RECENT DEVELOPMENTS ON THE X-RAYS APPROACH TO HOLE-CUTTING

William M. Chan

Shishir Pandya

NASA Ames Research Center

11th Symposium on Overset Composite Grids and Solution Technology, Dayton, Ohio, October 15-18, 2012

OVERVIEW

- Recent advances in automation

- A fast approximate wall distance function algorithm for initial hole boundary estimate

- A study on aerodynamic loads sensitivity to hole boundary locations

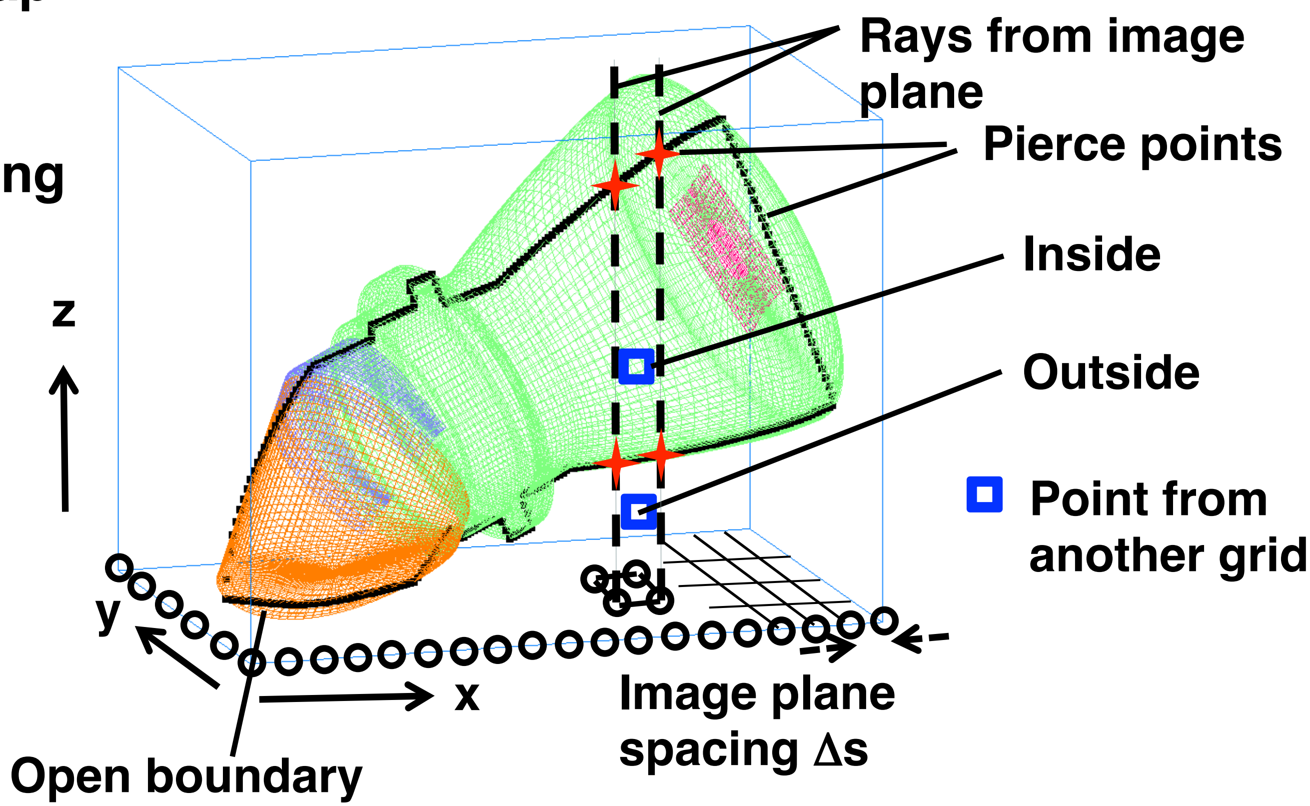
- Summary and conclusions

HOLE-CUTTING METHODS AND SOFTWARE

Methods
- Cartesian hole map
- Line of sight
- X-rays
- Implicit hole-cutting

Software
- PEGASUS5
- OVERFLOW/DCF
- SUGGAR++
- PUNDIT
- OVERTURE

Object X-rays: Meakin, AIAA Paper 2001-2537



- Fast hole cutting
- Low memory

RECENT ADVANCES IN AUTOMATION

Automated

- Closure of component open boundaries to provide proper X-ray pierce points pairing
- Determination of grid points to be cut by each X-ray
- Adaptive image plane map to handle components in close proximity
- Hole boundary adjustment to provide appropriate grid overlap

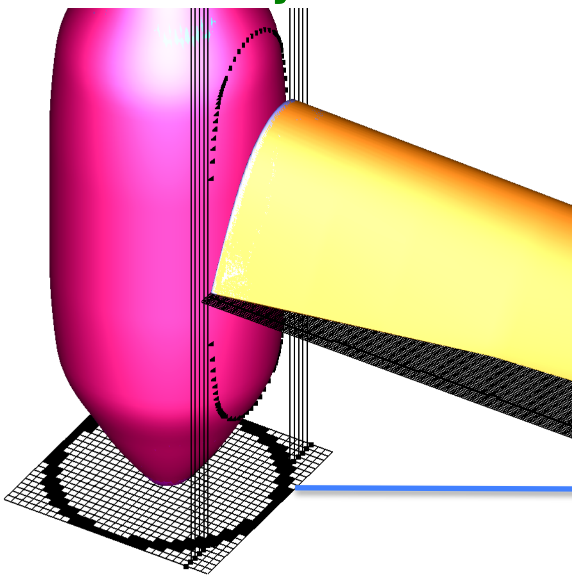
Software

- Chimera Components Connectivity Library (C3LIB)
- Chimera Components Connectivity Program (C3P)
- Input: flow solver boundary conditions, component ID on solid walls
- Output: X-ray maps, hole point locations, fringe point interpolation stencils

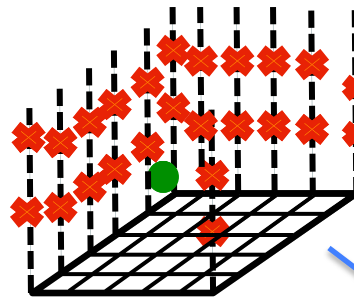
Chan, W. M., Kim, N., Pandya, S. A., Advances in Domain Connectivity for Overset Grids Using the X-rays Approach, Paper ICCFD7-1201, 7th International Conference on Computational Fluid Dynamics, Big Island, Hawaii, July, 2012 (http://www.iccfd.org/iccfd7).

ADAPTIVE X-RAYS FOR MINIMUM HOLE

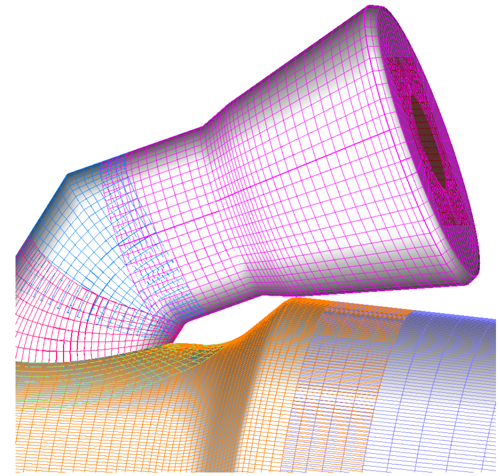
Proximity in X and Y

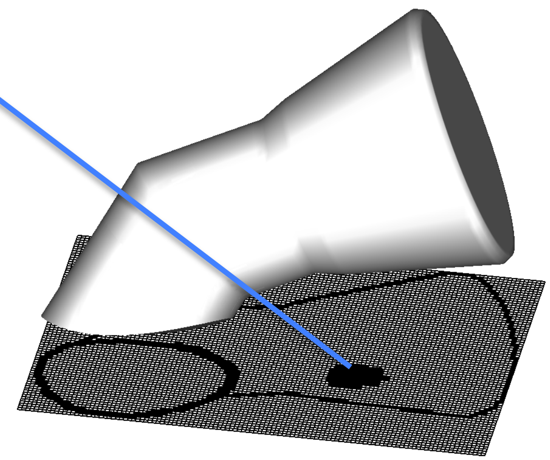


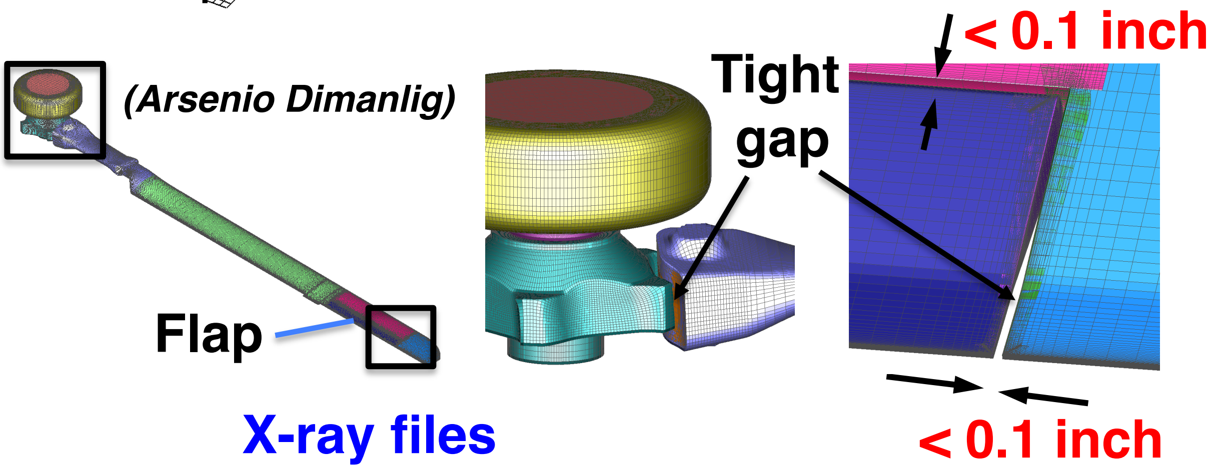
Each refined cell contains a secondary X-ray map



