TFAWS Aerothermal Paper Session

Aerodynamic and Aerothermal Simulations of Mars Concept Vehicles using Overset *DPLR*

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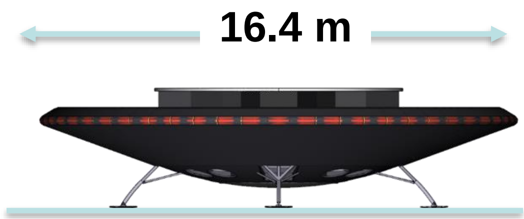
Outline

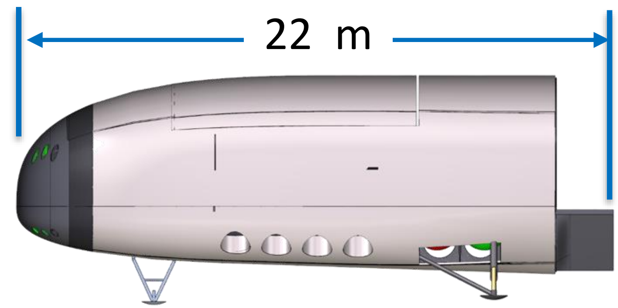
- Overview of Descent Systems Studies (DSS) Program
  - Concept vehicles for landing heavy payloads on Mars
- Grid generation for Data Parallel Line Relaxation (*DPLR*)
  - Point-matched volume grids
  - Oversetting grids framework
  - Overset approach for *DPLR*
- Overset *DPLR* results
  - *DPLR* solutions on a Mid-L/D configuration at various freestream conditions and body flap deflections
- Concluding remarks
- Future work

Descent Systems Studies Overview

Low-L/D



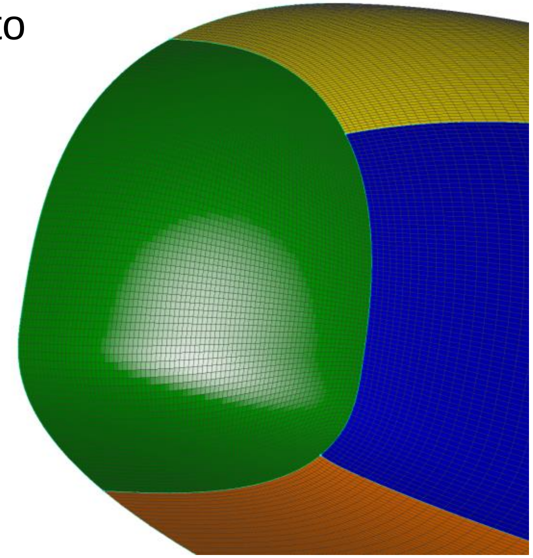
Mid-L/D



- A Low-L/D and a Mid-L/D vehicles are being evaluated for landing heavy payloads on the surface of Mars
- For the Mid-L/D configuration, we would like to anchor high-fidelity Computational Fluid Dynamics (CFD) solutions to the current aerodynamic and aerothermal databases
- *DPLR* (a structured, finite-volume, Navier-Stokes code with finite-rate chemistry) is used at Ames to run these CFD simulations

