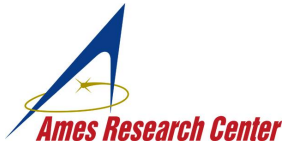

DEVELOPMENTS IN EFFICIENT MESH CONNECTIVITY FOR OVERSET GRIDS

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and

Shishir A. Pandya

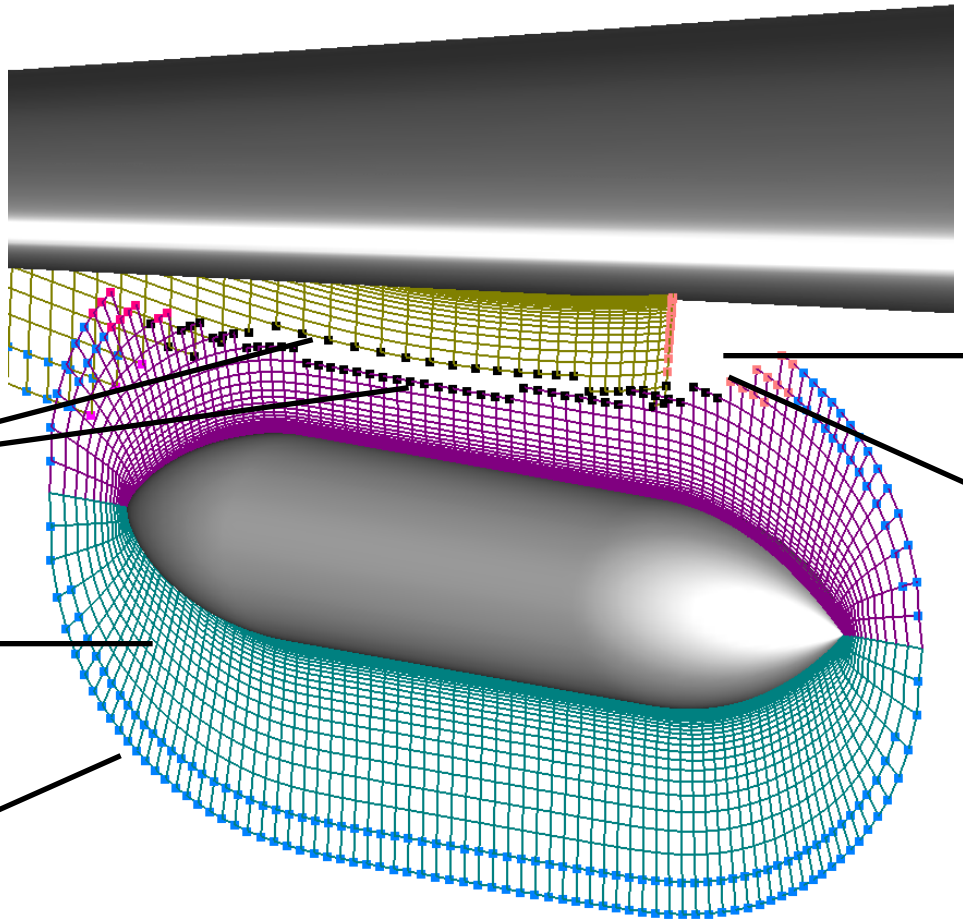
Applied Modeling and Simulation Branch
NAS Division

AMS Seminar Series, August 13, 2015

OVERVIEW

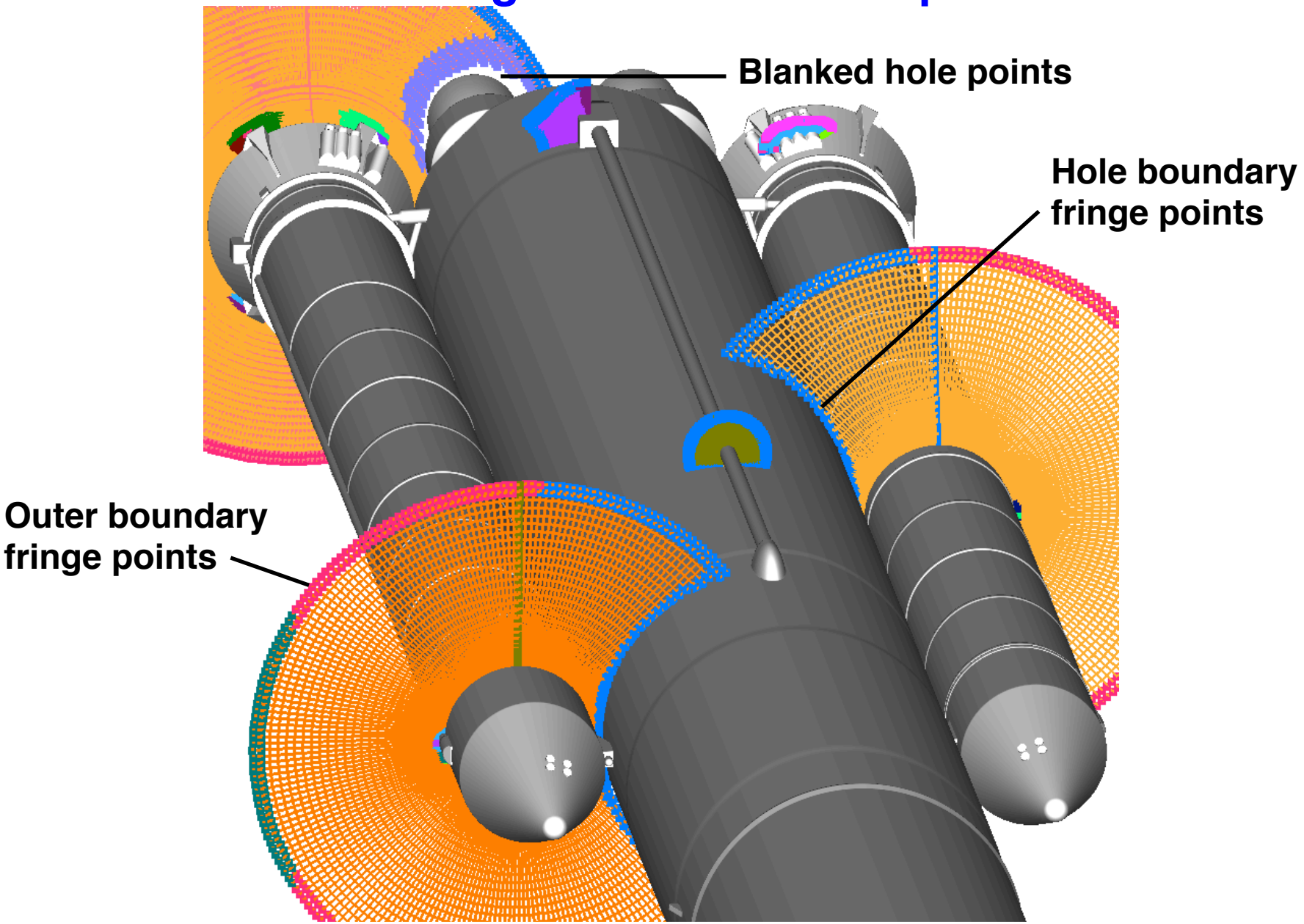
- Introduction and review of hole cutting
- Accurate minimum hole determination
- Spatially variable hole boundary offset
- Test cases
- Chimera Components Connectivity Program
- Summary and Conclusion

OVERSET GRID HOLE CUTTING TERMINOLOGY
Disjoint Components with Relative Motion



Number of layers of fringe points determined by flow solver differencing stencil
5 pt. stencil => 2 layers of fringe points

OVERSET GRID HOLE CUTTING TERMINOLOGY
Intersecting / Connected Components



REVIEW OF HOLE-CUTTING TECHNOLOGIES

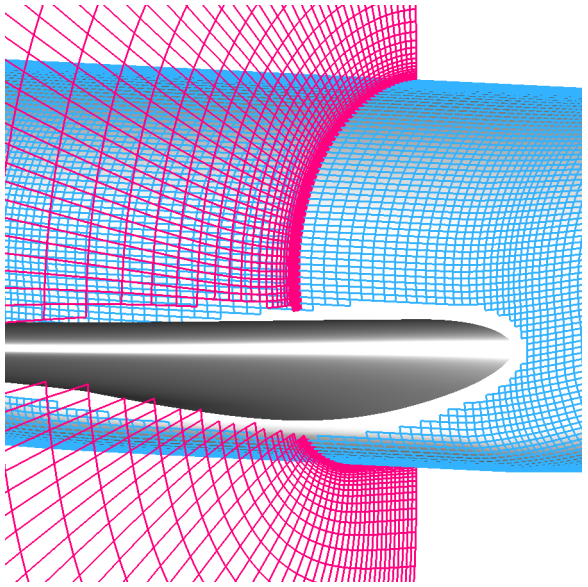
Hole map + line of sight + implicit hole cut
- PEGASUS5

Implicit hole-cut
- SUGGAR++
- OVERTURE
- PUNDIT

Explicit hole-cut (standard X-rays)
- OVERFLOW-DCF

Enhanced X-rays (2012)
- C3P (early version)

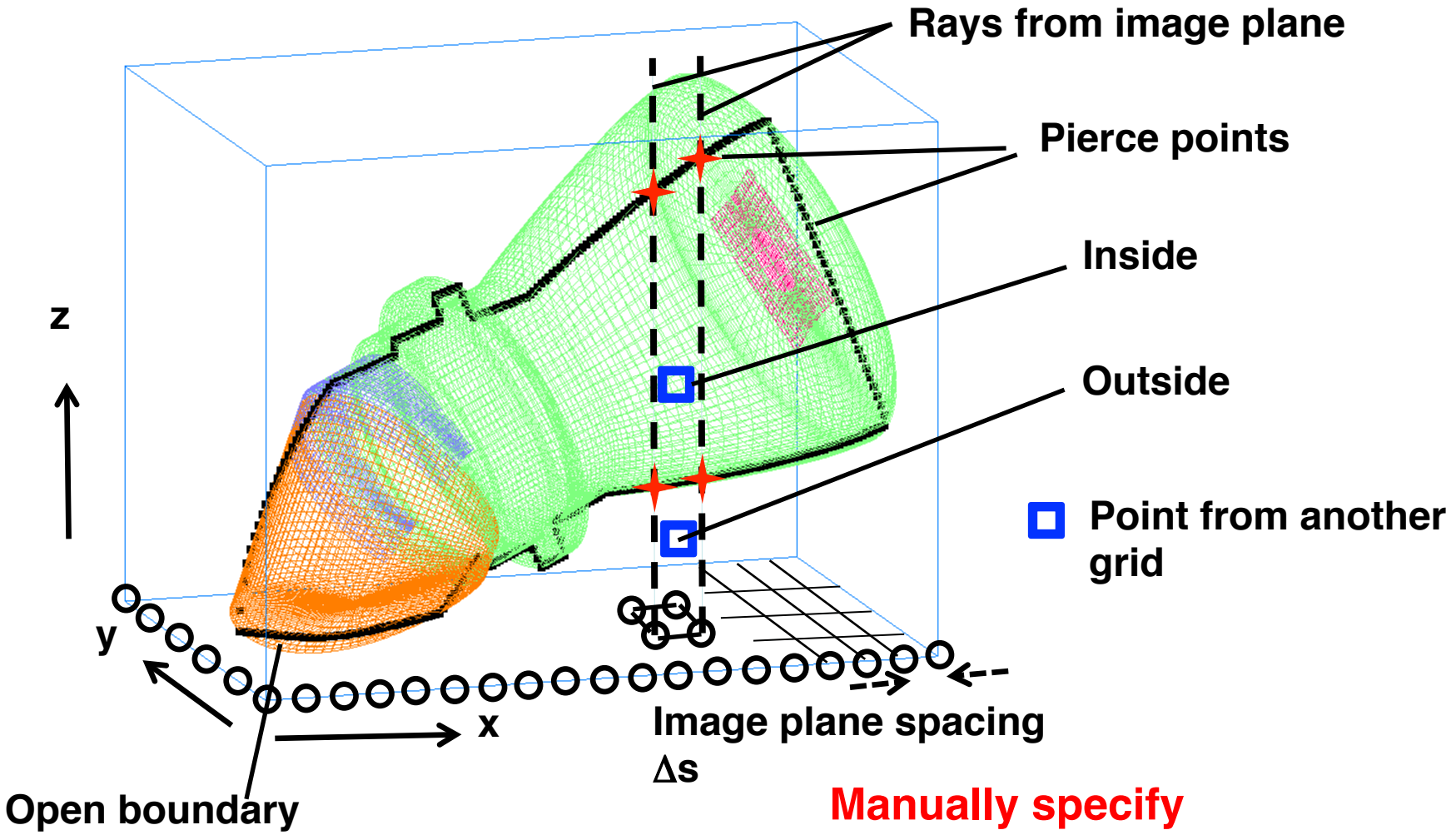
	IMPLICIT	EXPLICIT
User's Effort	Low	High
Compute Time	$O(N^3)$ donor stencil searches	$O(N^2)$ donor stencil searches



Chan W., Kim N., Pandya S., Advances in Domain Connectivity for Overset Grids Using the X-rays Approach, Paper ICCFD7-1201, 2012

STANDARD X-RAYS

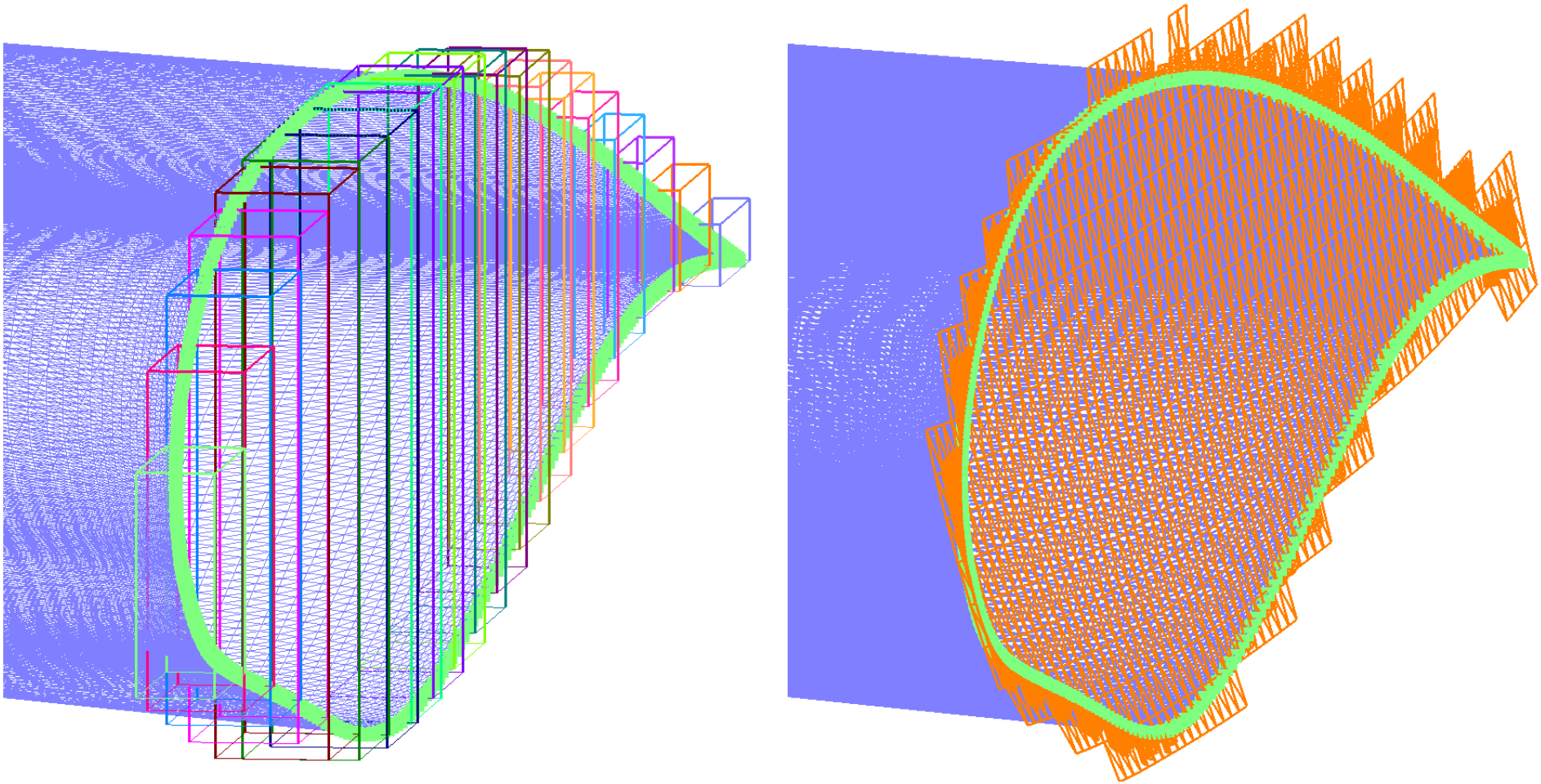
Meakin, AIAA Paper 2001-2537



Low
- CPU time
- Memory requirement

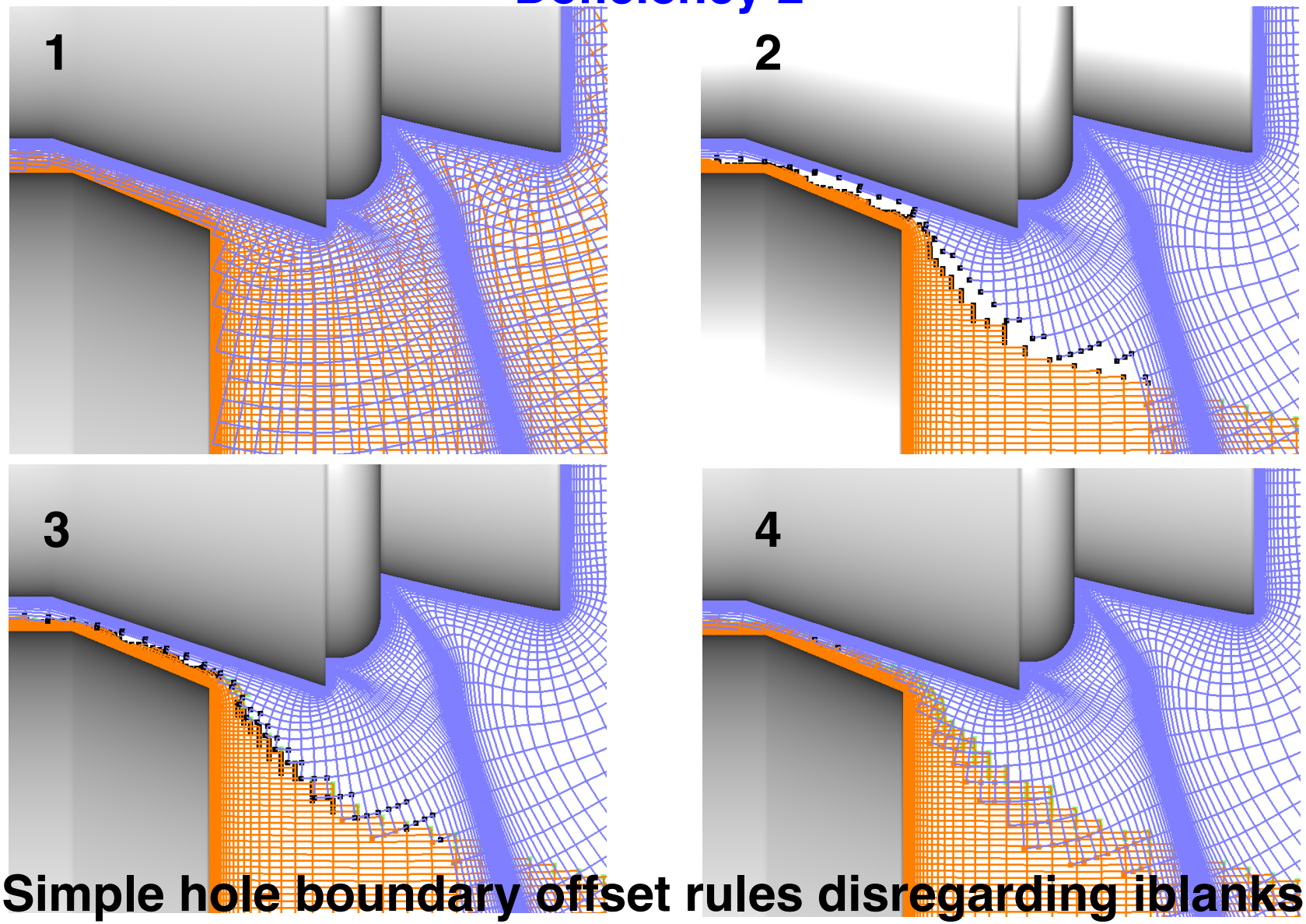
Manually specify
- Hole cutting surfaces
- Grids to be cut by each X-ray
- Constant distance offset