Proximity in Z







X-ray files

Original: 57 manual Xrays, 186 MB
Adaptive: 3 auto Xrays, 63 MB

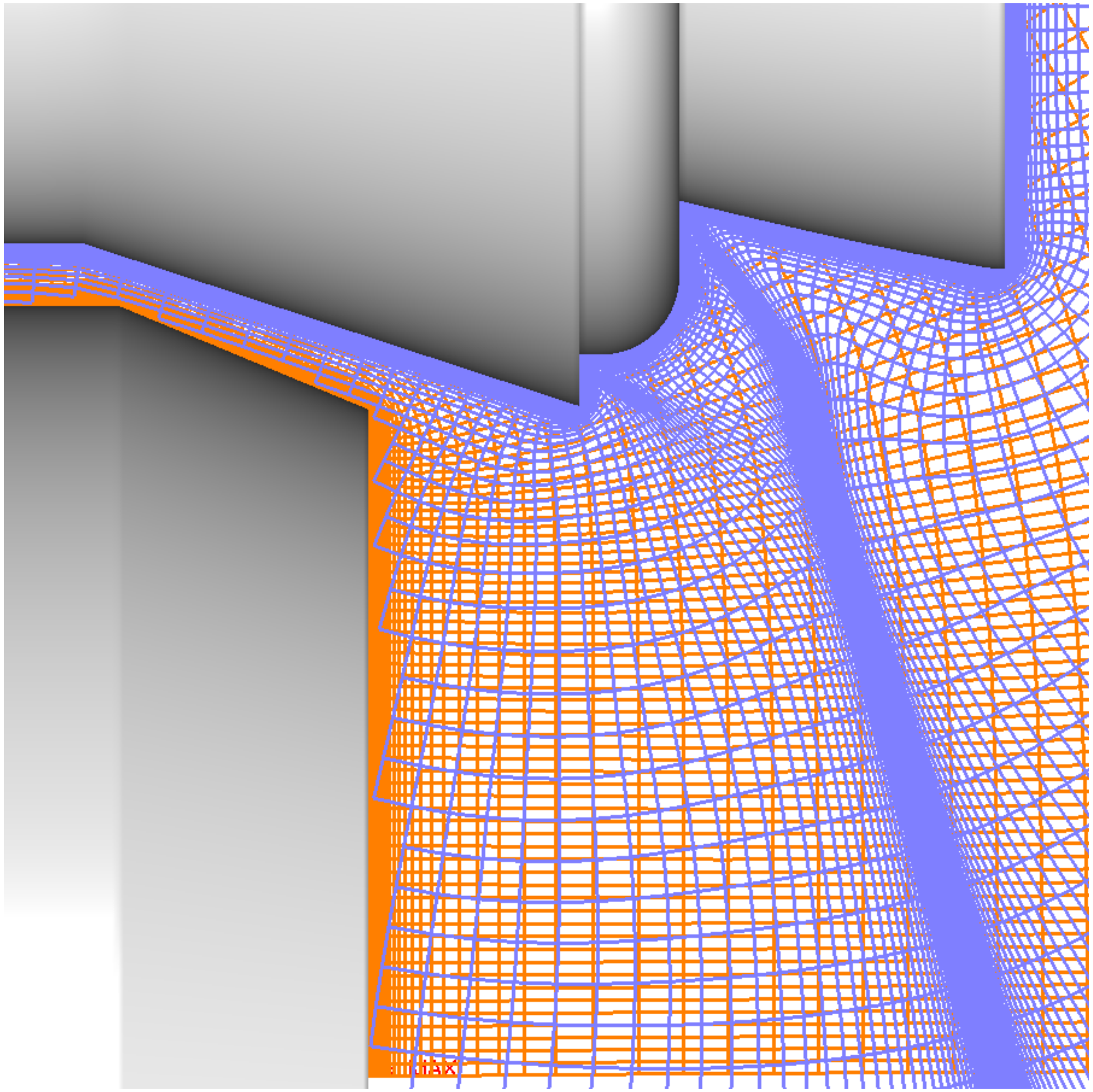
X-ray files

Original = 15.3 MB
Adaptive = 2.9 MB

Ames Research Center

AUTOMATED HOLE BOUNDARY ADJUSTMENT

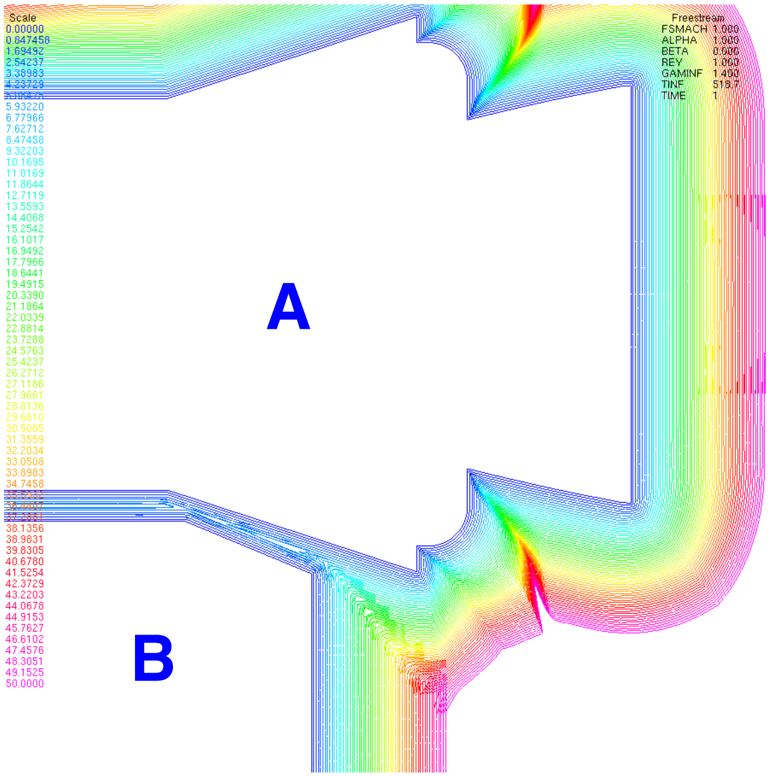
Minimum Hole Cut from Adaptive X-rays

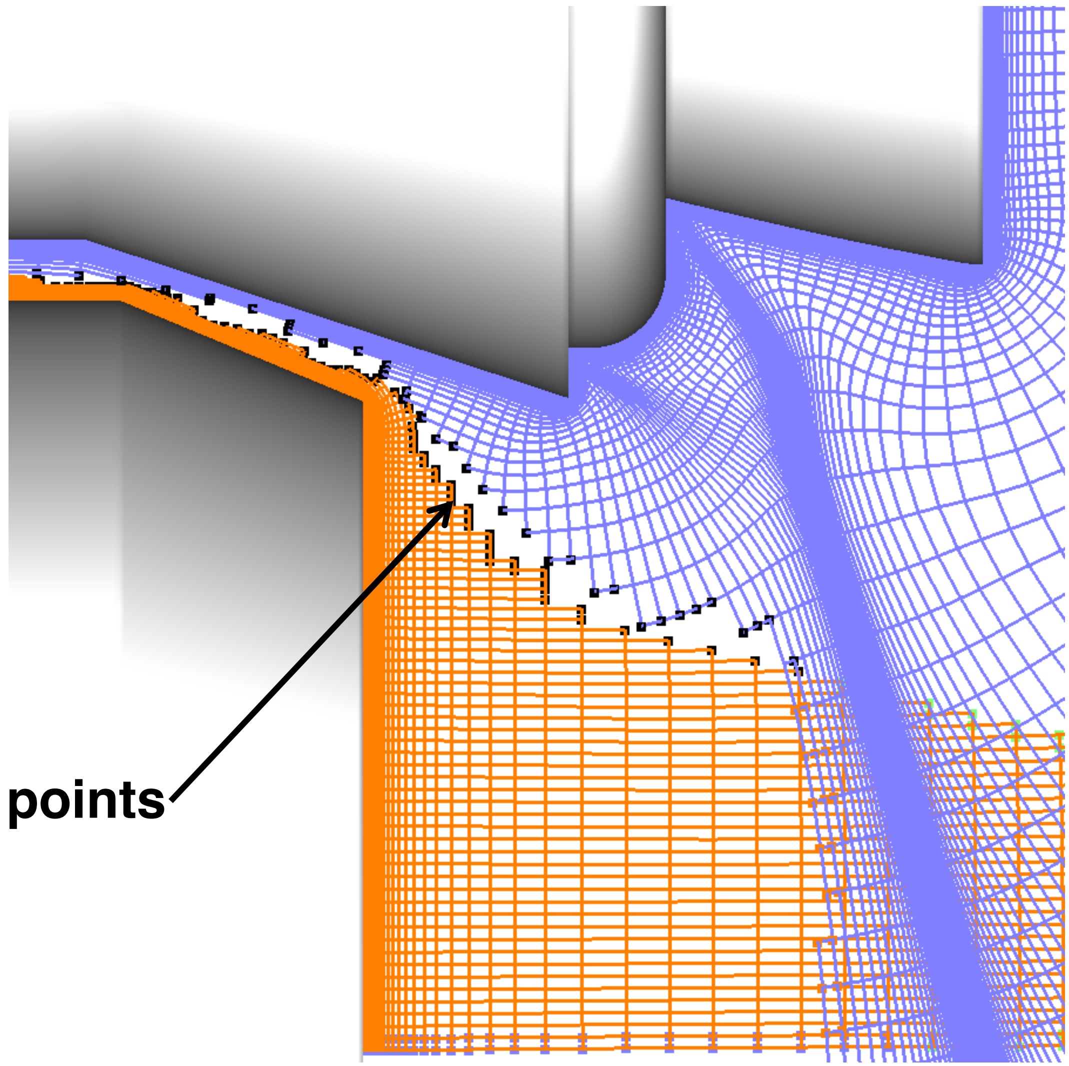


Ames Research Center

AUTOMATED HOLE BOUNDARY ADJUSTMENT

Initial Hole Boundary Estimate Using Wall-Distance Function



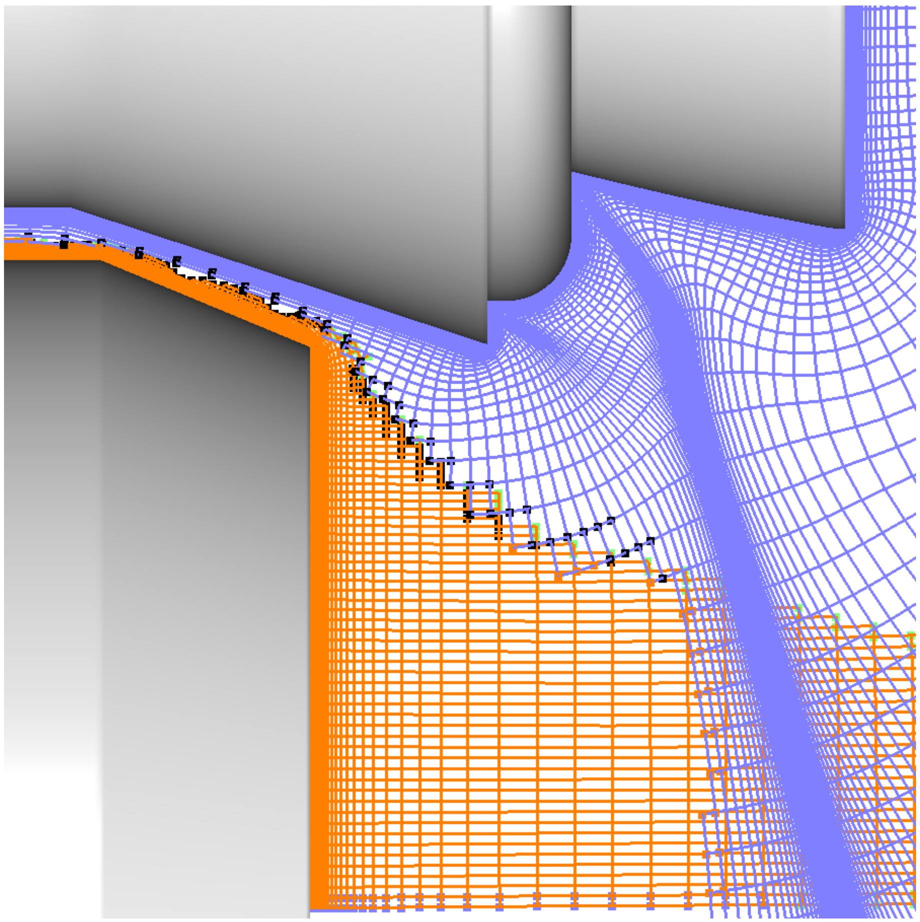


May result in orphan points

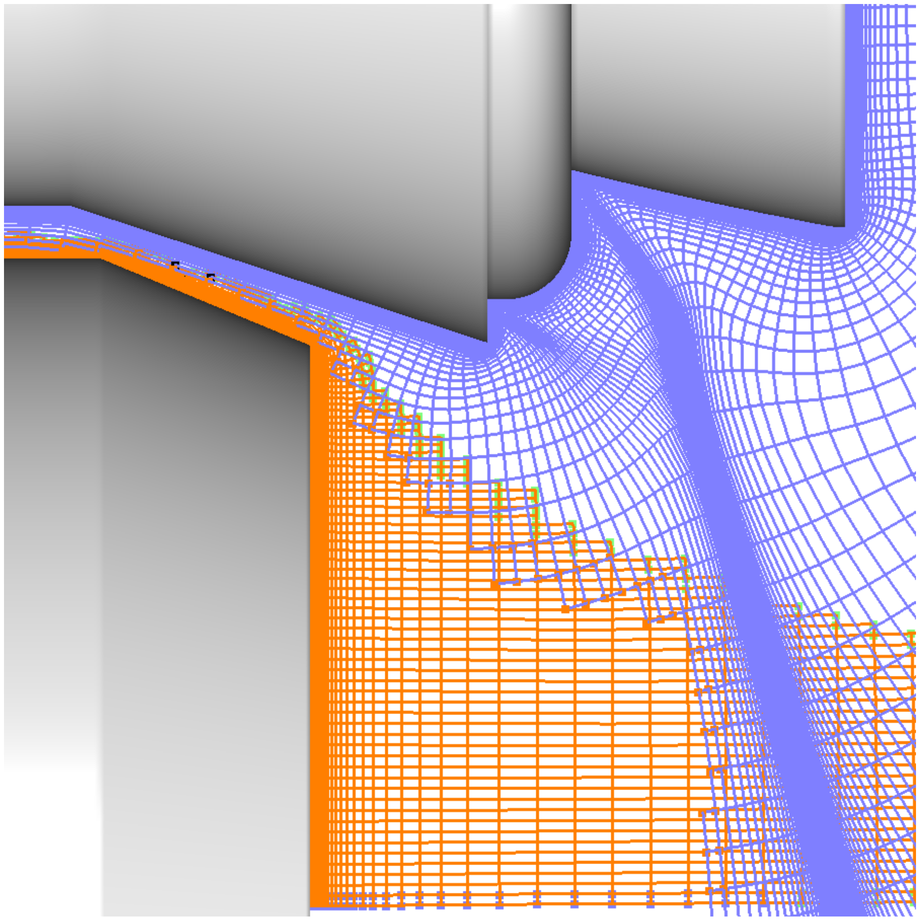
Ames Research Center

AUTOMATED HOLE BOUNDARY ADJUSTMENT

Orphan Removal Iterations



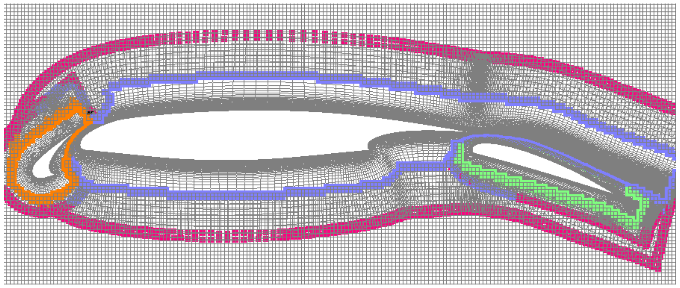
After 1 step

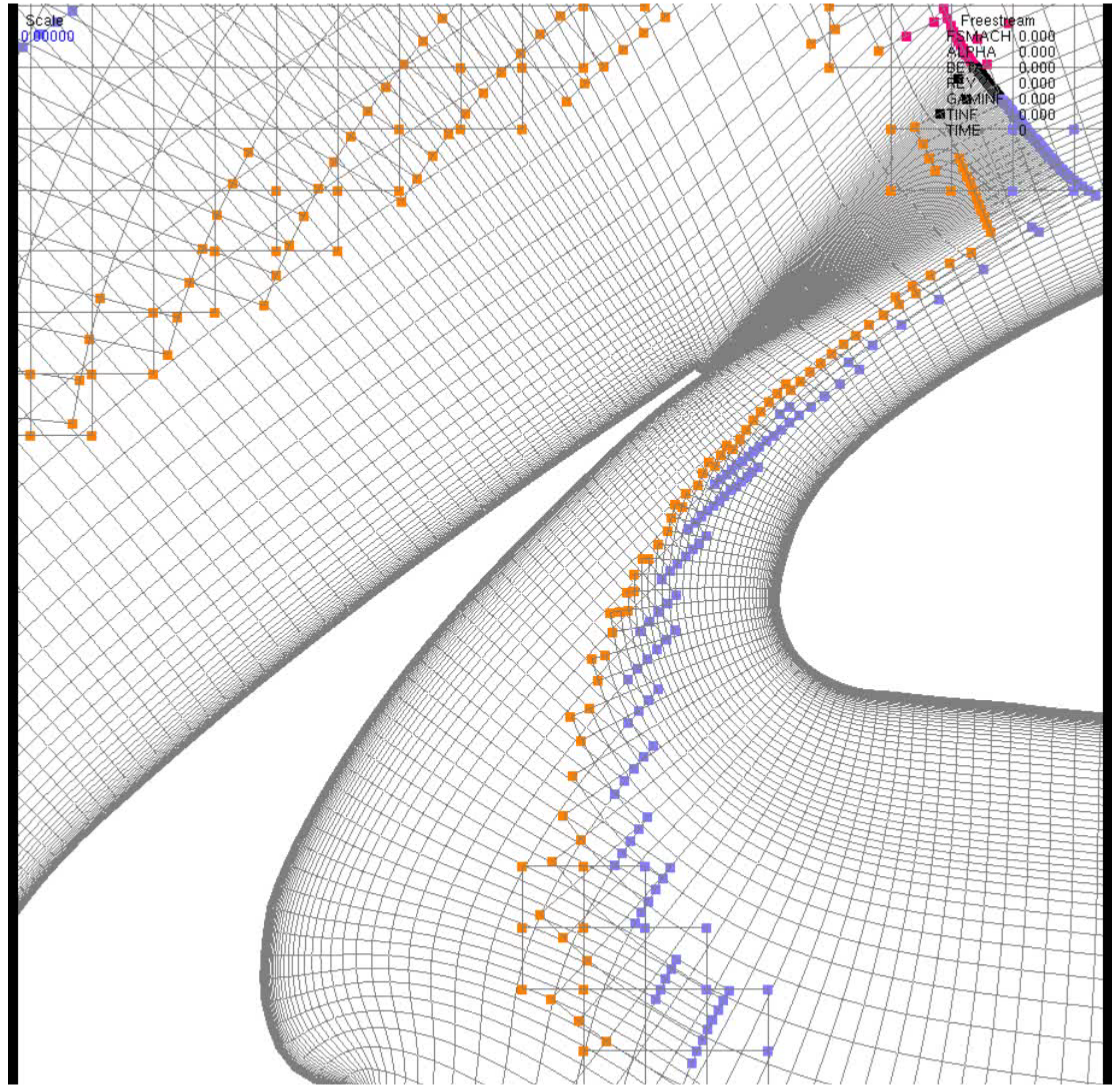


After 3 steps

Ames Research Center

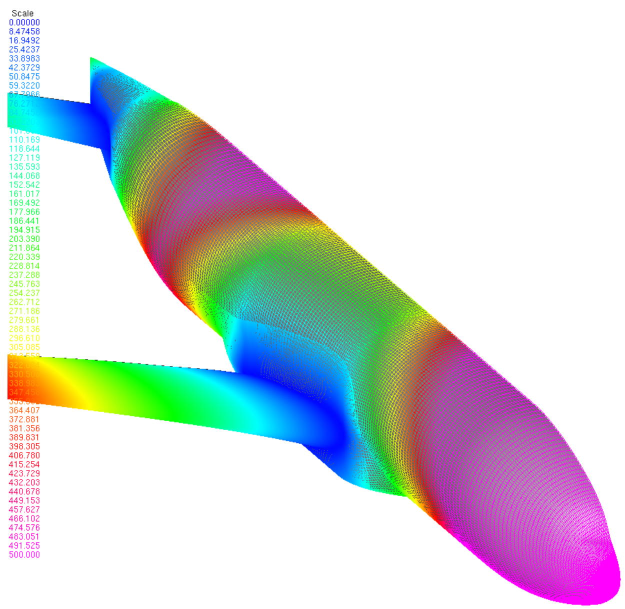
UNSTEADY 2-D HIGH-LIFT SYSTEM (SLAT REGION)





Spatially variable offset during relative motion simulation

OBJECTIVES OF CURRENT WORK



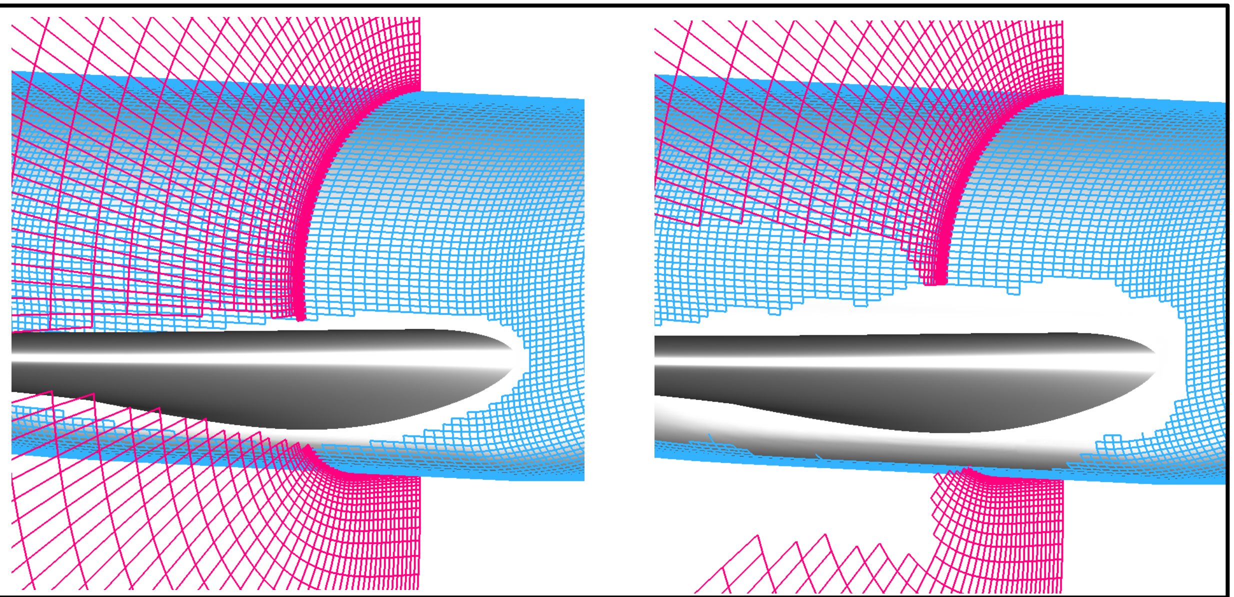