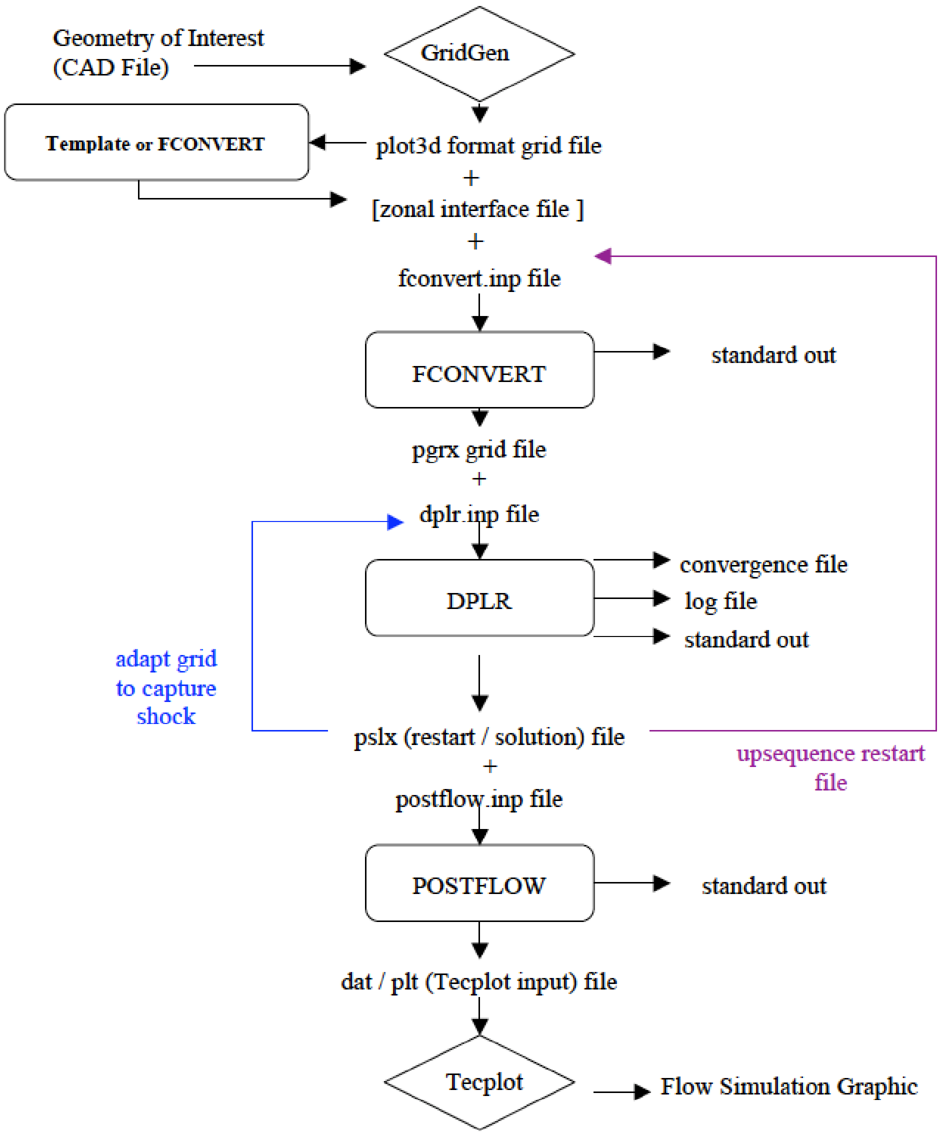
Grid Generation for *DPLR*

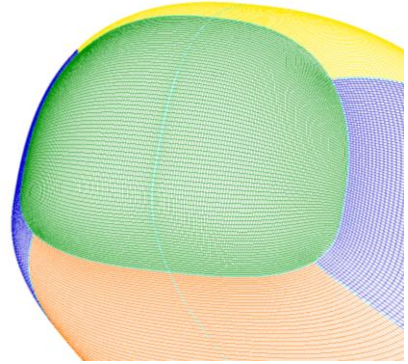
- Why is grid generation important?
  - Grid generation is the first step in any CFD analysis
  - Solution depends on the quality of the grids: meshes need to be aligned to the bow shock and sufficient grid resolution to capture boundary layer and other flow features
  - *DPLR* requires structured, multi-block grids with points matching at block interfaces
  - Grid generation and shock alignment on a complex configuration can often be a bottleneck in running a large number of cases
- Hyperbolic grid generation on a simple geometry
  - Simple grid topology: single layer of grid points from the vehicle's surface to the outer boundary
  - Build-in grid alignment and wall clustering tools in *DPLR* make grid adaptions easy for the user (requires a single-layer grid topology)
  - Many *DPLR* post-processing tools and inputs to other software (such as the NEQAIR radiation code) assume a single-layer grid topology



