Evaluation of Refined Tetrahedral Meshes with Projected, Stretched, and Sheared Prism Layers for Sonic Boom Analysis

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Scott D. Thomas

Outline

Motivation

Methodology

- Developing a Near-Field Cylindrically-Shaped Mesh
- Projecting a Layered Cylindrically-Shaped Prism Mesh
- Shearing & Stretching of the Prismatic Grid
- Circumferential Refinement of Outer Prismatic Grid

Results

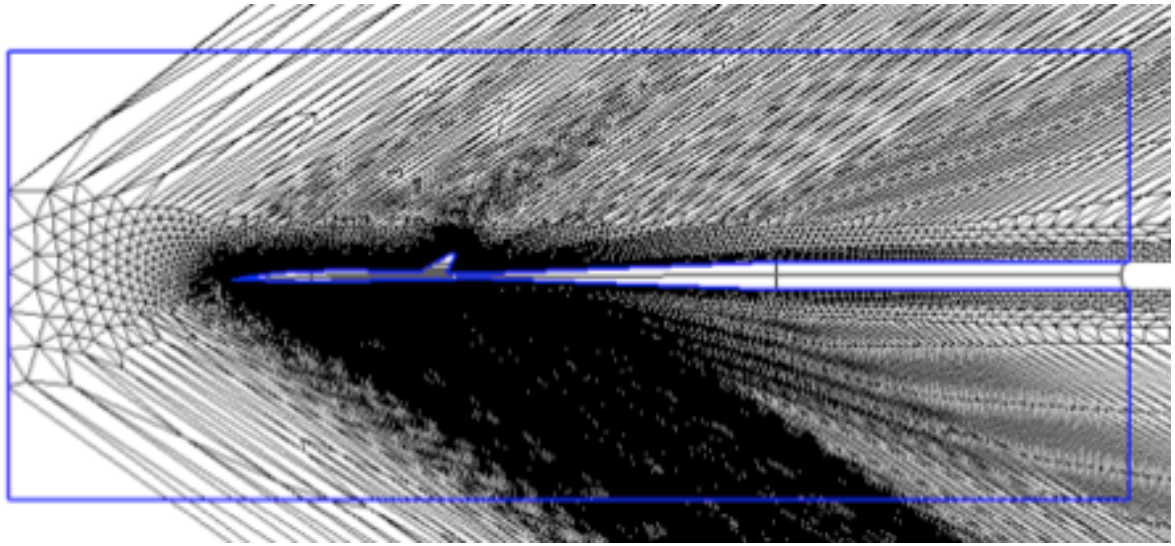


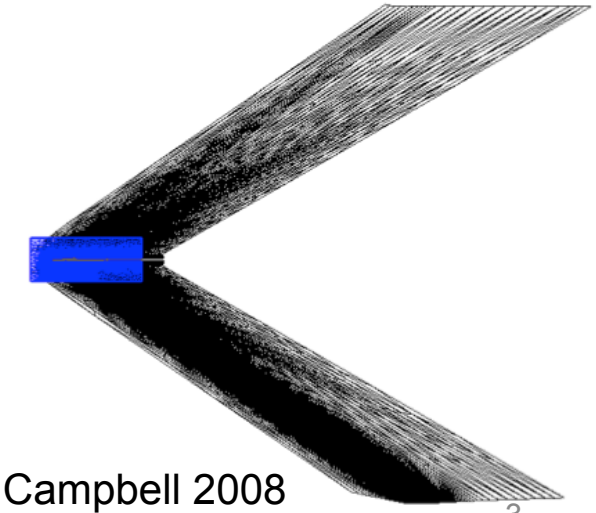
Best Practices

Conclusions

Motivation

- Accurate sonic boom pressure signatures at several body lengths
- Single mesh for accurate boom and drag
- Robust stretching / shearing method for tetrahedral meshes
- Single mesh for on- and off-track pressure signatures
- Automated tool to construct mesh with hands-off control





Campbell 2008

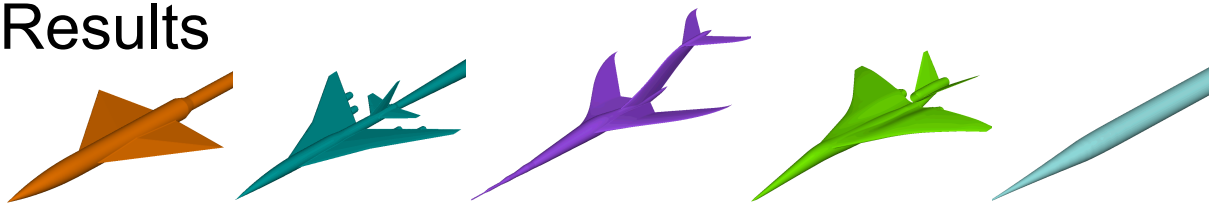
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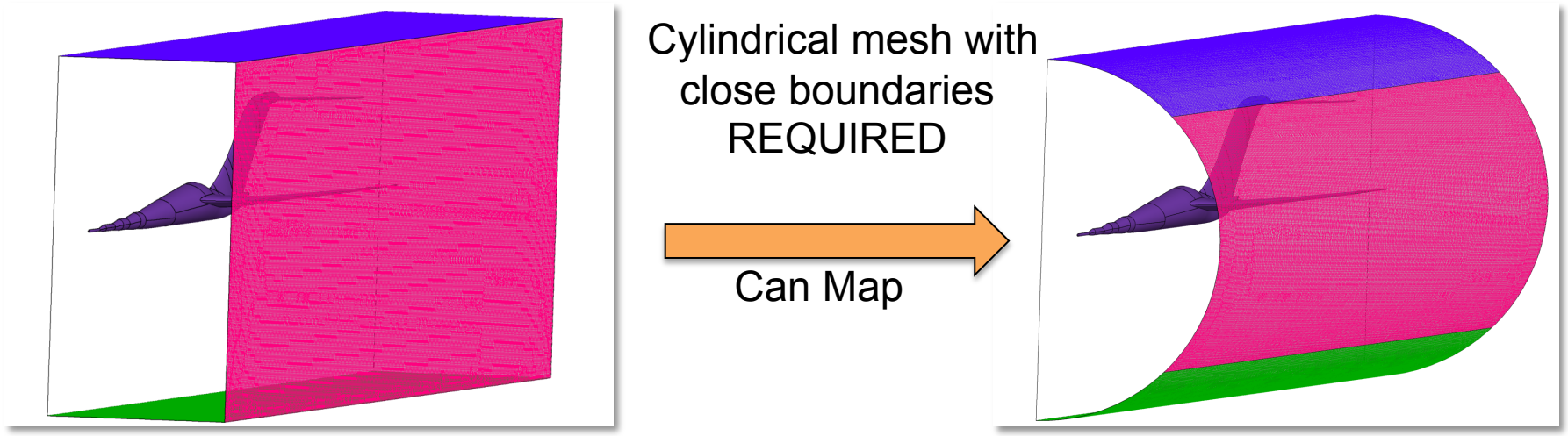
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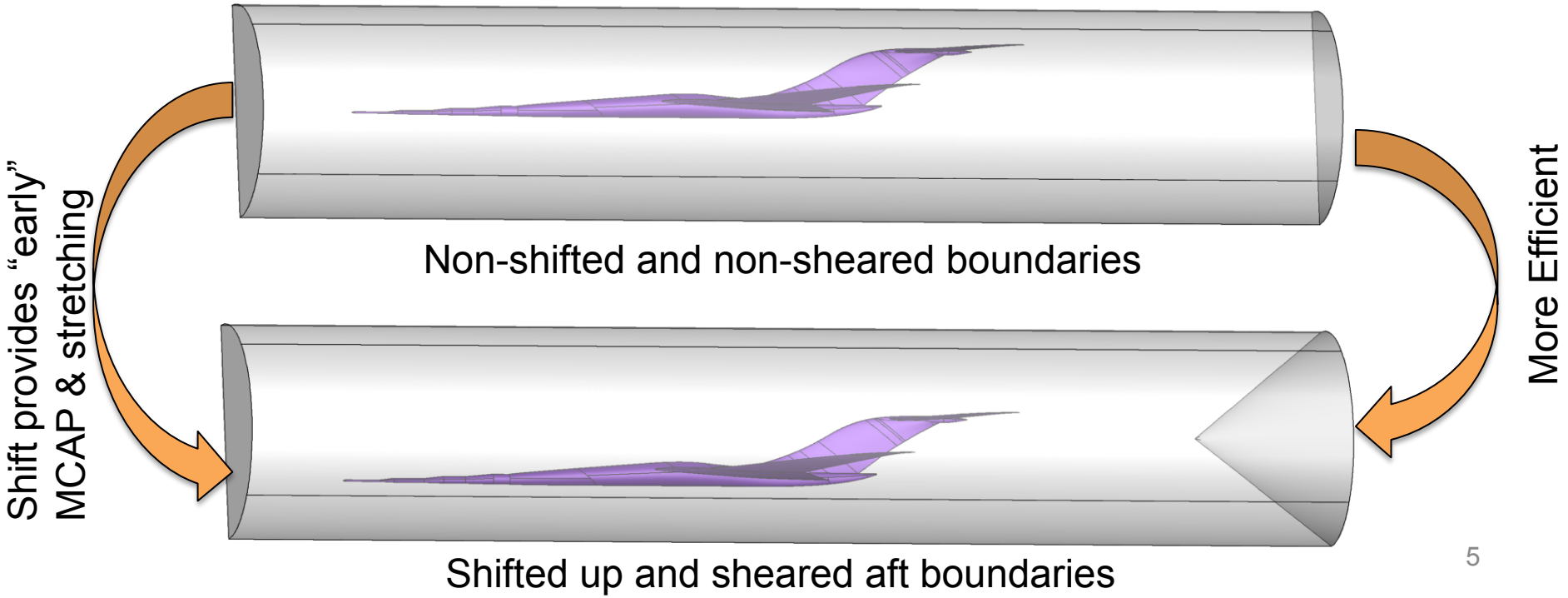


Best Practices

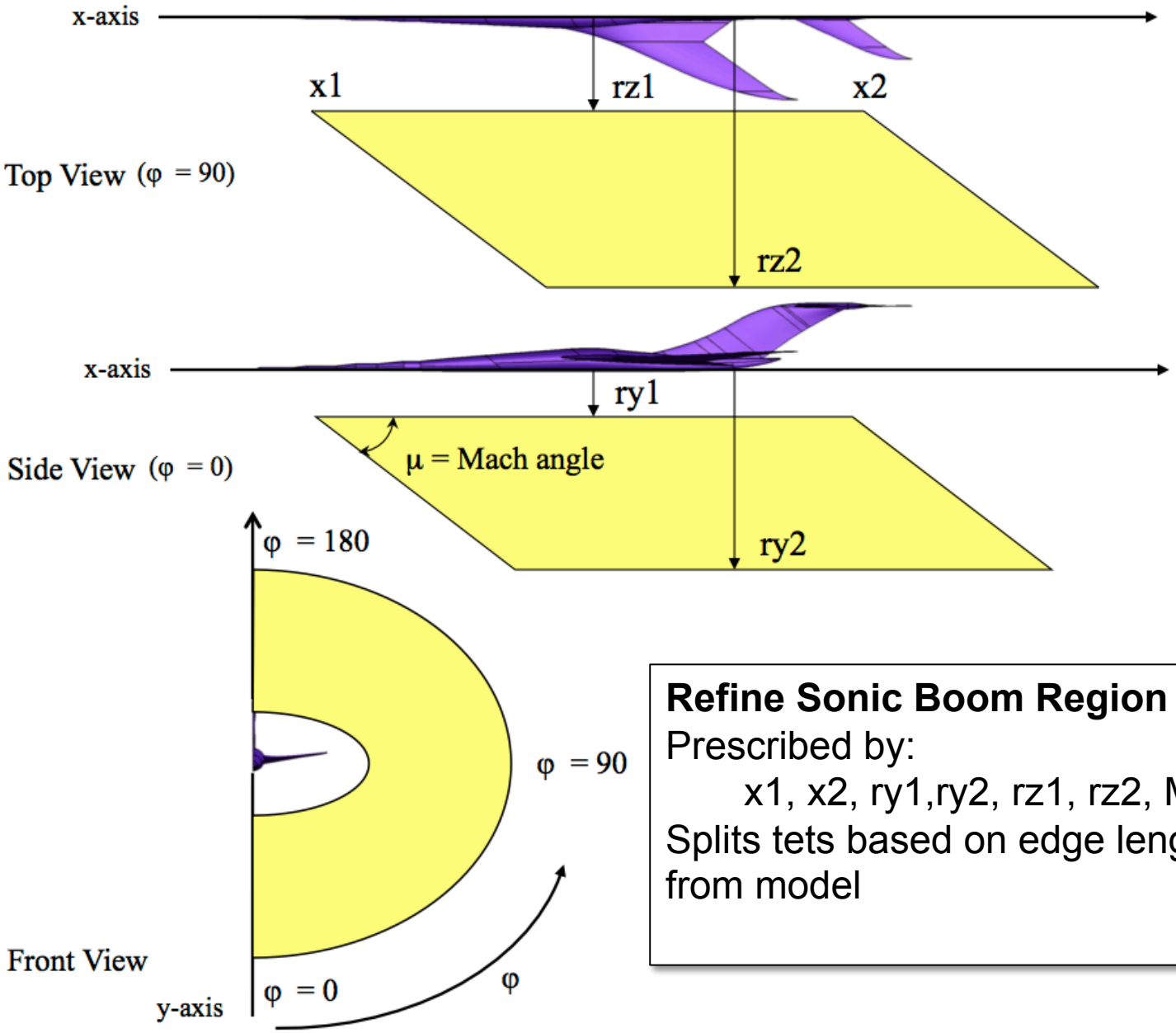
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Developing a Near-Field Cylindrically-Shaped Mesh