ENHANCED X-RAYS HOLE CUT ALGORITHM (2012)
Deficiency 1



Approximate closure of component open boundary
=> Minimum hole is approximate

ENHANCED X-RAYS HOLE CUT ALGORITHM (2012)
Deficiency 2



Simple hole boundary offset rules disregarding iblanks
=> Orphan point removal iterations required

OBJECTIVES OF CURRENT WORK

Enhance hole cutting procedure

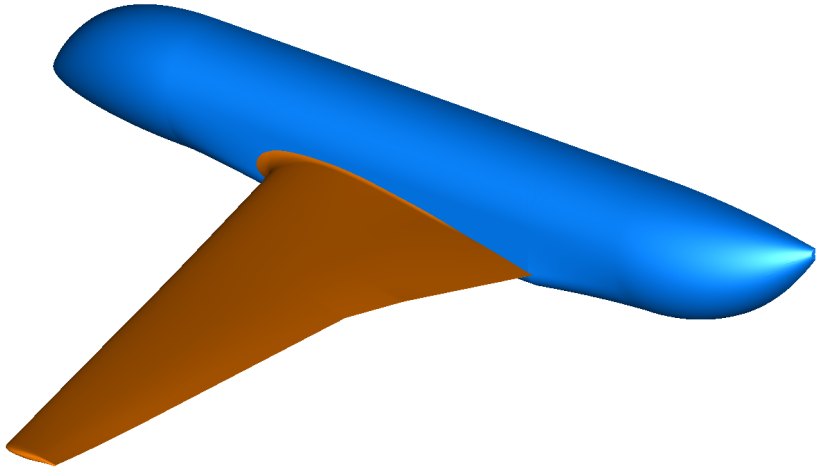
- Create accurate minimum hole by
  - more exact closure of open components
  - direct ray casting near geometry surface

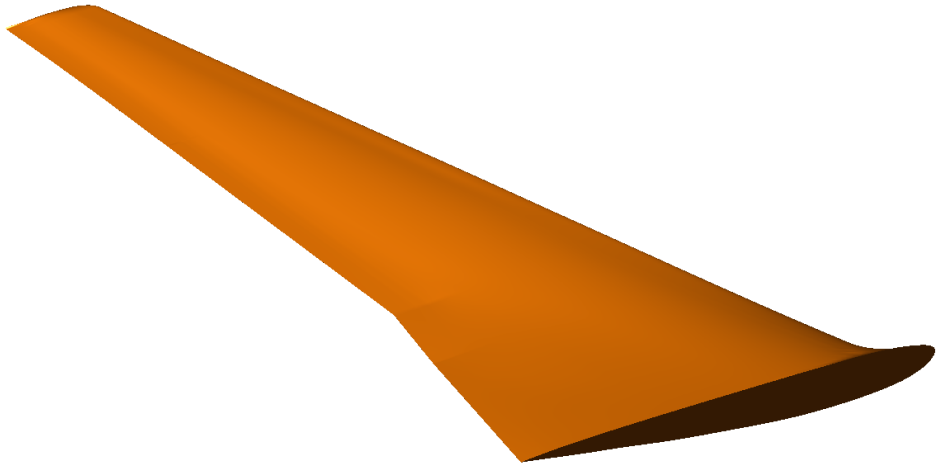
- Improve hole boundary offset estimate by
  - distance rules with iblanks accounting
  - donor stencil map

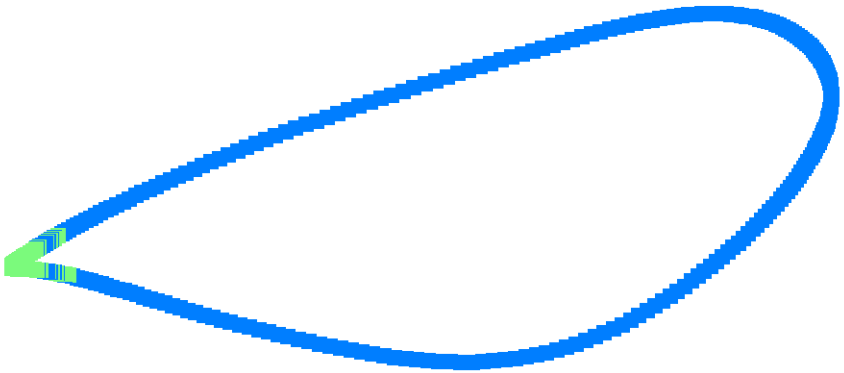
Chan W. M., Pandya S. A., Advances in Distance-Based Hole Cuts on Overset Grids, AIAA Paper 2015-3425, 22nd Computational Fluid Dynamics Conference, Dallas, Texas, June, 2015

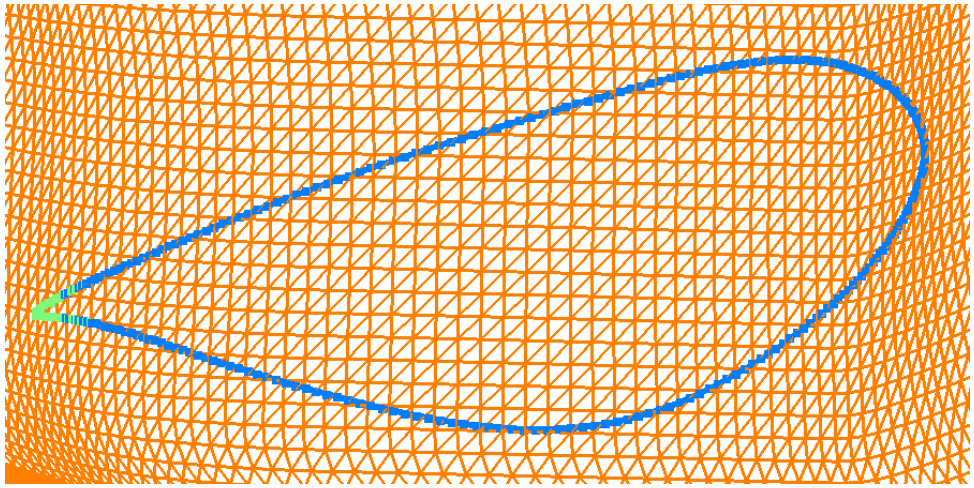
ACCURATE MINIMUM HOLE DETERMINATION
1. Closure of Component Open Boundaries

1.1. Identification and extraction of open boundary curves
1.2. Formation of closed loops

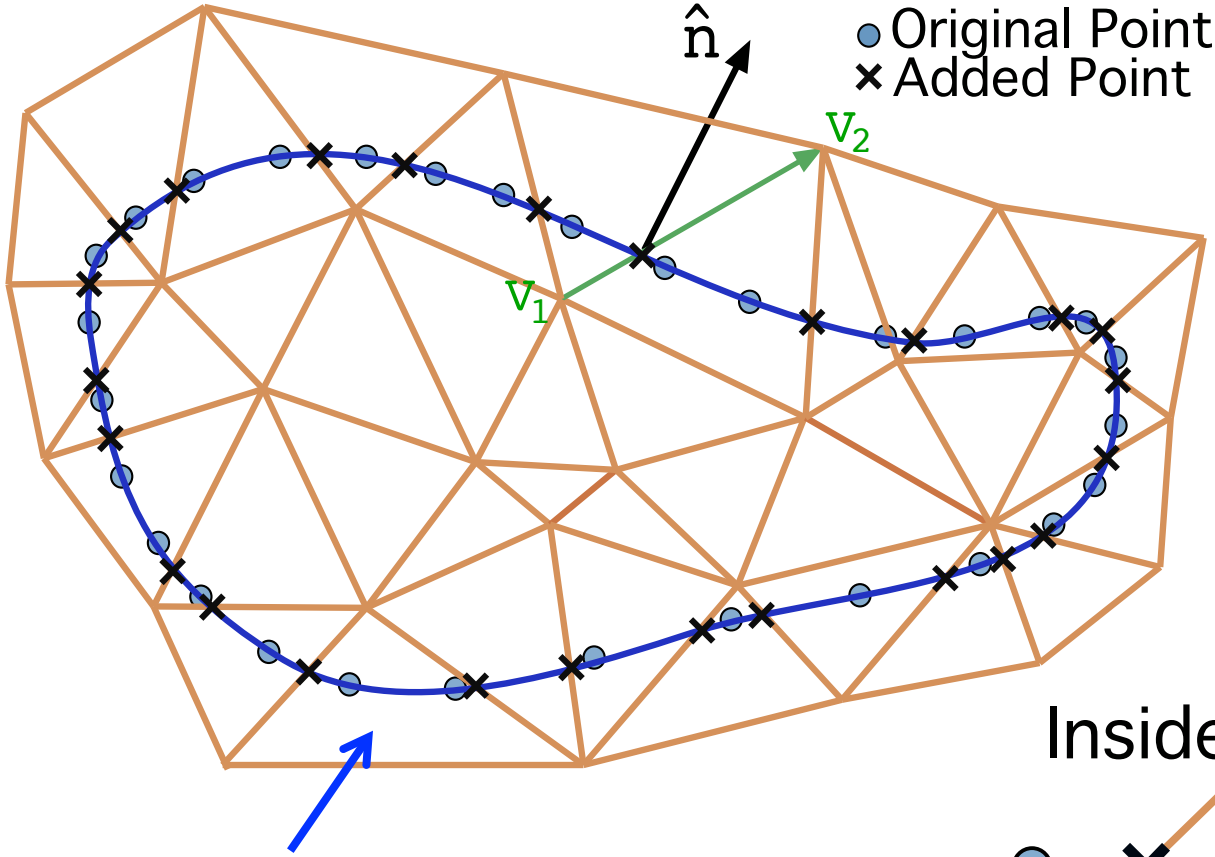




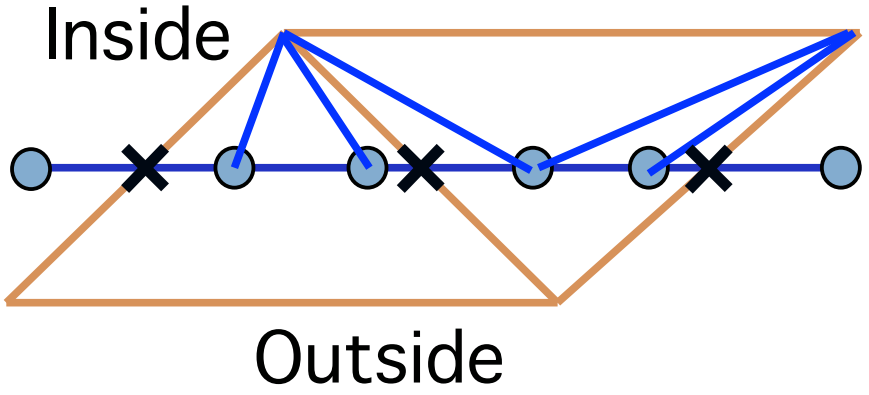




ACCURATE MINIMUM HOLE DETERMINATION
1. Closure of Component Open Boundaries
1.3. Cut reference surface triangulation using loop curves

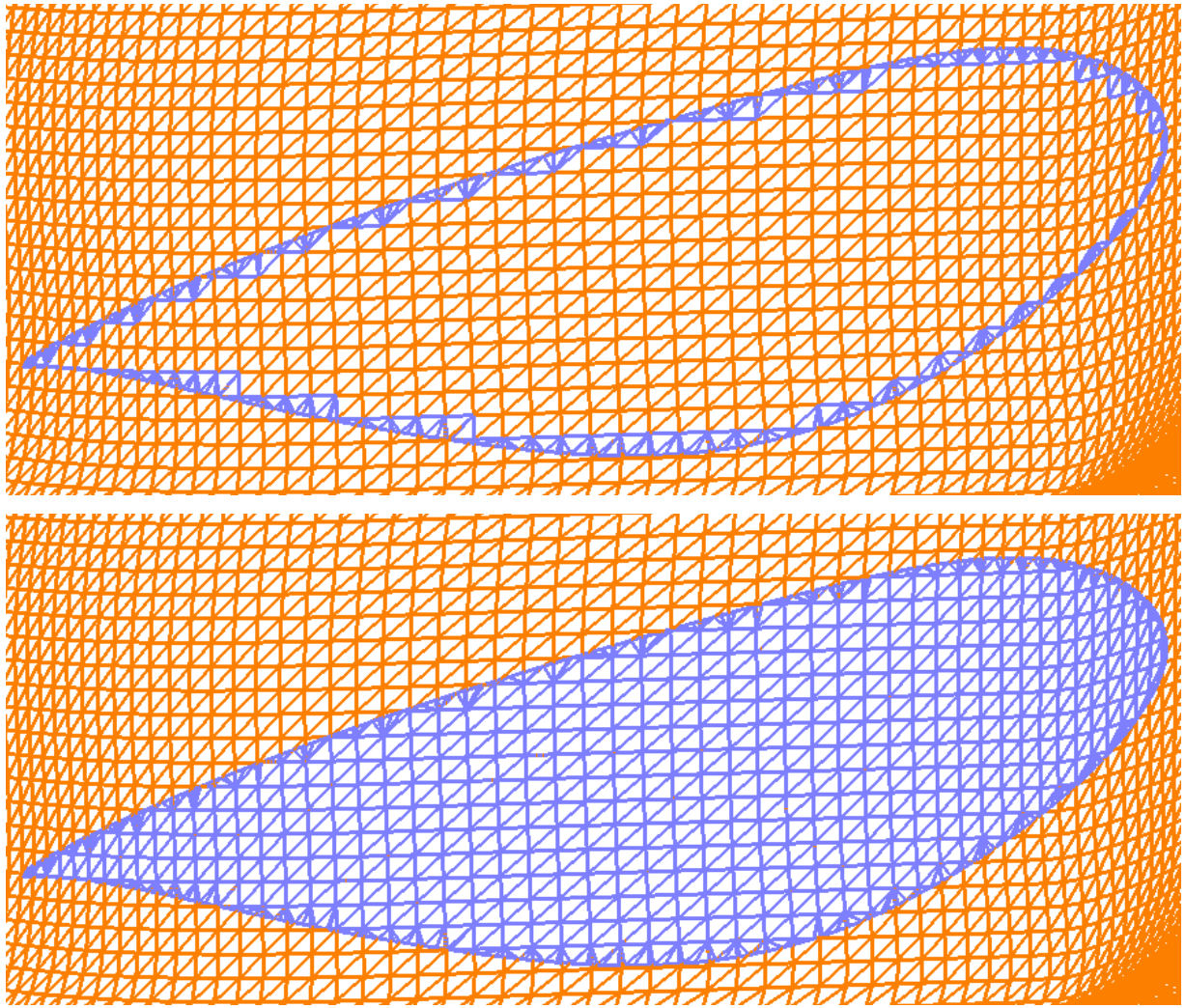


3-D triangulated surface used for closure



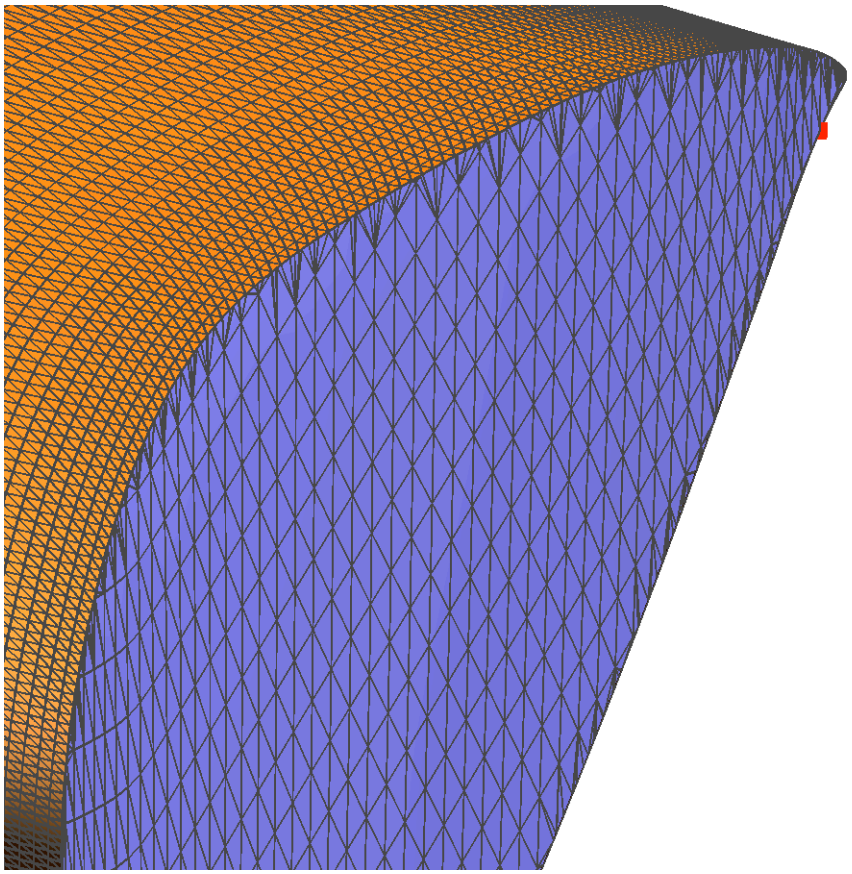
ACCURATE MINIMUM HOLE DETERMINATION
1. Closure of Component Open Boundaries