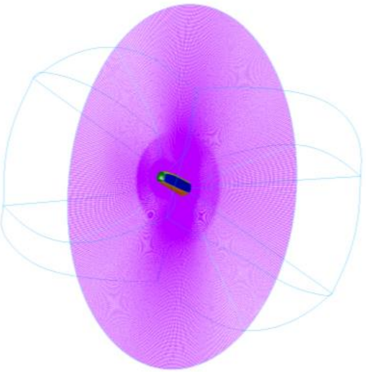
Point-matched surface grids

DPLR Work Flow Chart

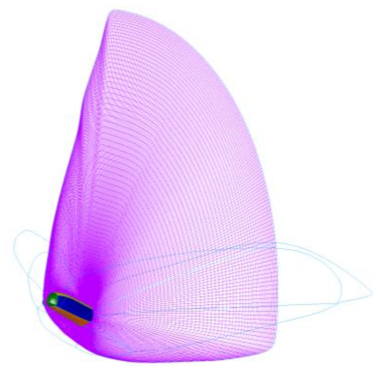




Point-matched surface grids on a smooth body



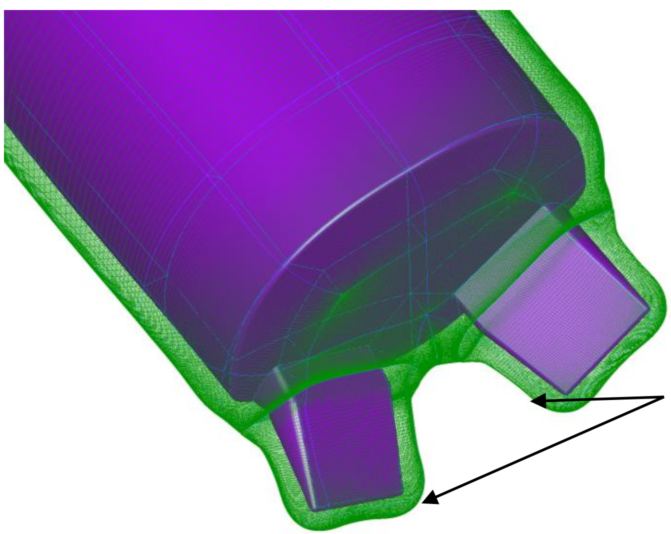
Initial volume grid generated hyperbolically



Adapted volume grid

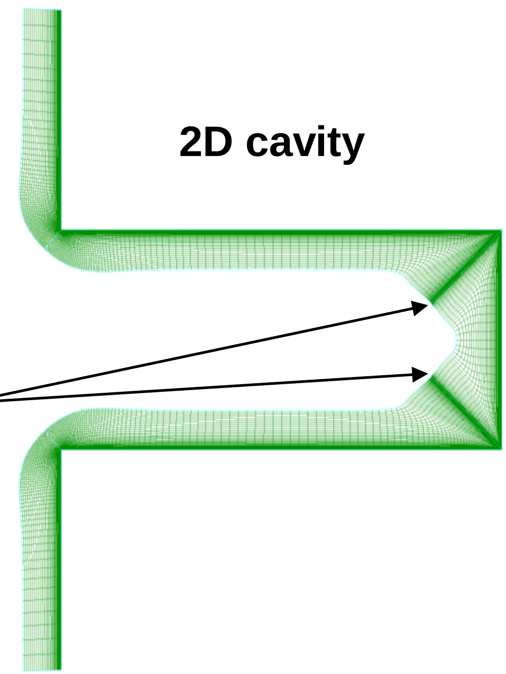
Grid Generation for *DPLR*

- Generating a single-layer, point-matched grid from vehicle's surface to the outer boundary can be difficult for certain geometries
- Alternative structured grid generation techniques
  - Algebraic methods
  - Elliptical grid generation
  - **Overset grids** (available in *DPLR* since 2009)