Developing a Near-Field Cylindrically-Shaped Mesh



Refine Sonic Boom Region of Influence

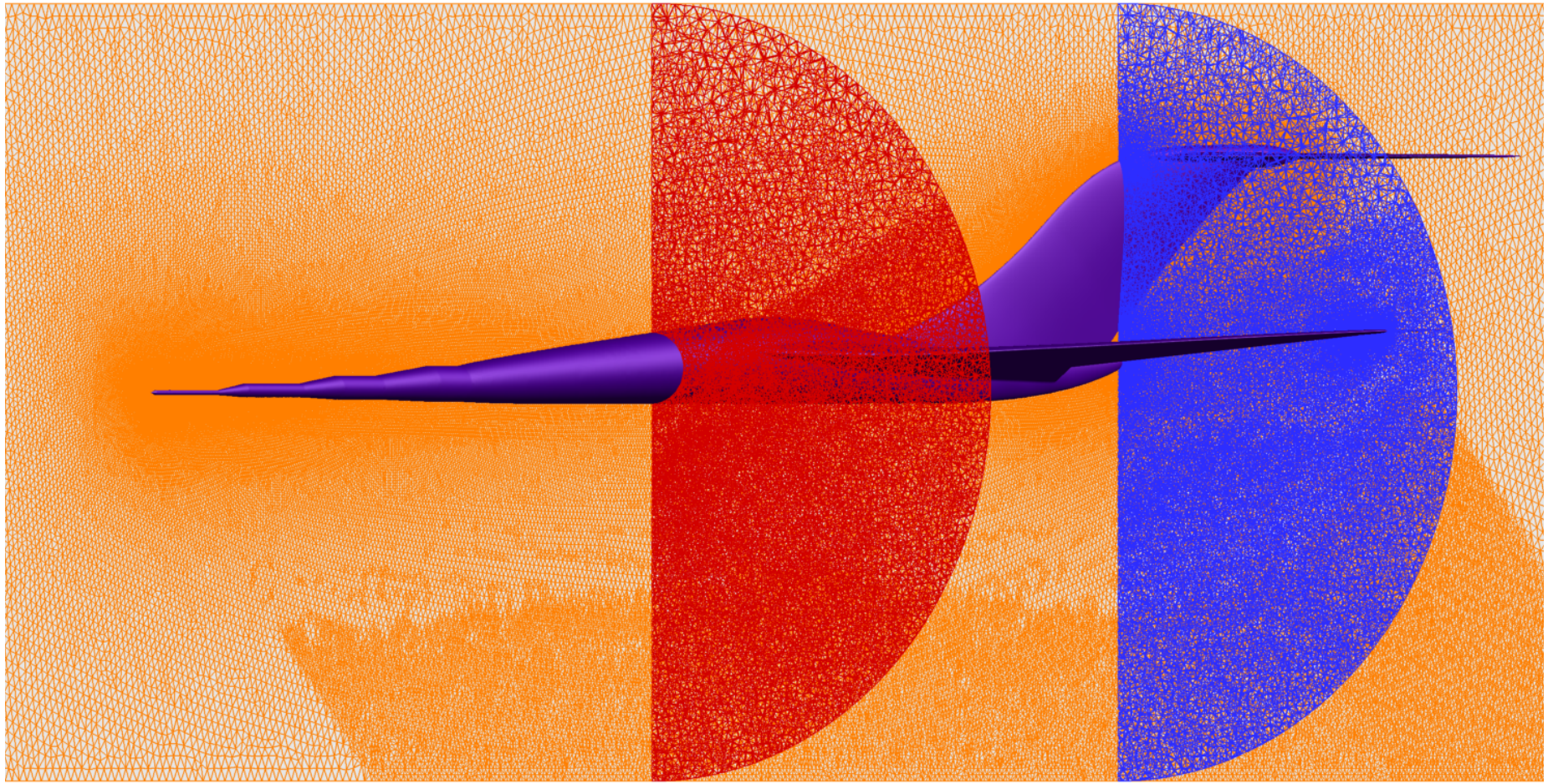
Prescribed by:

x1, x2, ry1,ry2, rz1, rz2, M, φ

Splits tets based on edge length and distance from model

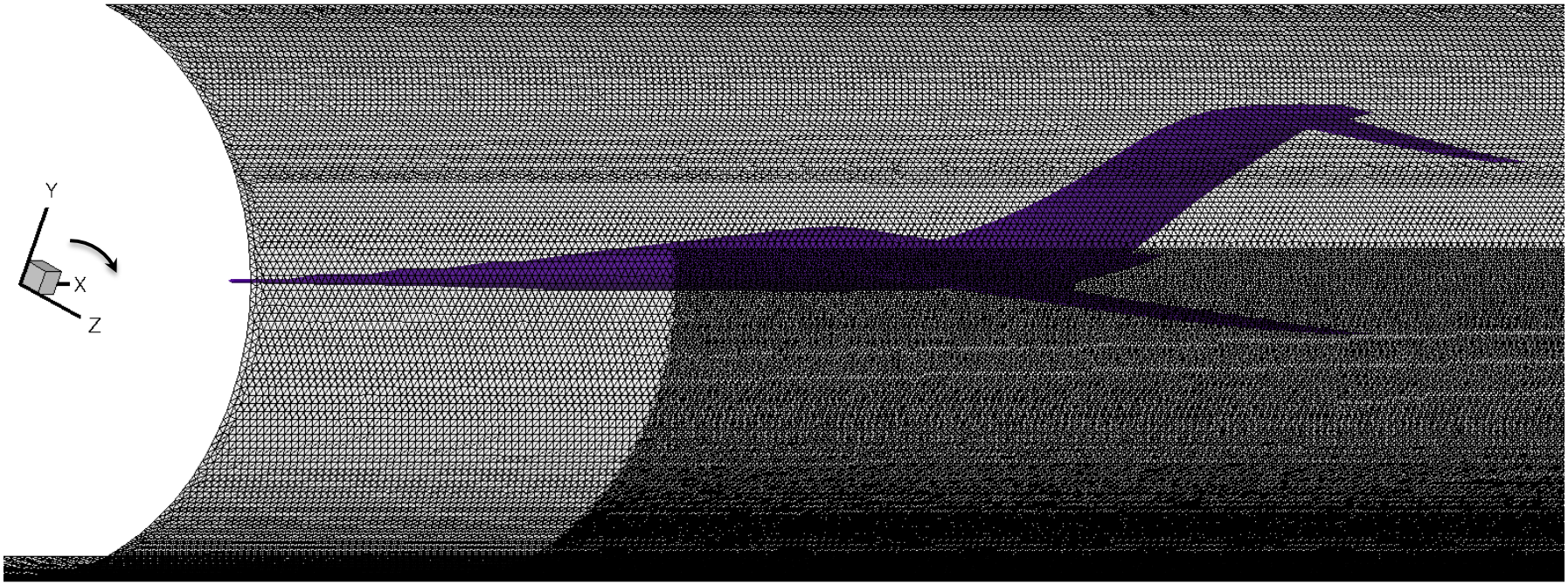
Developing a Near-Field Cylindrically-Shaped Mesh

Example of refined faces on symmetry plane and two axial cuts



Developing a Near-Field Cylindrically-Shaped Mesh

Refinement must occur on cylindrical boundaries to propagate into flow field



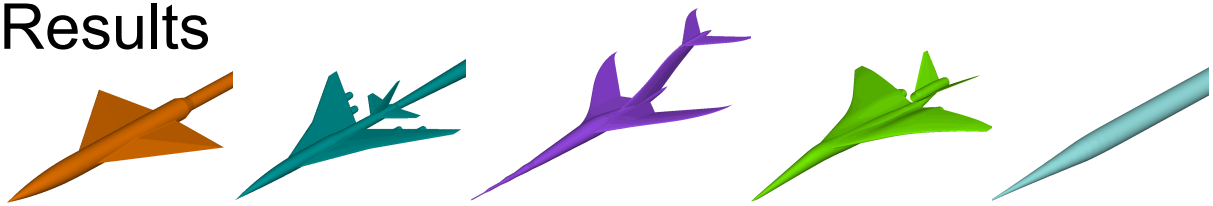
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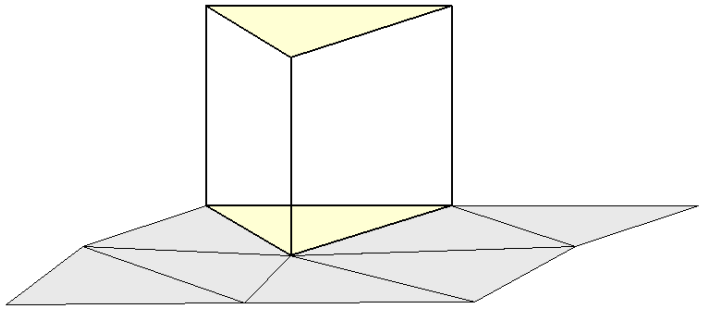


Best Practices

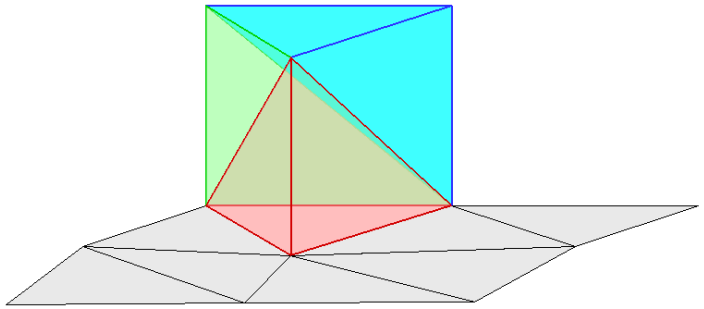
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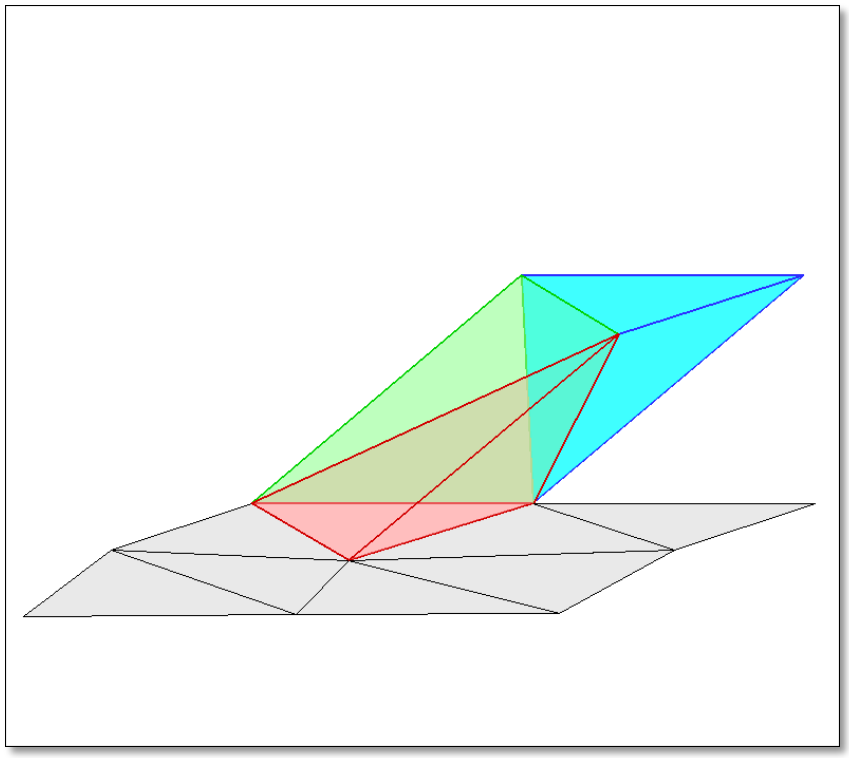
Projecting a Layered Cylindrically-Shaped Prism Mesh