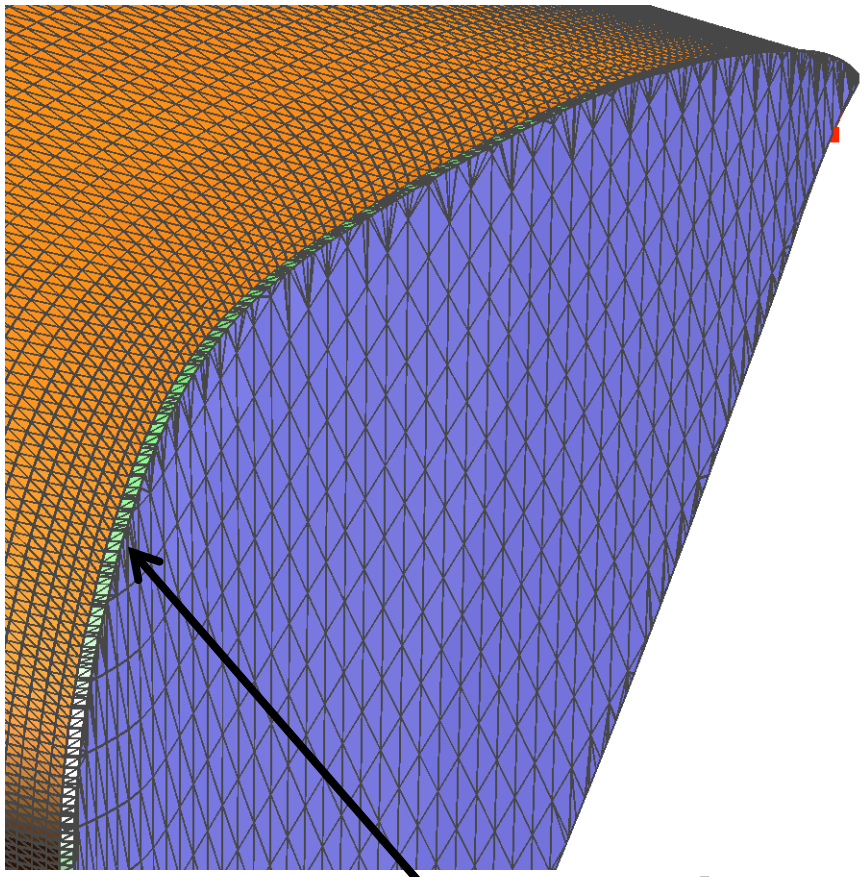
1.4. Fill loop interior using reference surface triangular cells by Painter's algorithm



ACCURATE MINIMUM HOLE DETERMINATION
1. Closure of Component Open Boundaries

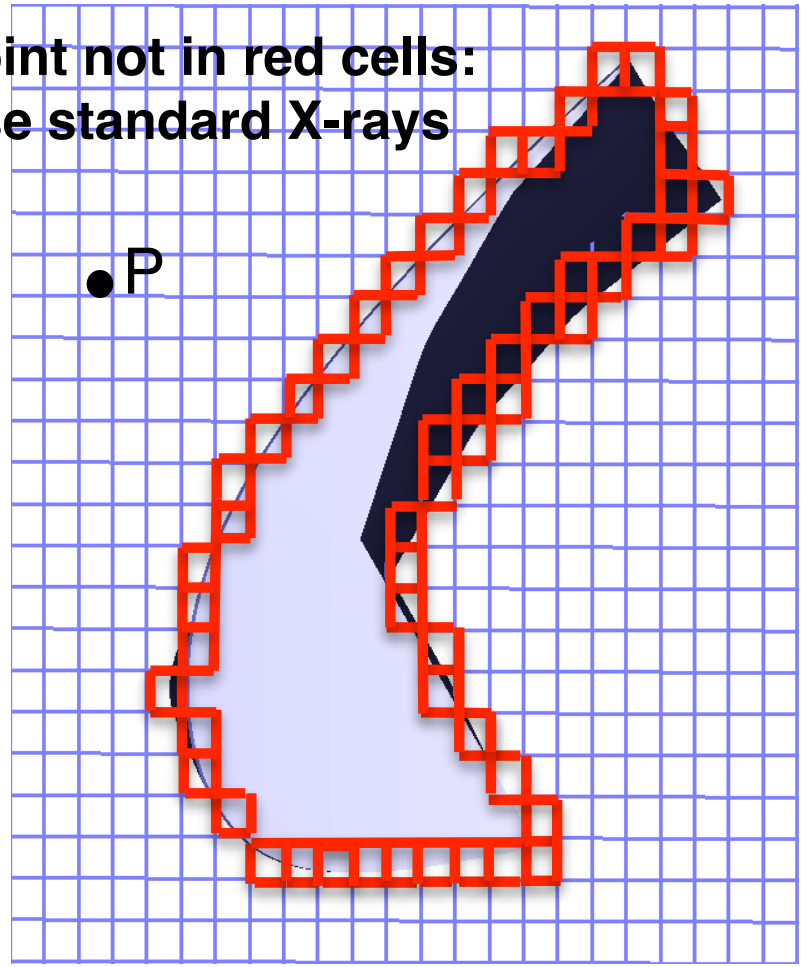
1.5. Add extension layer and merge with open boundary component triangulation to form closed triangulated surface





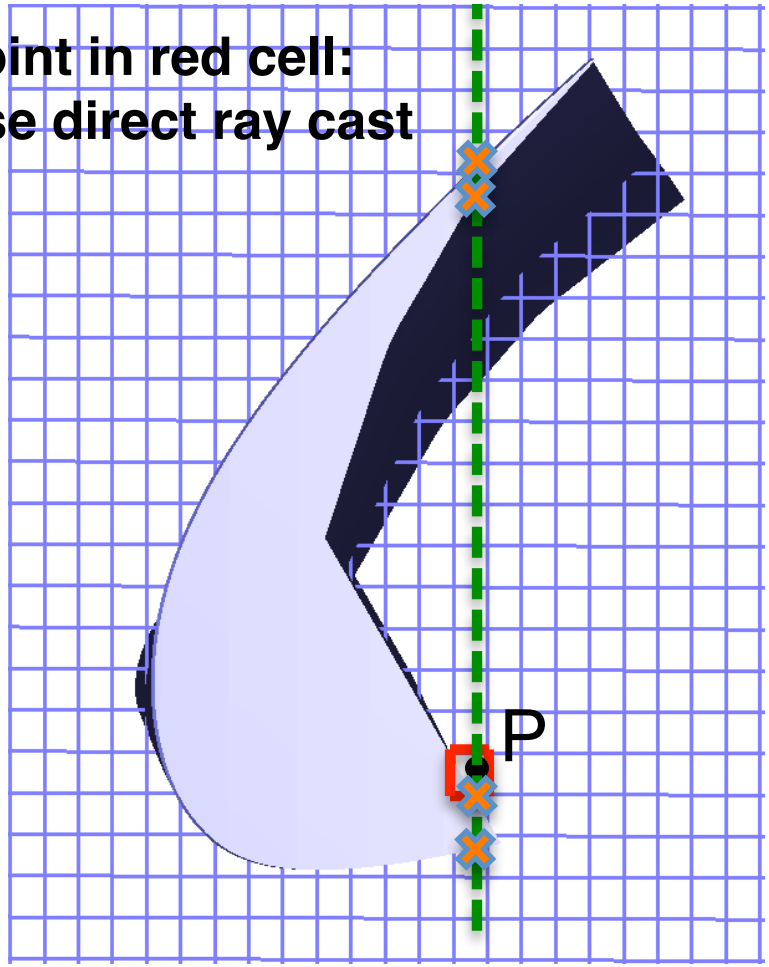
ACCURATE MINIMUM HOLE DETERMINATION
2. Direct Ray Casting Near Geometry Surface

Point not in red cells:
Use standard X-rays



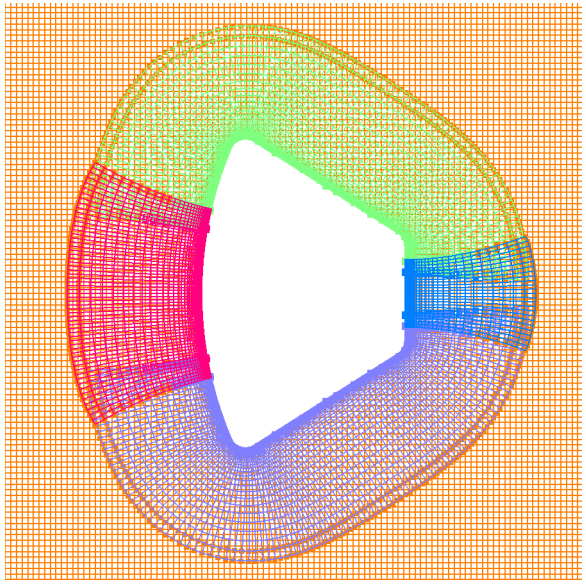
Use Cartesian map of component to identify grid points near geometry surface

Point in red cell:
Use direct ray cast

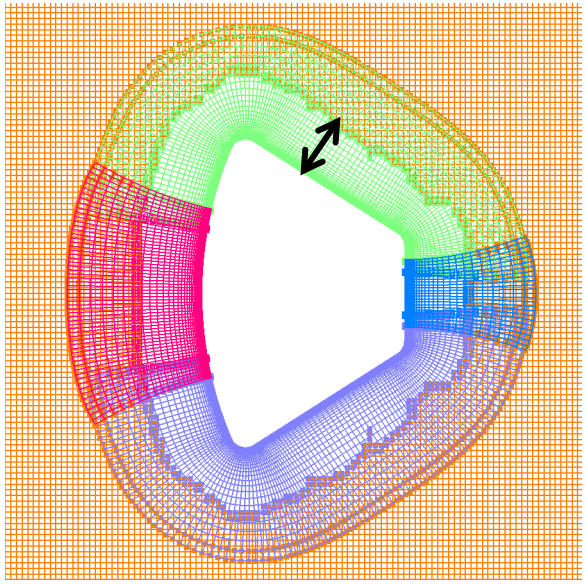


Cast ray directly through point for inside/outside test

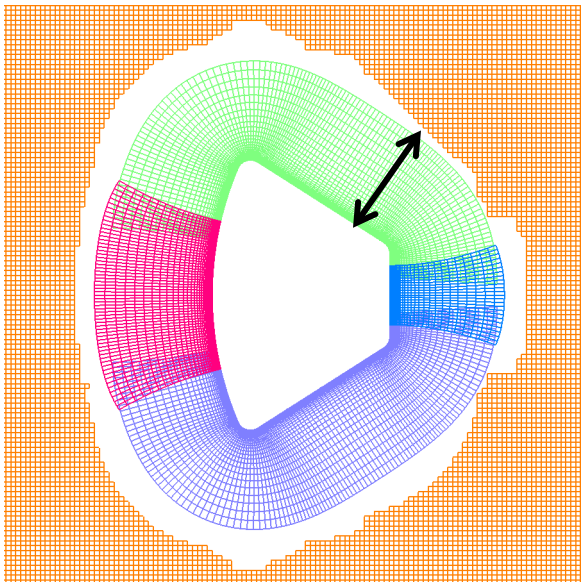
HOLE BOUNDARY OFFSET



Minimum Hole



Many acceptable intermediate locations



Too far

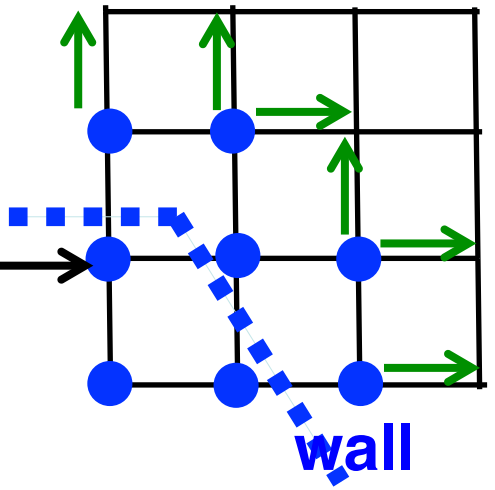
Chan W. M., Pandya S. A., Rogers, S. E., Efficient Creation of Overset Grid Hole Boundaries and Effects of Their Locations on Aerodynamic Loads, AIAA Paper 2013-3074, 21st Computational Fluid Dynamics Conference, San Diego, California, June, 2013

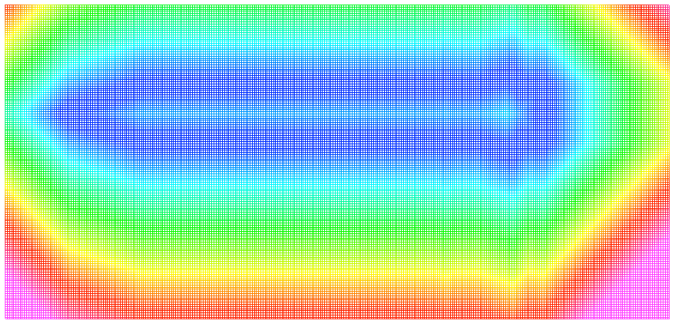
COMPONENT WALL DISTANCE FUNCTION COMPUTATION

Fast approximate method

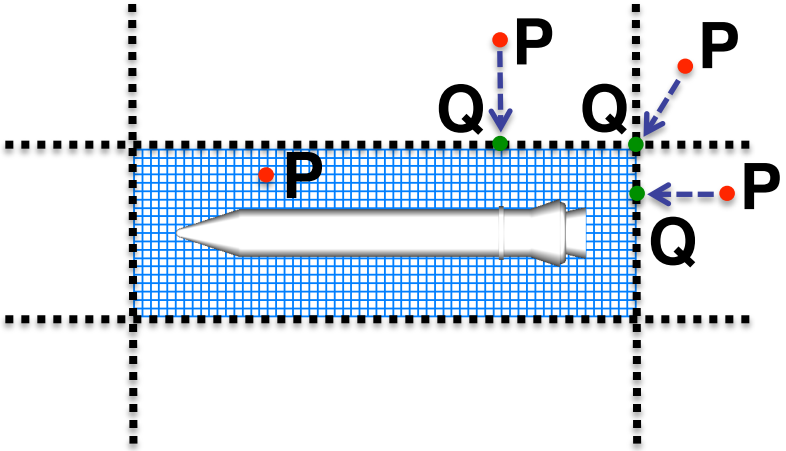
Determine accurate wall distance for vertices on cut-cells

