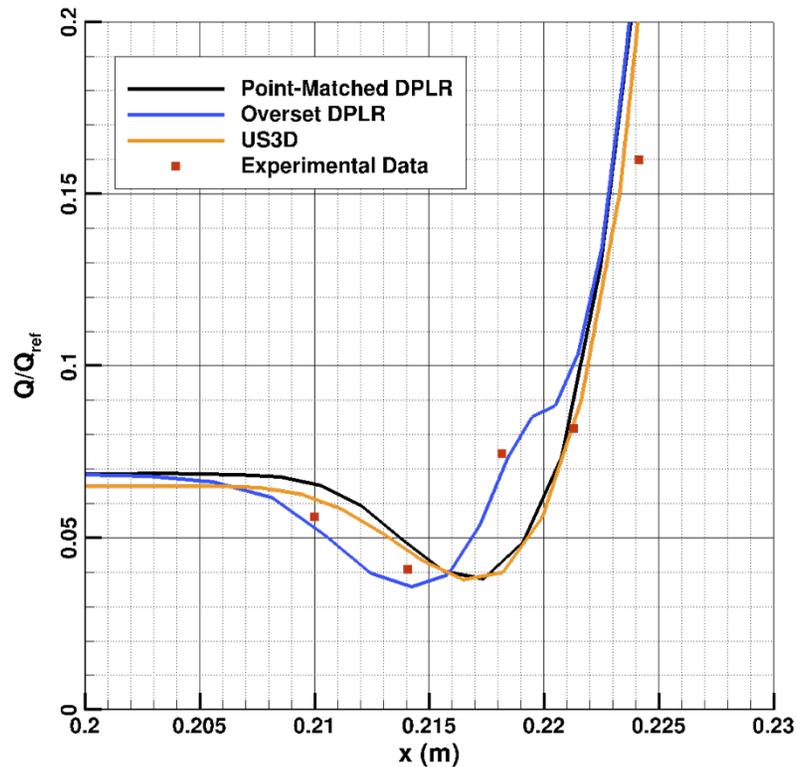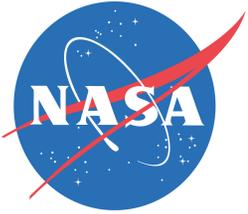**Heat Flux Contours** **Contour Lines of Pressure** **Shock Impingement Heating**

- 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
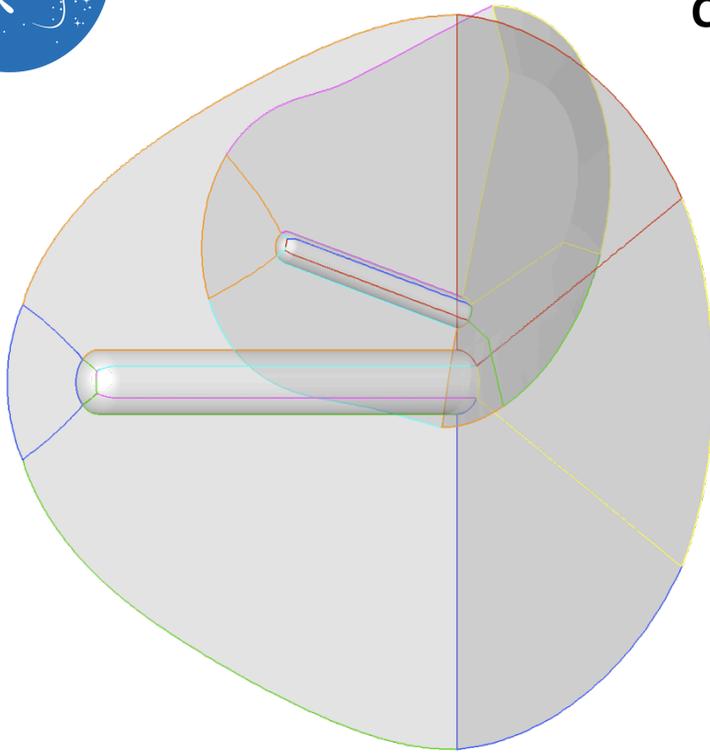
Advantage of Overset Grids