Grid points can collide and produce negative areas/ volumes

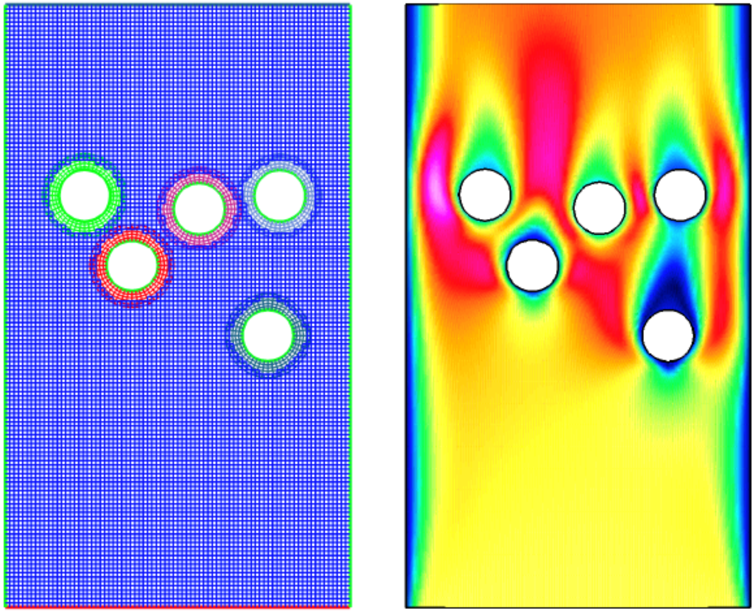
Mid-L/D configuration with body flaps



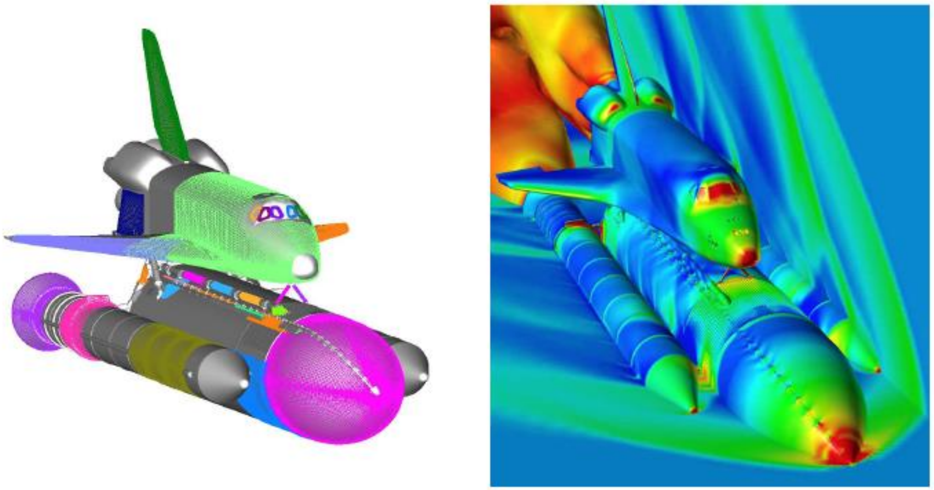
2D cavity

Oversetting Grids Approach

- Overset grids developed to handle complex geometries (for example, Overflow at NASA, Overture at LLNL)
  - Basic concept is to use overlapping structured grids to define the geometry and the computational domain
  - While this framework is efficient and powerful, new users may find it difficult to implement the hole-cutting and grid connectivity utilities (e.g., PEGASUS for Overflow, SUGGAR for *DPLR*)



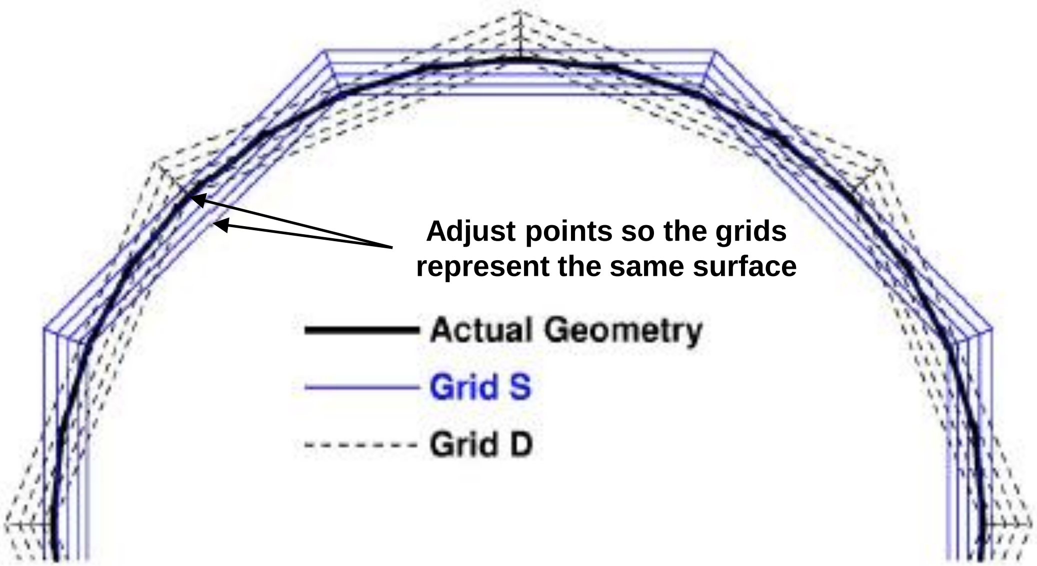
"An Introduction to Overset Grids" by Bill Henshaw, 2011