Fill approximate wall distance for remaining vertices with Fast Marching Method



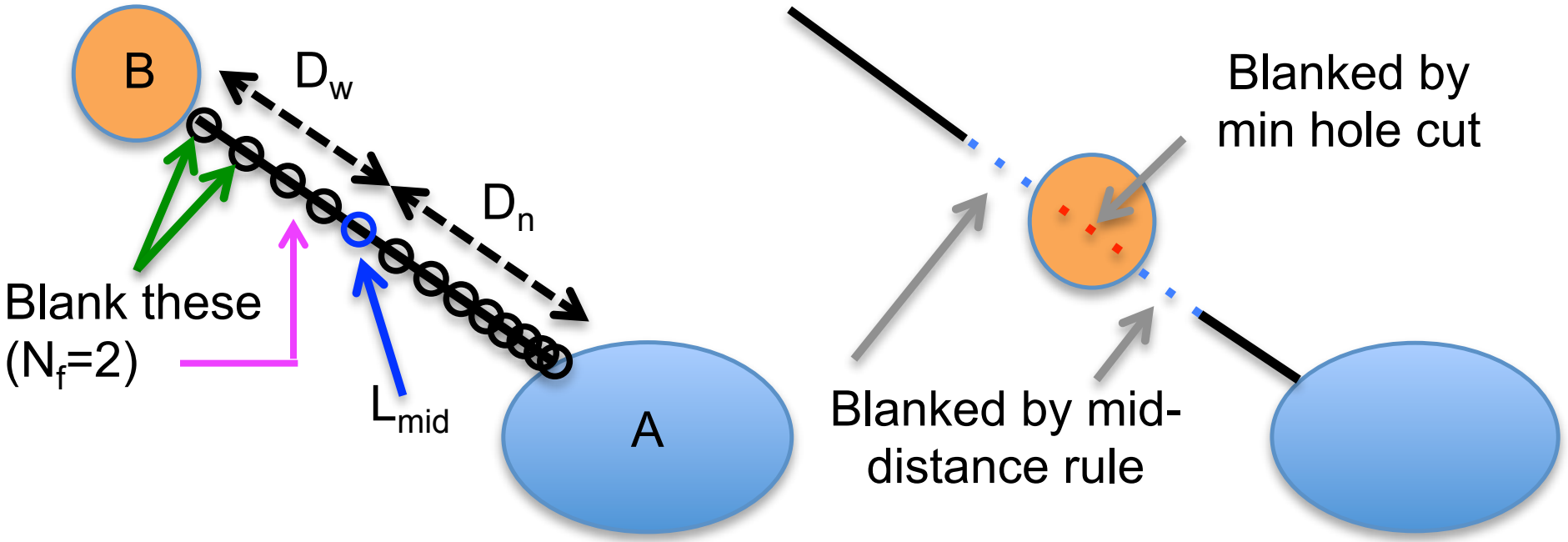


Wall distance look-up



HOLE BOUNDARY ESTIMATION
1. Blanking Between Near-Body Grids : Procedure

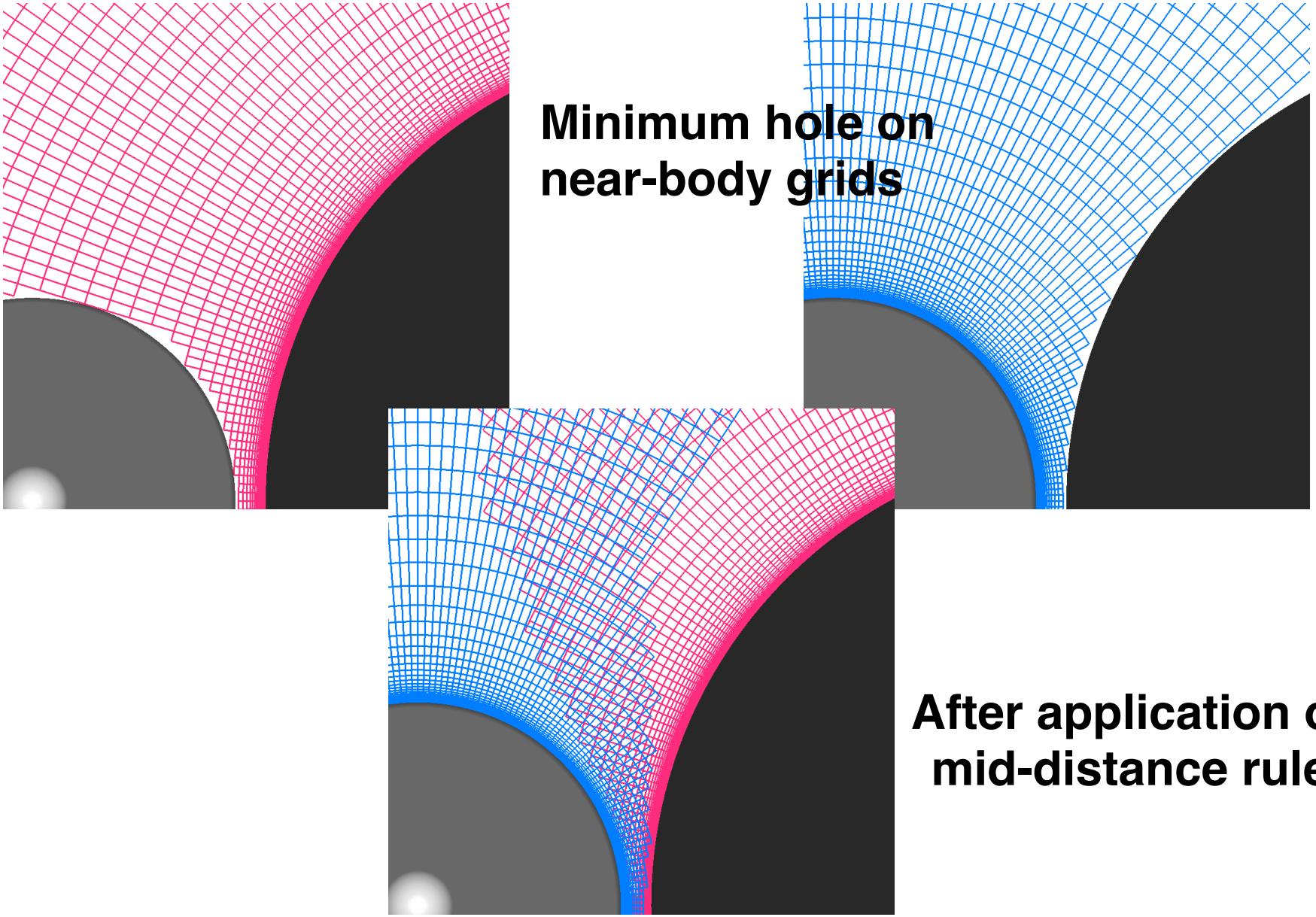
Mid-distance Rule



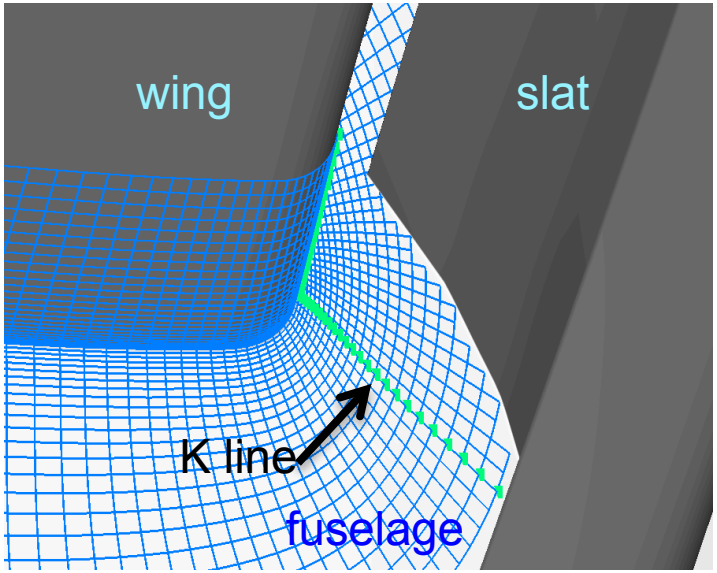
Lmid = grid index on normal grid line at mid-distance to another component

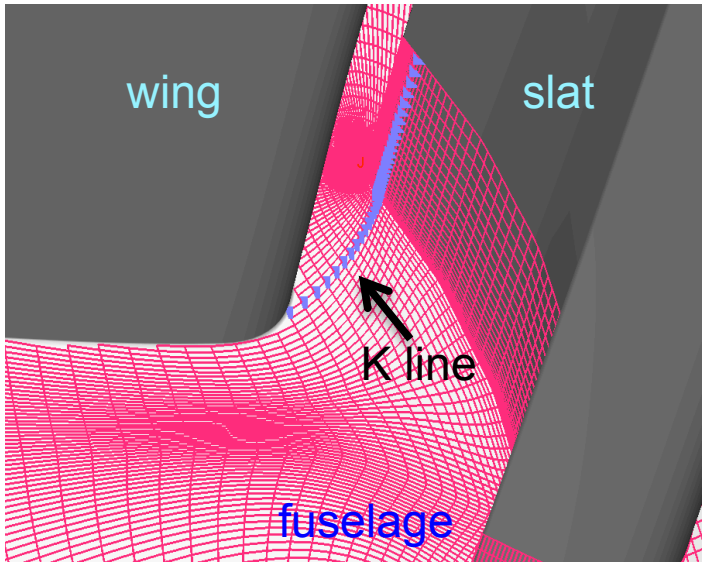
N_f = number of fringe point layers

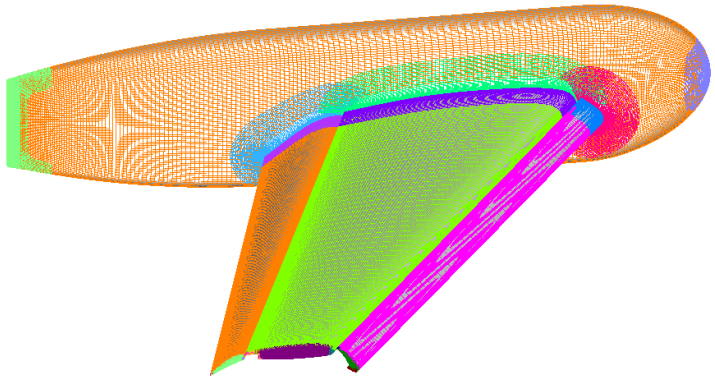
HOLE BOUNDARY ESTIMATION
1. Blanking Between Near-Body Grids : Example

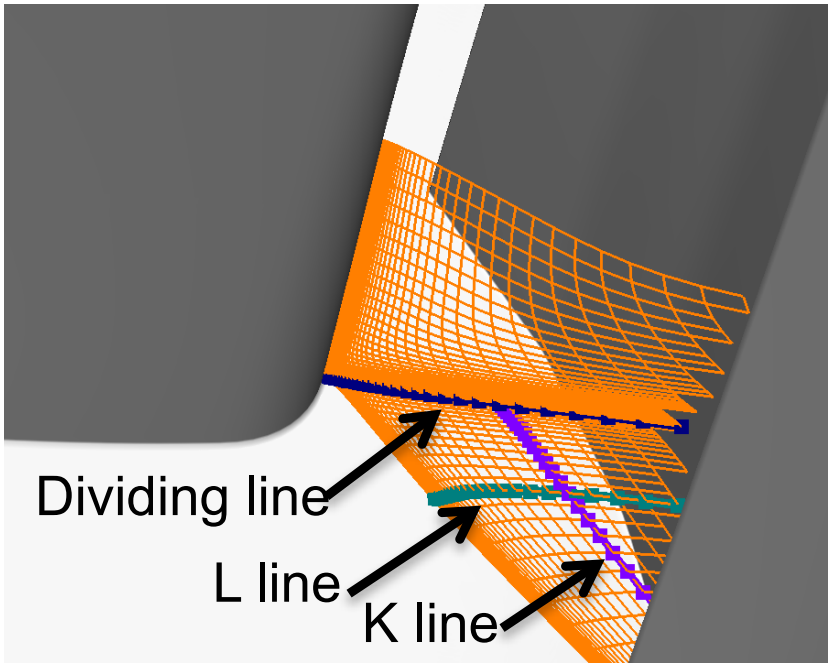


HOLE BOUNDARY ESTIMATION
2. Blanking Between Collar Grids with Common Parent Component : Procedure

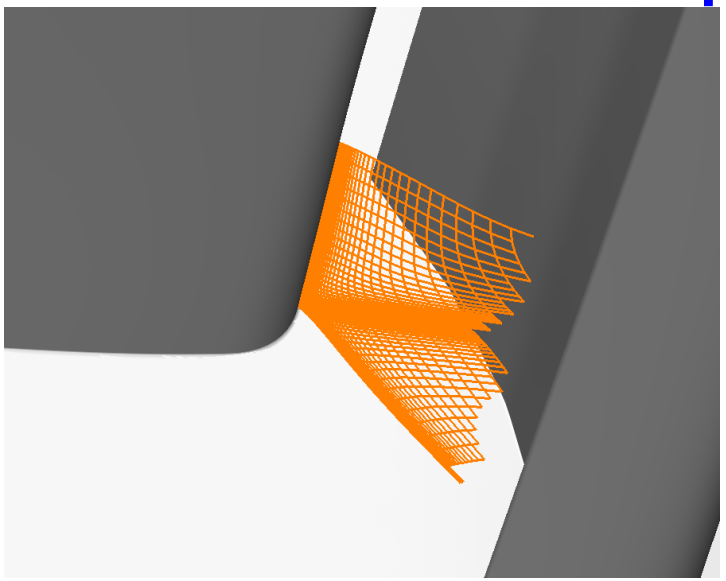


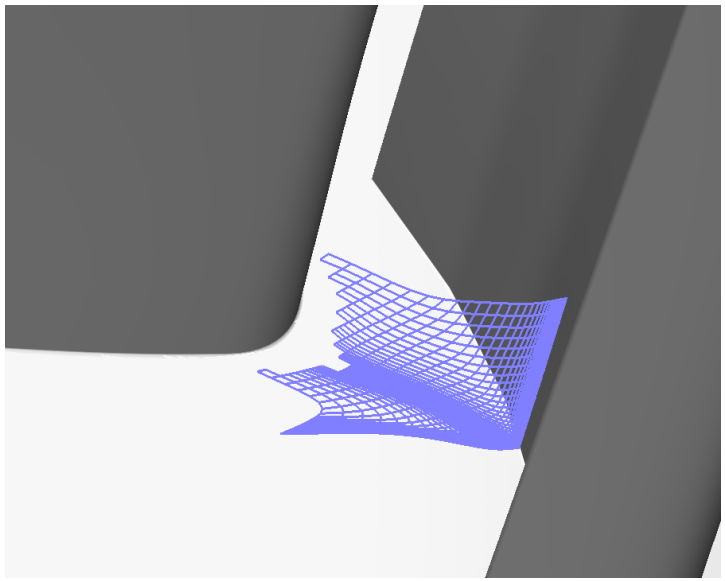


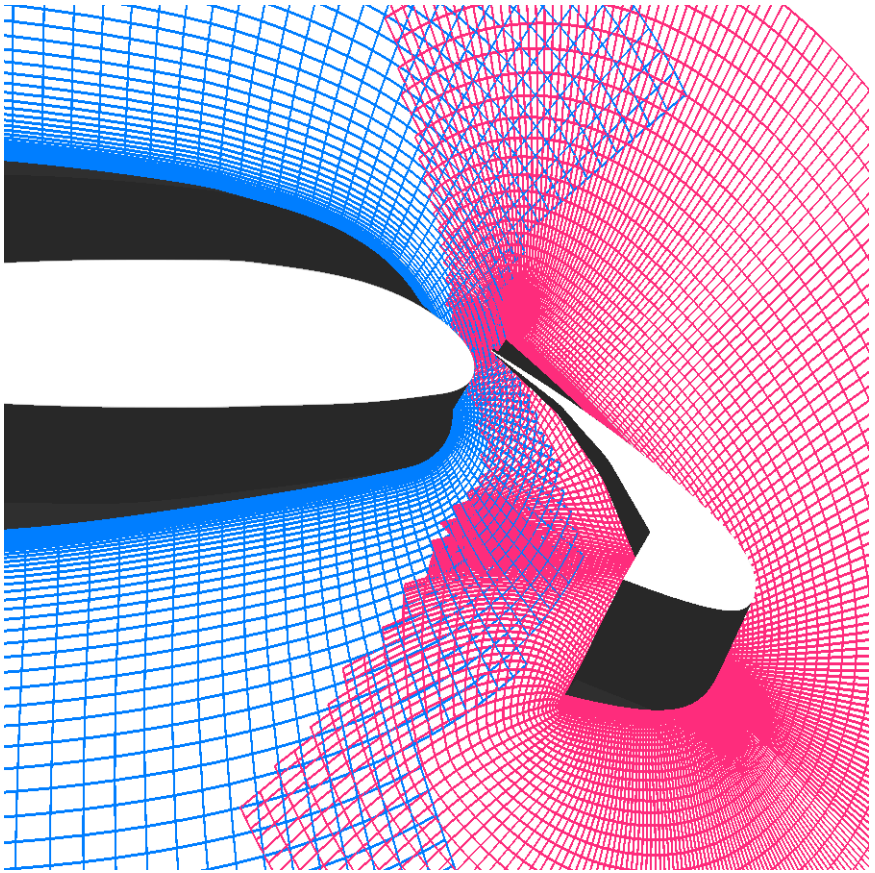




HOLE BOUNDARY ESTIMATION
2. Blanking Between Collar Grids with Common Parent Component : Example

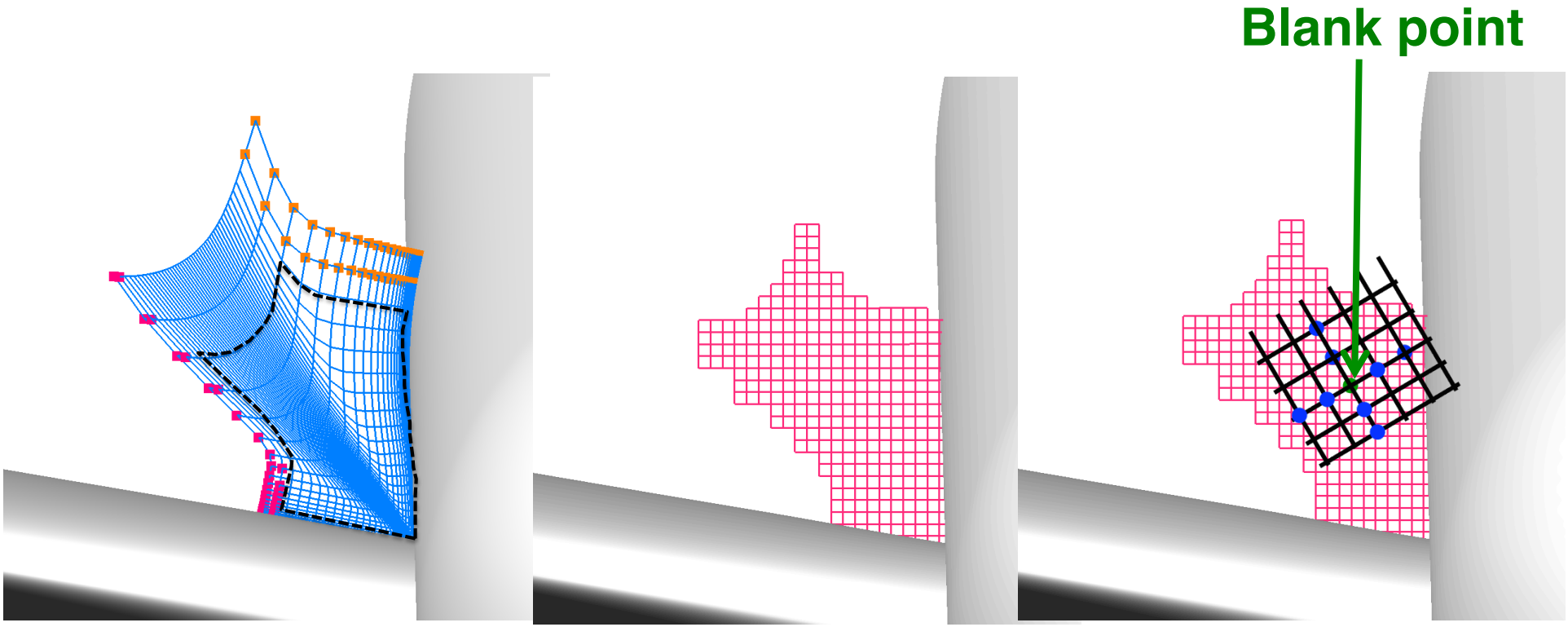




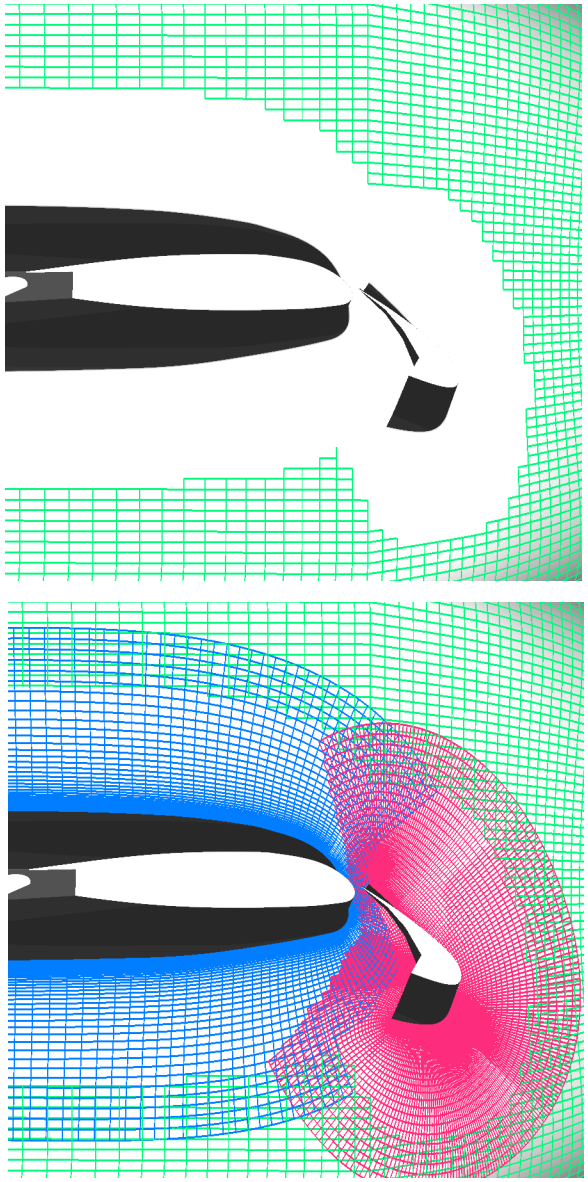


HOLE BOUNDARY ESTIMATION
Donor Stencil Maps

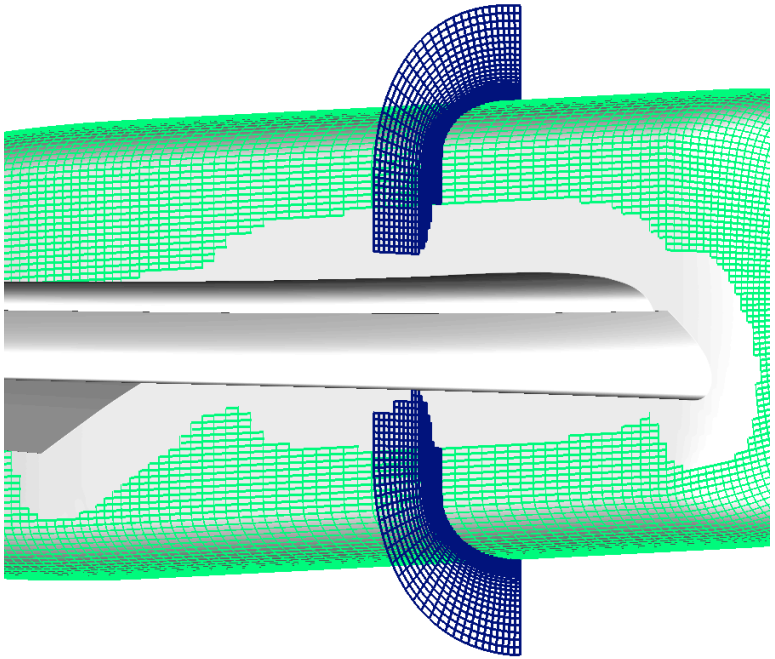
- Use Cartesian map to rapidly determine approximate locations of valid donor stencils
- A grid point from another grid can be blanked if itself and N_f neighbors are inside valid donor stencils