Project face on cylinder outer boundary in radial direction



Split each prism into three tetrahedra

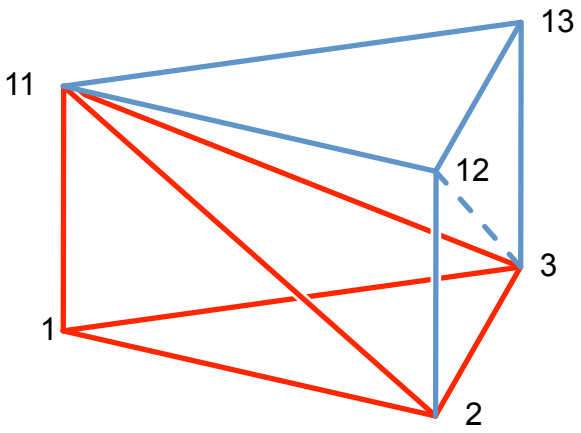


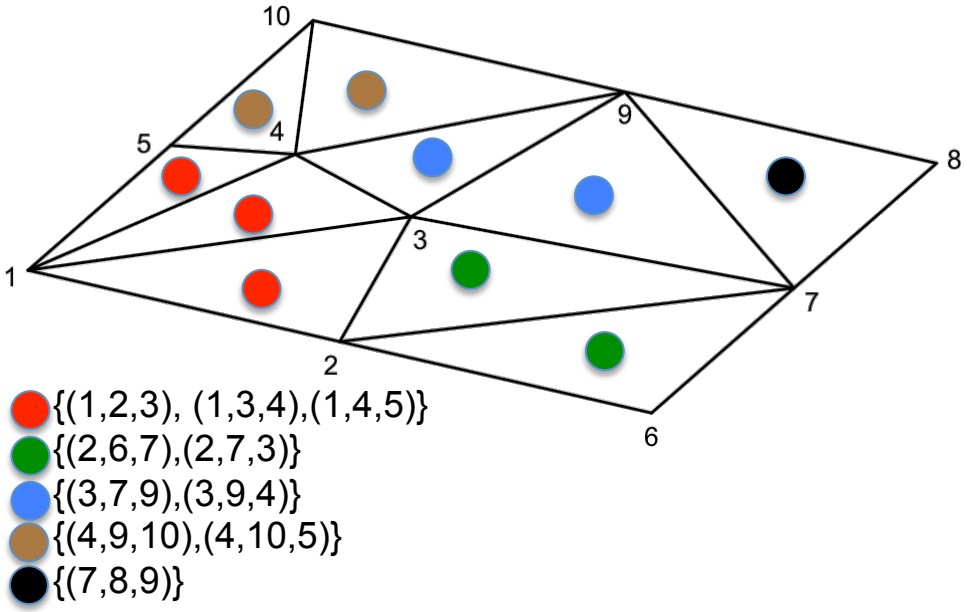


Exploding tetrahedra of sheared prism

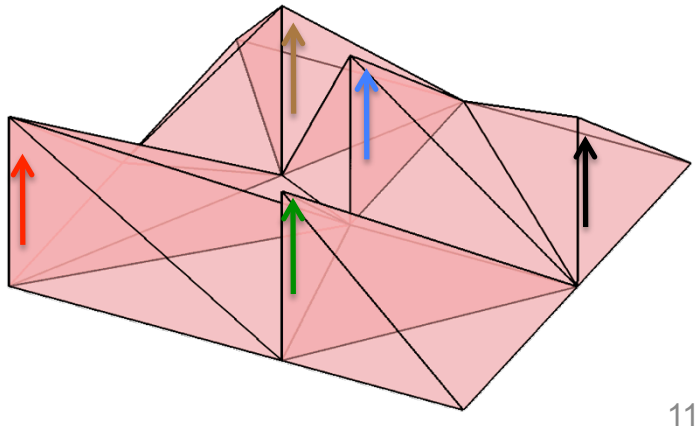
Splitting amounts to adding diagonal edges to the quadrilateral faces

Projecting a Layered Cylindrically-Shaped Prism Mesh Algorithm Basics





- Prism split into tet & pyramid
- Base tets formed first
- Form groups of triangles
- Project same smallest index
- Split pyramids
- Match diagonals



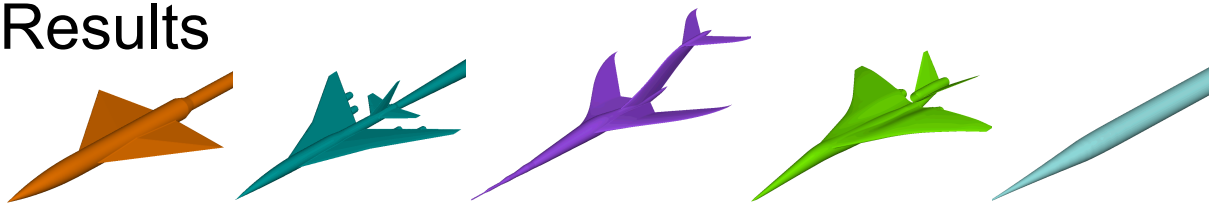
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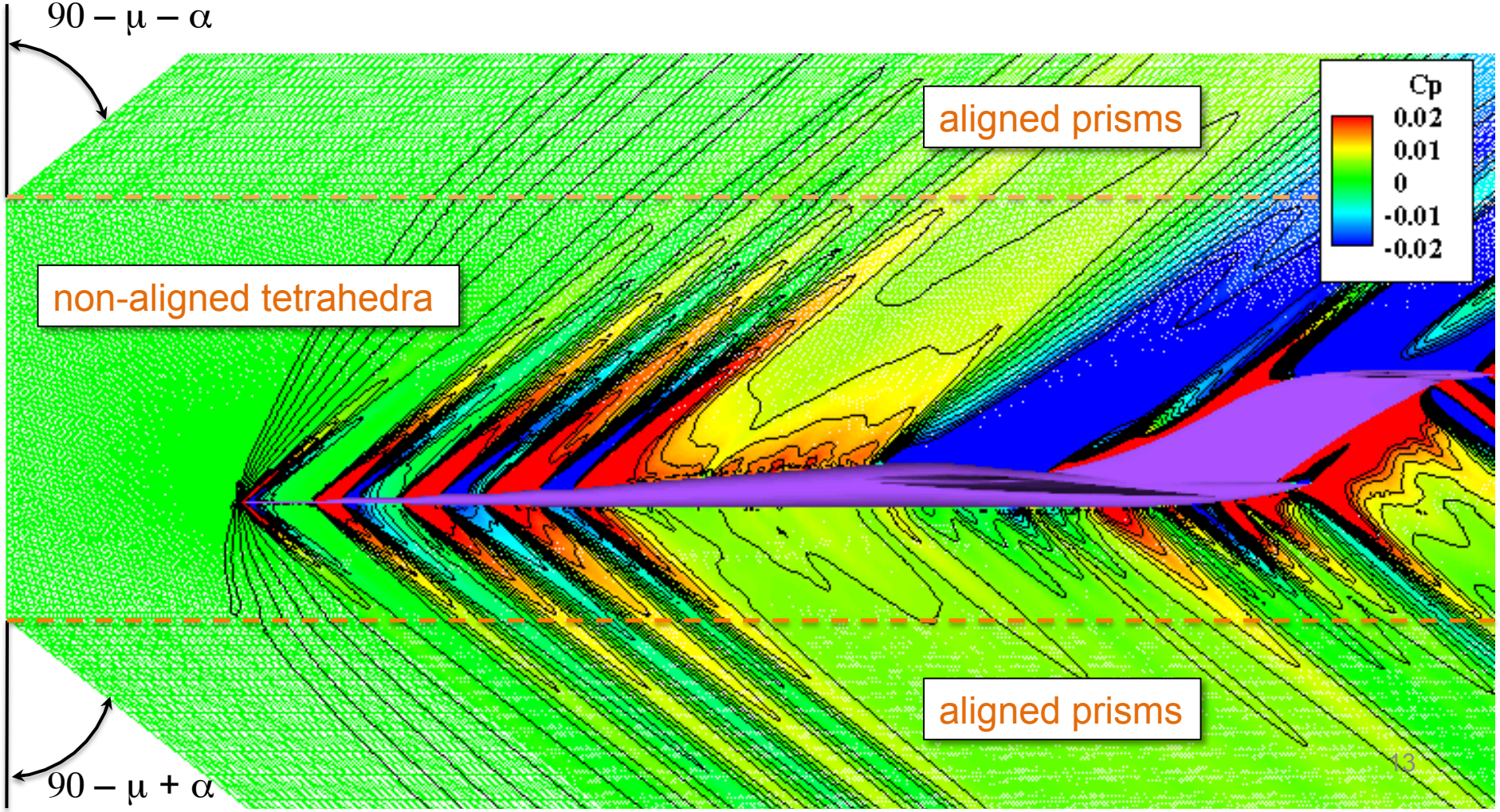


Best Practices

Conclusions

Shearing/Mach Angle Alignment of the Prismatic Grid

α= angle of attack
$\mu = \sin^{-1}(1/M)$



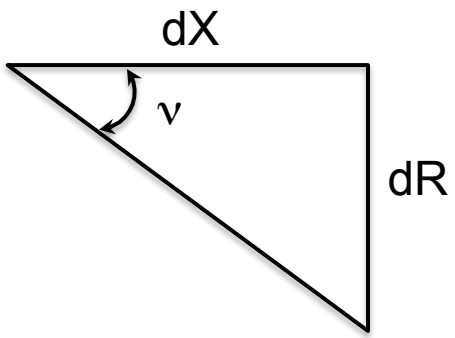
Shearing/Mach Angle Alignment of the Prismatic Grid

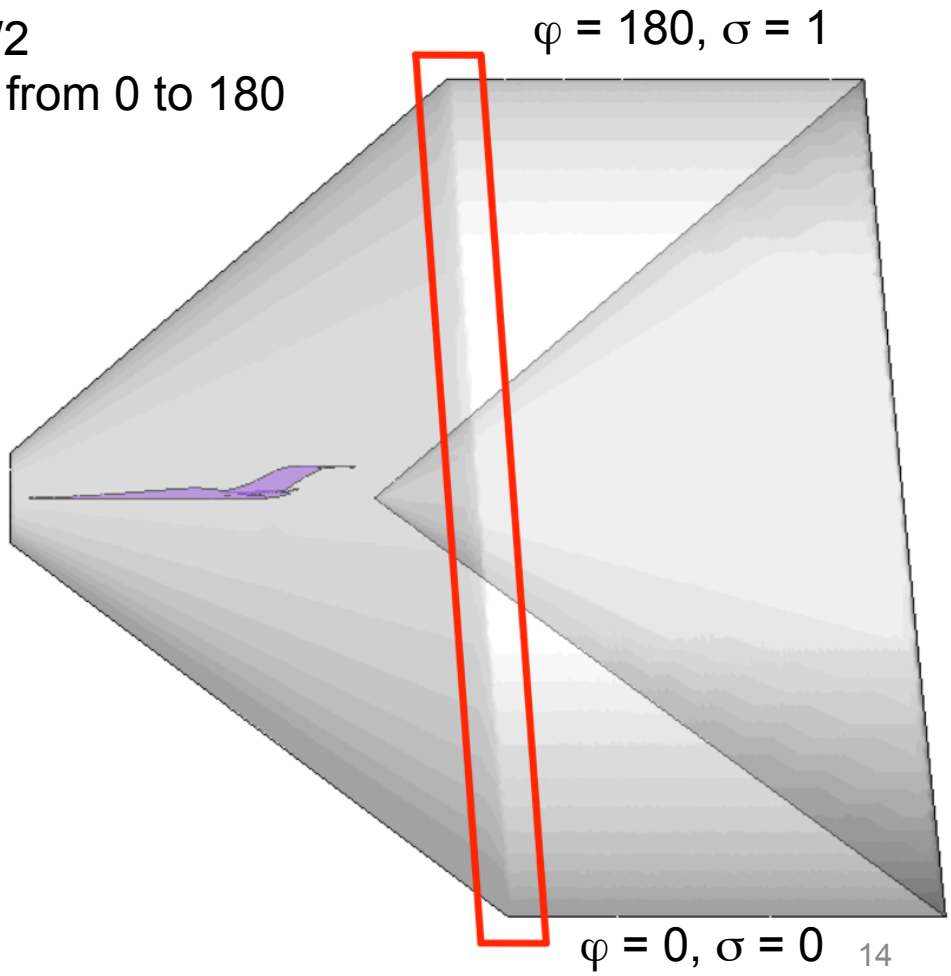
A simplified transition in circumferential direction from under-track to above model was implemented

Weighting function $\sigma = (1 - \cos(\varphi))/2$
which varies from 0 to 1 as φ goes from 0 to 180

Add dX to X of each point where

$dX = dR / \tan(\nu)$ where
$\nu = \mu + ((-\alpha)(1 - \sigma) + (\alpha)\,\sigma)$





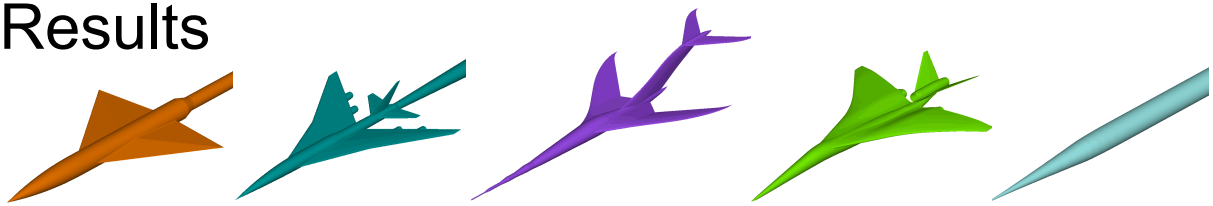
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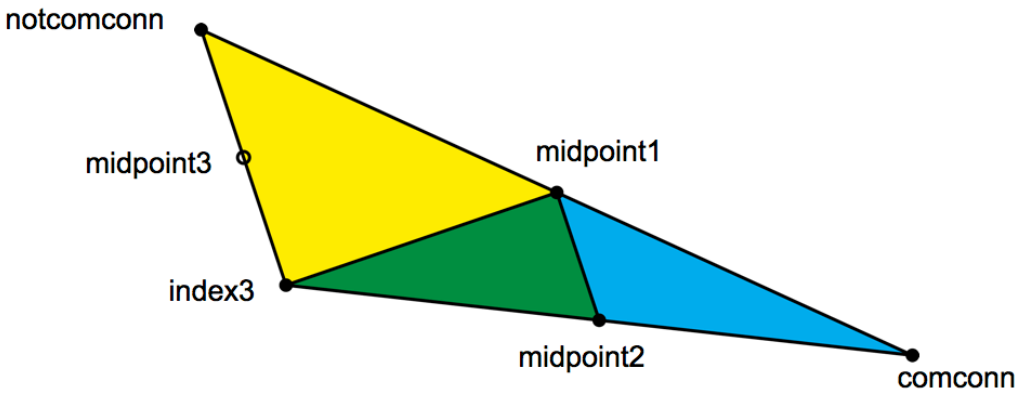