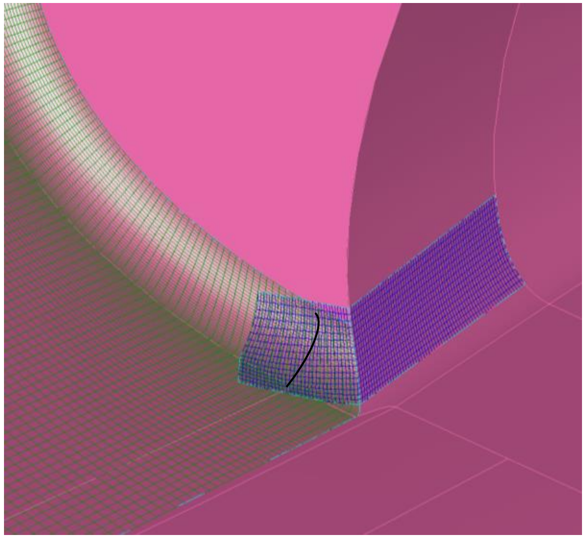
Space Shuttle figures by William Chan and Reynaldo Gomez

Example of Grid Connectivity Issues

- One common problem is surface assembly errors for overlapping grids with viscous spacing at the body surfaces
  - Overlapping surface grids have different resolutions and representation of the same geometry. This can result in the erroneous marking of points near the surface as holes or failure to find the correct donor information
  - One fix is to adjust the grid points of one grid so that they are consistently located relative to the discrete grid (within a specified tolerance)
  - Difficult to visualize errors due to small grid spacings (on the order of microns) and overlapping grids

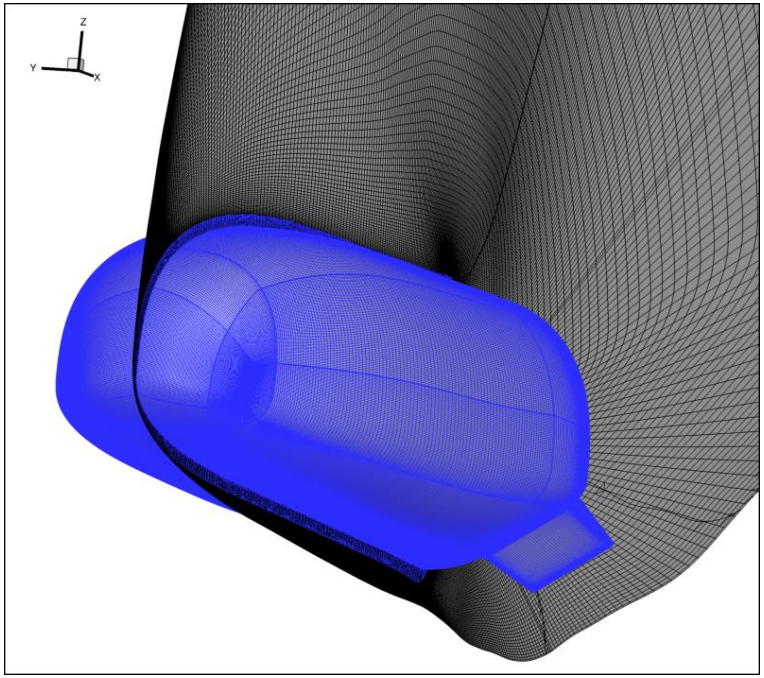


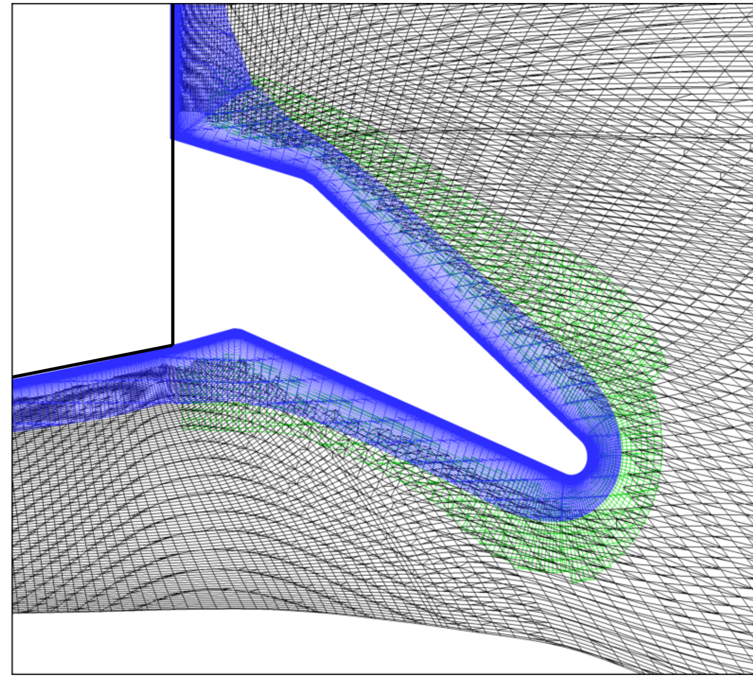
From SUGGAR Users Guide V2.52 by Ralph Noack