HOLE BOUNDARY ESTIMATION
3. Blanking of Parents of Collar Grids

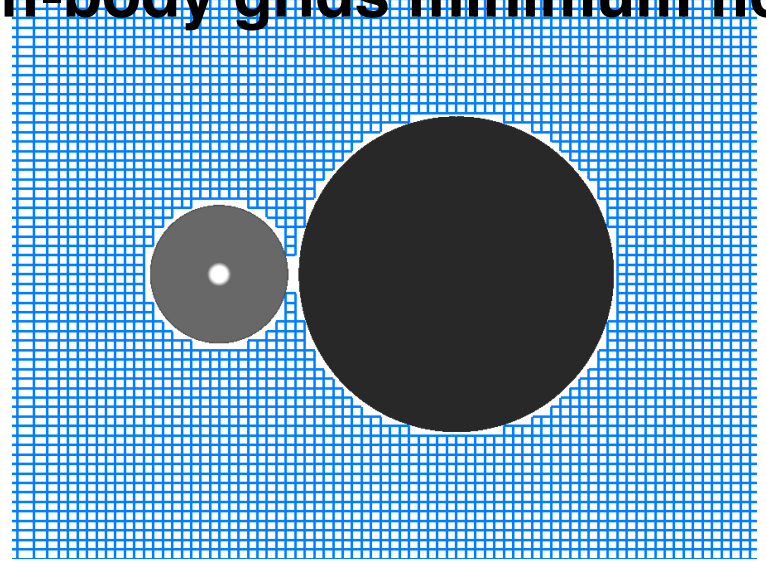


Use donor stencil maps of collar grids to blank parent grids

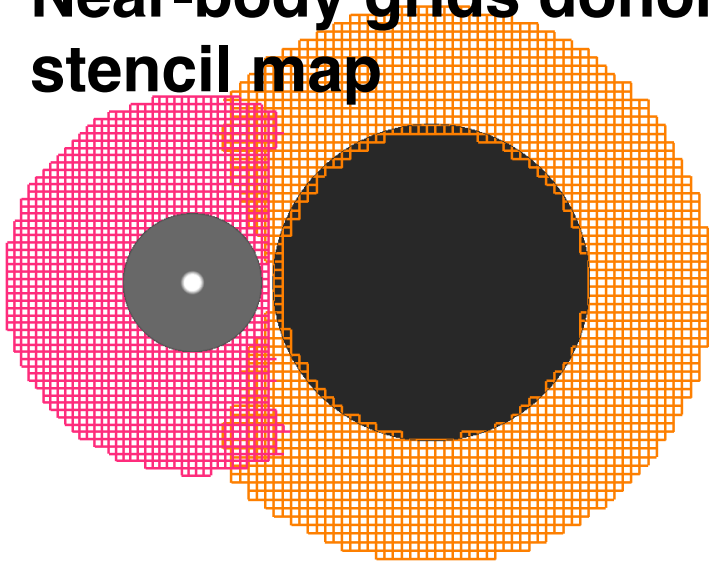


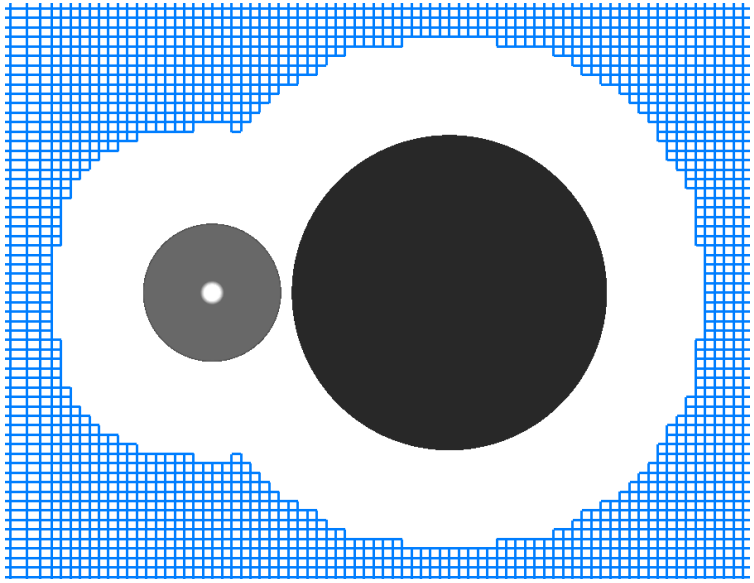
HOLE BOUNDARY ESTIMATION
4. Blanking of Off-Body Grids

Off-body grids minimum hole



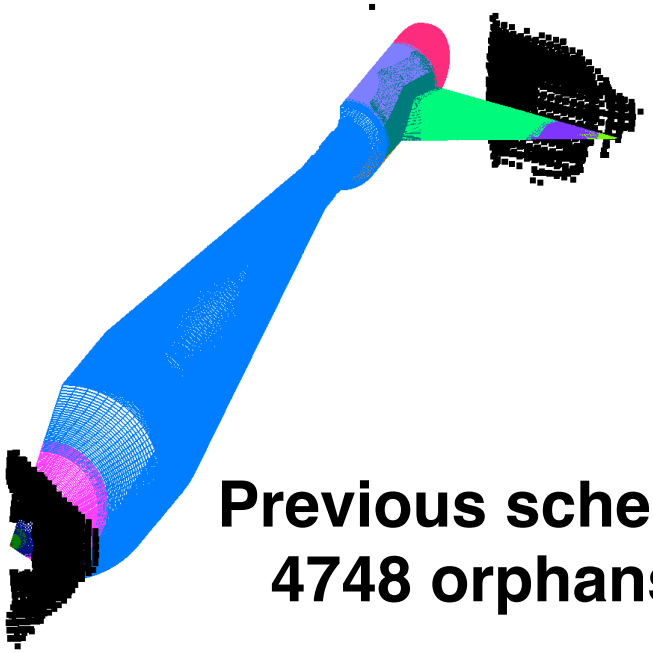
Near-body grids donor stencil map



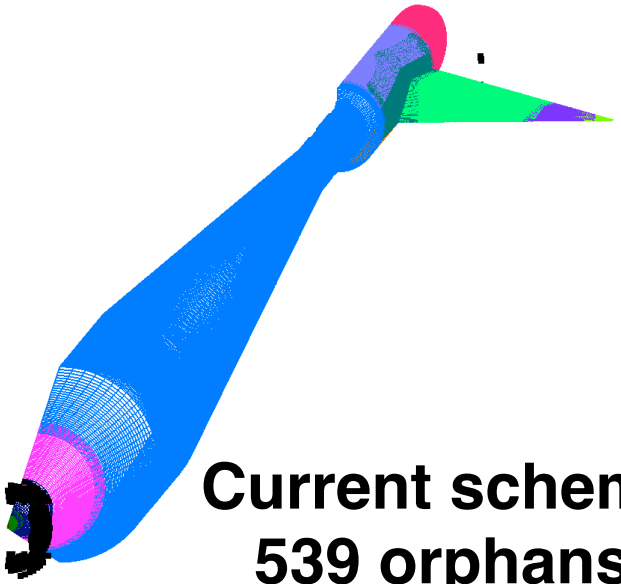


Off-body grids hole boundary estimate

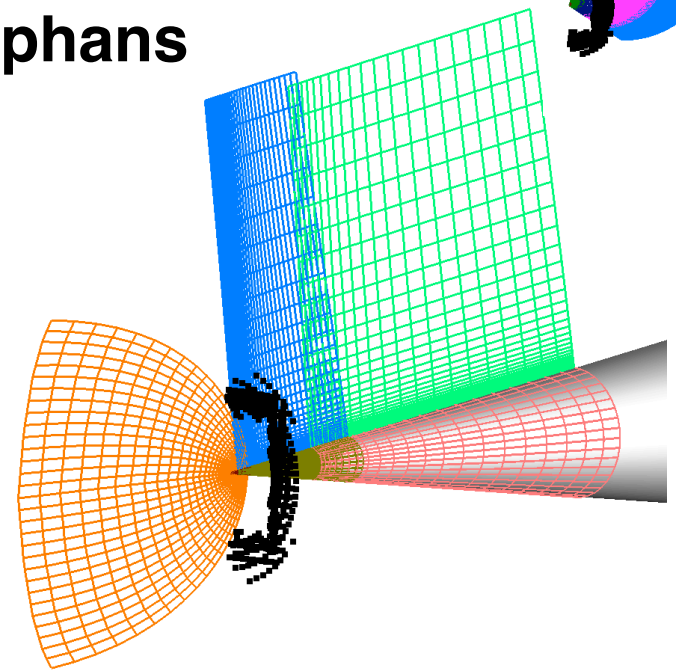
DELTA-WING-BODY
32.6 million points, 17 grids, 1 component



Previous scheme
4748 orphans

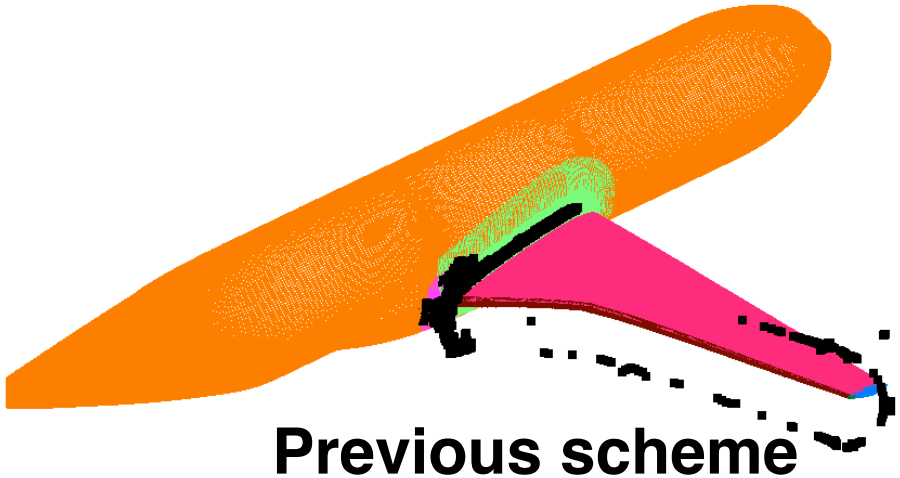


Current scheme
539 orphans

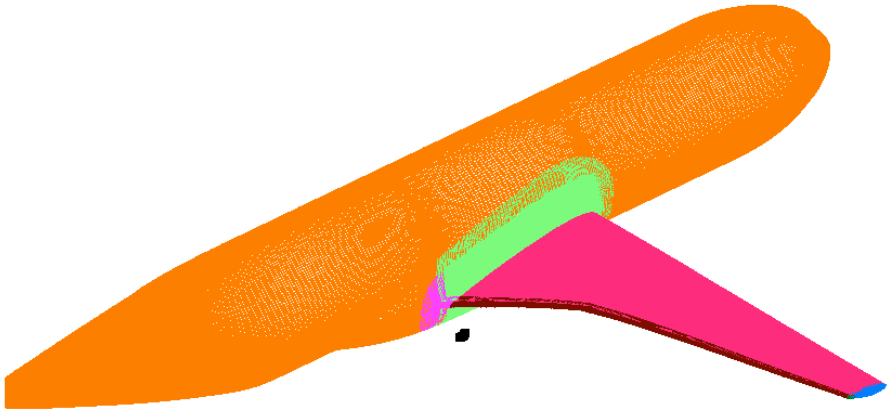


Lack of near-body grid overlap in volume grids

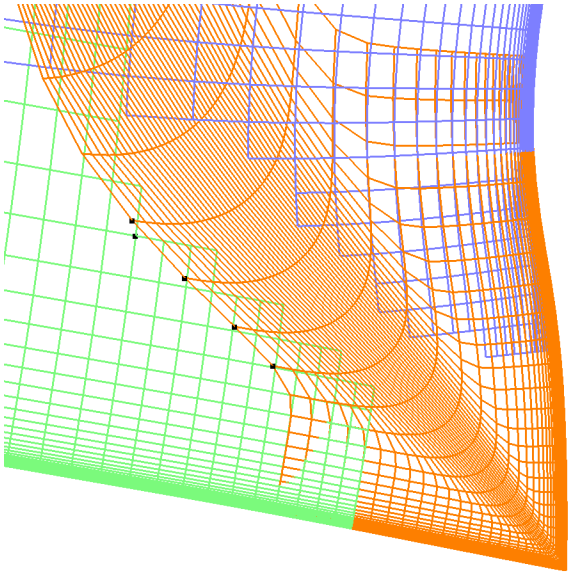
COMMON RESEARCH MODEL
17.8 million points, 14 grids, 2 components

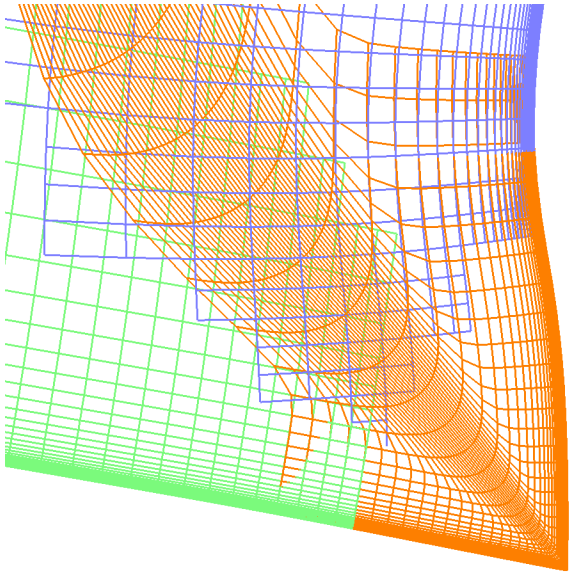


Previous scheme
2576 orphans

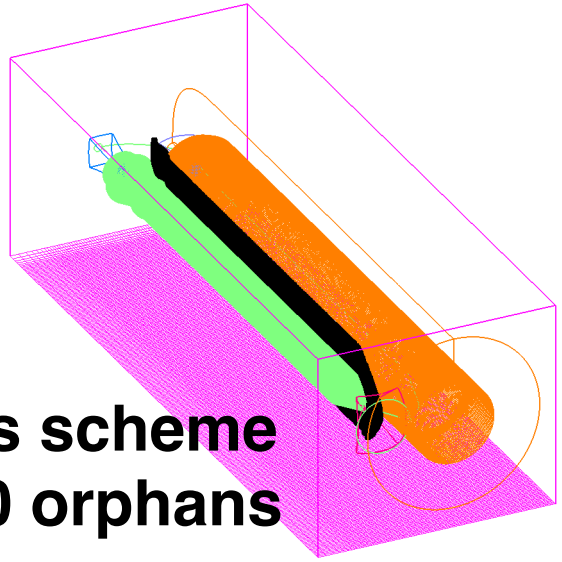


Current scheme
10 orphans

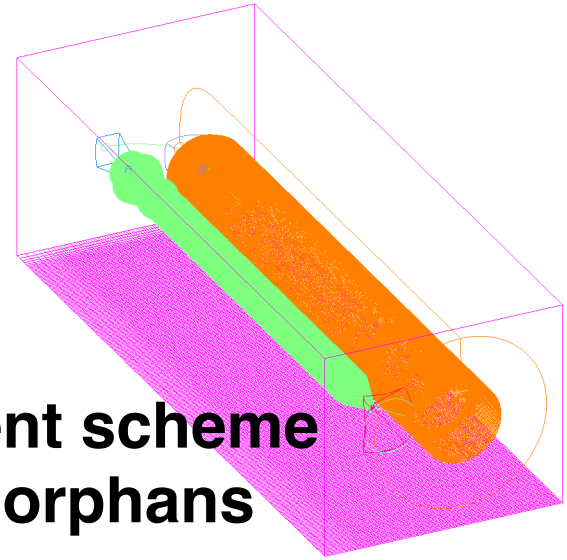




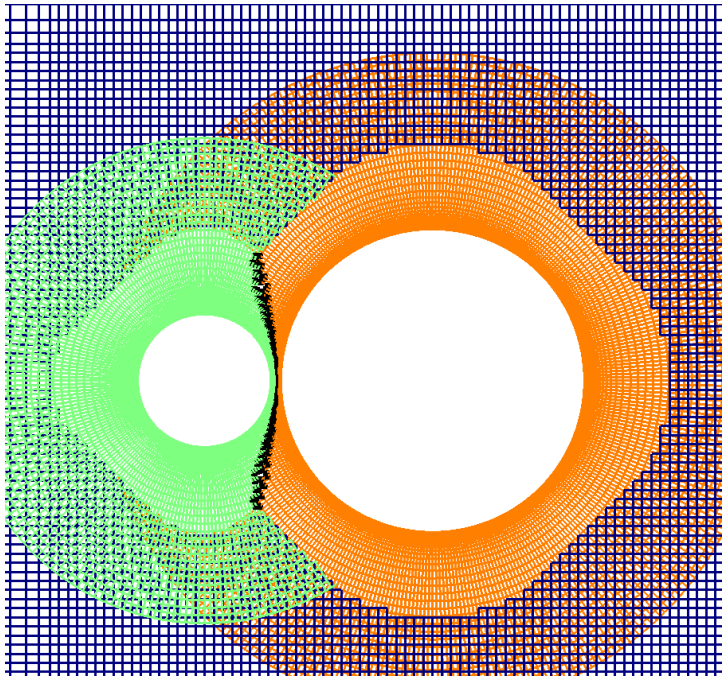
TANK-BOOSTER
28.5 million points, 6 grids, 2 components