Composite wall distance function is needed to cut holes between components on surface but was expensive to compute

Domain connectivity CPU time
OVERFLOW/DCF = 68 sec.
C3P = 107 sec. (54 sec. on computing composite wall distance function)

Investigate faster algorithms

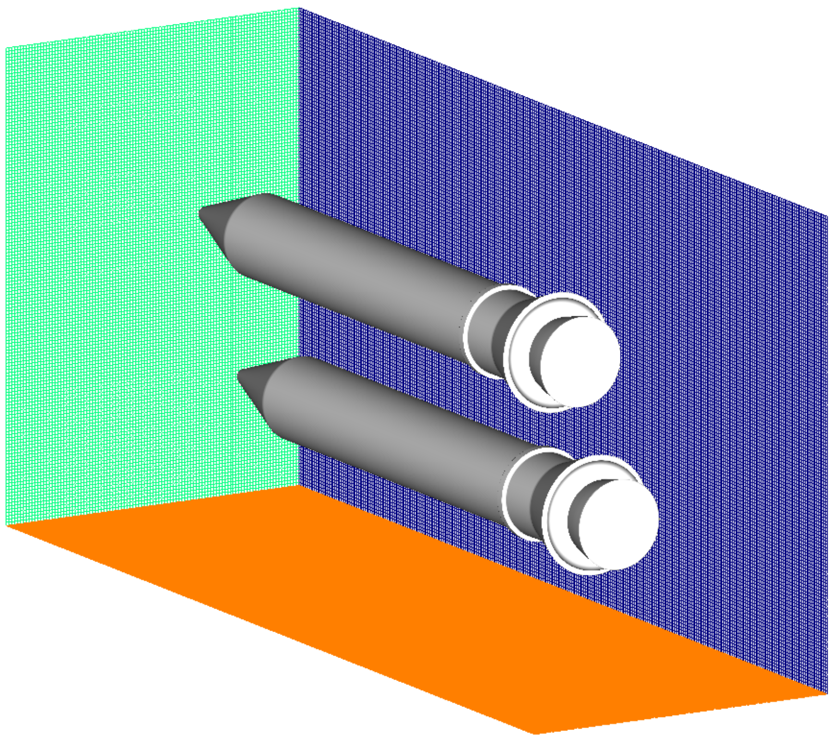
Manually specified or automatically created hole boundaries can have varying locations

Investigate sensitivities of aero load values and convergence rates

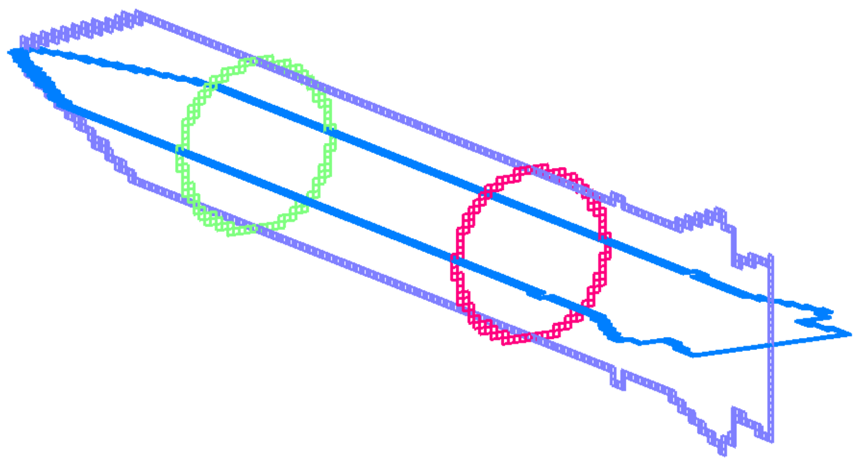


Ames Research Center

FAST APPROXIMATE COMPOSITE WALL DISTANCE FUNCTION COMPUTATION (1)

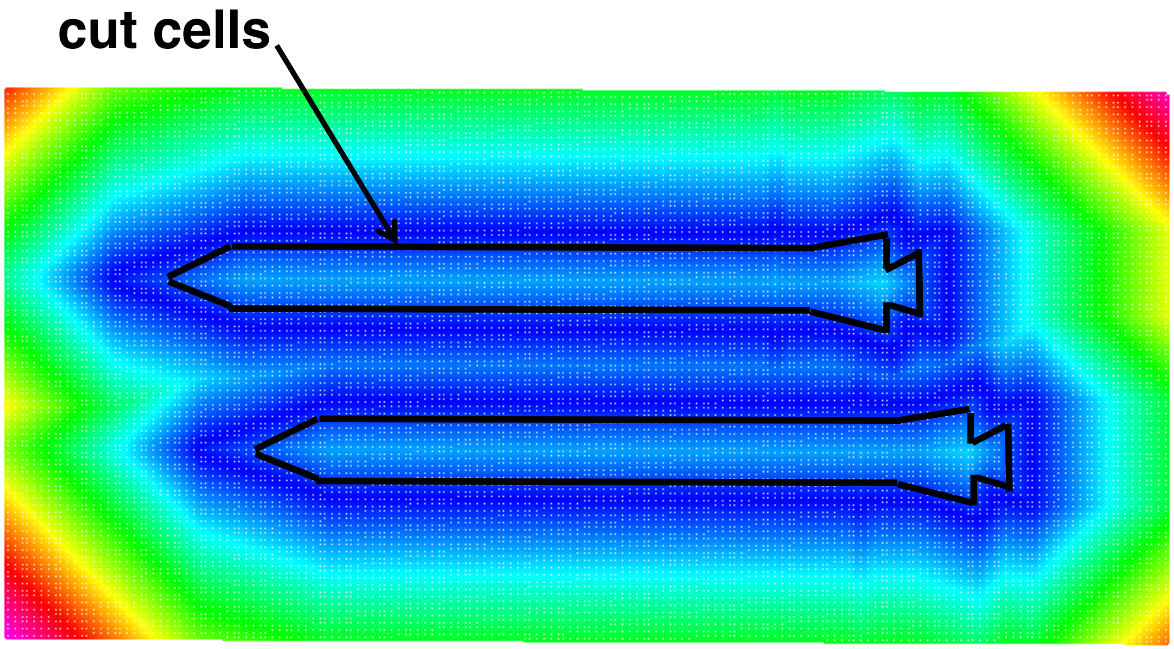


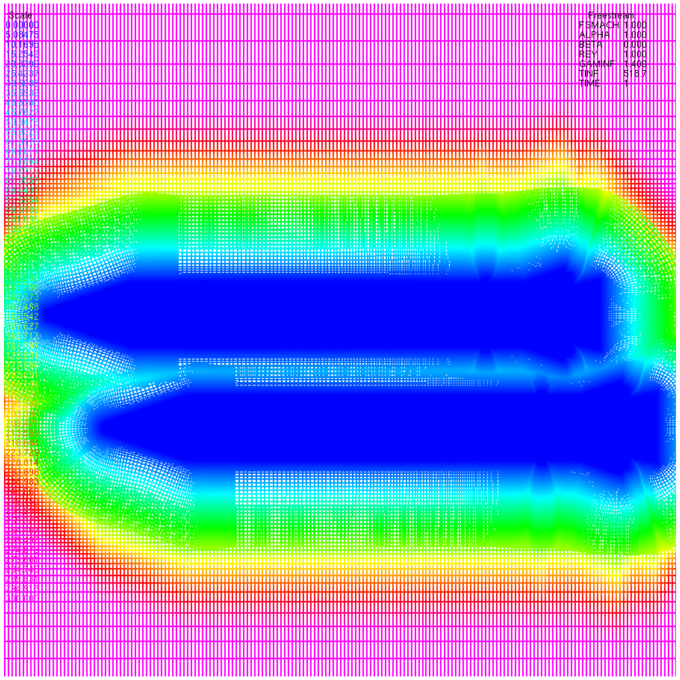
Construct uniform reference Cartesian grid around near-body volume grids



Identify cut-cells for each component

FAST APPROXIMATE COMPOSITE WALL DISTANCE FUNCTION COMPUTATION (2)





Determine accurate wall distance for vertices on cut-cells. Fill approximate wall distance for remaining vertices with Fast Marching Method