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

Overset Grid Topology

Configuration C

Lower Cylinder Grid

Field Cells
Out Cells
Fringe Cells
Orphan Cells

Upper Cylinder Grid

Combined Grid System

- 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
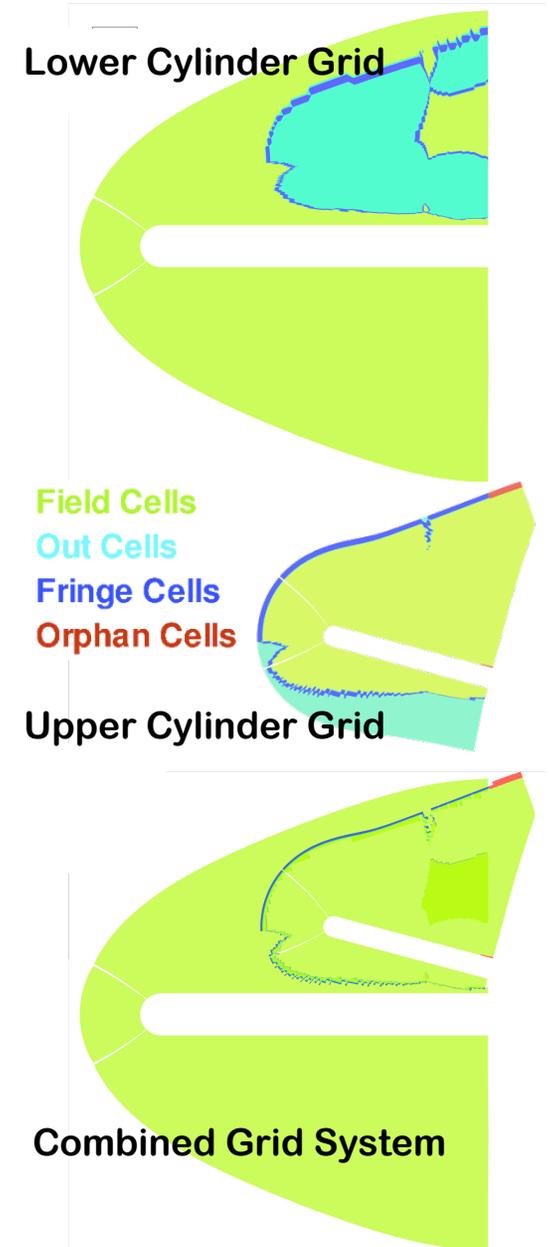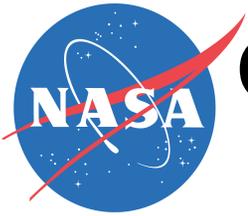
Overset Boundary Between Bodies

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
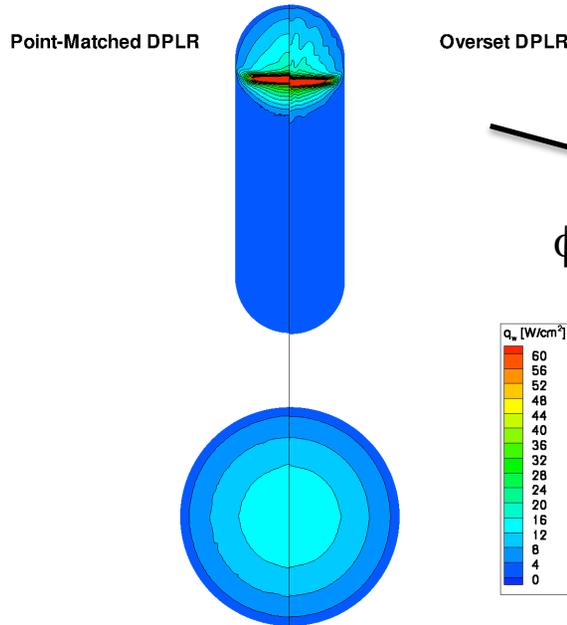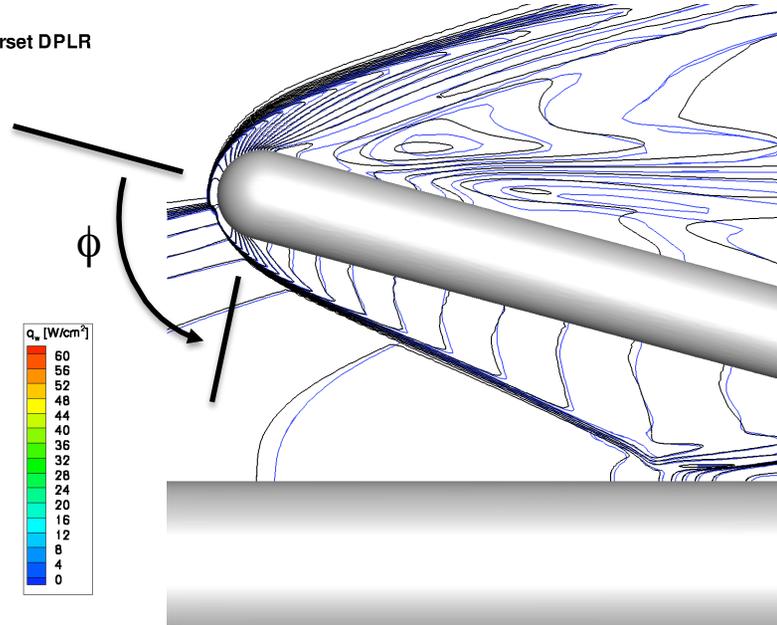 - Spreading of the shock through the overset boundary