Overlapping grids near body flap

Overset *DPLR* Grids





Overset grids for Mid-L/D configuration

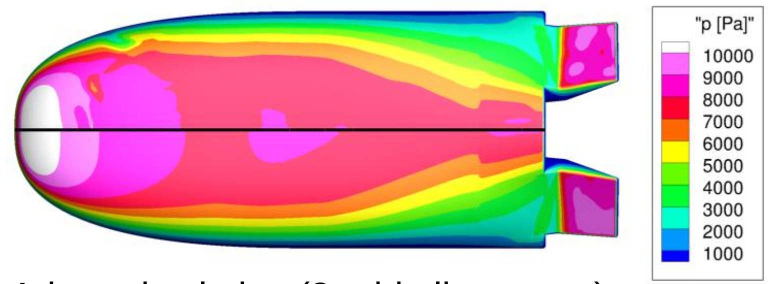
- Hyperbolically generated meshes using Gridgen: point-matched, near-body grids (**blue**); shock-aligned, point-matched background grids (**black**) from a smooth ”no flap” geometry; interface grids in flap region (**green**) to fill gaps between near-body and background grids
- No surface assembly issues because grids are point-matched. No need to “stitch” surface meshes to create a watertight surface for force and moment integrations
- Grid sequencing is straightforward. It was used to reduce the computational costs of running these simulations (2 grid alignments on coarse grid and 1 alignment on fine grid)
- A total of 55 million grid points on the fine grid

Sample Overset *DPLR* Solutions

Overset *DPLR* simulations for Mid-L/D configuration

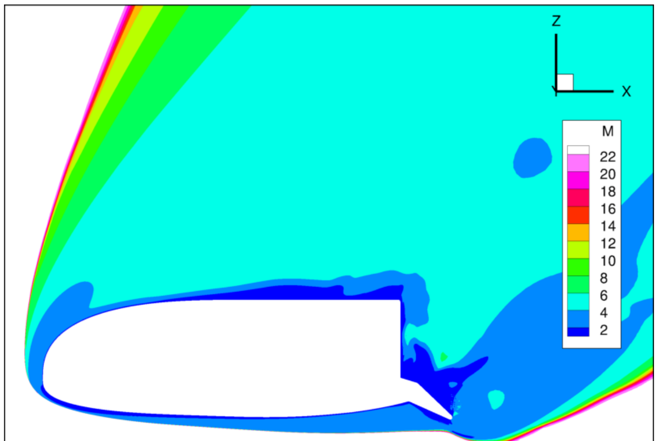
- 27 cases (laminar and turbulent SST for each case)
- 8-species chemistry model for Mars (by Mitcheltree)
- Assuming fully-catalytic CO_2 model and radiative equilibrium at the wall
- Each simulation took around 20 walltime hours using 1,200 cores on NASA's Pleiades system
- Results were time-averaged
- Splitting the wall clustering and grid alignment steps in separate grids allows for better control of the grid adaption process

Initial solution



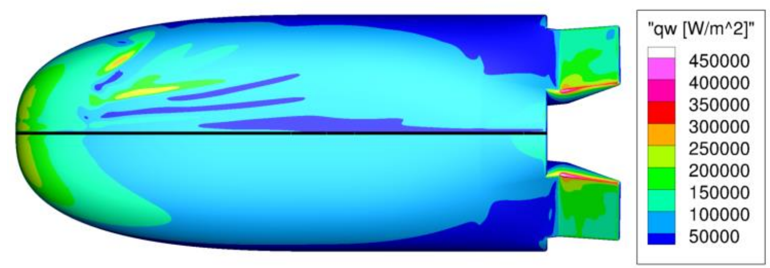
Adapted solution (3 grid alignments)

Surface pressure (laminar)