Interpolate wall distance from reference Cartesian grid onto original volume grids

DOMAIN CONNECTIVITY CPU TIME COMPARISONS

Not load balanced for connectivity
OVERFLOW/DCF (original) – 8 MPI processes
C3P (improved) – 8 OpenMP threads

Test Case	# Grid pts ($x10^6$)	OVERFLOW/DCF	C3P
XV-15	10.0	0.8 min.	0.7 min. (-12.5%)
DPW4	16.8	1.2 min.	1.5 min. (+25%)
2 Rockets	24.5	1.0 min.	0.6 min. (-40%)
D8	77.7	11.5 min.	6.0 min. (-48%)

Number of wall-distance function computations needed for connectivity

OVERFLOW/DCF	C3P
0	N

N = number of components

Ames Research Center

AERODYNAMIC LOADS SENSITIVITY STUDY

Objectives

Investigate correlation between component aerodynamic loads (values and convergence) with

- hole boundary offset distance
- cell attribute compatibility between fringe point and interpolation stencil

Approach

- Define a normalized hole boundary offset distance and a cell attribute compatibility measure
- Compute solution on test cases with different normalized hole boundary offset distances
  - Single capsule
  - Two rockets
  - 4th AIAA Drag Prediction Workshop Common Research Model
  - D8 Double Bubble Aircraft

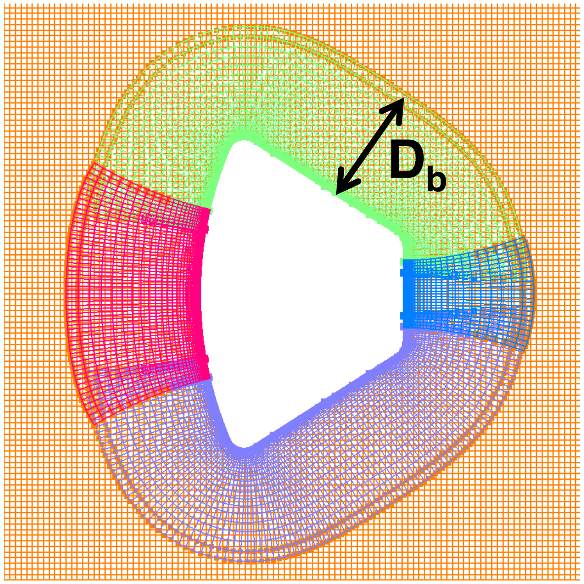
NORMALIZED HOLE BOUNDARY OFFSET DISTANCE

Hole in off-body grids

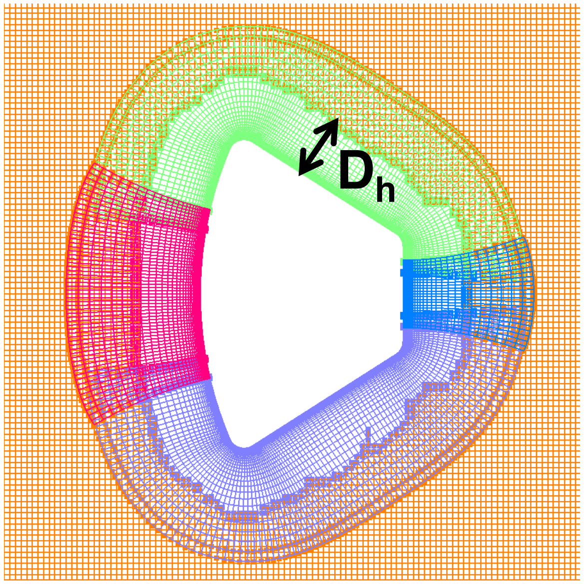
Define normalized hole boundary offset distance $\delta = D_h / D_b$

Hole in near-body grids

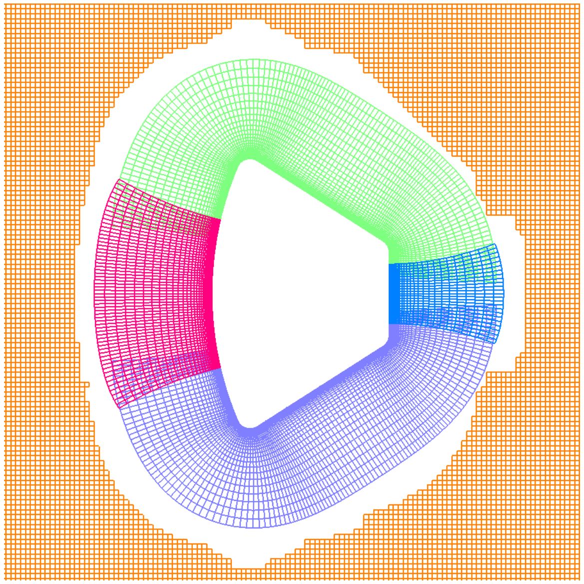
Define similar δ based on min distance between components



$\delta = 0.0$



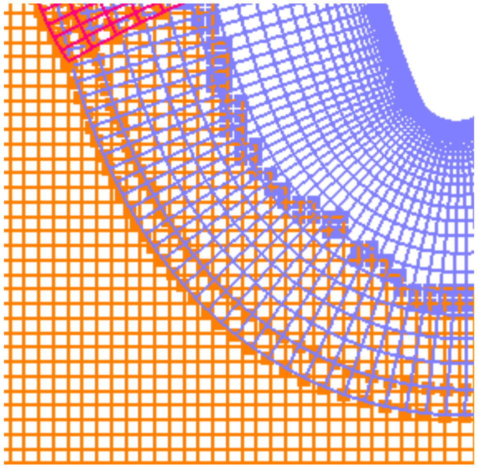
$\delta = 0.5$



$\delta > 1.0$

CELL ATTRIBUTE COMPATIBILITY

Possible measures: cell volume, aspect ratio, orientation



Current simple measure:

Let V_f = cell volume at fringe point
V_i = cell volume at interpolation stencil

Local compatibility measure $c = \min(V_f / V_i , V_i / V_f)$

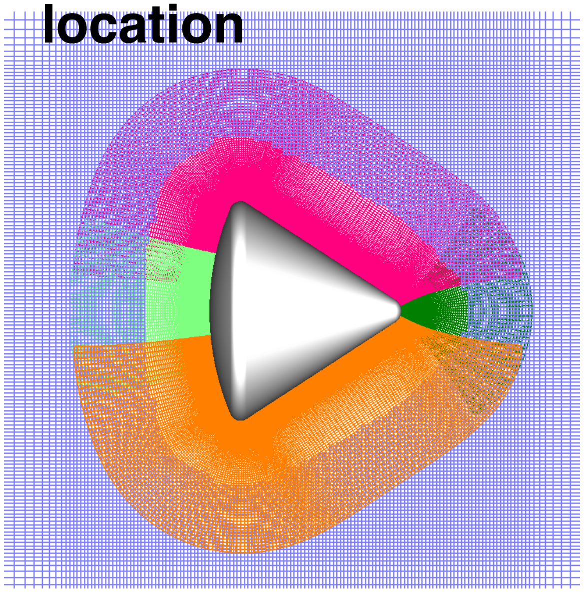
Global cell size compatibility C = average c over all fringe points (orphan points get value zero)

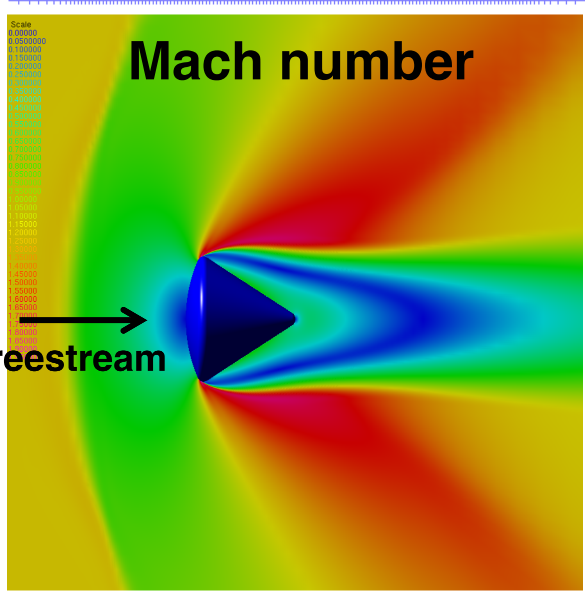
(all fringes are orphans) $0 \leq C \leq 1$ (ideal compatibility)

SINGLE CAPSULE

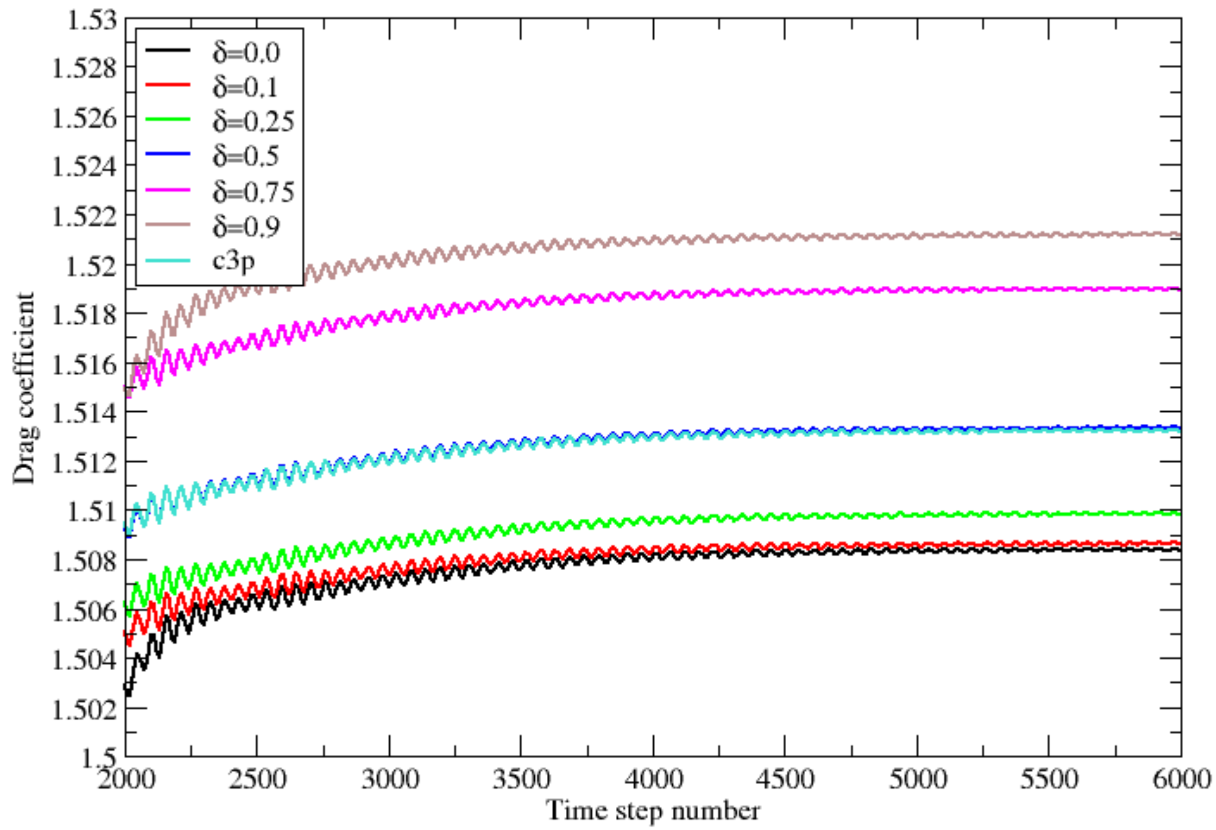
M=1.2, α=180.0, Re/in.=18200

C3P hole boundary location





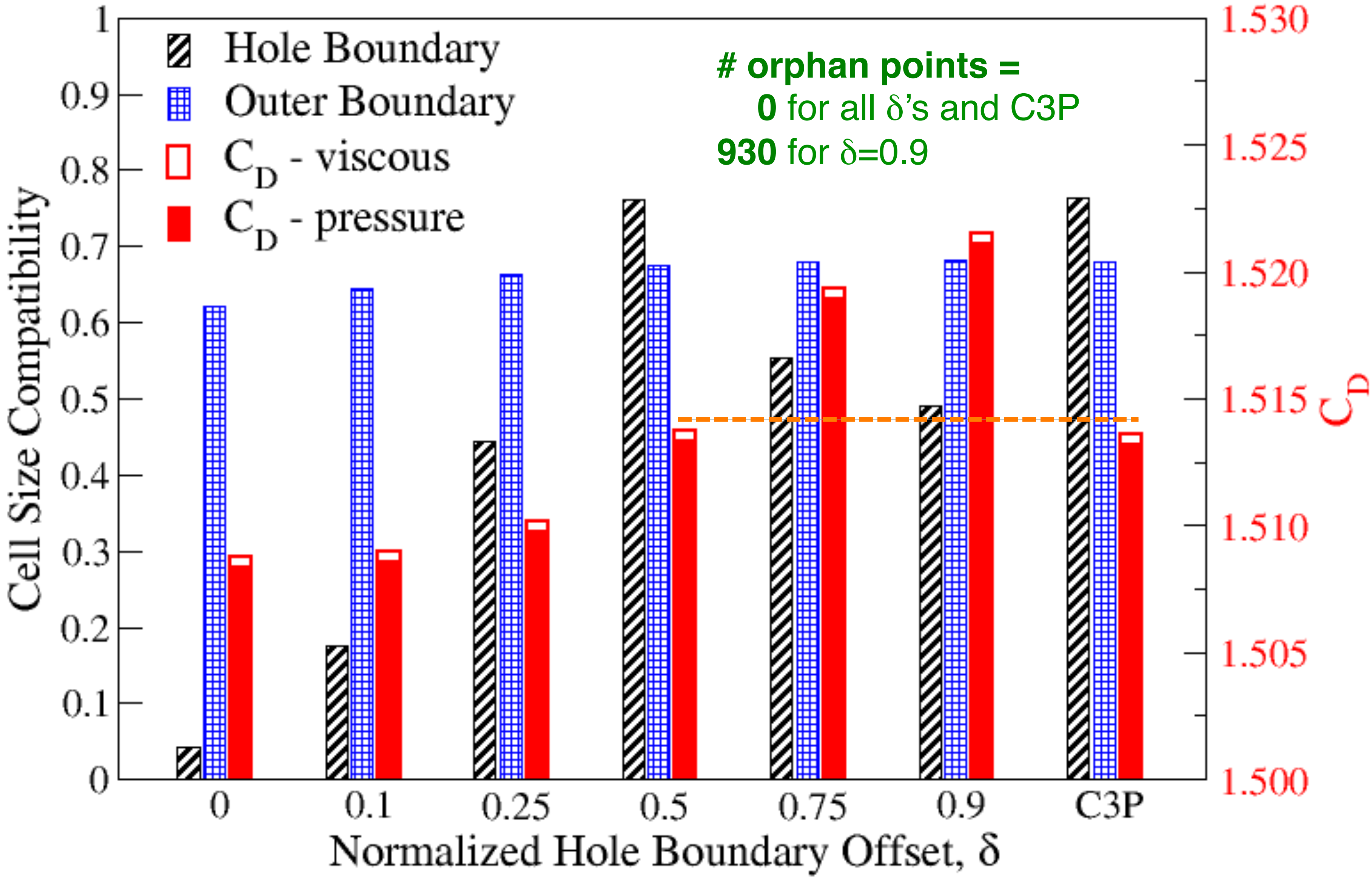
Drag coefficient convergence history



Converged value variation from δ=0.5:
-0.3% to +0.5%
Convergence is similar for all cases