Shock / Shock Interaction

M
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
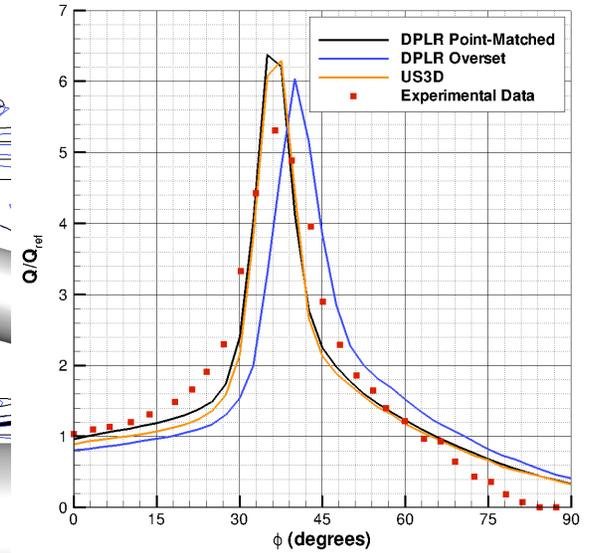1.0
0.5
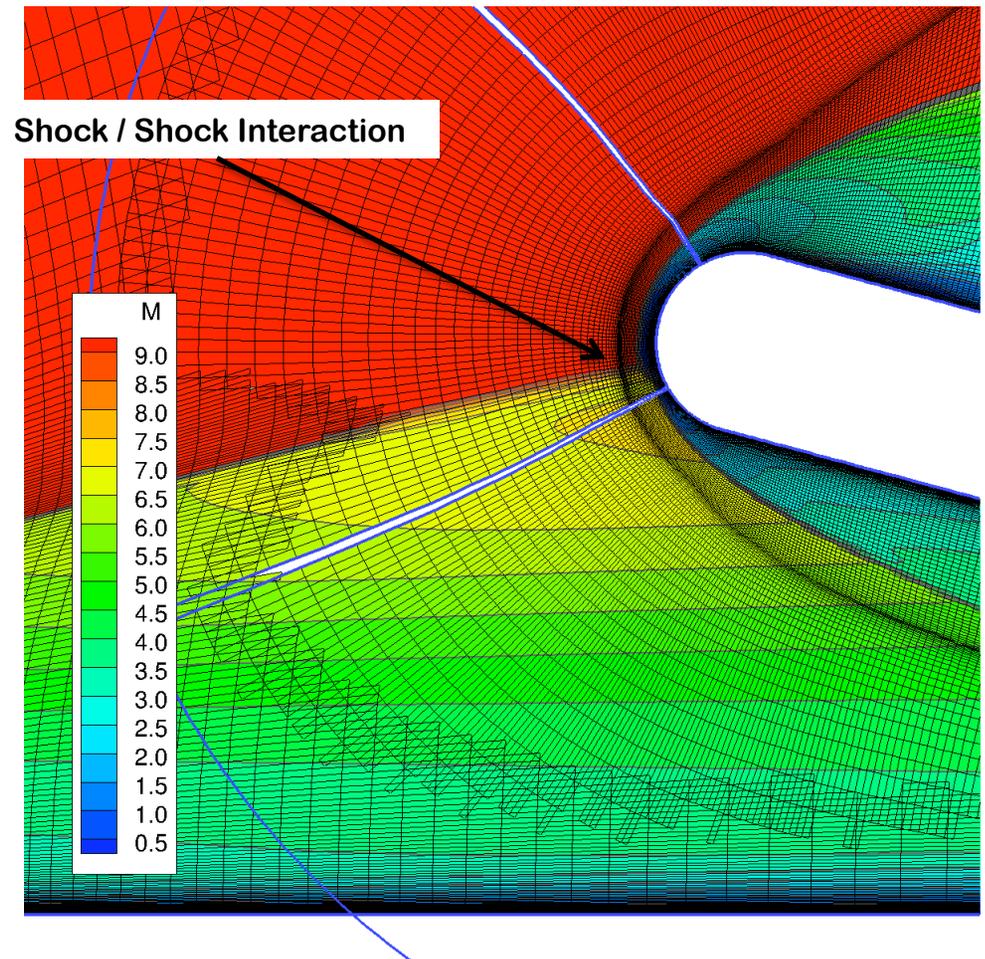
Overset Evaluation