Mach Contours on adapted grid
(M_∞ = 23.2, H_∞ = 34.72 km, α = 55º)

Initial solution



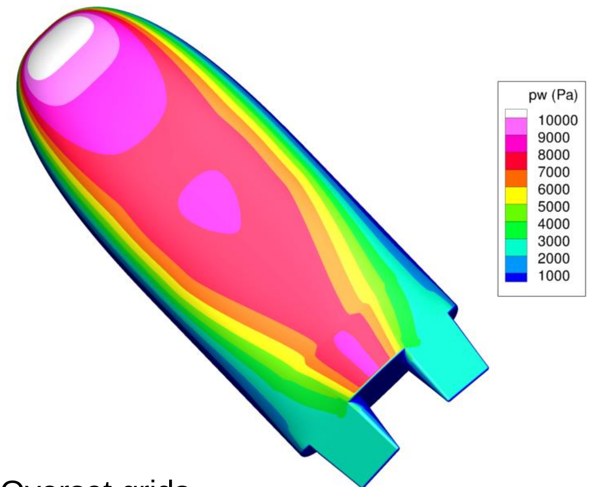
Adapted solution

Surface heat flux (laminar)

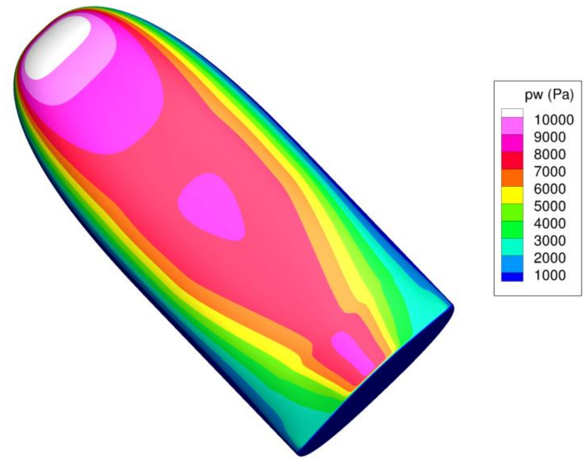
Comparisons between Point-Matched vs. Overset *DPLR* Solutions

M_{∞} = 28.9, H_{∞} = 38.32 km (laminar, $\alpha = 55^{o}$, flap = 0^{o})