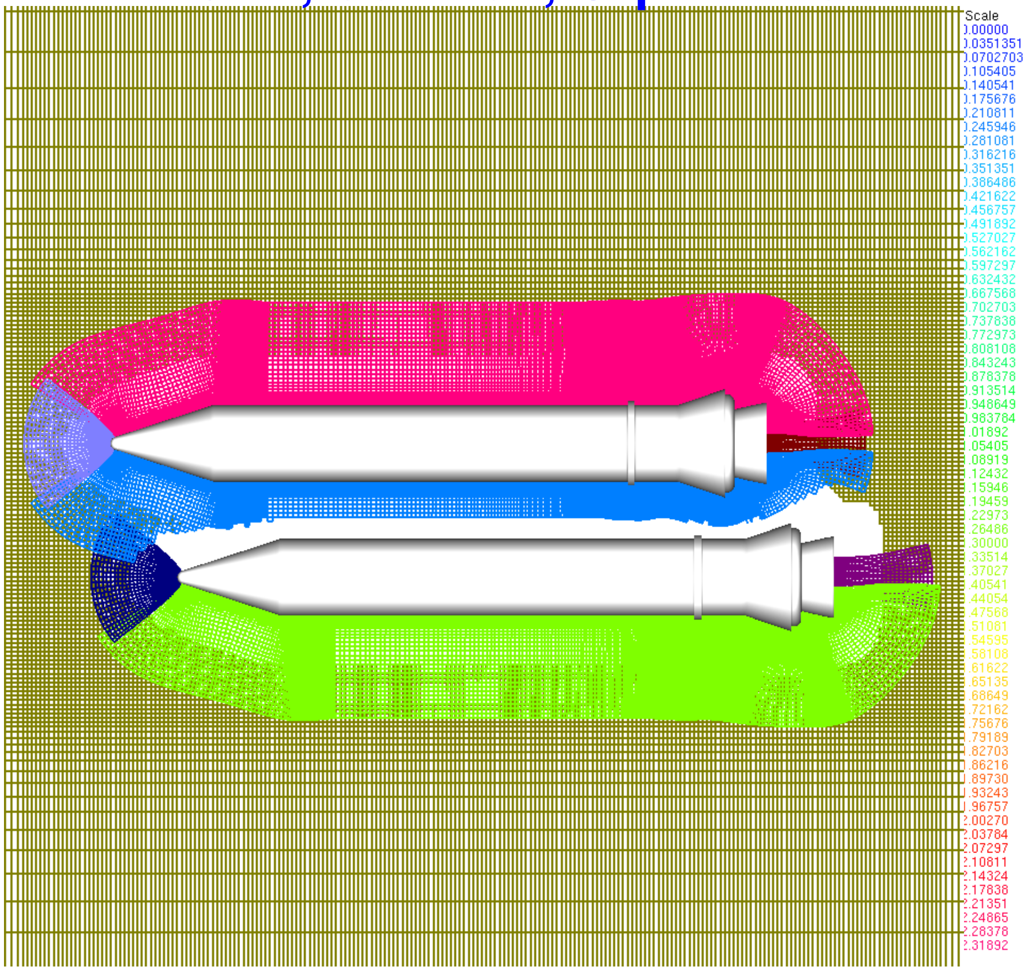
SINGLE CAPSULE

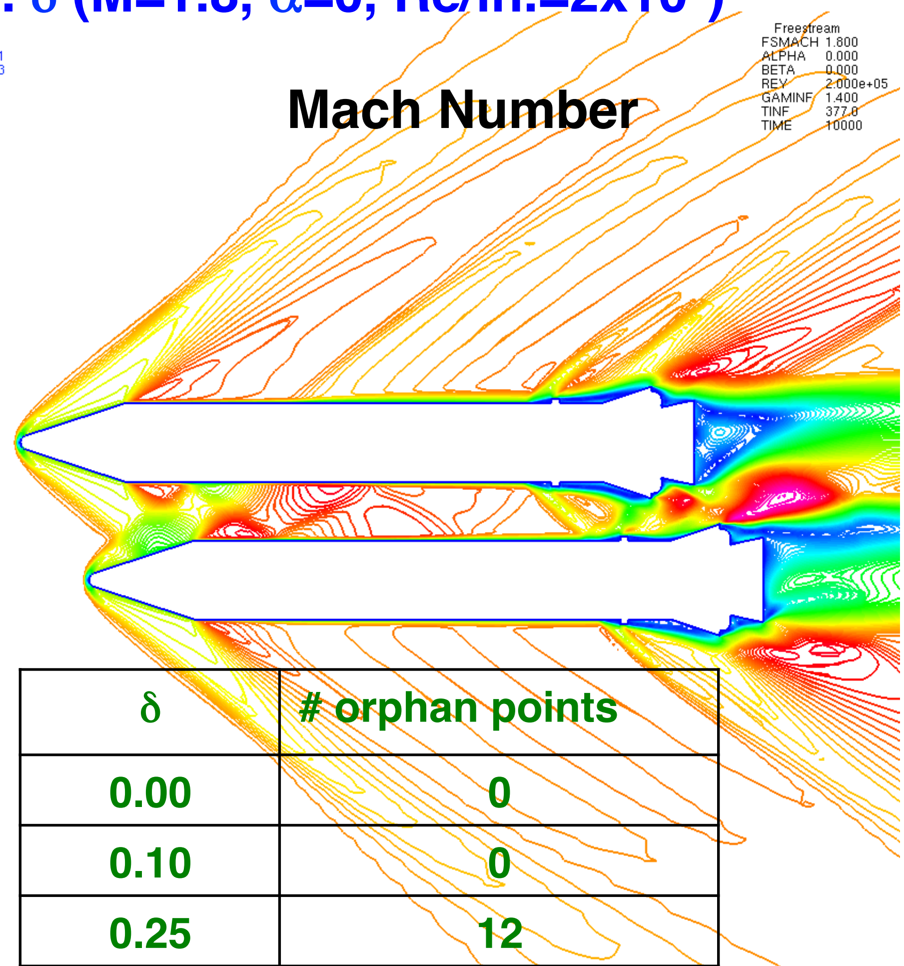
Cell Size Compatibility and Converged C_D for different δ's



TWO ROCKETS

Grid, Solution, Orphan Points Vs. δ (M=1.8, α=0, Re/in.=2x10^5)



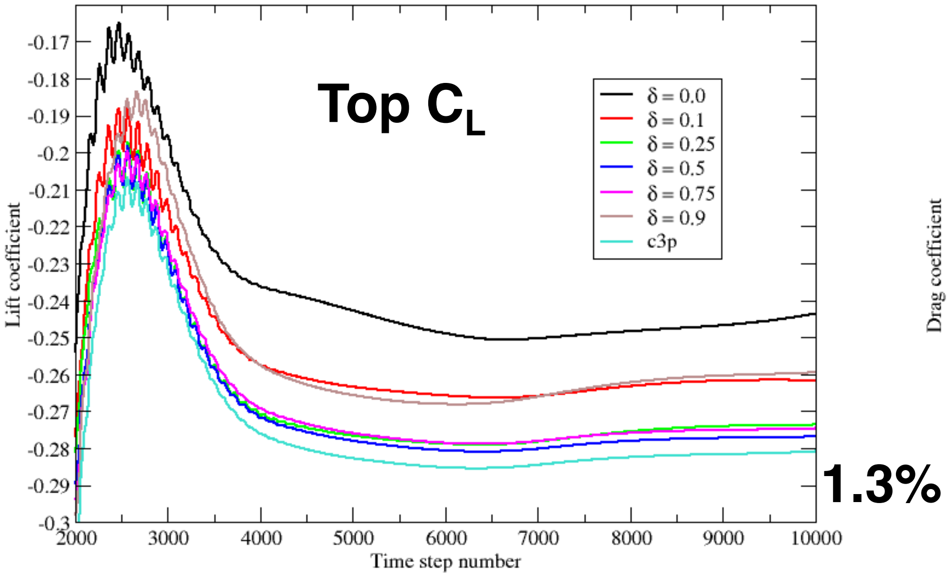


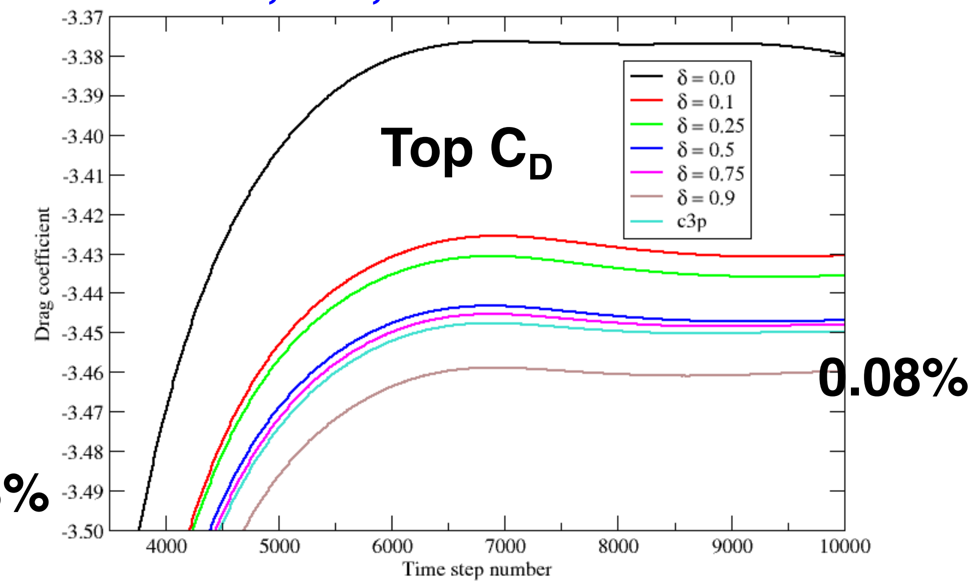
δ	# orphan points
0.00	0
0.10	0
0.25	12
0.50	136
0.75	1091
0.90	35149
C3P	1

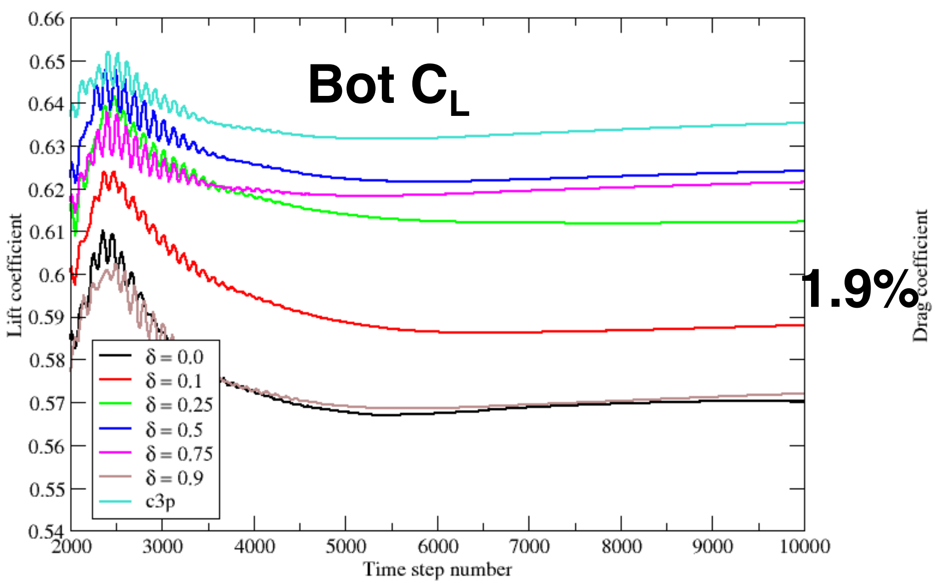
Ames Research Center

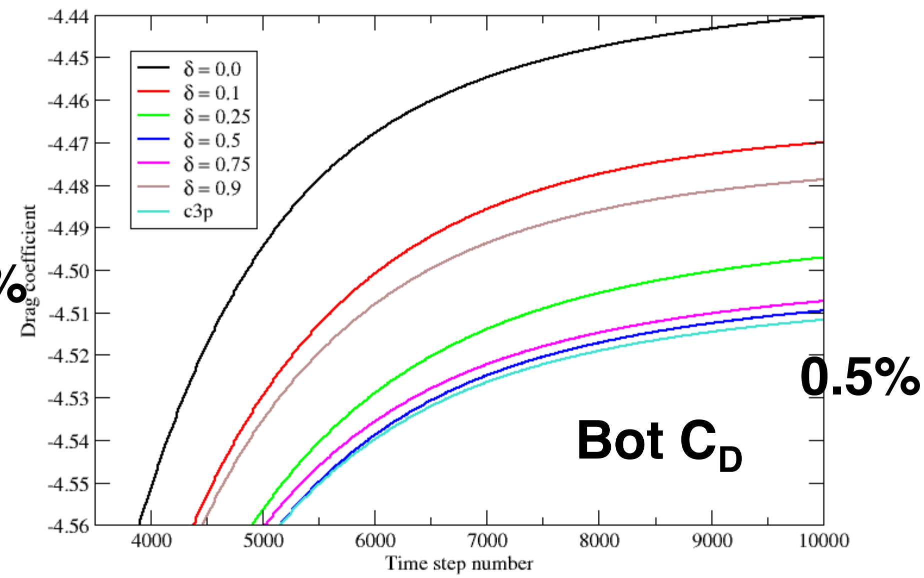
TWO ROCKETS

Lift and Drag Convergence Histories and Deviations from Group Mean for δ=0.25, 0.5, 0.75 and C3P