Configuration C

Heat Flux Contours

Contour Lines of Pressure

Shock Impingement Heating

Point-Matched DPLR

Overset DPLR

q_w [W/cm²]

60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0

ϕ

- 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
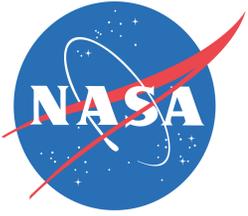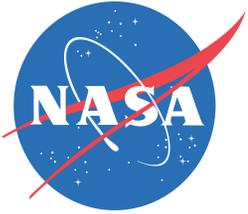
Overset Grid Topology (Updated)
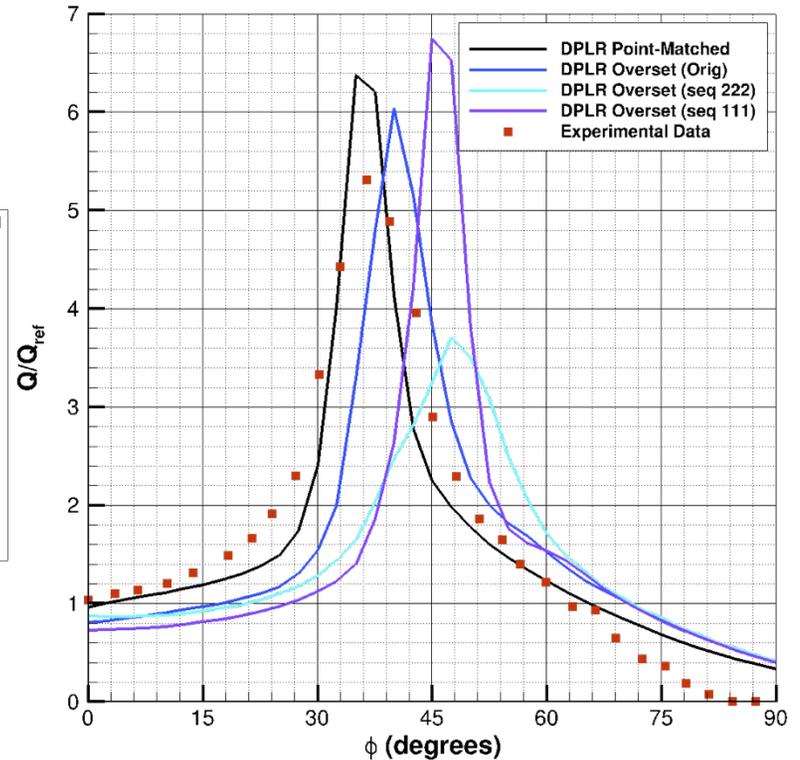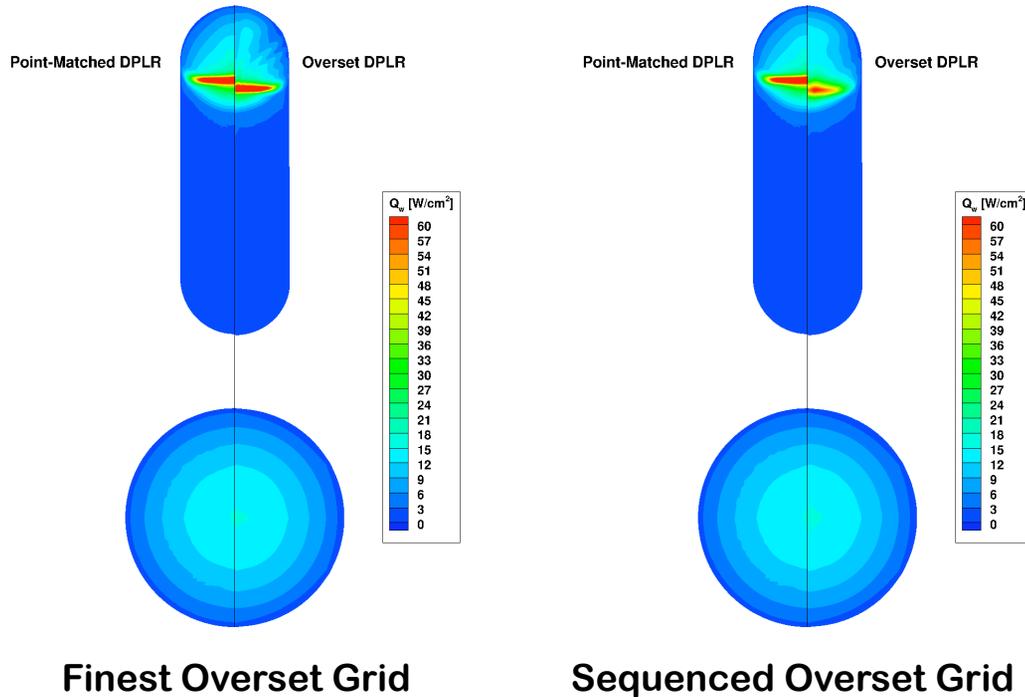
Configuration C
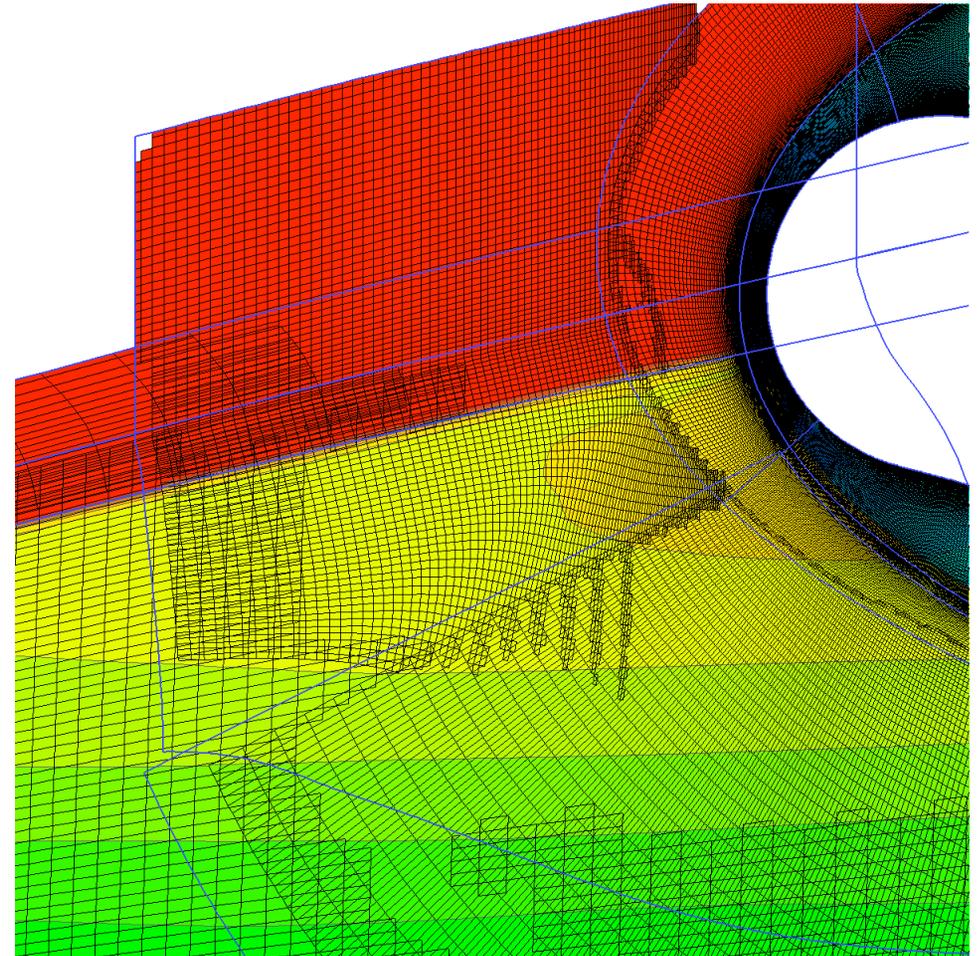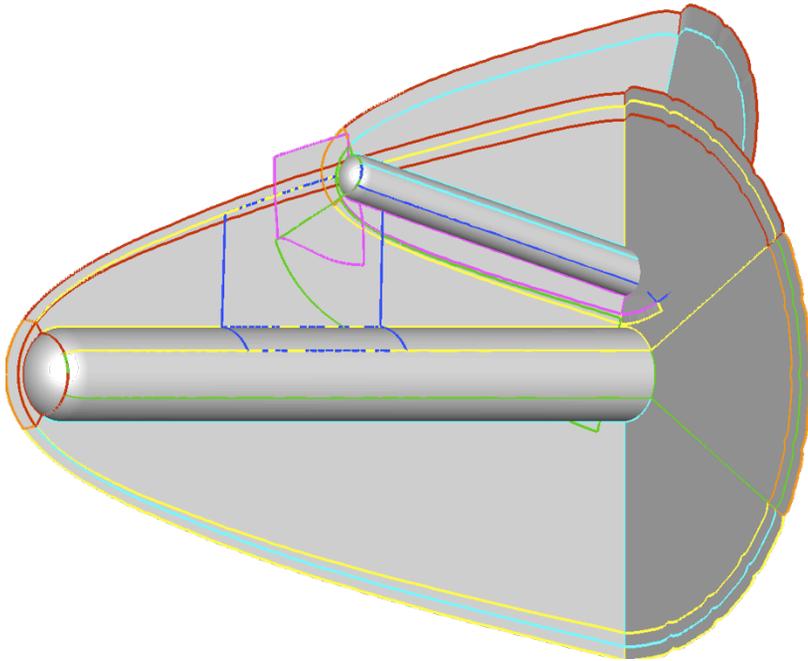
- Orphans on outer boundary