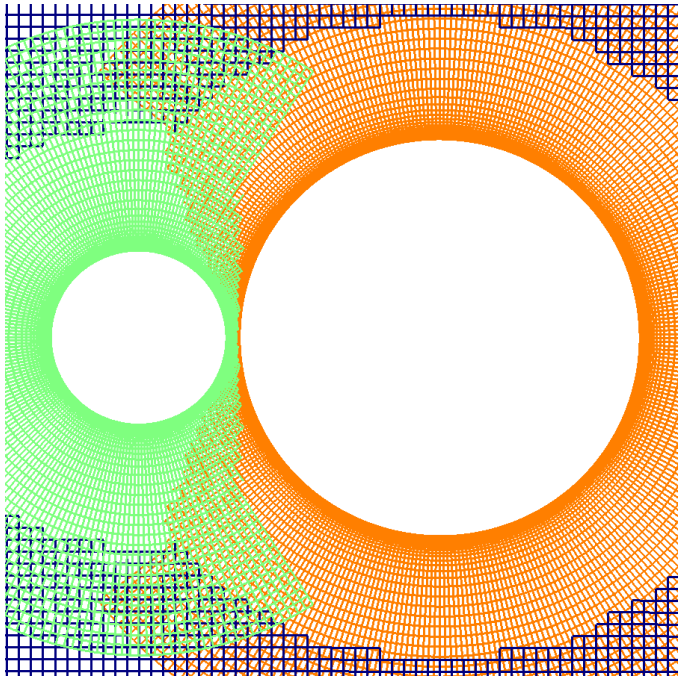


Previous scheme
102210 orphans

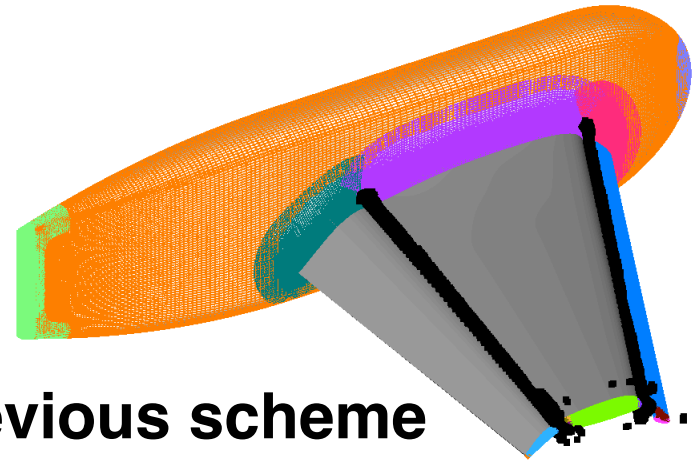


Current scheme
0 orphans

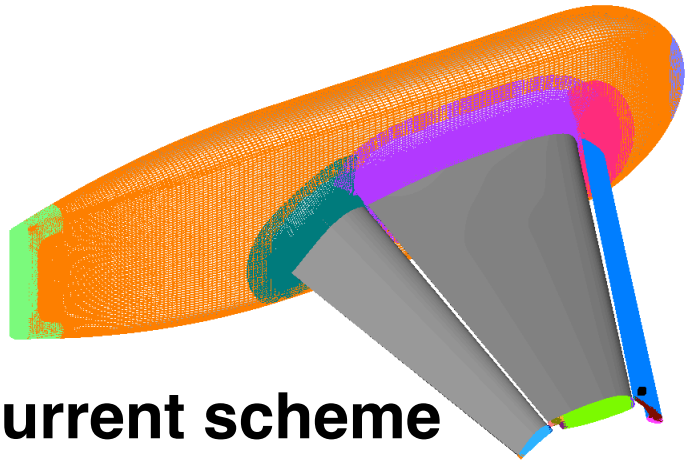




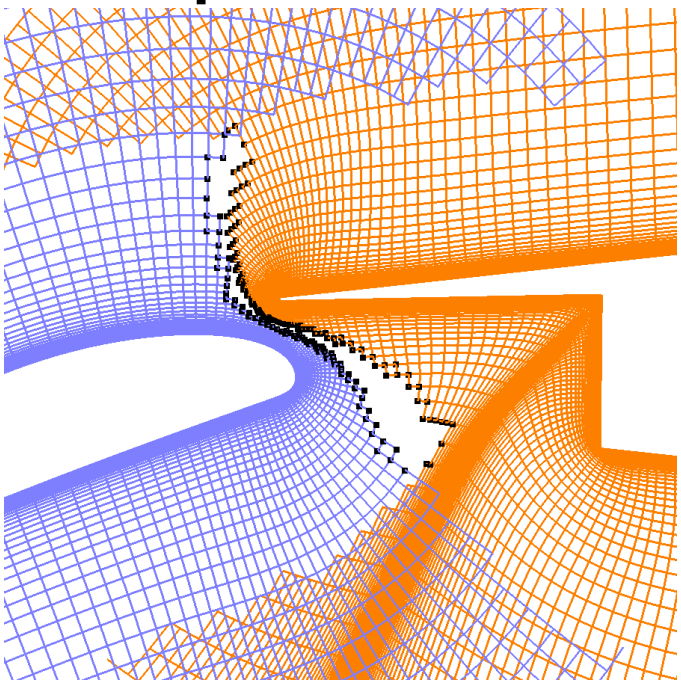
TRAPWING 3-ELEMENT HIGH LIFT SYSTEM
50.6 million points, 24 grids, 4 components

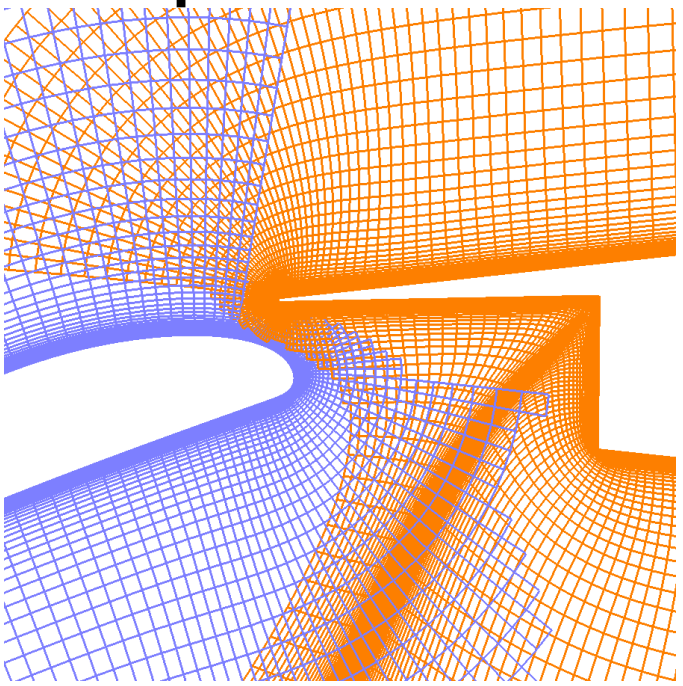


Previous scheme
85000 orphans

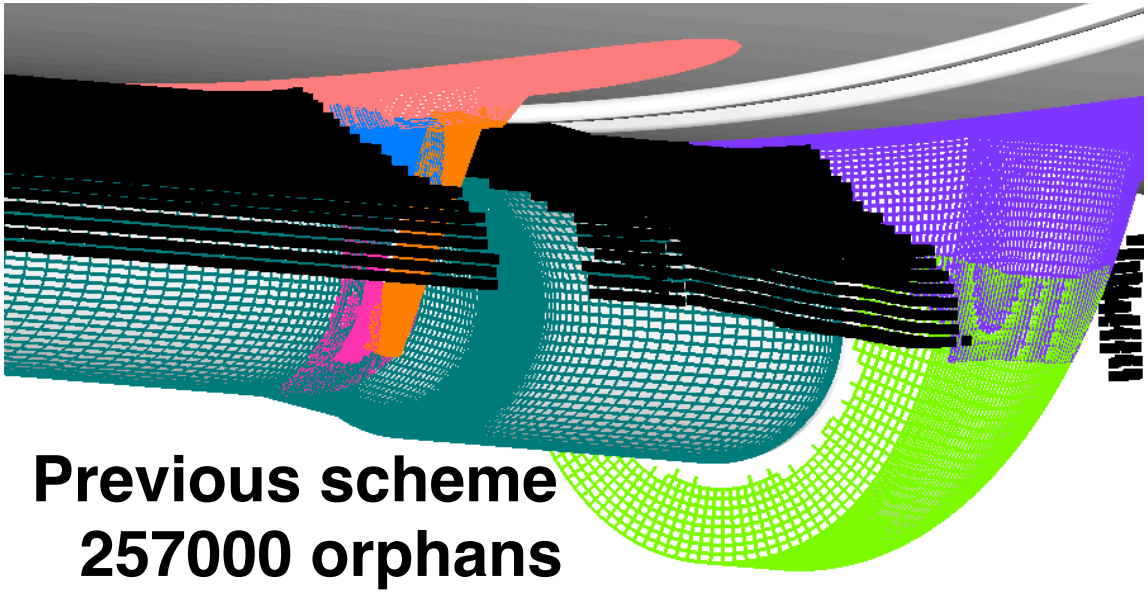


Current scheme
25 orphans

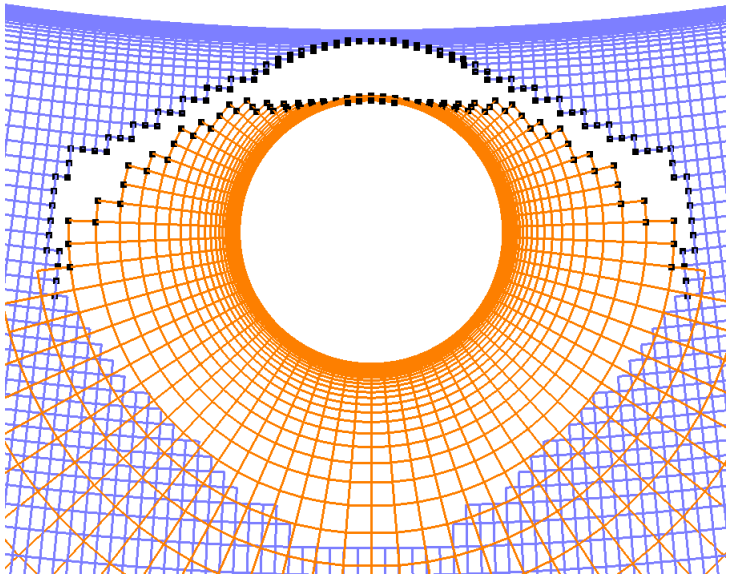


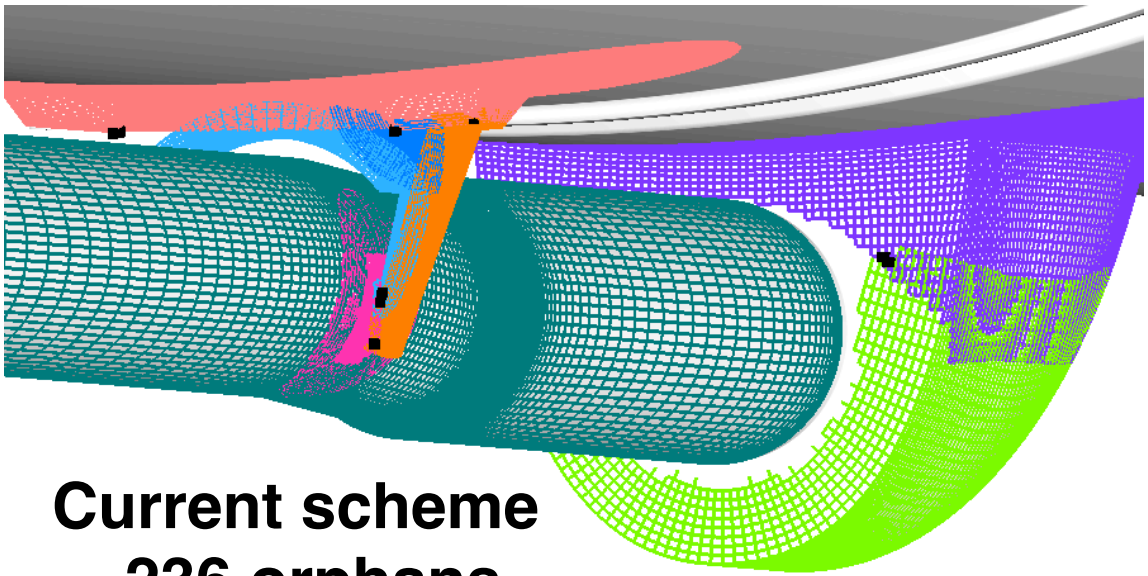


FEEDLINE WITH BRACKET
82.7 million points, 23 grids, 4 components

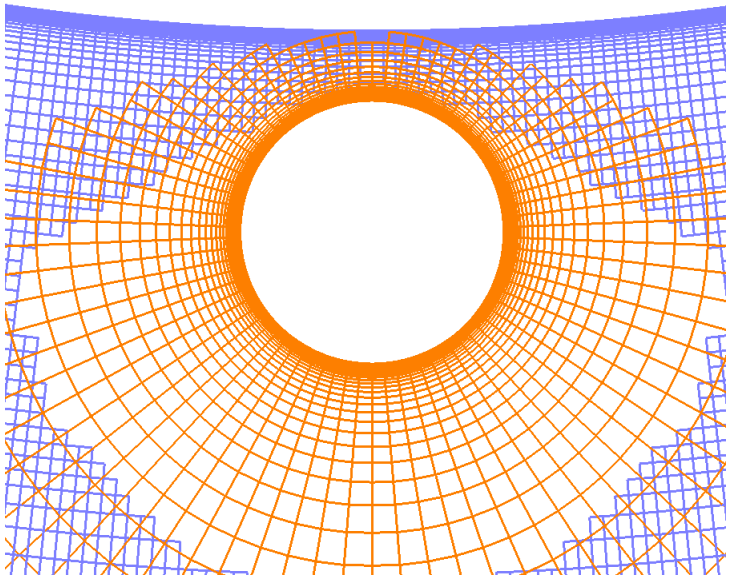


Previous scheme
257000 orphans

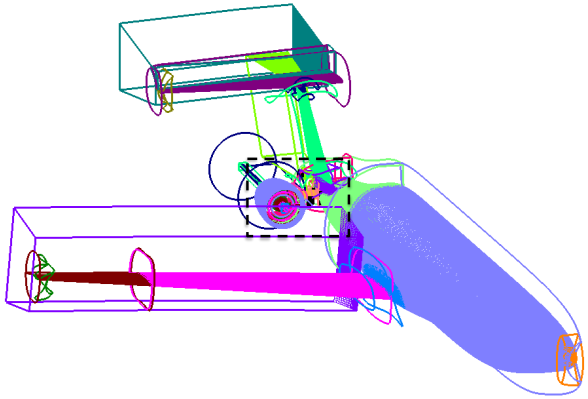


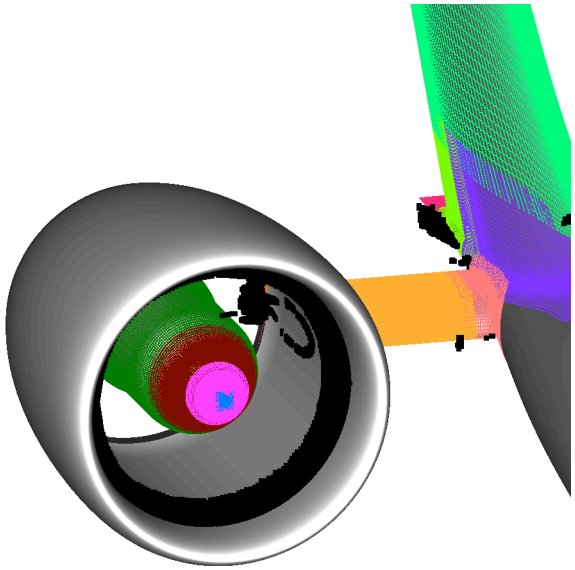


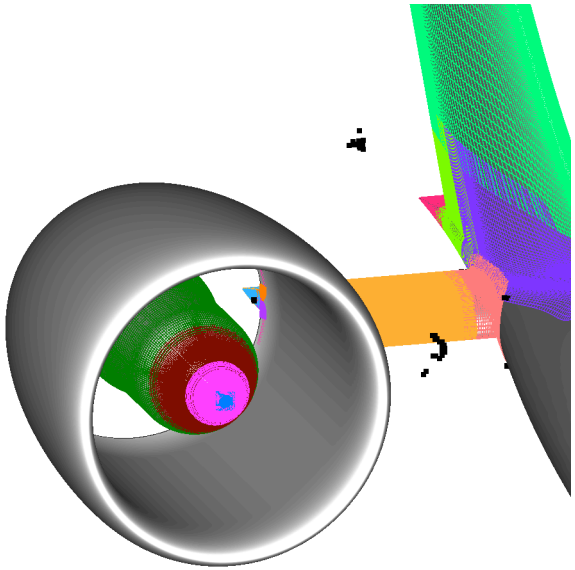
Current scheme
236 orphans



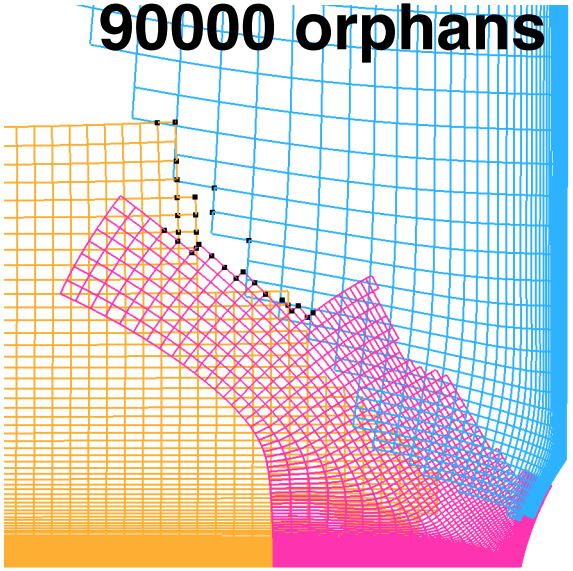
D-8 DOUBLE BUBBLE WITH PODDED NACELLE
140.5 million points, 36 grids, 7 components