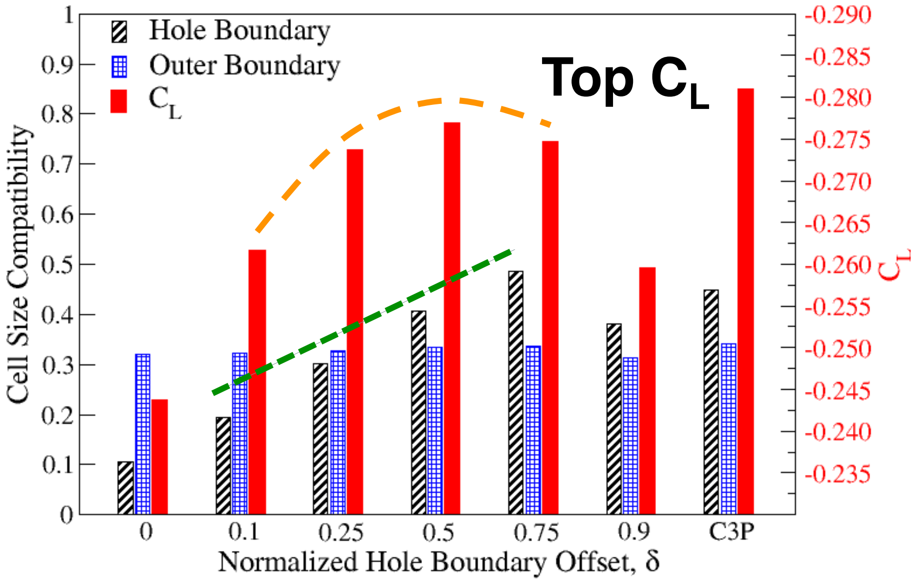


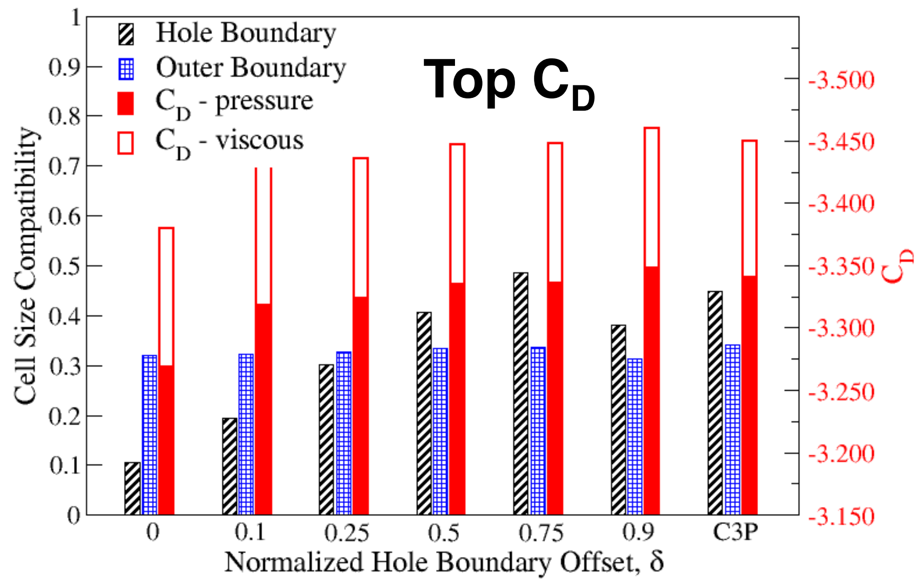


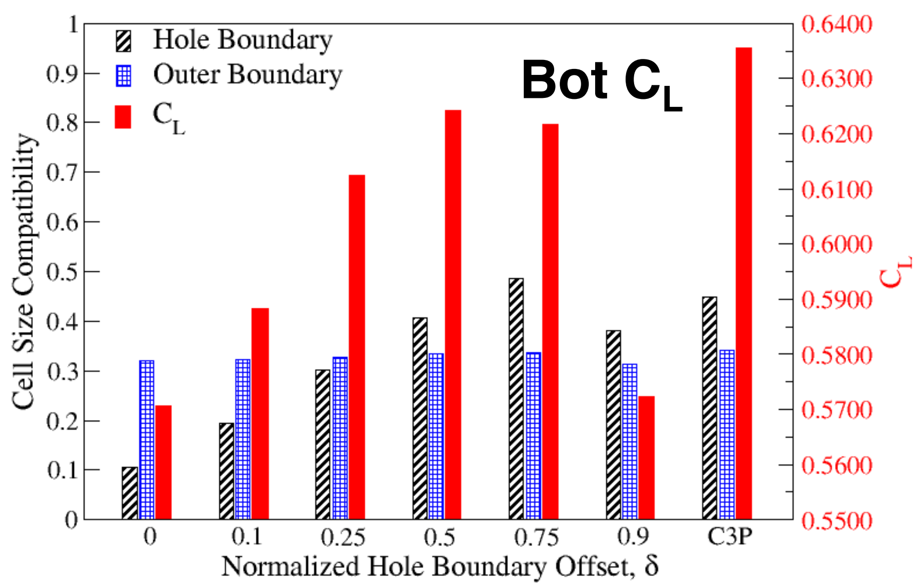


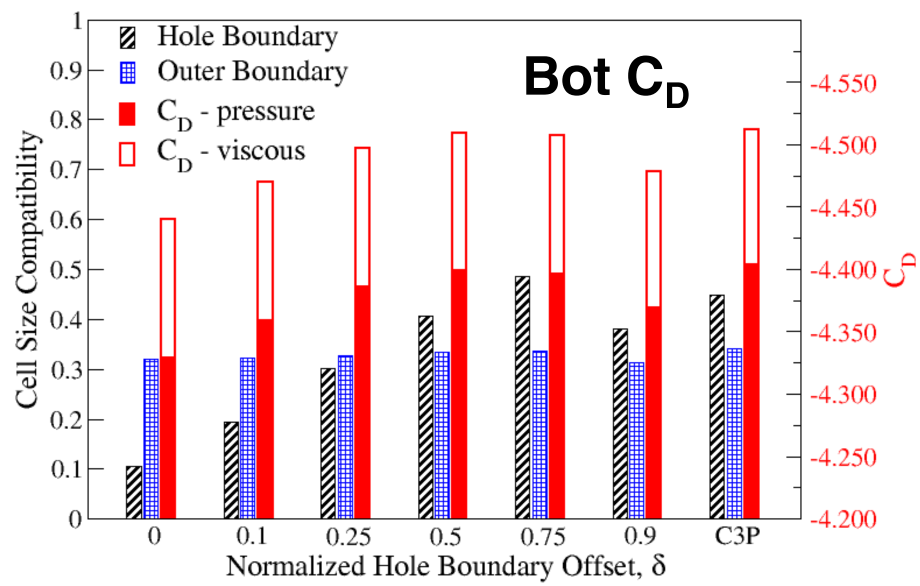
Ames Research Center

TWO ROCKETS
Cell Size Compatibility, C_L, C_D for different δ's





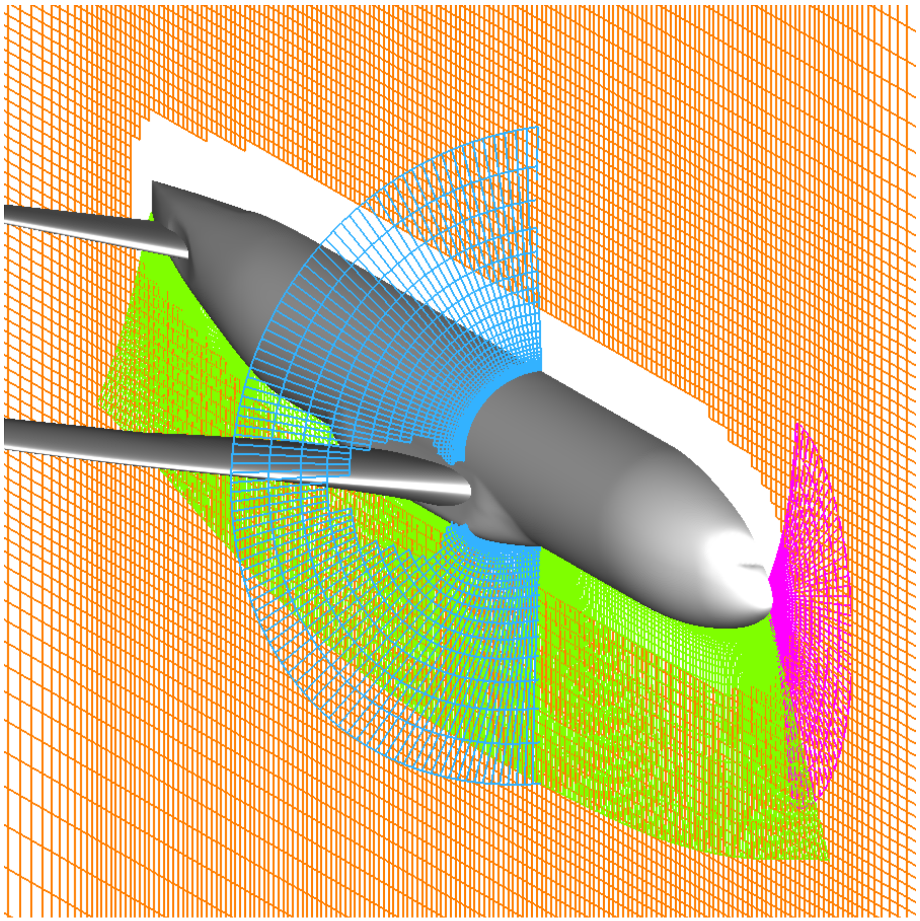




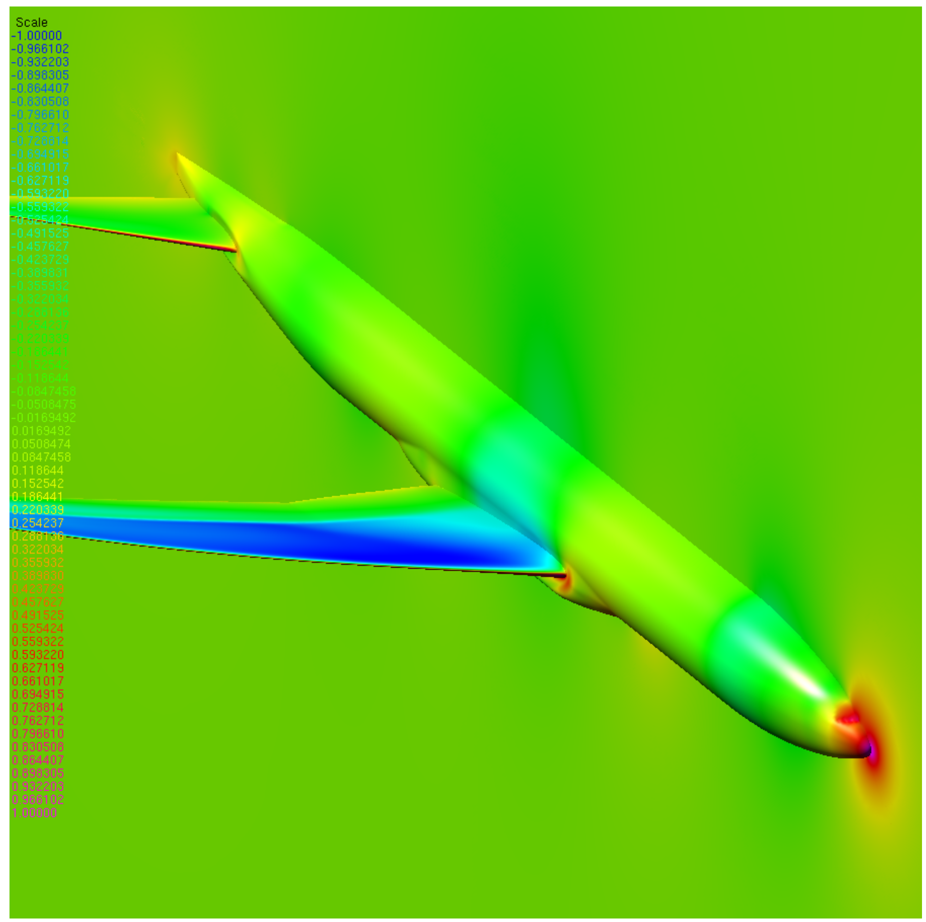
Ames Research Center

AIAA 4TH DRAG PREDICTION WORKSHOP CRM
Grid and Solution (M=0.85, α=2.363 deg., Re/in.=18129.08)