- 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

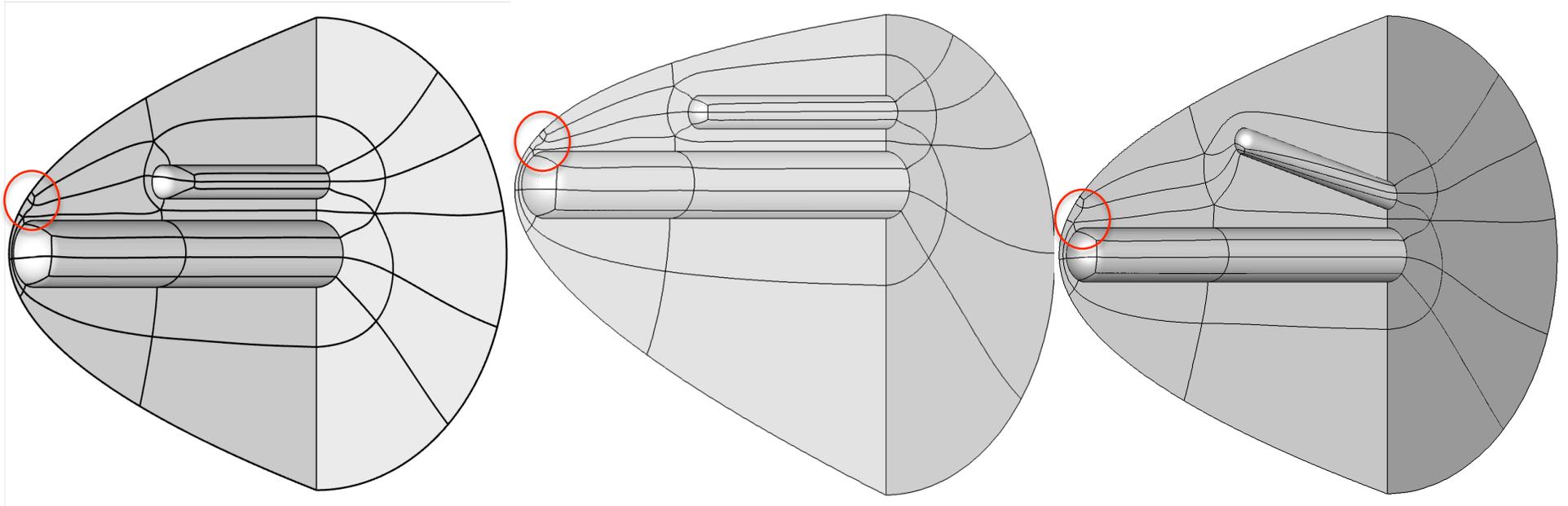- Peak heating location is the same at both grid resolutions
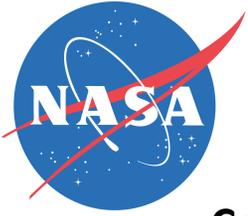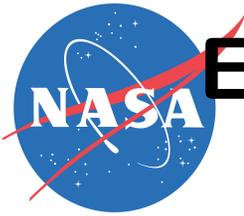
Point-Matched Grid Topology