Best Practices

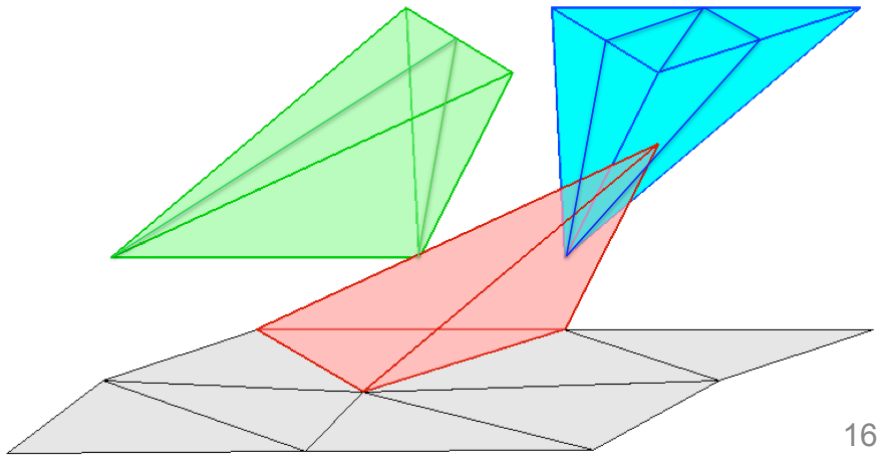
Conclusions

Circumferential Refinement of Outer Prismatic Grid Algorithm Basics

- Longest 2 edges of face split
- Faces split into 3, (1 – 4) possible
- Split tetrahedron of split face (search #1)
- Split neighboring tetrahedra (search #2)
- Copy connectivity to subsequent layers



midpoint1	midpoint of longest edge
comconn	common point between largest and mid length edge
index3	point opposite longest edge
notcomconn	point is other triangle point
midpoint2	midpoint of mid length edge
midpoint3	midpoint of smallest edge



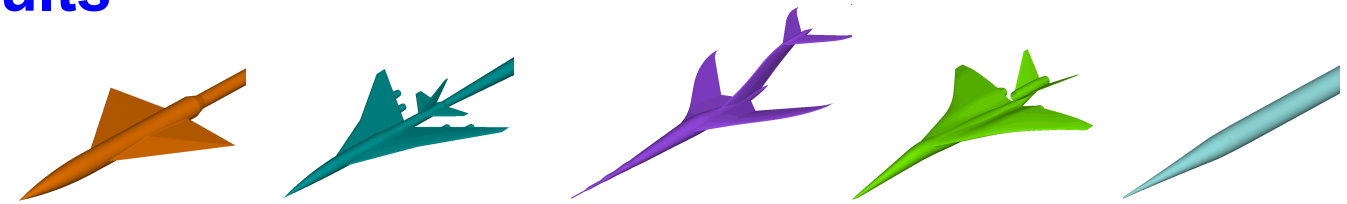
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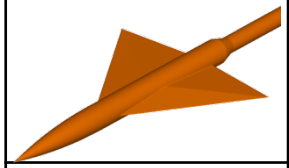
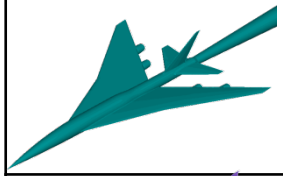
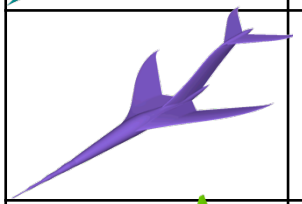
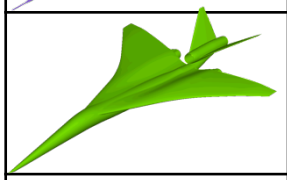
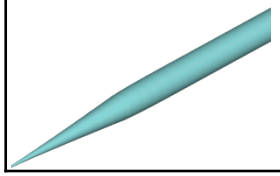


Name	Delta Wing Fuselage	Ames Low Boom Wing Tail		Gulfstream Public	Lockheed Public	Lockheed OptSig
Mach	1.68	1.6	2.0	1.6	1.6	1.6
h/l	3.6	2.65,1.76	1.16	1.7, 1.2	0.5-3.0	1.28, 1.92
φ	0.0	0.0	0.0	0, 20, 45	0	0.0, 20

Best Practices

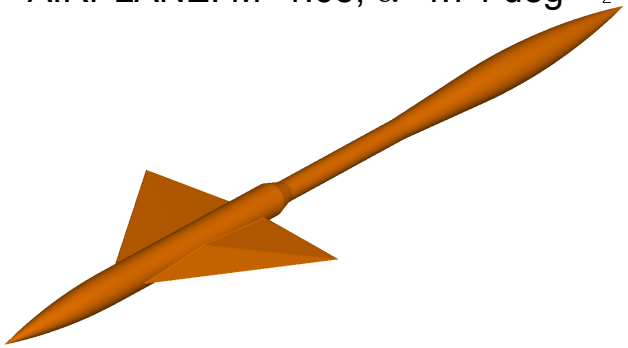
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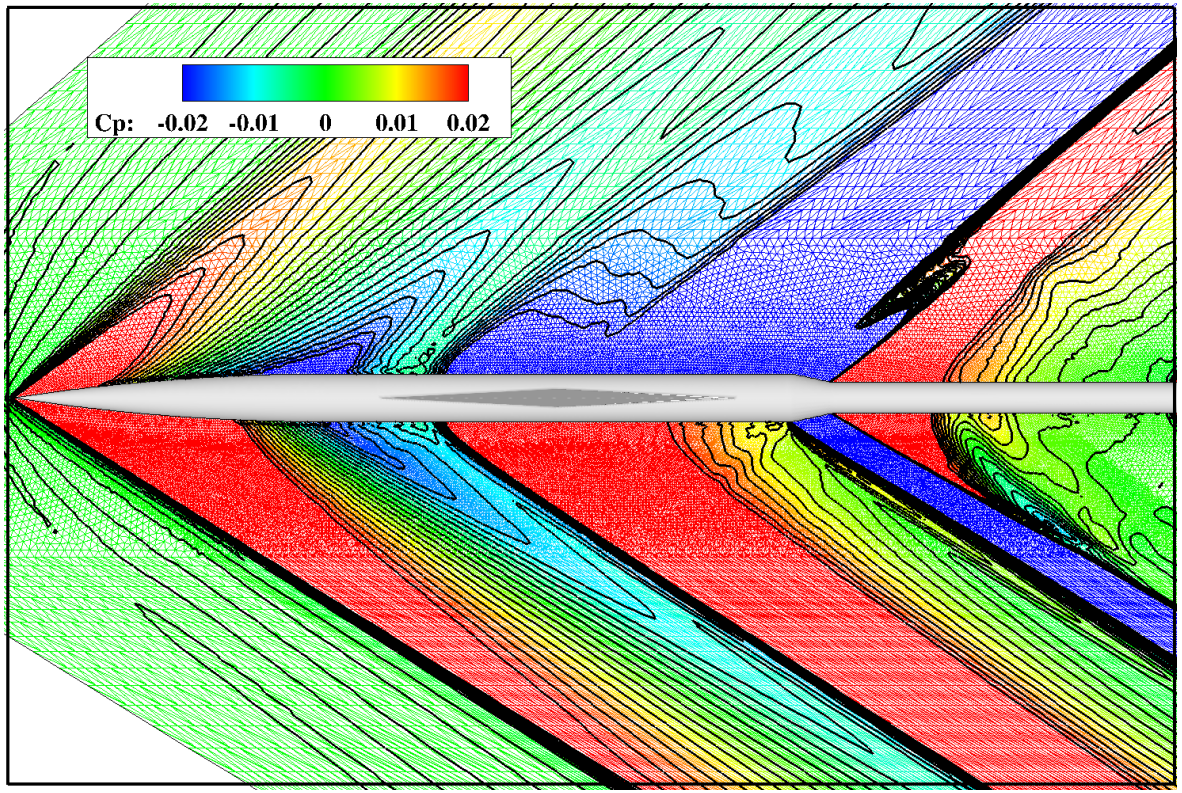
Models & Validation

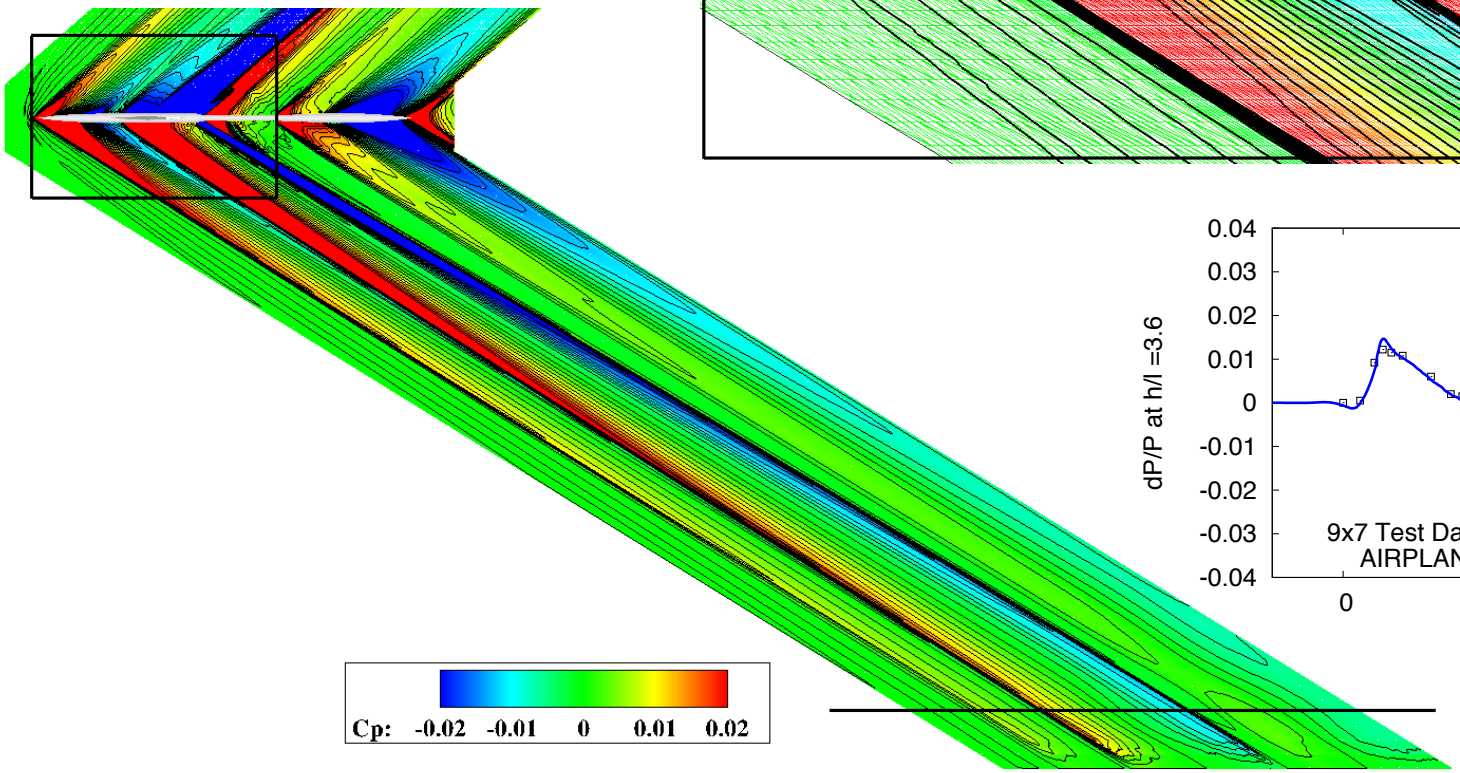
	Name	Why?	Valid. Source	Date / Inst.	Tunnel
	Delta Wing	•Validation ‘92 •Validation ‘08 •Large h/l	Exp.	1974 / probe	9x7
	Ames LBWT	•Validation ‘92 •Validation ‘08 •New Rail	Exp. CFD	1993 / probe 2010 / rail	9x7
	Gulfstream	•State-of-Art •N.S. •Off-track	Exp. CFD	2008 / probe	4x4
	Lockheed	•State-of-Art •N+2 design	CFD	TBD / rail	9x7
	Lockheed BOR	•State-of-Art •Off-track •New Rail	Exp.	2010 / rail	9x7