Hole Boundaries from C3P



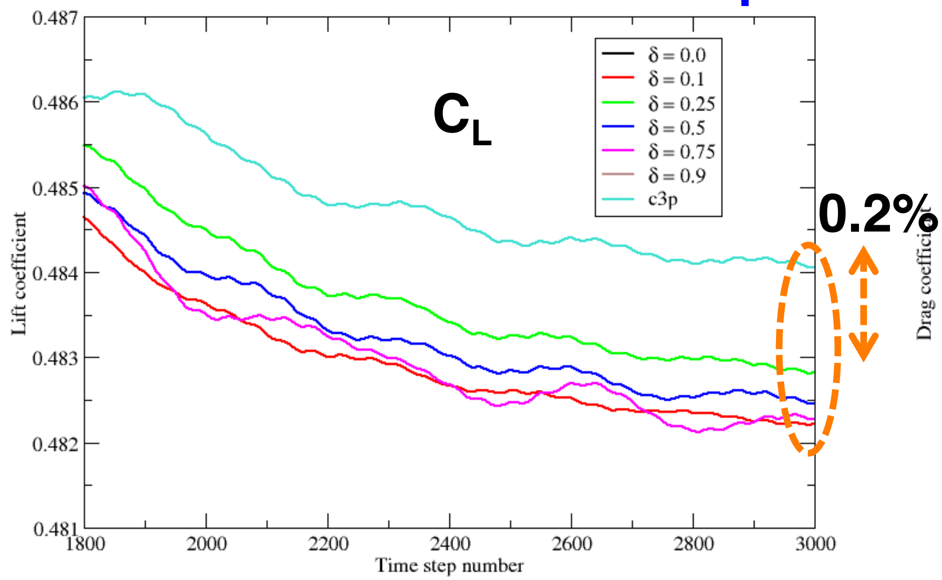
Pressure Coefficient

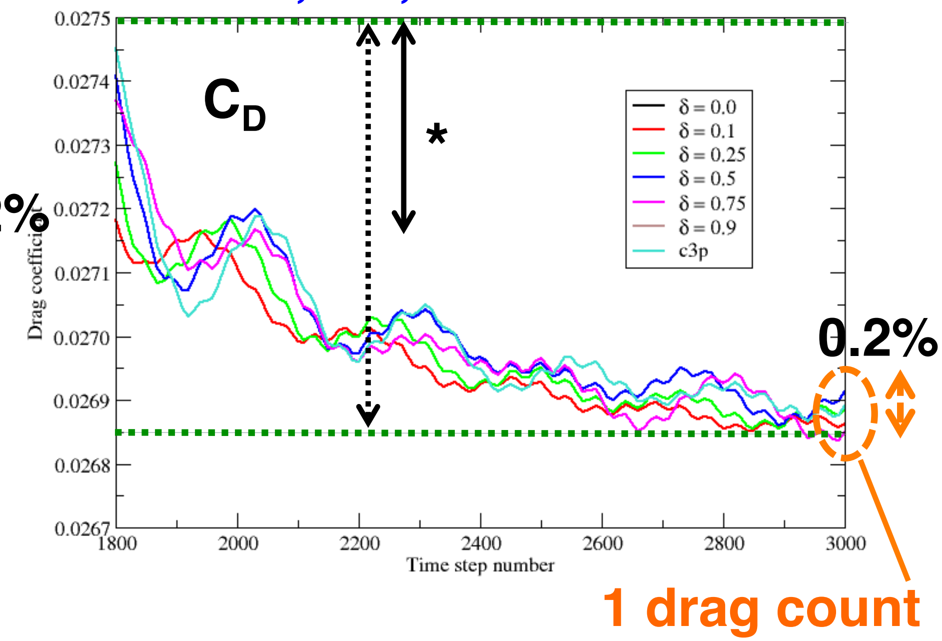


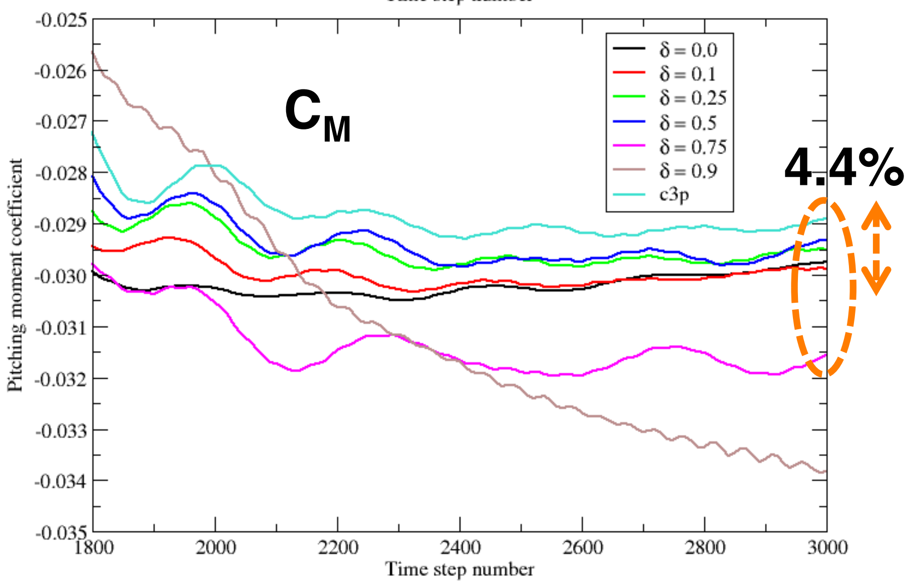
Ames Research Center

AIAA 4TH DRAG PREDICTION WORKSHOP CRM

C_L, C_D, C_M Convergence Histories and Deviations from Group Mean for δ=0.25, 0.5, 0.75 and C3P







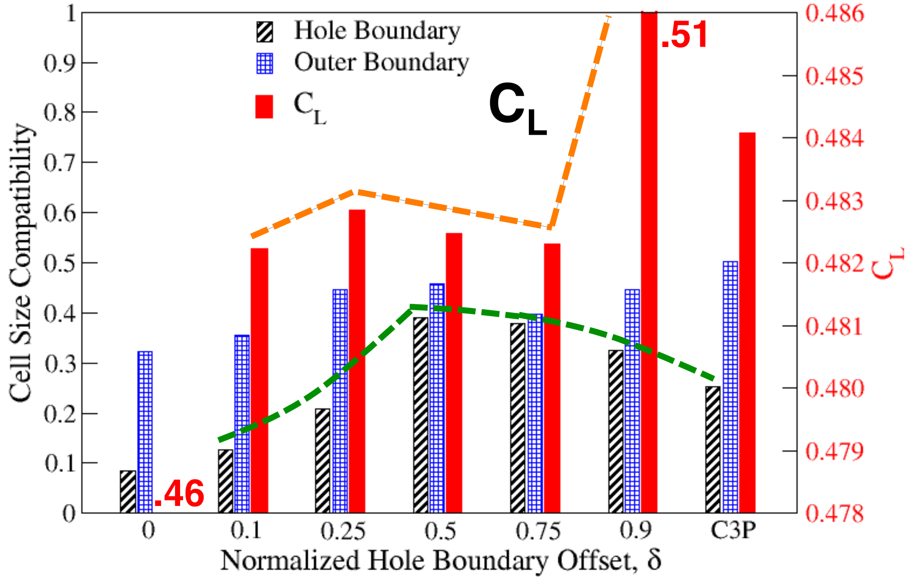
Spread for different structured grid flow solvers from DPW4

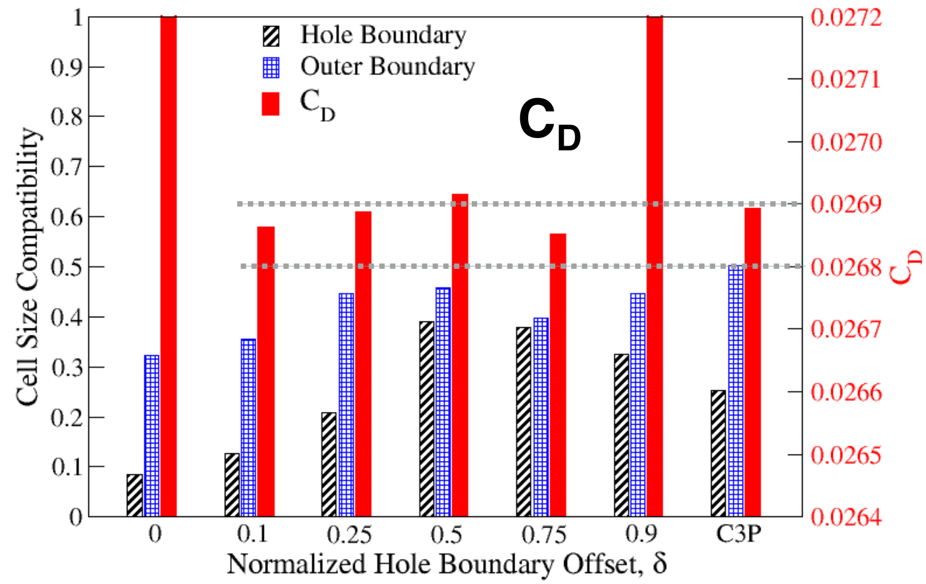
	Deviation from mean
C_D *	1.2%
C_M	18.9%

Ames Research Center

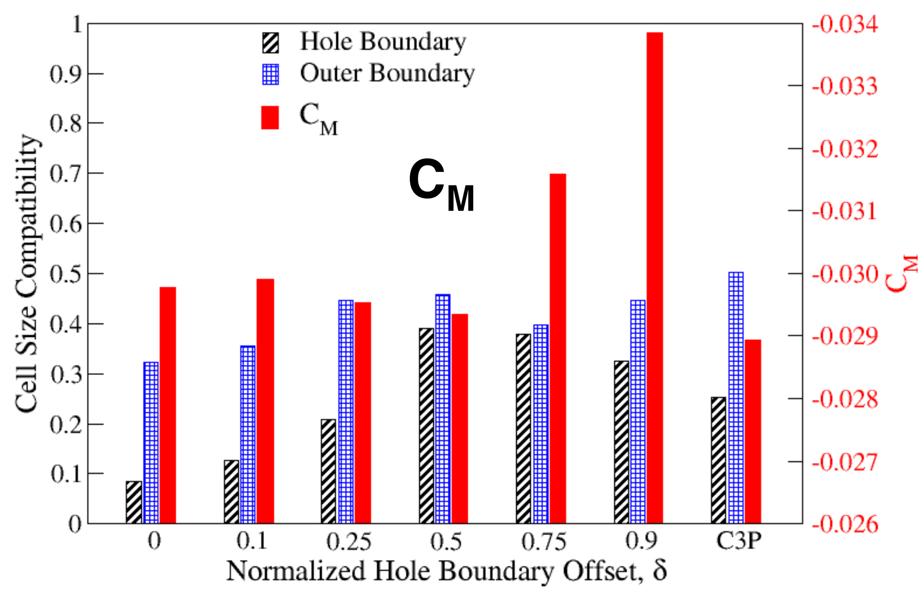
AIAA 4^{TH} DRAG PREDICTION WORKSHOP CRM

Cell Size Compatibility, C_L, C_D, C_M for different δ's



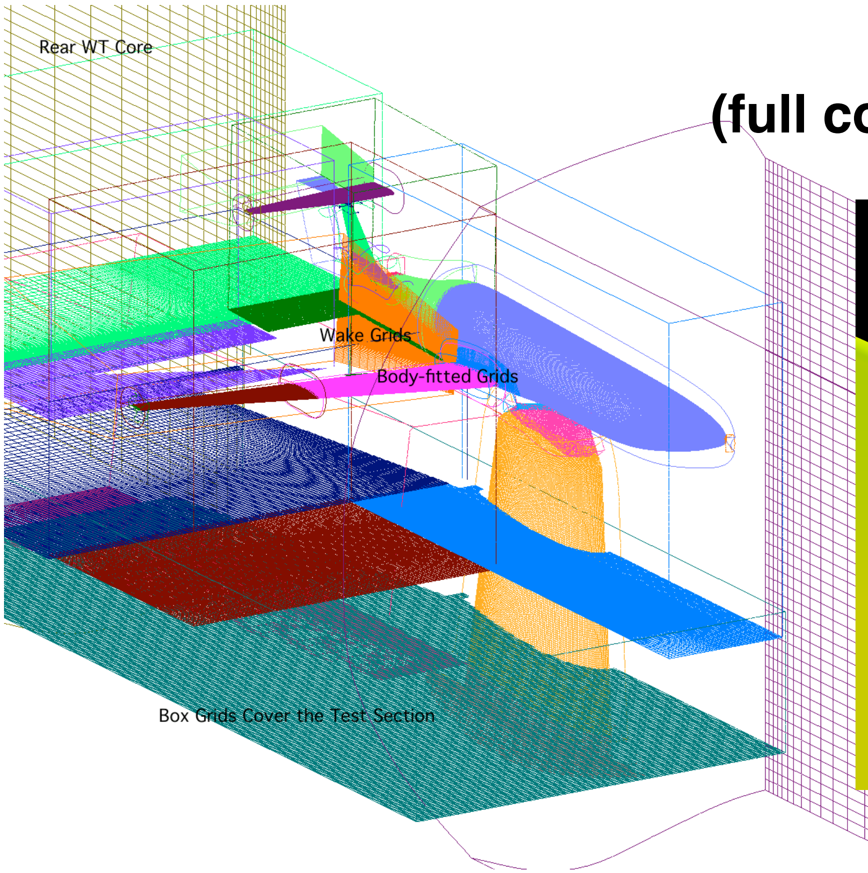


δ	# orphan points
0.00	0
0.10	0
0.25	4
0.50	614
0.75	2528
0.90	24599
C3P	36

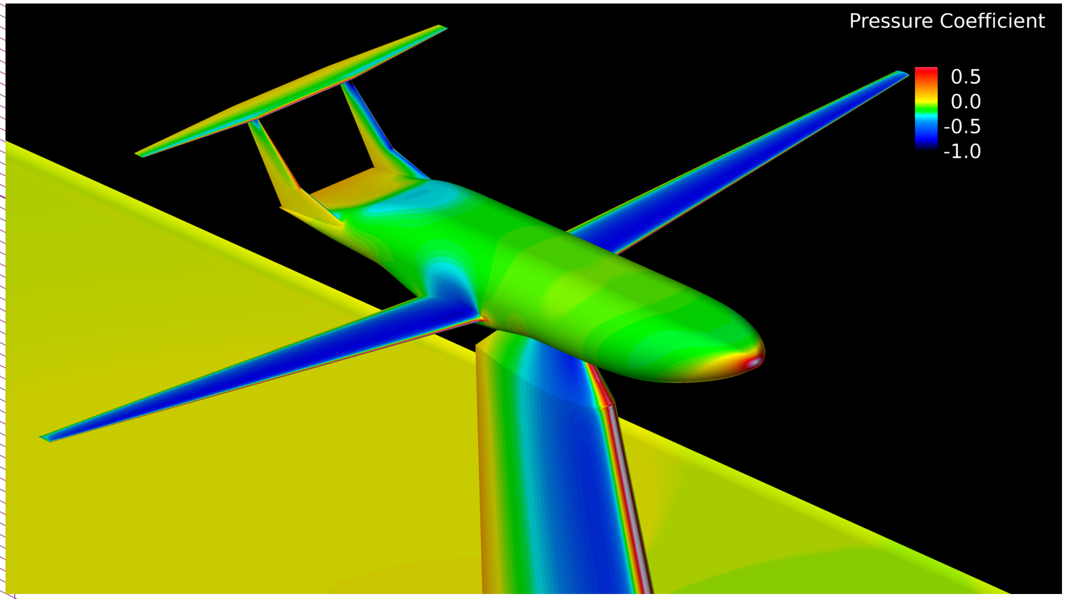


D8 DOUBLE BUBBLE AIRCRAFT WITH STRUT SUPPORT IN WIND TUNNEL (HALF-BODY)