Pressure contours

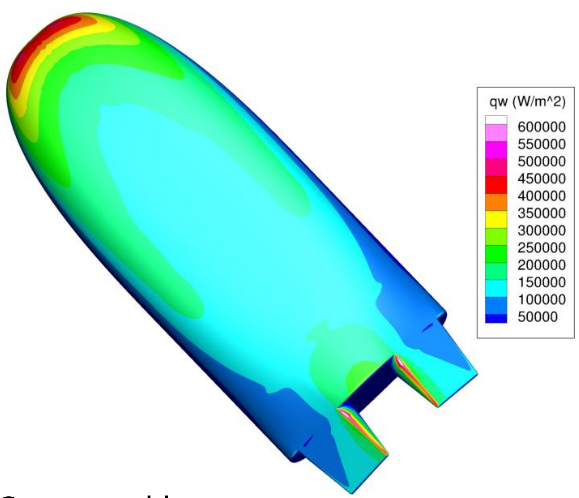


Overset grids

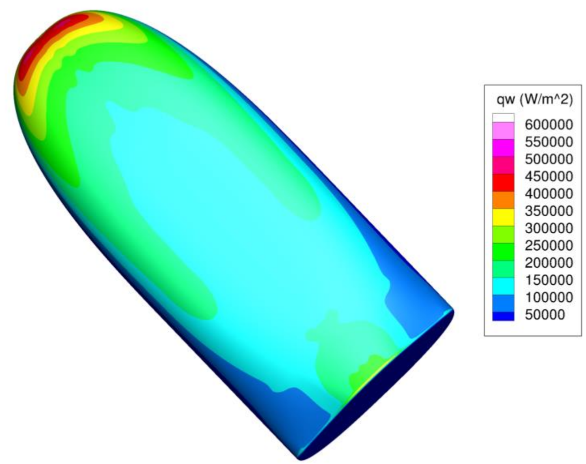


Point-matched grids

Heat flux contours

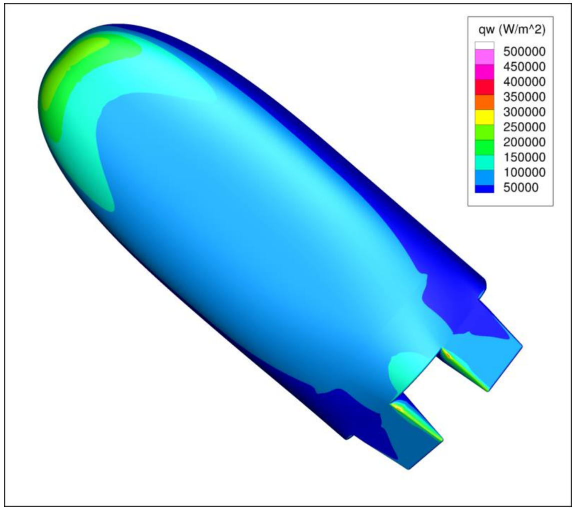


Overset grids

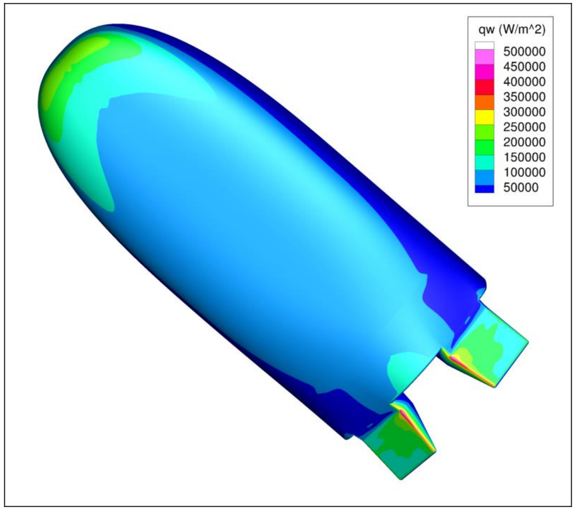


Point-matched grids

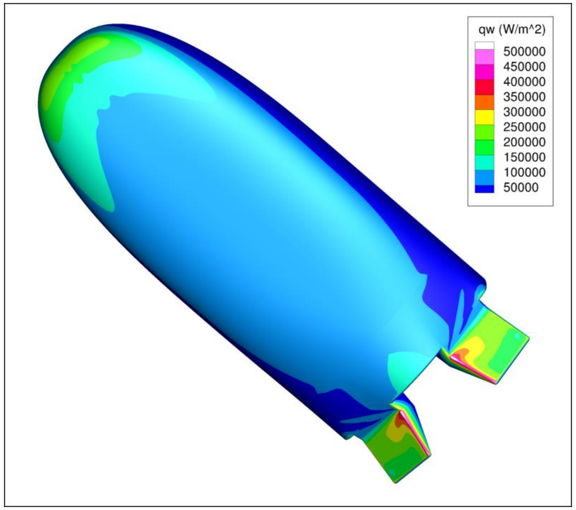
Heat Flux Comparisons (M_∞ = 23.2, H_∞ = 34.72 km, α = 55º, Laminar)



Flap = 0º



Flap = 20º



Flap = 30º

- CFD solutions are used to anchor current aerothermal and aerodynamics databases
  - Anchored aerothermal database used to select materials for the Thermal Protection System (TPS) and to size the TPS thickness
  - Anchored aerodynamics database used to estimate force and moment changes due to flap deflections

Concluding Remarks

- Overset *DPLR* solutions were presented for a Mid-L/D configuration for the DSS program. The overset solutions are in excellent agreement with results from point-matched volume grids
- Proposed overset approach for *DPLR* can significantly reduce the time required (~ 1-2 days) for grid generation on complex geometries
- This process reduces the complexity of hole-cutting and surface assembly issues. This straight-forward approach makes the overset framework more accessible for new users
- Overset grids can be grid sequenced and shock-aligned just like point-matched volume grids so the work flow process is familiar to current *DPLR* users
- Meshes can be added/modified to existing overset grids without major changes to the overall grid topology

Future Work

- Update *DPLR* and software tools for overset grids
  - Modify build-in subroutines in *DPLR* to streamline grid adaptions for overset grids
  - Update post-processing tools (such as the *BLAYER* utility for computing boundary layer quantities) for overset grids
  - Update flow interpolation tools to use iblank information (i.e., only interpolate from active cells)
  - Replace work flow steps developed for *Gridgen* to *Pointwise*

- Extend *NEQAIR* (radiation code) for overset grids

Questions?