Configuration A   **Configuration B**   **Configuration C**
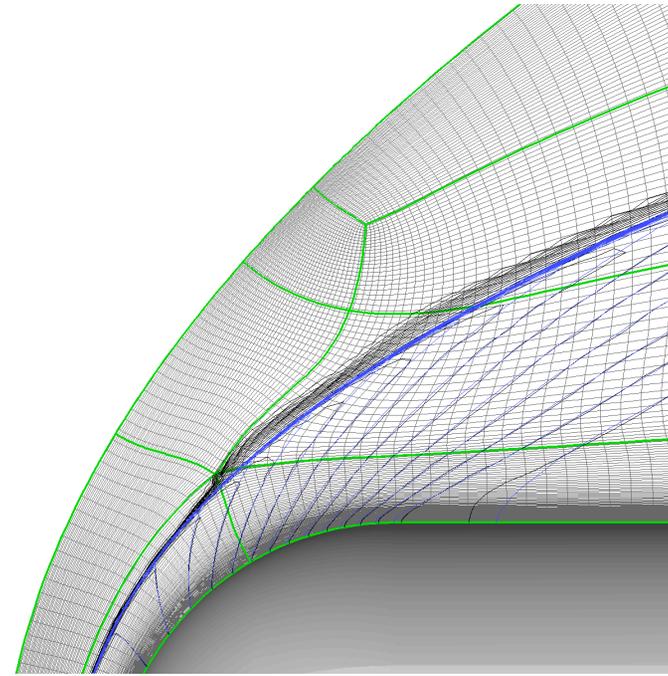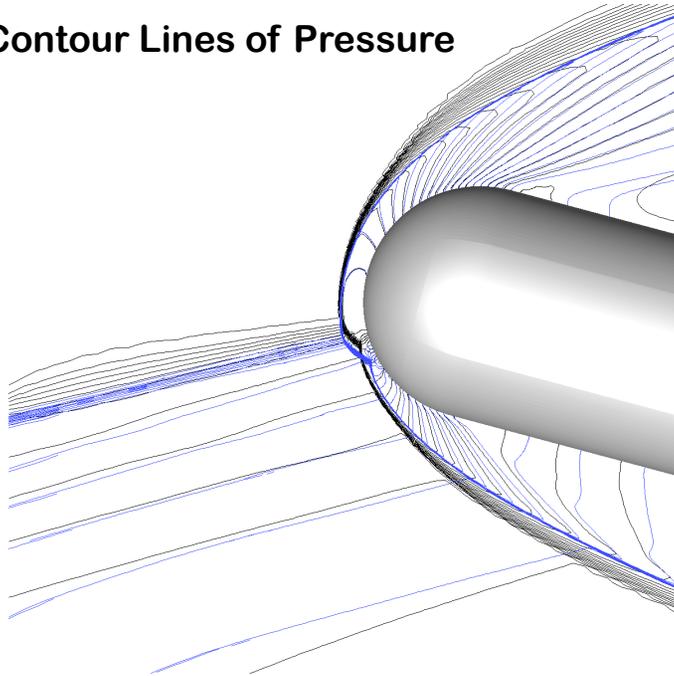