(M=0.16, α=0 deg., Re=477000)



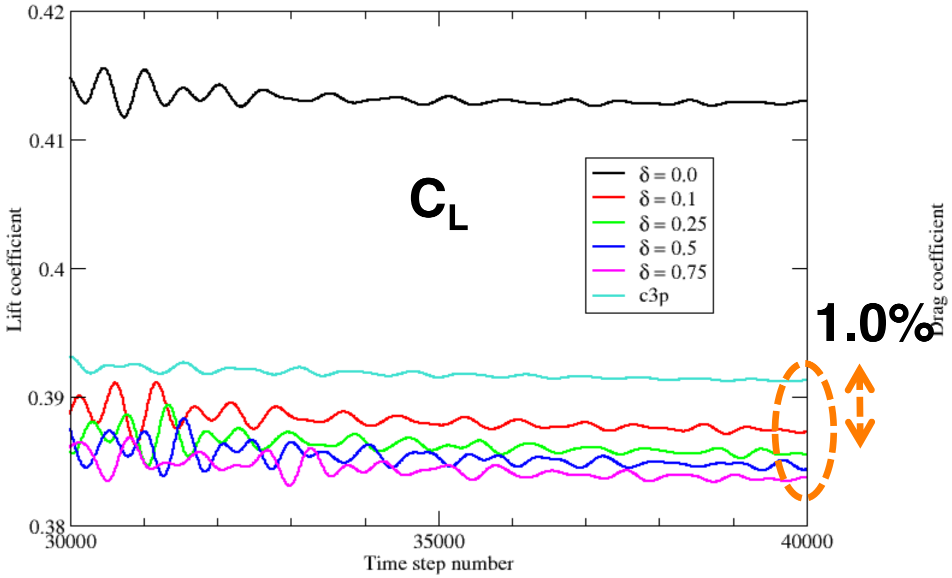
Pressure Coefficient
(full configuration solution obtained by mirror)

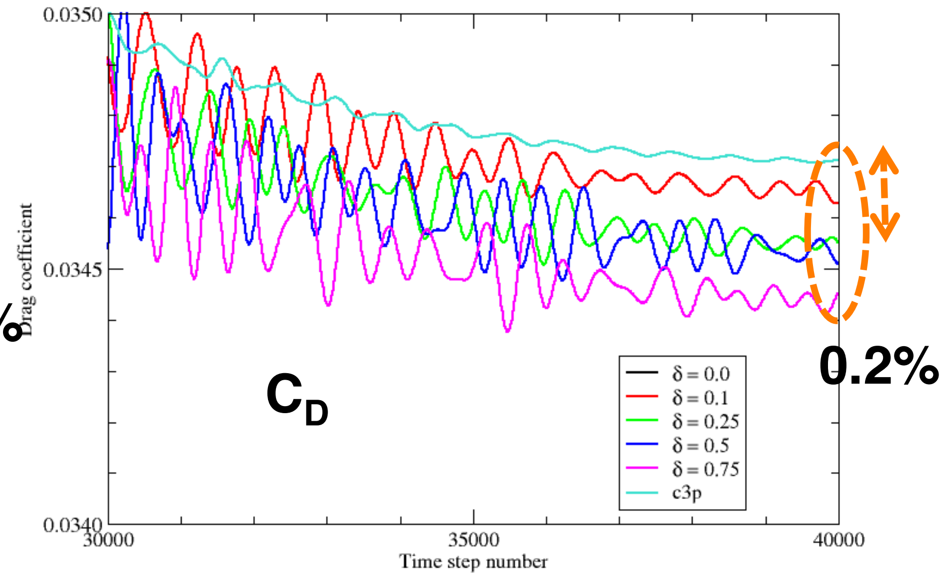


35 grids, 83 million grid points

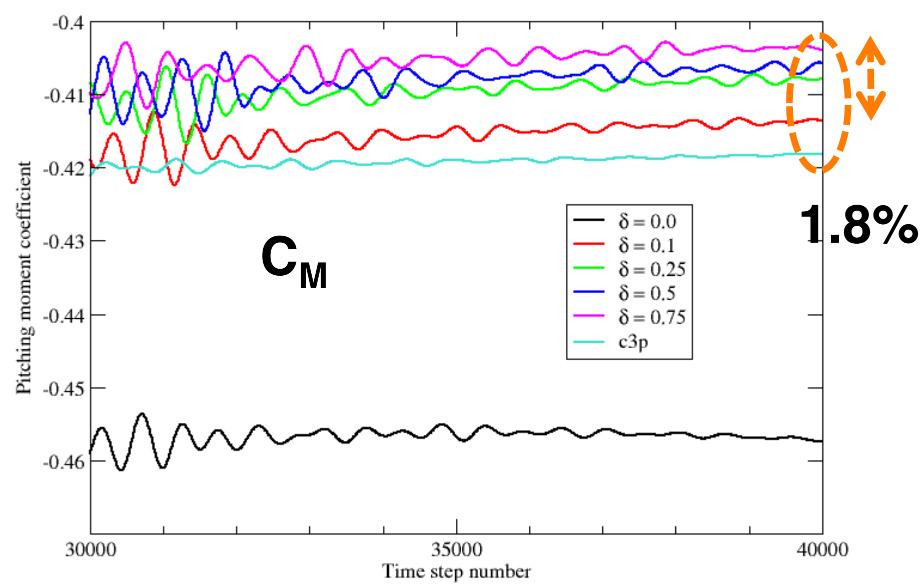
D8 DOUBLE BUBBLE AIRCRAFT

C_L, C_D, C_M Convergence Histories and Deviations from Group Mean for δ=0.25, 0.5, 0.75 and C3P





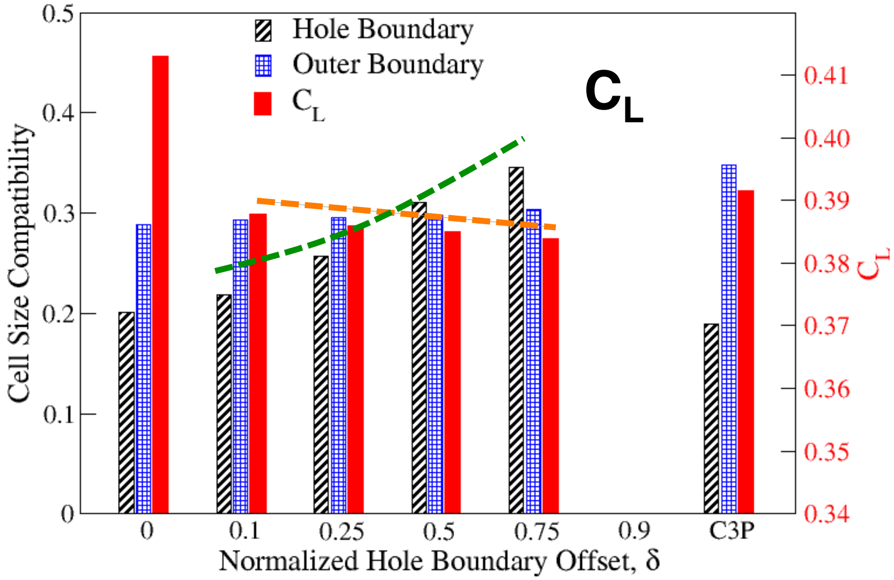
	C_L, C_D variations
Turb. models: SA, BB, SST (relative to SA)	2.1% – 5.5%
Grid stretching:1.1-1.25 (relative to 1.1)	1% - 12.5%

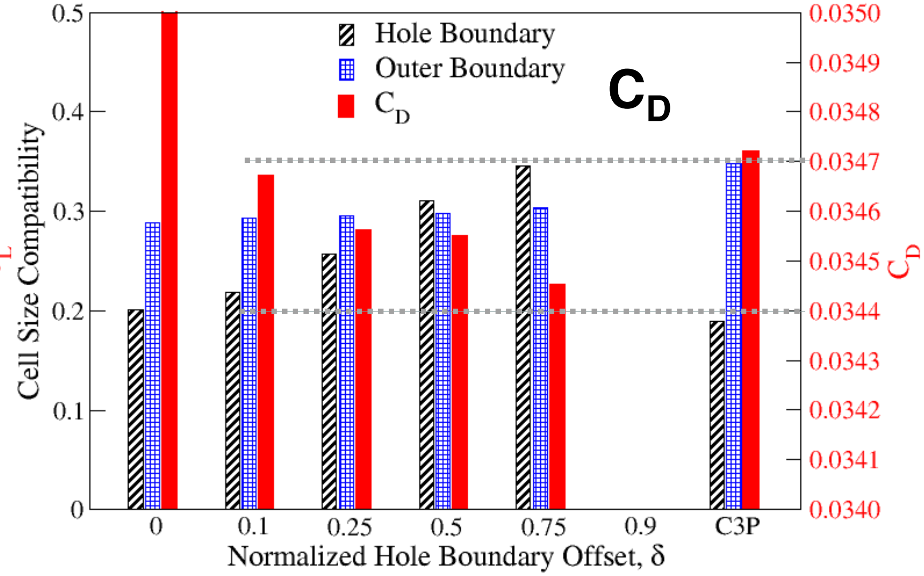


Pandya, S. A., External Aerodynamics Simulations for the MIT D8 "Double-Bubble" Aircraft Design, Paper ICCFD7-4304, 7th International Conference on Computational Fluid Dynamics, Big Island, Hawaii, July 2012 (http://www.iccfd.org/iccfd7)

D8 DOUBLE BUBBLE AIRCRAFT

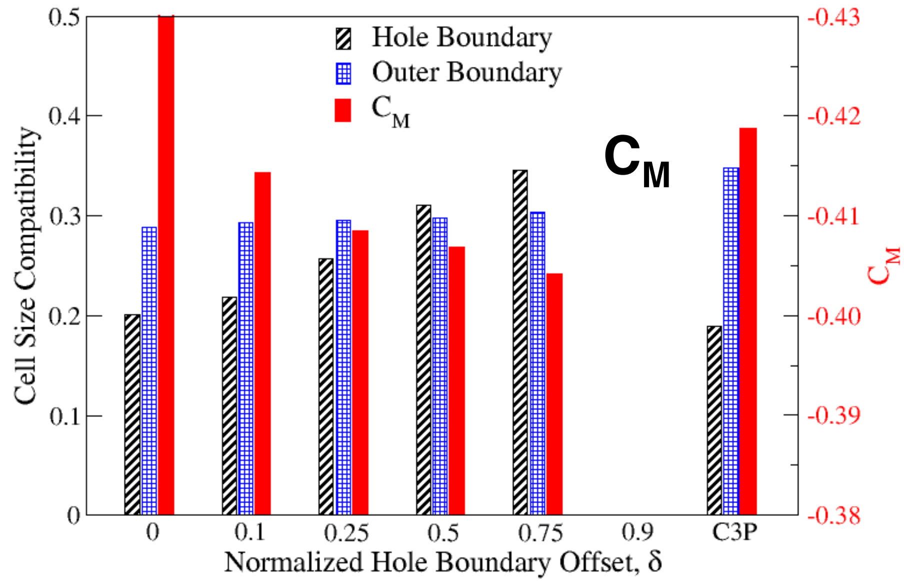
Cell Size Compatibility, C_L, C_D, C_M for different δ's





δ=0.9 case failed to converge due to large number of orphan points

δ	# orphan points
0.00	0
0.10	1
0.25	1
0.50	46
0.75	21690
0.90	240094
C3P	5



SUMMARY AND CONCLUSIONS

Enhanced X-rays - C3P software

- Inputs only require flow solver b.c. and component tags on walls
- Automated efficient treatment of components in close proximity
- Automated spatially variable hole boundary offset from minimum hole

Fast Wall Distance Function Computation

- CPU time mostly comparable to OVERFLOW/DCF (original X-rays)
- Benefits more significant if usable for solving turb. model equations

Aerodynamic Loads Sensitivity Study

- Similar aero load convergence rates observed for all δ's and C3P
- For best practice hole boundary offset distances ($\delta = 0.25 - 0.75$), aero load converged values do not appear to correlate with δ or cell size compatibility
- Typical variations of aero loads for $\delta = 0.25 - 0.75$ and C3P are small relative to typical variations between different flow solvers, grid stretching ratios, turbulence models