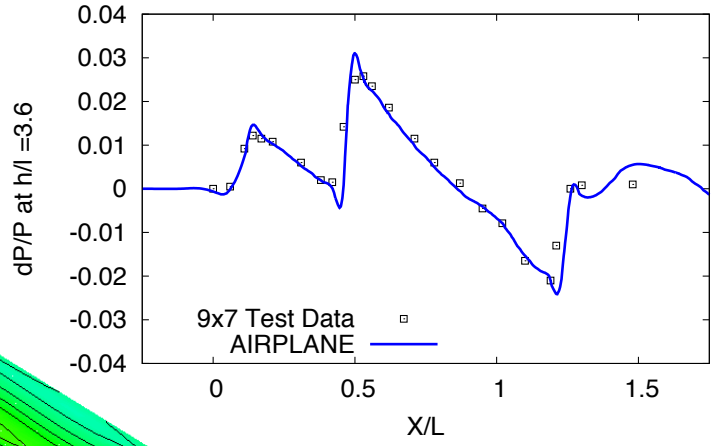
Delta Wing Body

AIRPLANE: M=1.68, α=4.74 deg



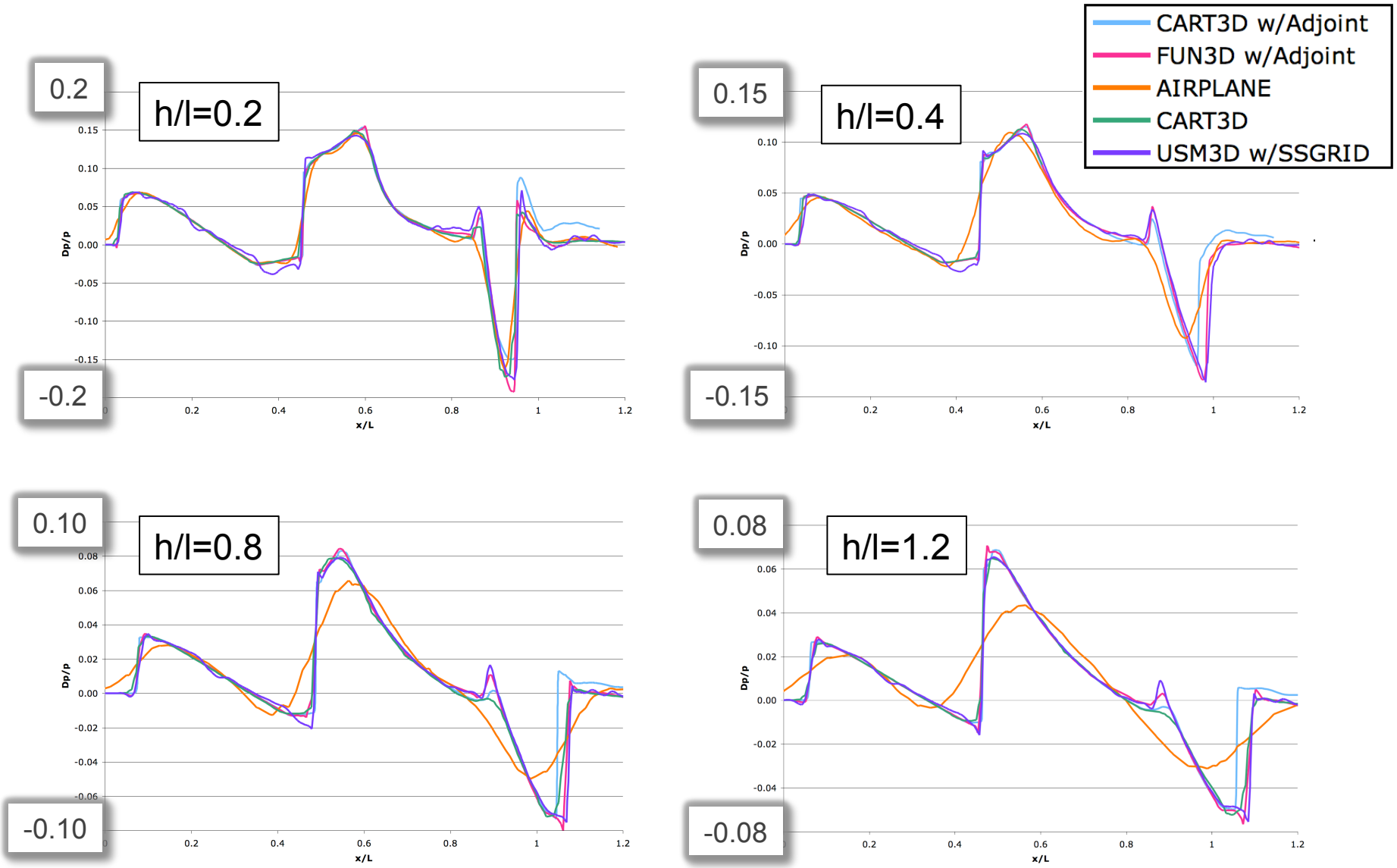






H/L=3.6

2008 Boom Workshop
AIRPLANE using Non-Aligned Non-Stretched Tetrahedra

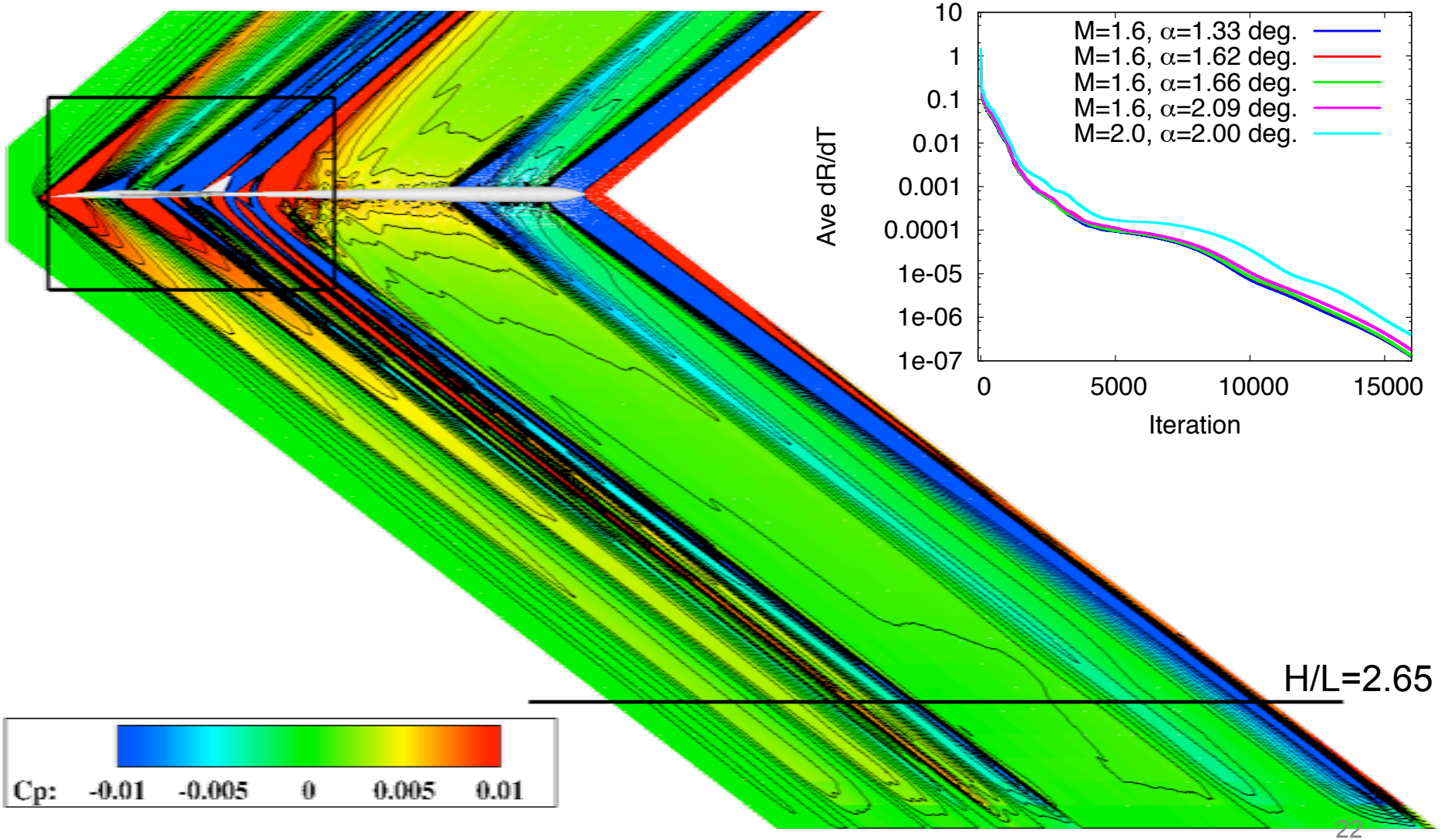


M. Carter

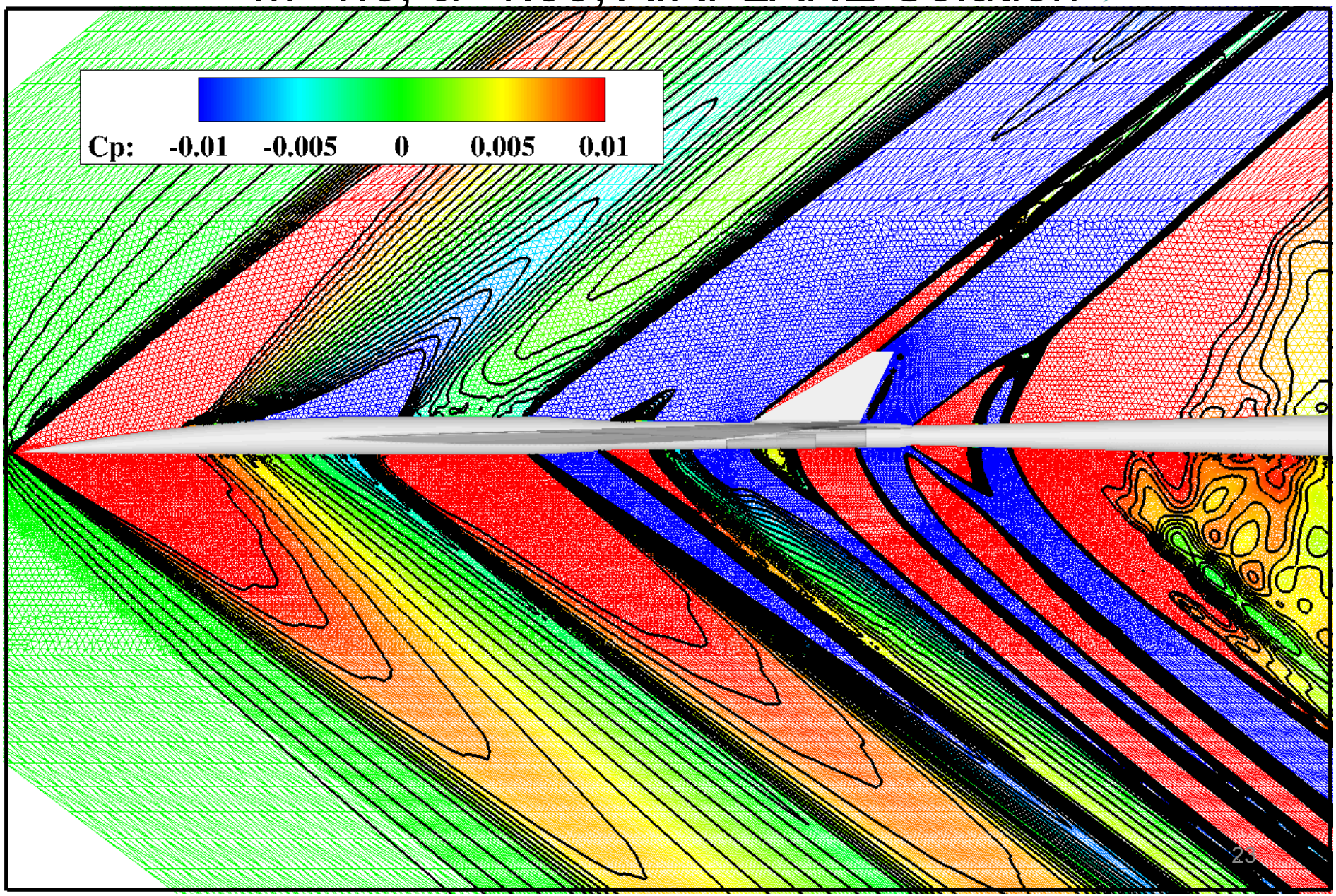
Low Boom Wing Tail
New RF 1.0 pressure rail in 9x7