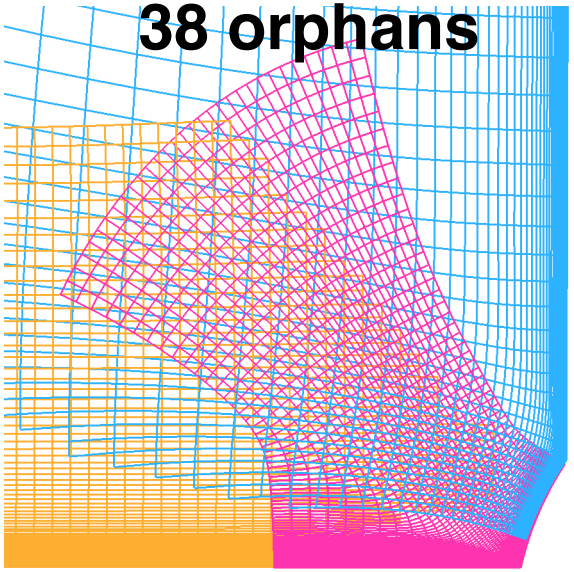




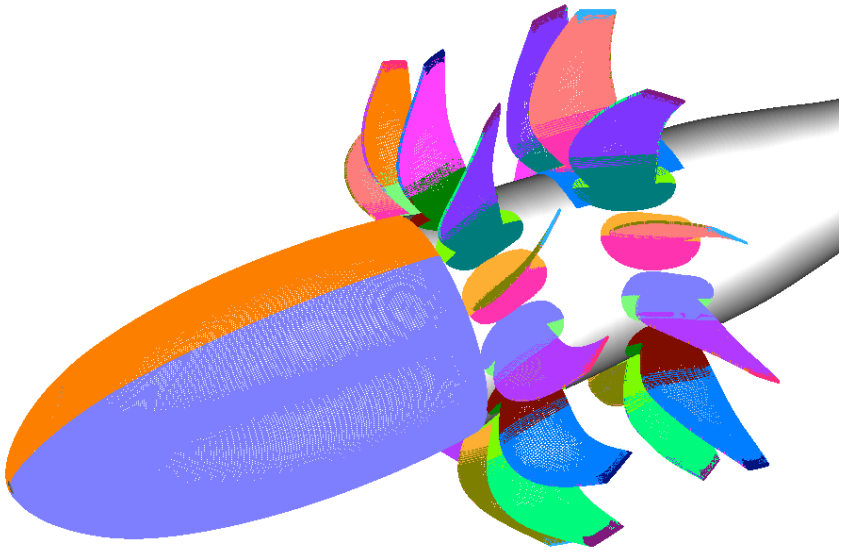
Previous scheme
90000 orphans

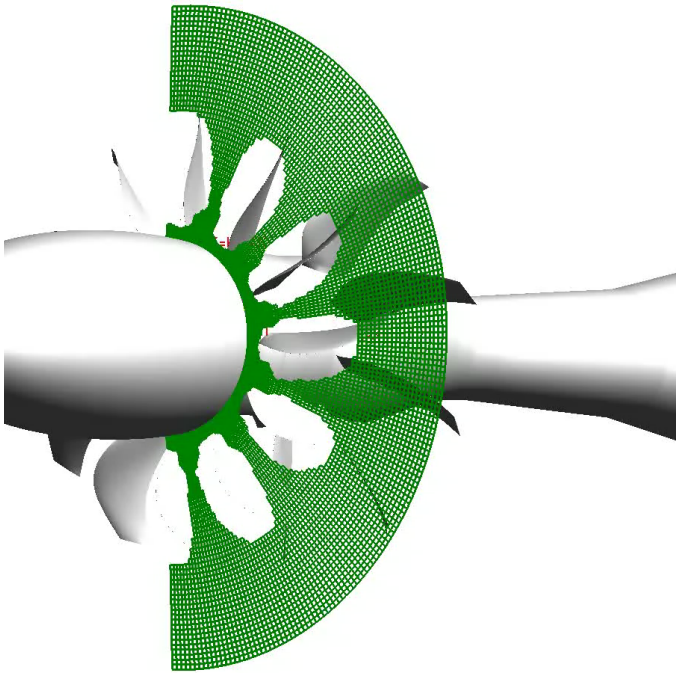


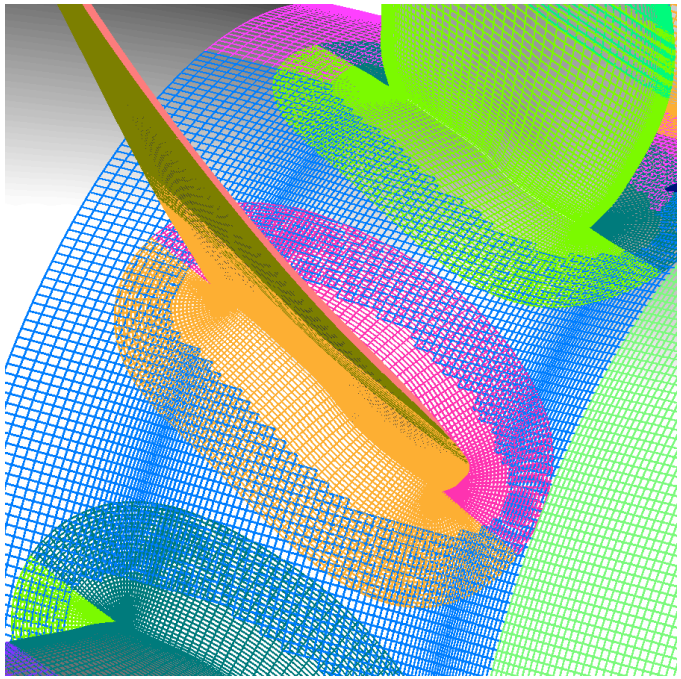
Current scheme
38 orphans

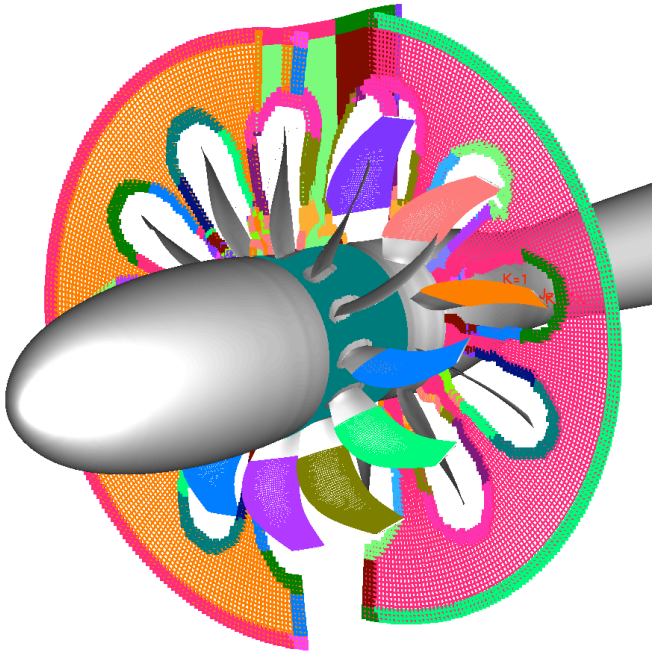


OPEN ROTOR
164.6 million points, 123 grids, 23 components









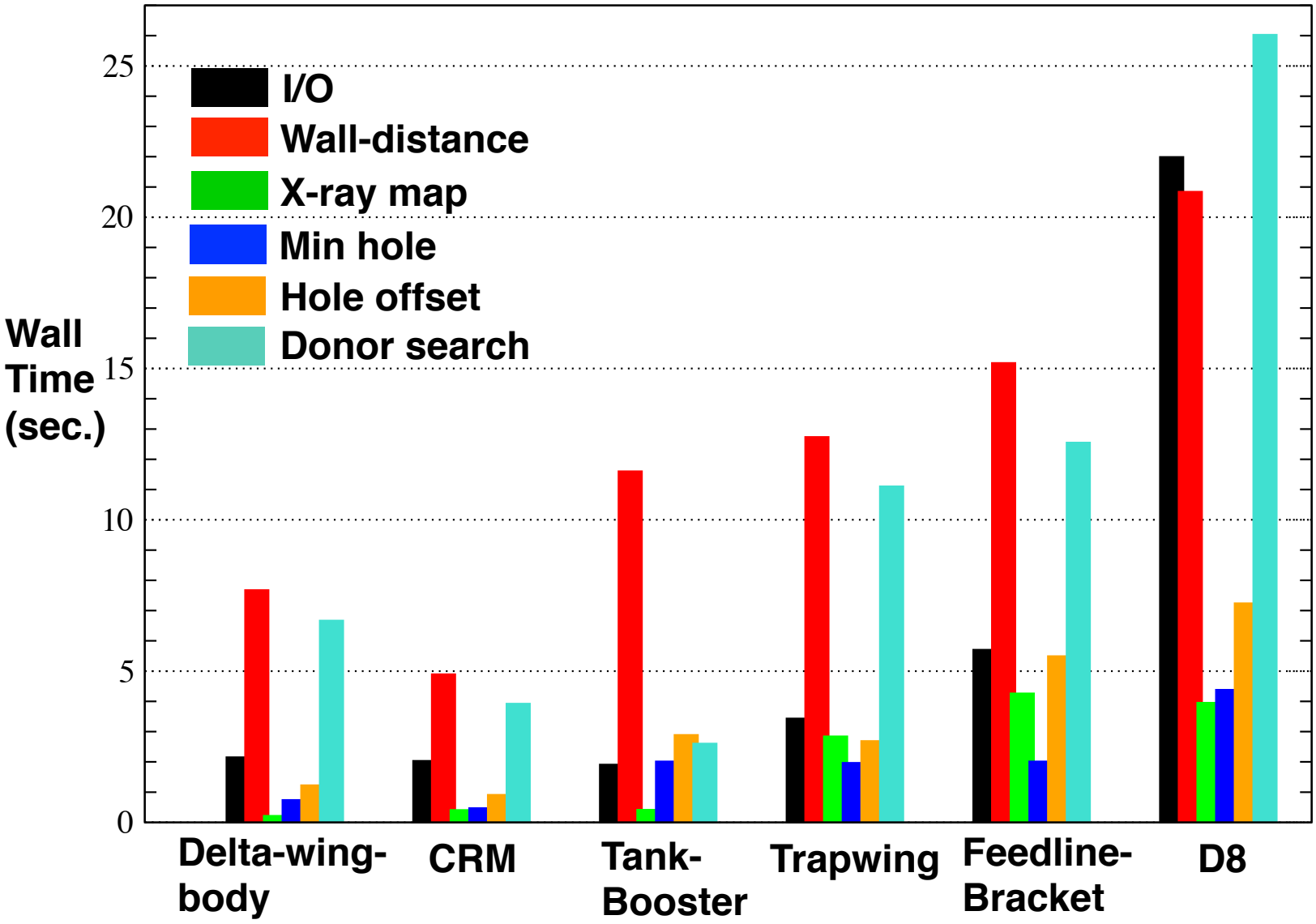
Triple fringe, zero orphans

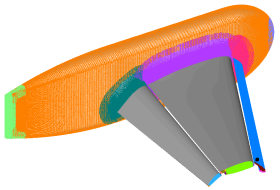
COMPUTATIONAL EXPENSE

- Linux workstation with 24 OpenMp threads
- All cases use double fringe, except Open Rotor which uses triple fringe

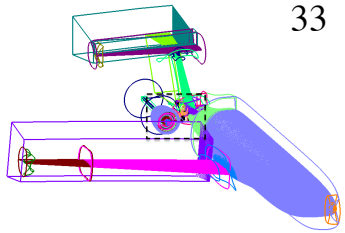
				Previous		Current	
Test Case	Grid Pts ($x10^6$)	#Grid / #Comp	MemUse (GB)	Orphn	Wall time (sec.)	Orphn	Wall time (sec.)
Delta-Wing-Body	32.6	17 / 1	4	4748	32	539	19
CRM	17.8	14 / 2	2	2576	22	10	13
Tank-Booster	28.5	6 / 2	4	102210	37	0	22
Trapwing High-Lift	50.6	24 / 4	7	85000	100	25	35
Feedline-Bracket	82.7	23 / 4	9	257000	110	236	46
D-8 Pod. Nacelle	140.5	36 / 7	15	90000	344	38	89
Open Rotor	164.6	123 / 23	35	N/A	N/A	0	730

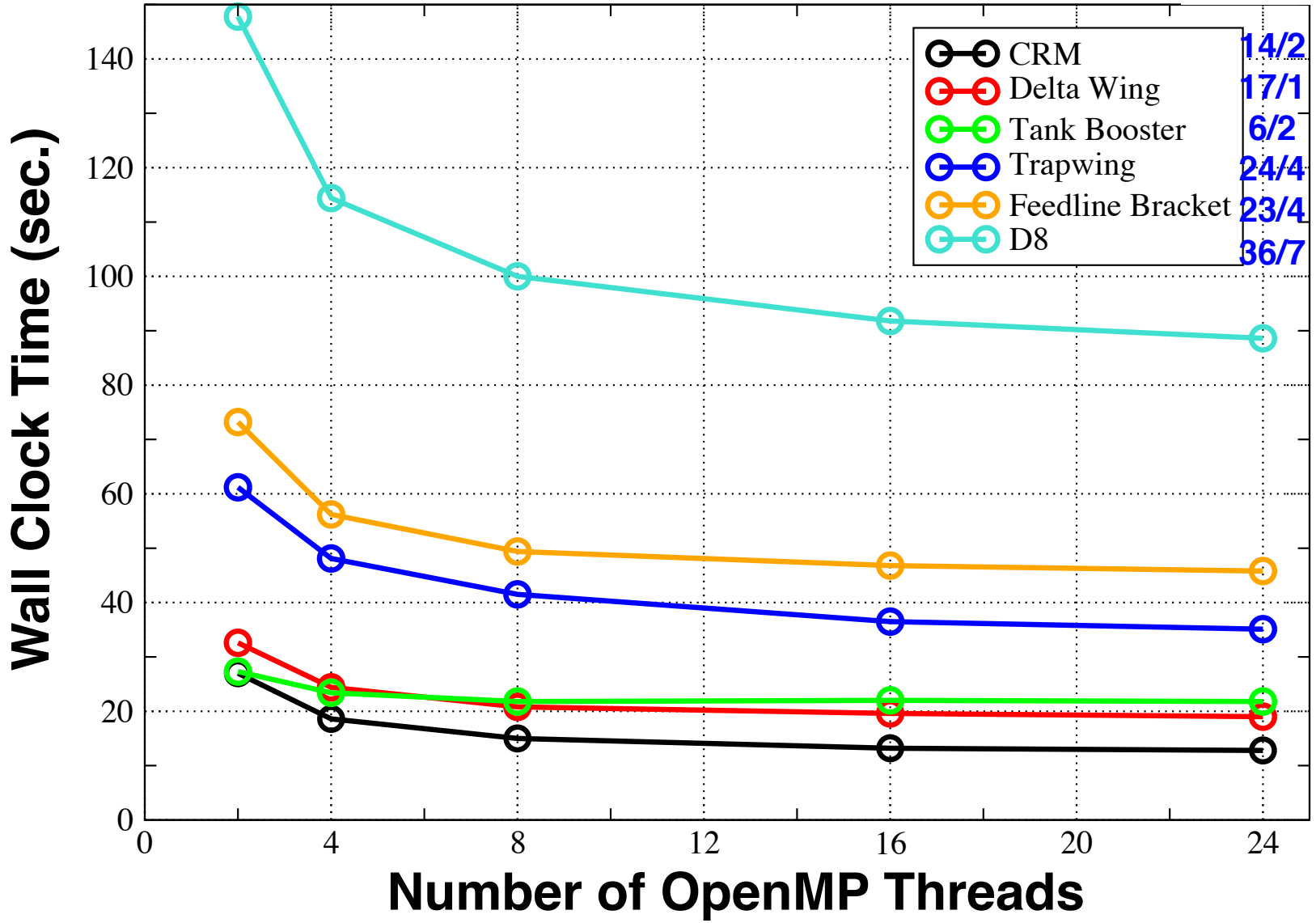
WALL TIME FOR EACH PART OF PROCESS



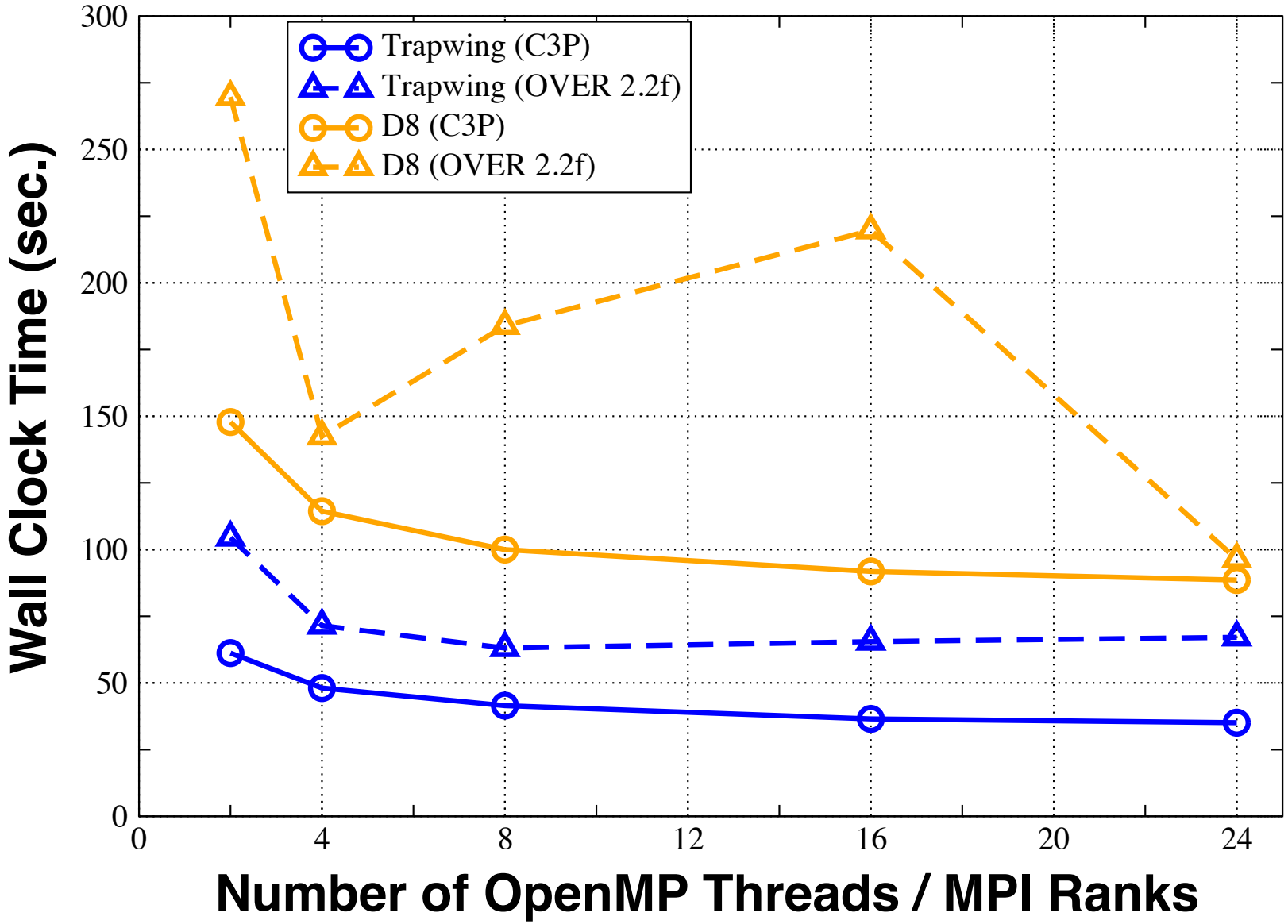


OPENMP SCALING





C3P (OpenMP) AND OVERFLOW/DCF 2.2f (MPI) COMPARISON



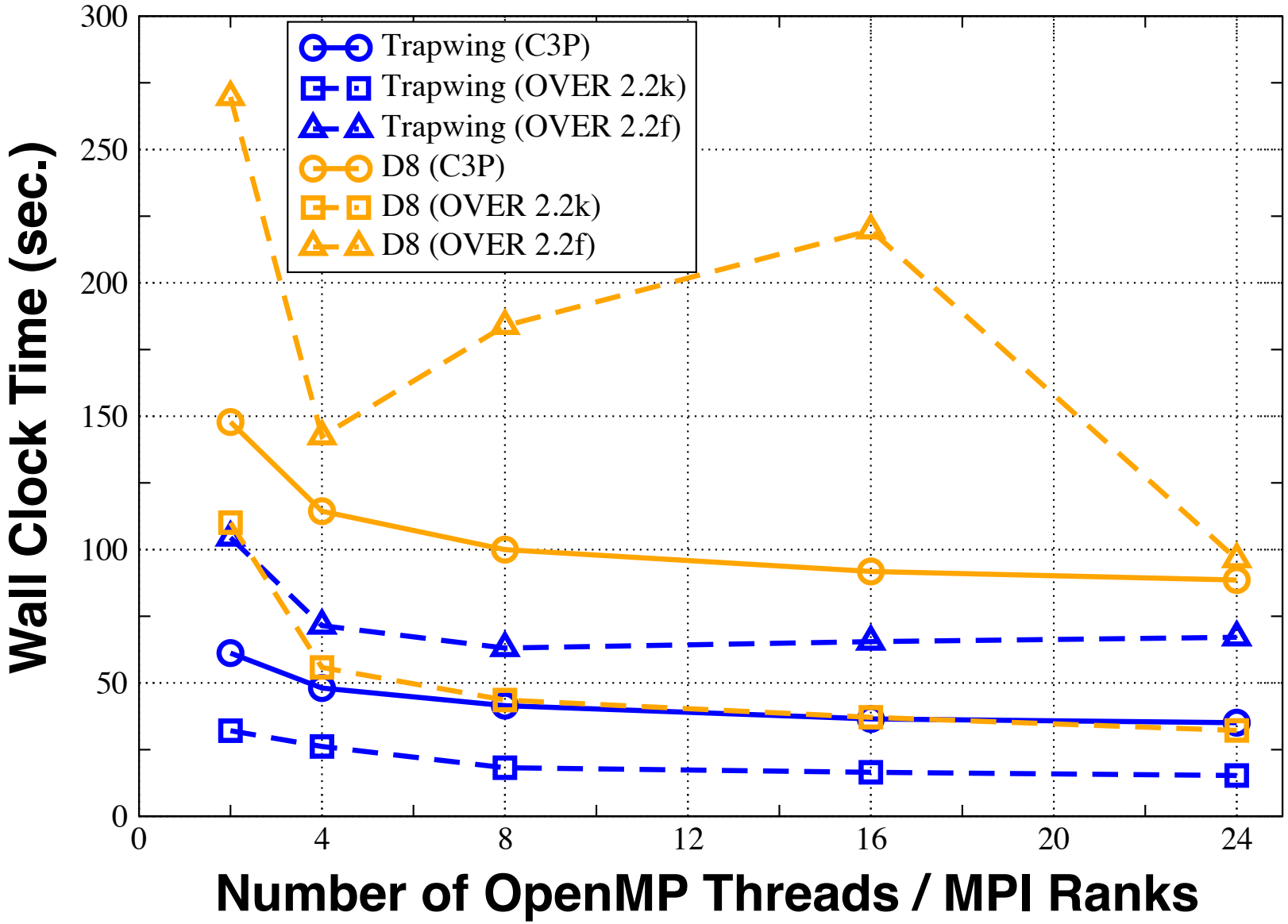
C3P AND OVERFLOW/DCF CONNECTIVITY PROCESS