- Several topological singularities
- Topology required for this geometry made it impossible for the grid to remain aligned with the shocks
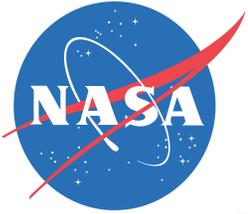
Evaluation of Point-Matched Solution

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
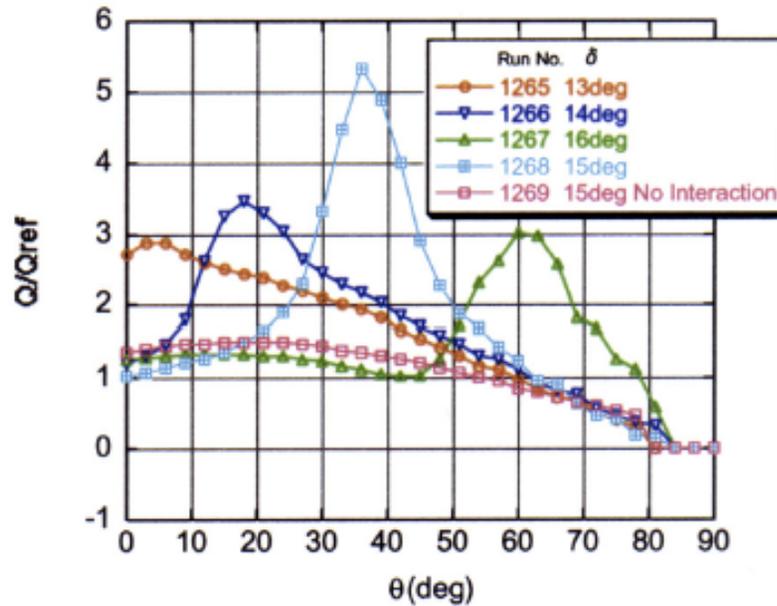
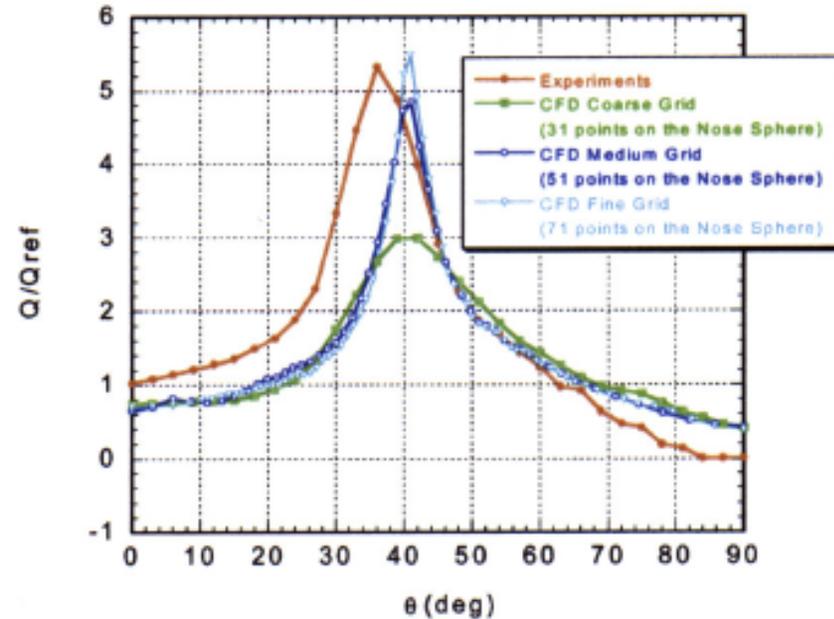# Evaluation of Test Data

Configuration C

Experimental Sensitivity
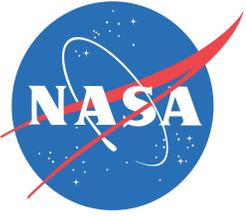
Run No.1265-1269

**CFD Results of Yamamoto et al.**

Run.1268

- 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
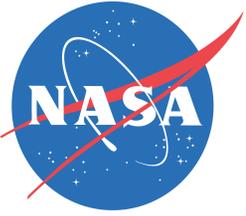
Acknowledgment

- 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