Low Boom Wing Tail
M=1.6, α=1.33, AIRPLANE Solution

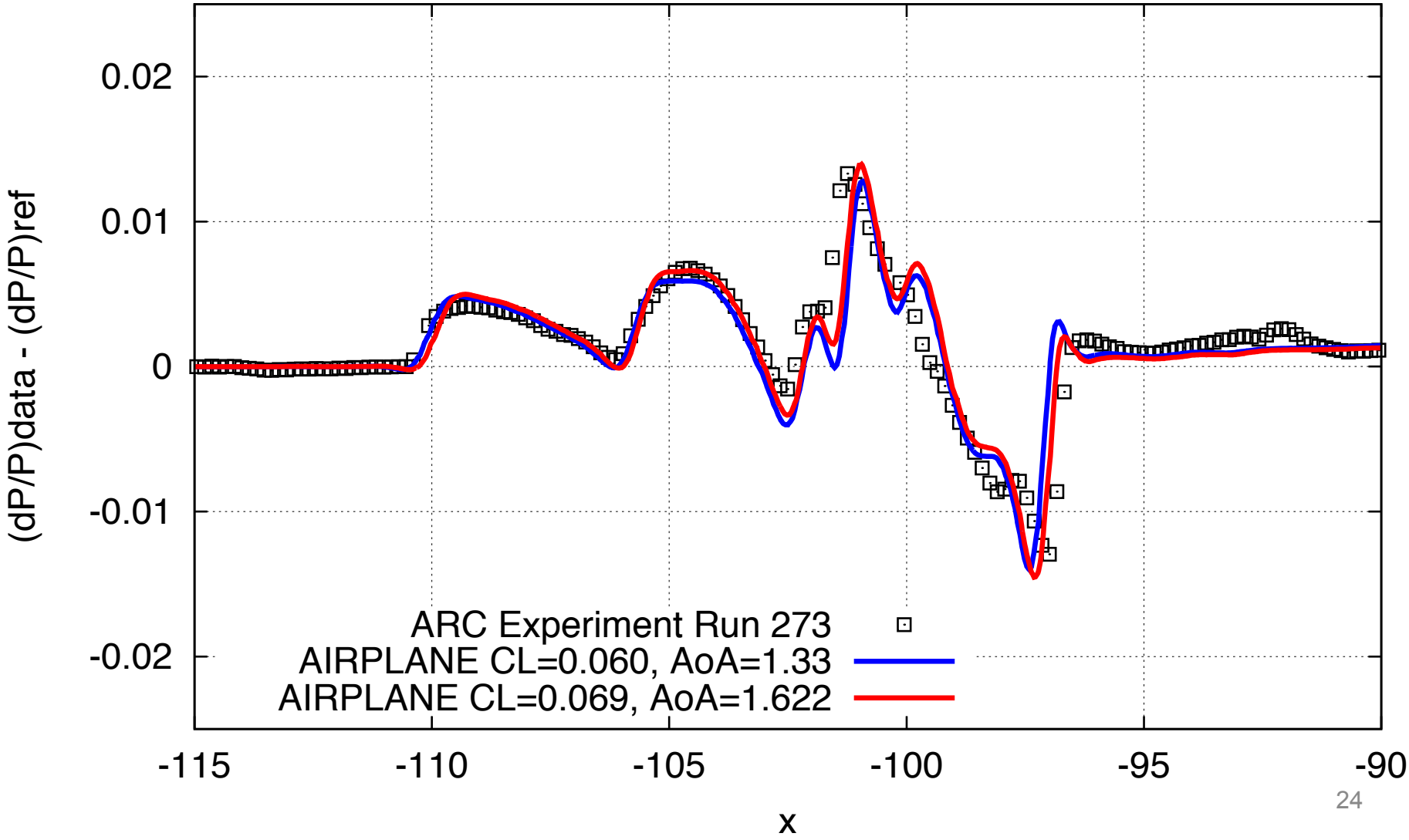


Low Boom Wing Tail
M=1.6, α=1.33, AIRPLANE Solution



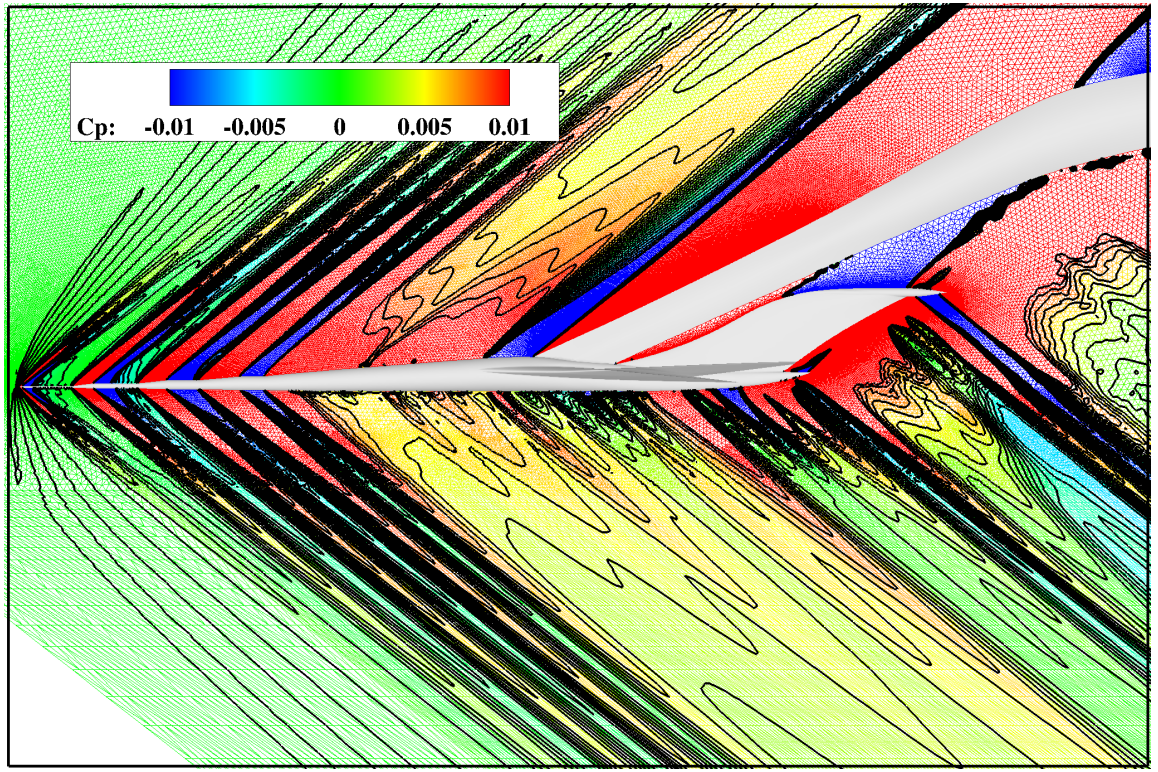
Low Boom Wing Tail
RF 1.0 rail data compared with AIRPLANE