	C3P	OVERFLOW/DCF
Component specification		N/A
X-ray maps		
Cutting instructions		
Minimum hole		
Hole offset		
Donor search		

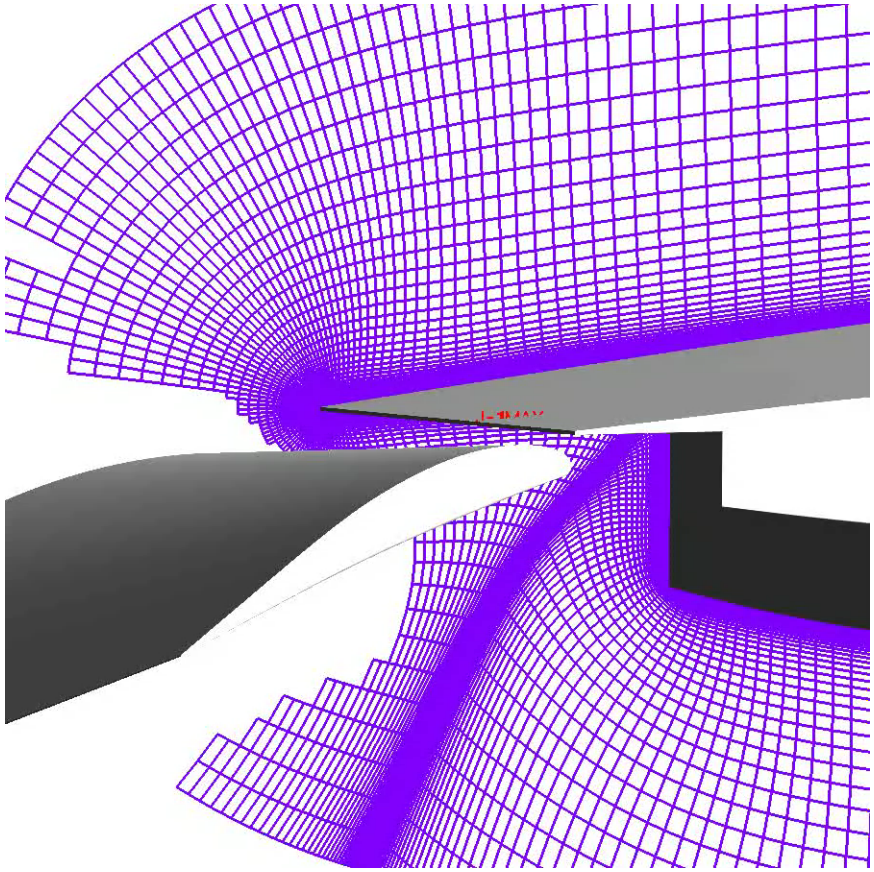
Manual creation/specification and read from input file

Automatically computed

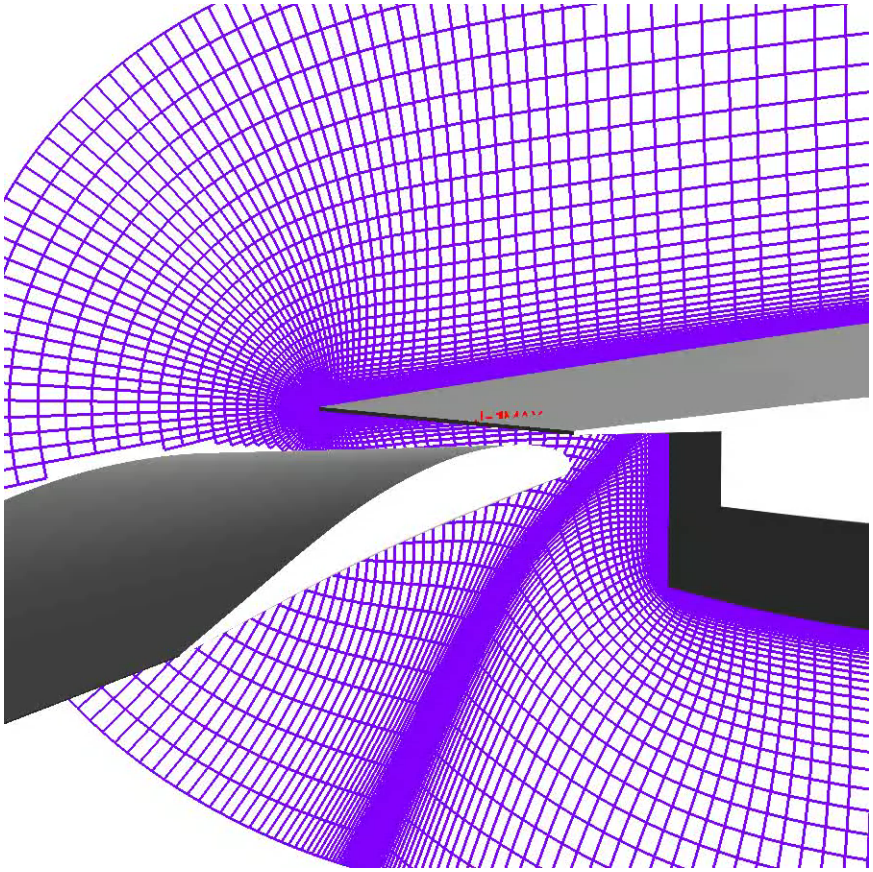
C3P (OpenMP) AND OVERFLOW/DCF 2.2k (MPI) COMPARISON



TRAPWING 3-ELEMENT HIGH LIFT SYSTEM
Grid Plane Sweeps for Wing

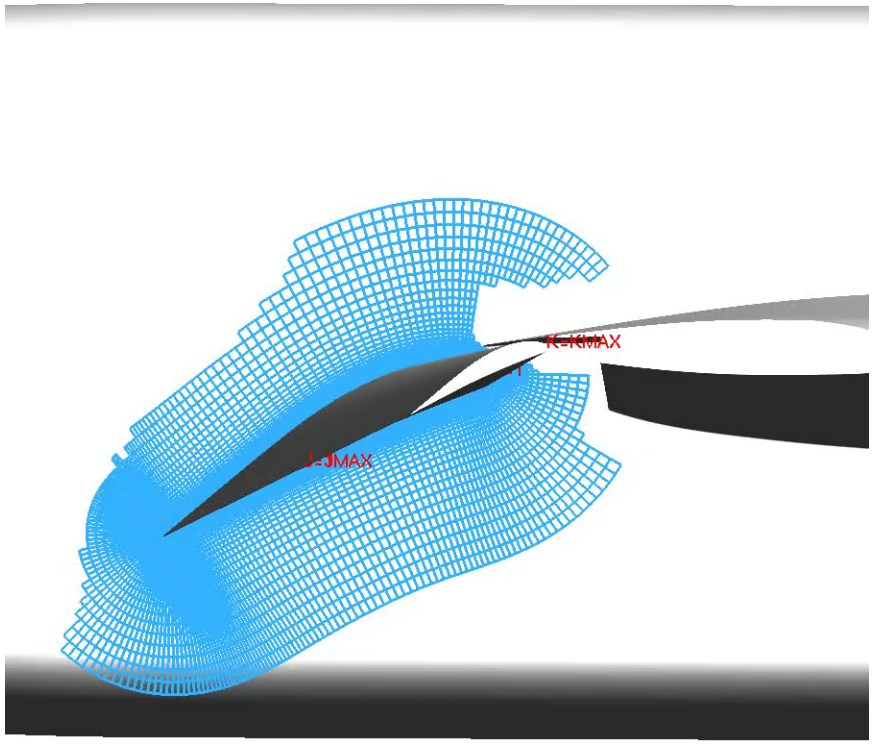


C3P
variable offset

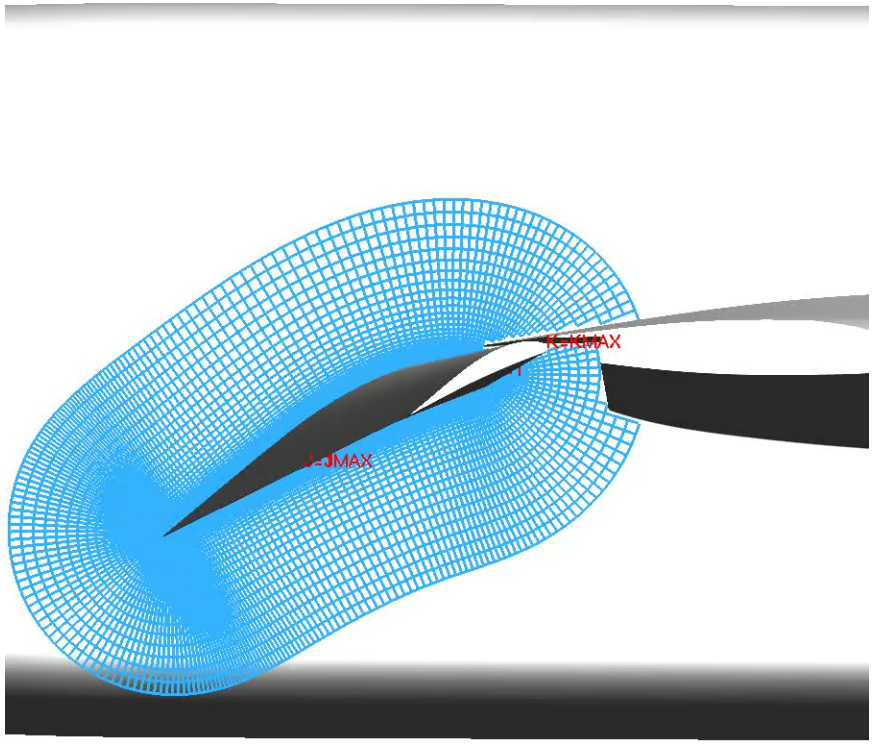


OVERFLOW/DCF
constant offset

TRAPWING 3-ELEMENT HIGH LIFT SYSTEM
Grid Plane Sweeps for Flap



C3P
variable offset



OVERFLOW/DCF
constant offset

CHIMERA COMPONENTS CONNECTIVITY PROGRAM (C3P)

- Fortran 95 with OpenMP parallelization

Input

- Flow solver boundary conditions for each grid
- Component name for each solid wall boundary condition
- Grid file
  - Multiple surface grids without or with iblanks
  - Multiple volume grids without or with iblanks

Output

- Standard X-ray map for each component cutter
- List of grid subsets cuttable by each cutter
- Grid file with connectivity iblanks (x.save)
- Donor stencil information file (INTOUT / XINTOUT)
- Donor stencil quality table

DONOR STENCIL QUALITY TABLE

Stencil Quality Summary

Quality	Number
Q = 0.0	0
0.0<= Q < 0.1	0
0.1<= Q < 0.2	7
0.2<= Q < 0.3	2
0.3<= Q < 0.4	5
0.4<= Q < 0.5	11
0.5<= Q < 0.6	4666
0.6<= Q < 0.7	4328
0.7<= Q < 0.8	4426
0.8<= Q < 0.9	4359
0.9<= Q < 1.0	5012
Q = 1.0	3147532
Sum =	3170348

C3P FEATURES

- Auto generation of standard X-ray for each component from input grids, with option to use user-provided surface triangulation as cutting surface

- Auto determination of grid subsets cuttable by each component X-ray, with optional user-specified overrides

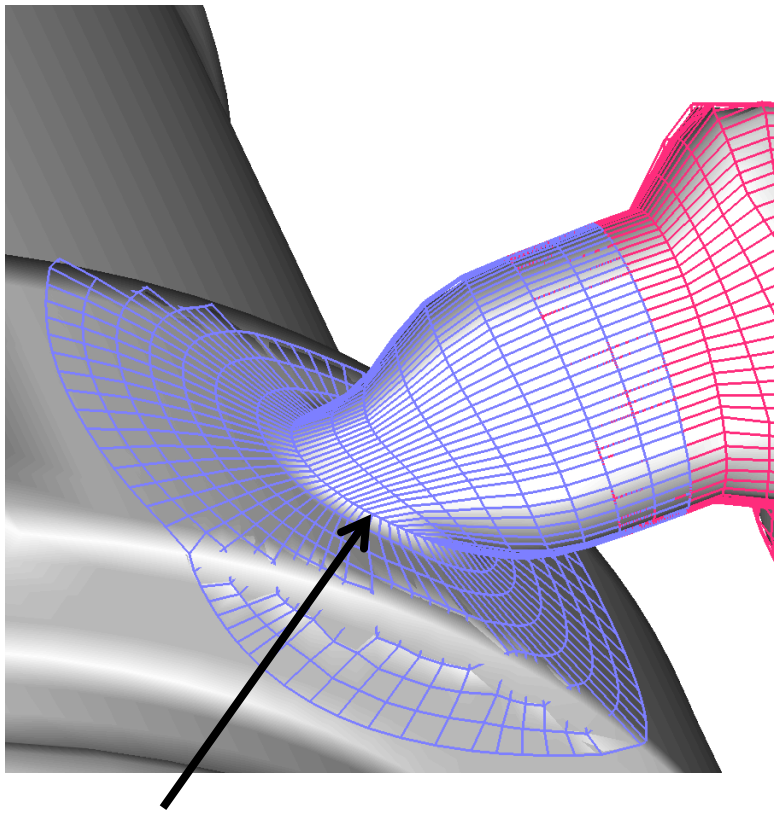
- Auto detection of external versus internal cutters

- Options to specify blanked regions in physical space or index space

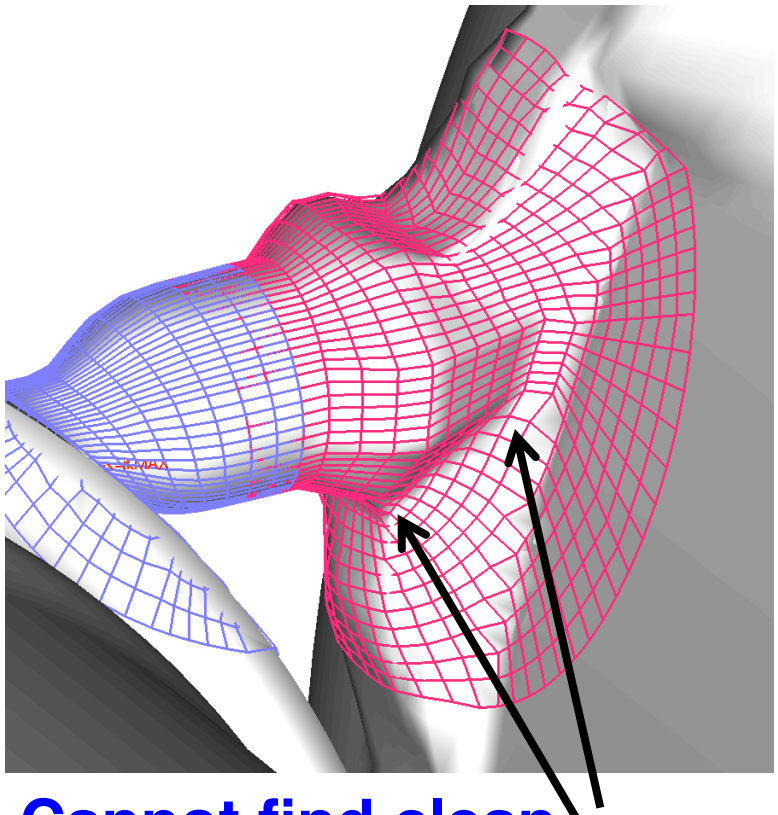
- Currently available for internal testing / use only

LIMITATIONS

1. Need clean intersection curve at component junctions



Clean intersection curve



Cannot find clean intersection curve (will also have difficulty in component specification for loads computation)

2. OpenMP parallelization

FUTURE WORK

- Implement MPI parallelization

- Explore load balancing options

- Creation of library (C3LIB)
  - Component approximate wall distance computation
  - Determination of minimum hole
  - Hole boundary offset (distance rules and stencil maps)
  - Donor stencil search

- Improve robustness by trying more test cases

SUMMARY AND CONCLUSION

- A new robust method was developed to construct a closed surface for open components -> proper minimum hole determination

- Distance rules and donor stencil maps were used to build a variable-distance offset from the minimum hole -> small number of orphan points for most test cases

- Method implemented into C3P software
  -> connectivity computation for surface and volume grids
  -> comparing with OVERFLOW/DCF (2.2k) standard X-rays
    - mixed operational possibilities
    - preliminary tests show about 2x more CPU time using C3P but with significant user's effort savings and automatic variable distance offset