Run	M	H/L	α	β	CN	H (avg.)
273	1.6	2.652	1.622	-0.156	0.059	190.16

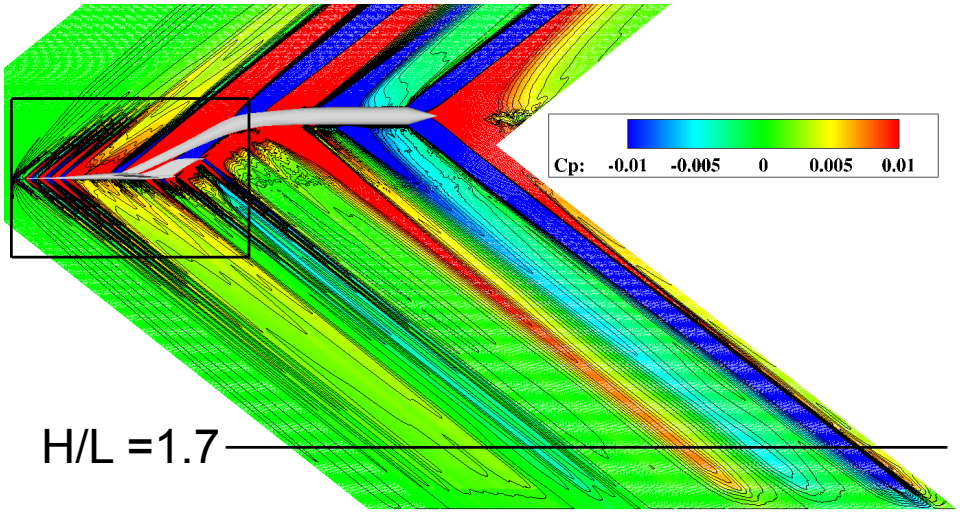


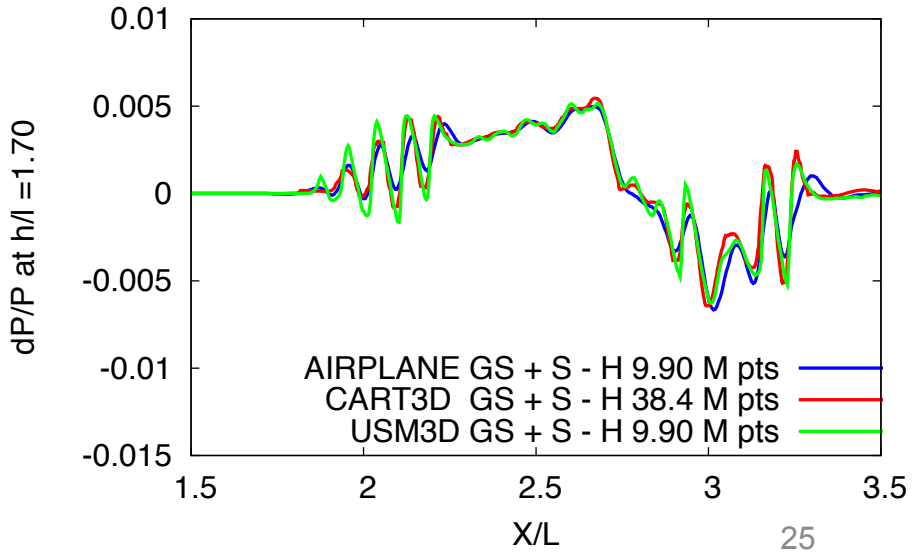
Gulfstream Configuration



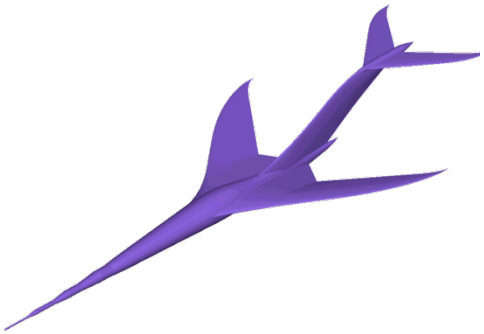


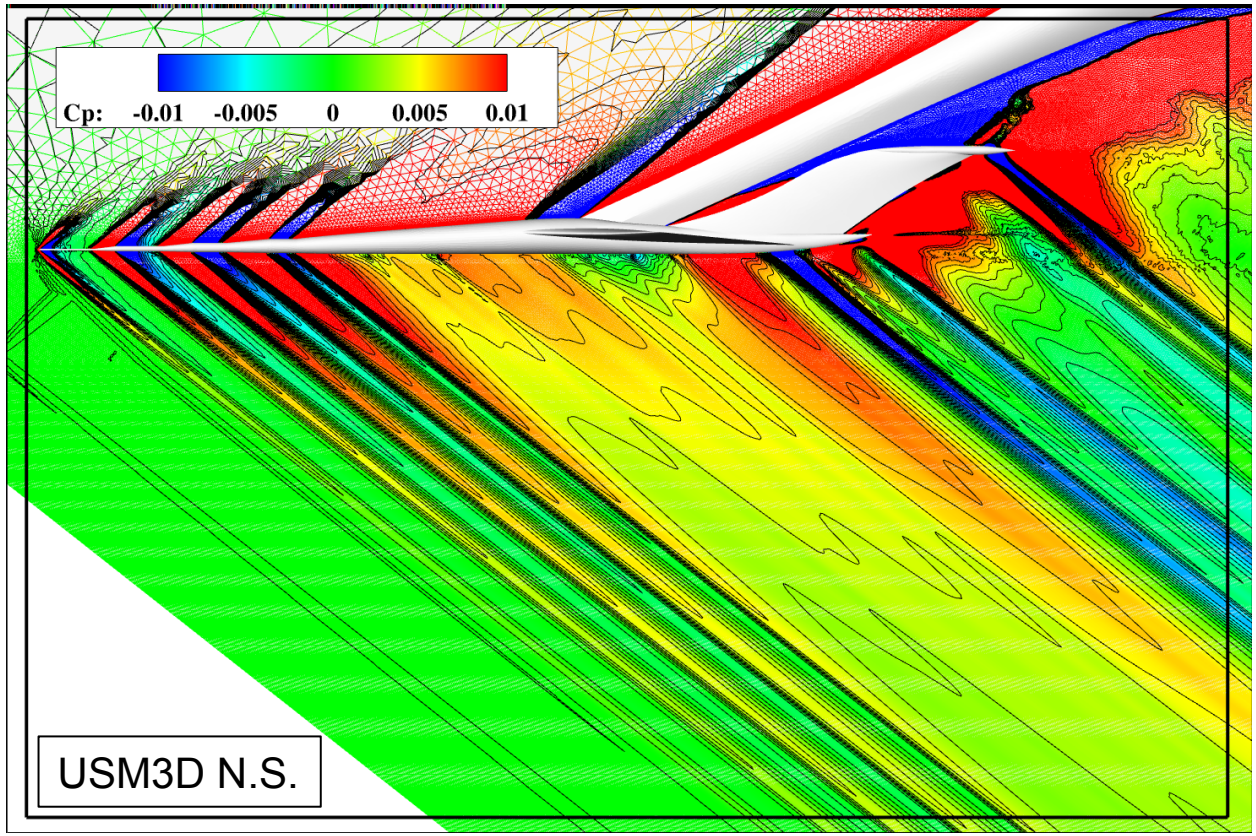
AIRPLANE: M=1.6, α=0.3 deg



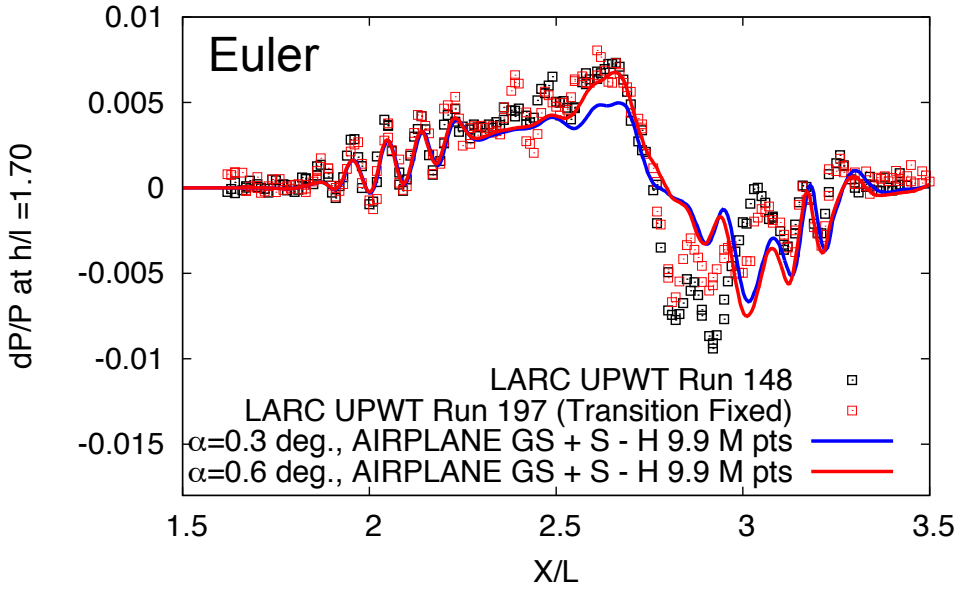


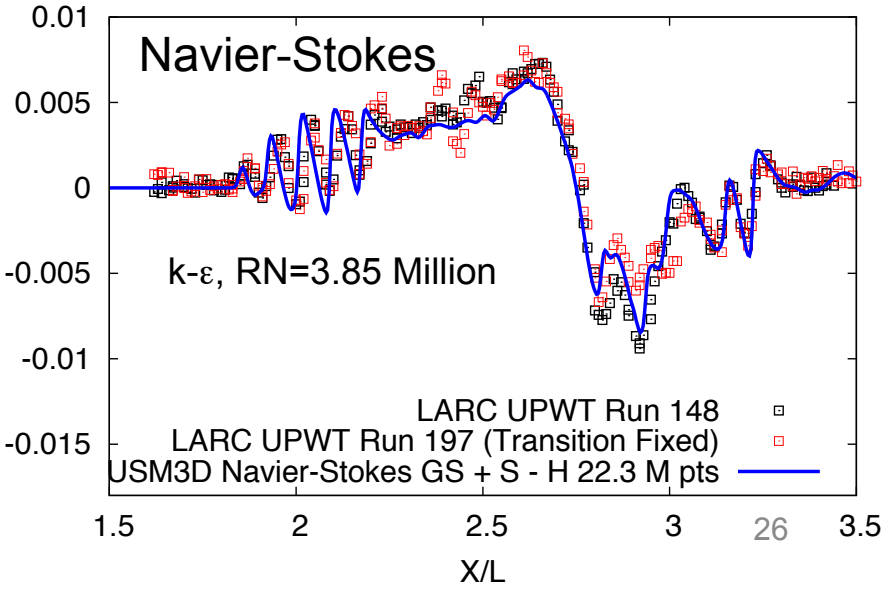
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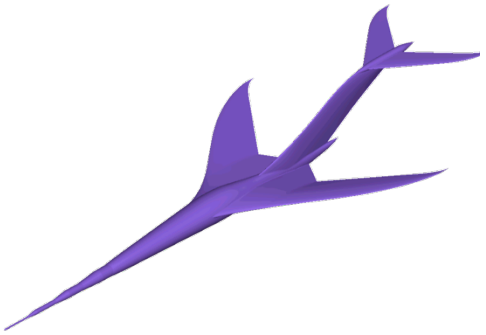


M=1.6 α=0.3 deg.



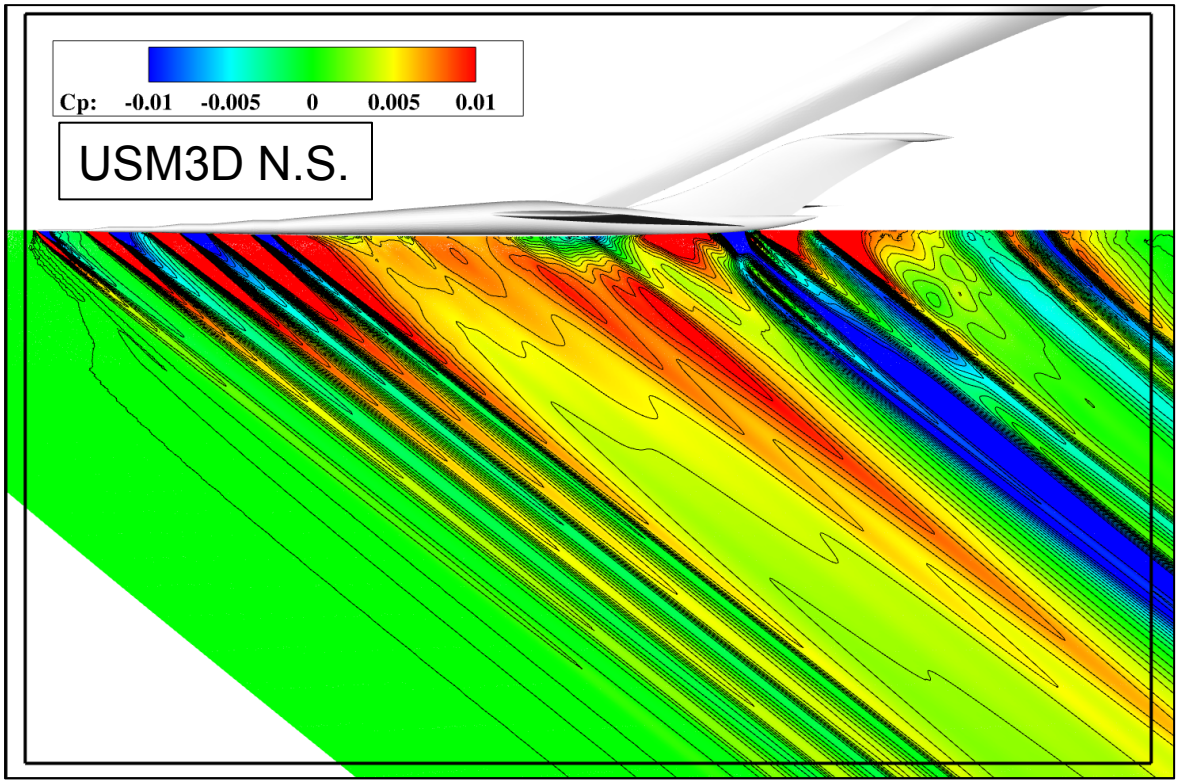


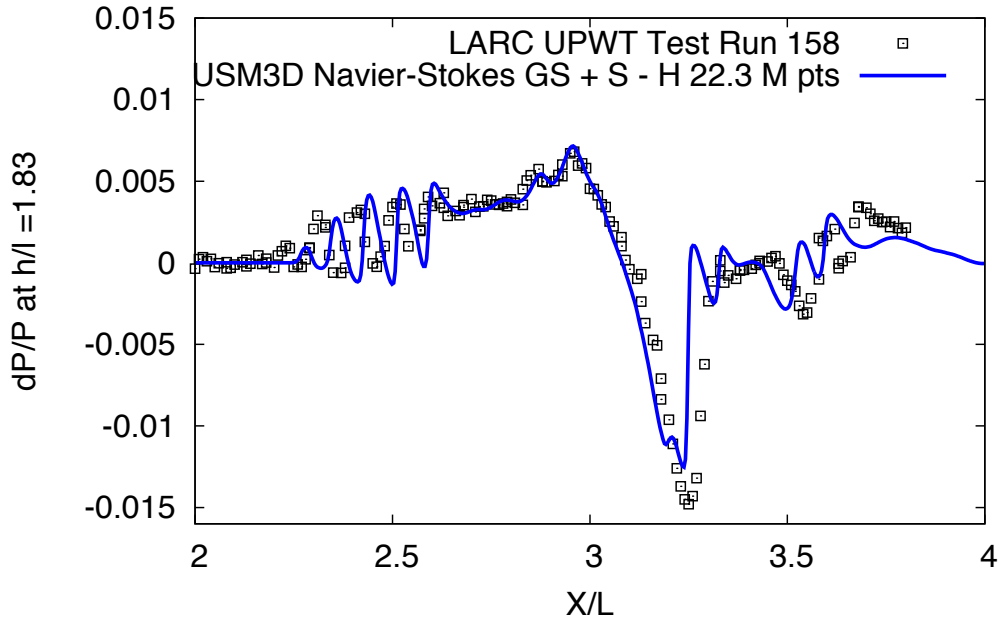
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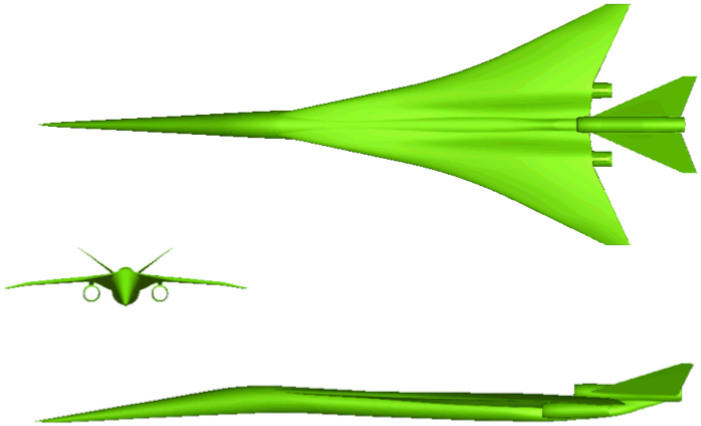
Off-Track 53.4 degrees

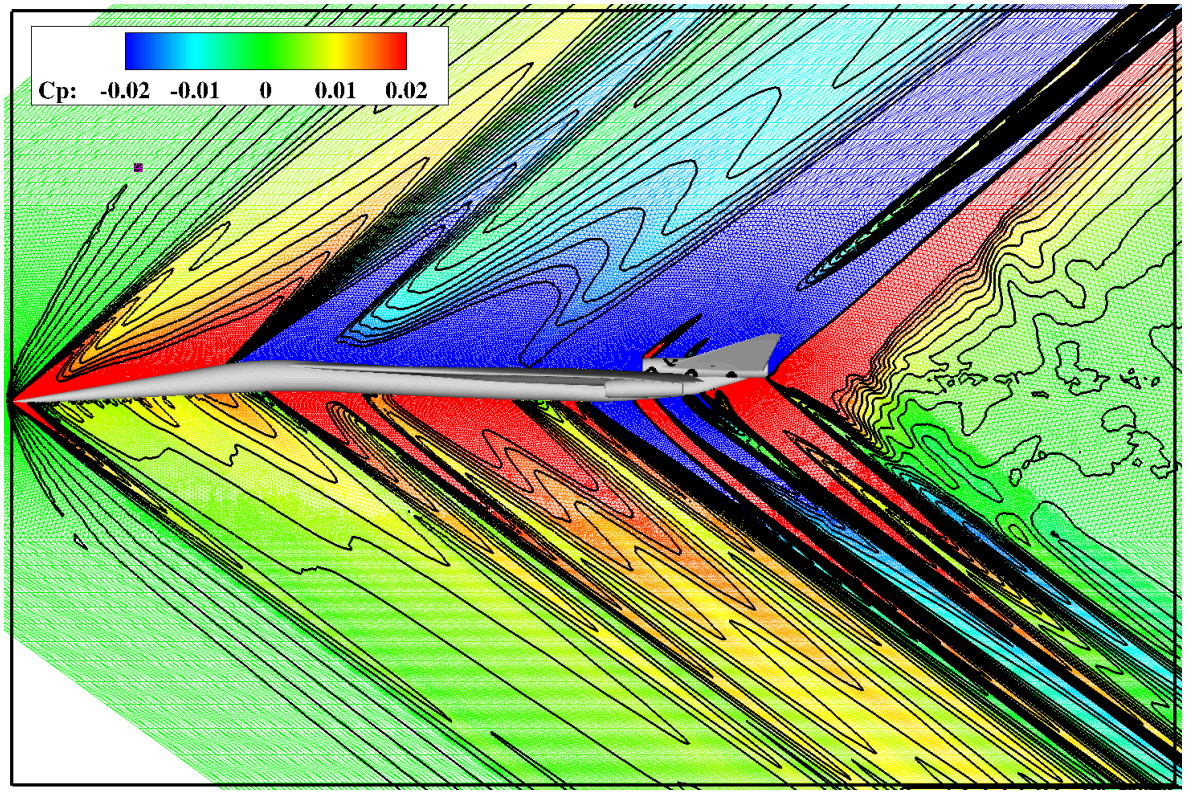
M=1.6 α=0.3 deg.



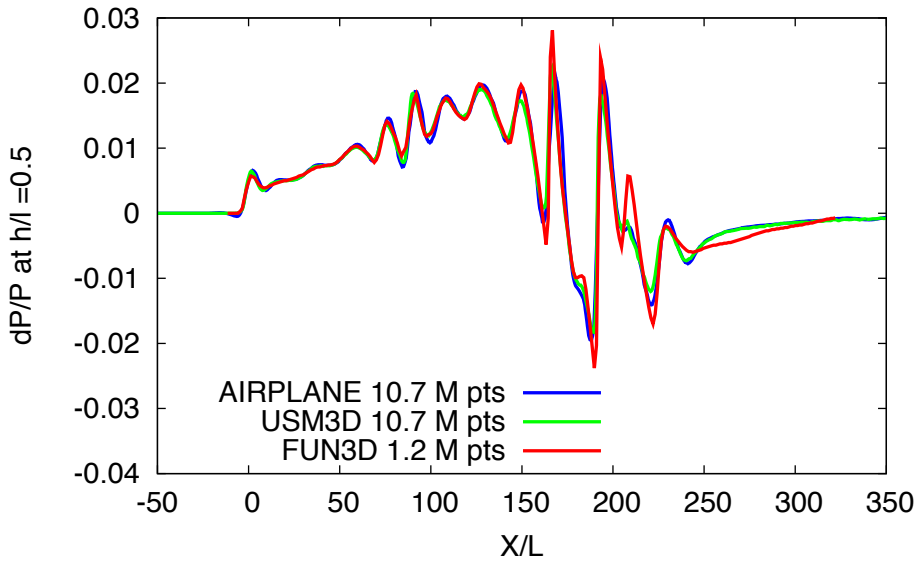


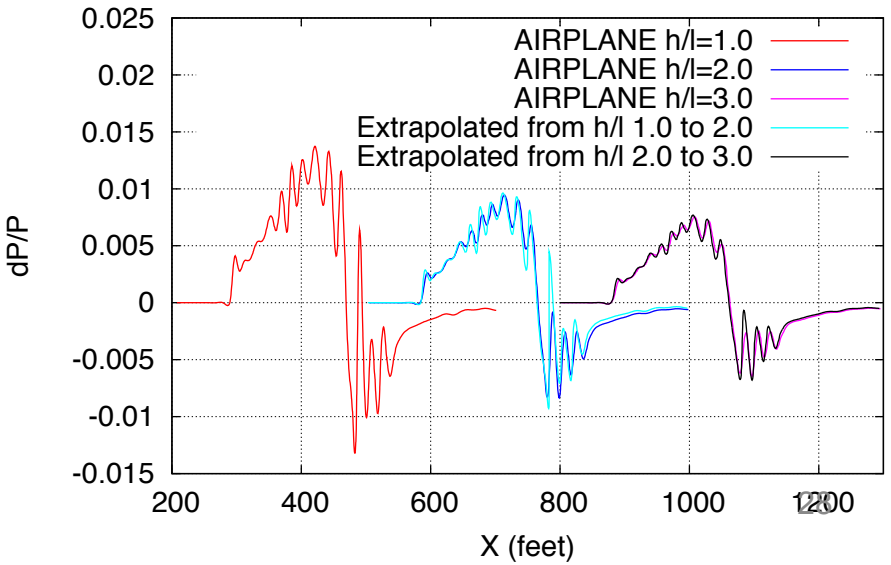
Lockheed Preliminary Design





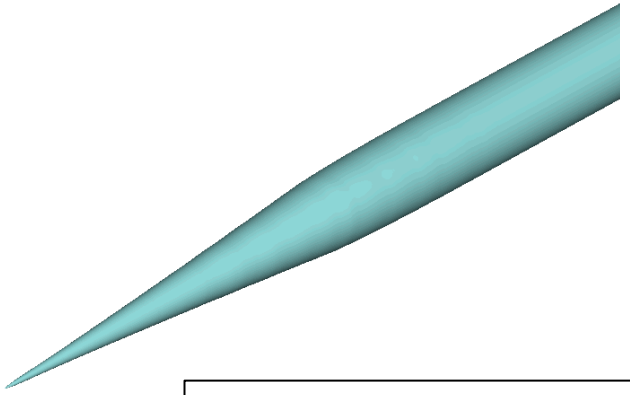
M=1.6, α=2.5 deg



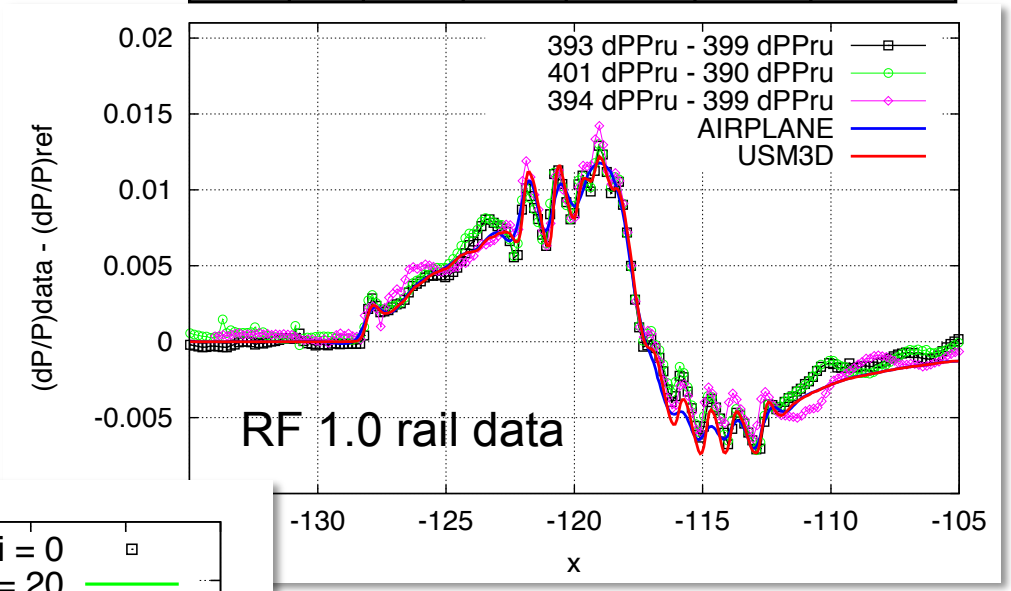


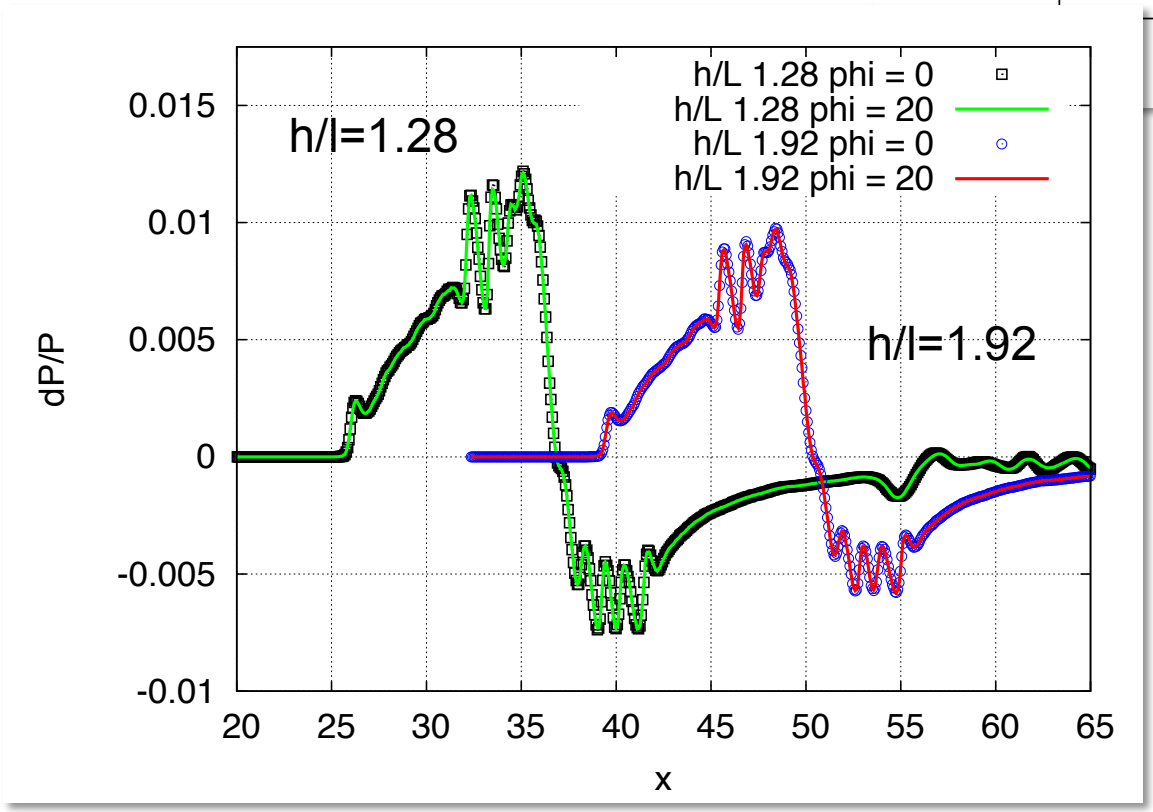
Lockheed Opt Sig B.O.R

Run	M	H/L	α	β	CN	H (avg.)
393	1.6	1.279	0.026	-0.014	-0.009	202.84
401	1.6	1.279	0.025	-0.007	-0.007	200.48
394	1.6	1.278	0.022	-0.012	-0.007	201.89



USM3D: M=1.6, α = 0.0





Best Practices – Keys to Success

- Converge flow solutions 6-7 orders for convergence to the far field boundaries
- Reduce the dissipation in the flow solver
- Align with Mach and angle of attack and only use flare if warranted
- Start the alignment ASAP below configuration - cylindrical boundaries encompass the geometry and consider raising the boundaries
- Limit radial stretching to 1/10 body length.
- Refine beyond model and off track
- Refine outer prism layers if necessary for signatures or convergence
- Add several prism layers beyond the sampling location

Concluding Remarks

- Demonstrated the MCAP method can provide accurate signatures at moderate body lengths, corroboration with:
  - Wind tunnel data
  - Adjoint-based solution adapted grid methods

- Important achievements
  - Full carpet (on and off-track) solutions
  - Robust automated tool with hands off control
  - N.S. result implies sonic boom + F & M possible

- Future work
  - Develop MCA overset grids for OVERFLOW and USM3D
  - Elliptical shaped boundaries of inner non-aligned mesh
  - Directional refinement within inner boundaries
  - VGRID automation of inner boundaries and refinement

Flow Solver Information

AIRPLANE:

- Euler - tetrahedra
- Finite volume
- Explicit Runge Kutta
- vertex based
- 2nd order time stepping
- scalar dissipation
- residual smoothing
- multigrid
- MPI

USM3D:

- Euler/N.S. - tetrahedra
- Finite volume, cell centered
- Upwind Differencing
- 1st & 2nd order time stepping
- Flux limiters
- Spalart-Allmaras turbulence model
- MPI

CART3D/AERO

- Euler (non body-fitted)
- Finite volume - 2nd order
- Cell Centered
- van Leer flux
- Barth-Jespersen limiter
- Explicit Runge-Kutta
- Multigrid
- OpenMP
- Adjoint-based mesh adaptation

FUN3D:

- Euler/N.S.
- Finite volume, vertex based
- Upwind Differencing
- 1st & 2nd order time stepping
- Flux Limiters
- Spalart-Allmaras turbulence model
- Output-based adaptation
- MPI

MCAP Timings

cylndr pts	cylndr bnd pts	total layers	# prism splits	initial split layer	time (s)	mesh pts
2.42 M	48,664	25	0	N/A	272	3.64 M
2.42 M	48,664	25	1	18	1883	4.41 M
6.24 M	112,493	33	0	N/A	1108	9.95 M
6.24 M	112,493	33	1	28	9258	11.29 M

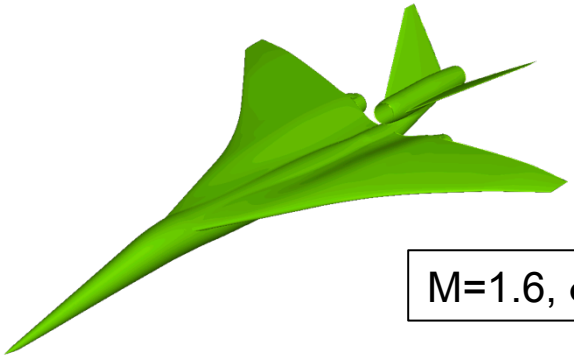
Pleiades Westmere single processor times

Splitting prisms on outer boundaries take 6-8x longer and 2x pts/layer for:

- higher quality meshes
- More accurate solutions (less rounding of shocks)
- improved convergence

Most points reside within cylinder grid

Lockheed Preliminary Design
20° Off-Track



M=1.6, α=2.5 deg.

