SciTech2014, National Harbor, Maryland

Sonic Boom Prediction with FaSTAR and HexaGrid

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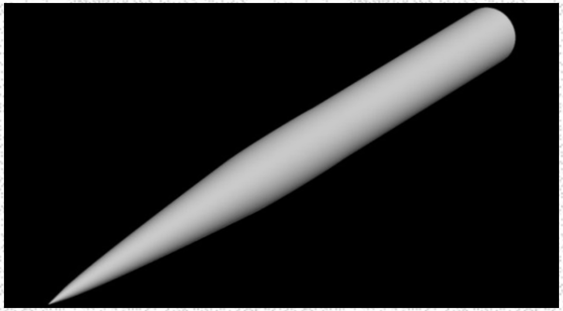
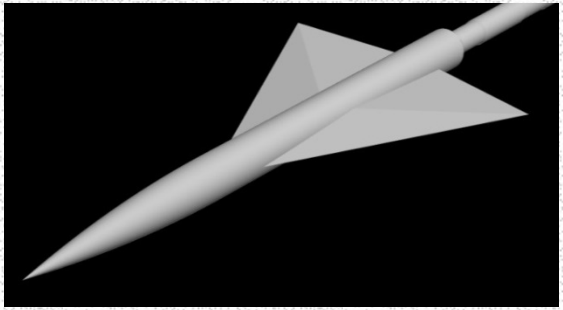
Introduction / Outline

- The objectives of 1st SBPW
  - to assess the techniques for predicting signatures suitable for sonic boom prediction
  - to compare the solutions of each participants
- Models provided from workshop are:
  - SEEB-ALR Body of Revolution
  - 69-Degree Delta Wing Body
  - Lockheed Martin 1021 Full Configuration : not considered



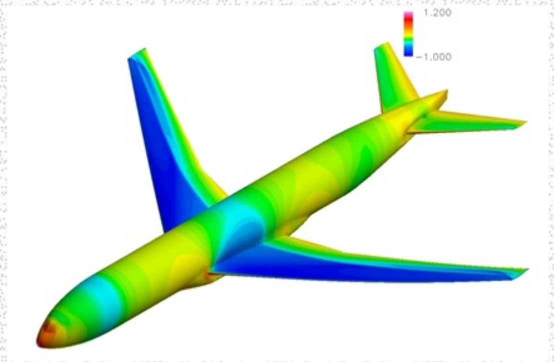


- Two models are analyzed with FaSTAR and HexaGrid:
  - for GIVEN grid
  - for OWN grid

About Flow Solver FaSTAR

- FaSTAR (FAST Aerodynamic Routines)
  - fast flow solver for unstructured grid (1.4 hour/case using 100cores, 10M grid)
  - sufficiently accurate results obtained
  - many options available

Governing equation	Compressible Euler/Navier-Stokes equation
Discretization	Finite volume method (Cell center/Cell vertex)
Inviscid flux	HLLEW, Roe, HLLE, AUSM+-UP, SLAU
Gradient evaluation	Least-Square, Green-Gauss, GLSQ
Limiter function	Hishida, Venkatakrishnan, Barth-Jespersen, minmod
High resolution	MUSCL, U – MUSCL
Turbulence model	SA，SST，EARSM，DES，LES
Transition model	Forced, Natural(γ-$Re_{\theta t}$)
Parallelization	MPI
Time integration	LU-SGS (steady/unsteady, local/global time step), Preconditioning for low-speed flow
Convergence acceleration	Multigrid(FAS), Krylov method (GMRES)
Element type	Tetrahedra, Pyramid, Prism, Hexahedra
Grid input	Gridgen，Pointwise, HexaGrid, MEGG3D
Result output	Fieldview(FV-UNS), Tecplot, Paraview(VTK)



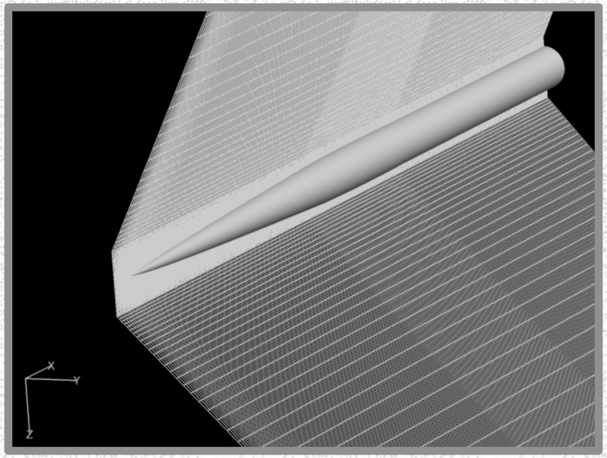
from 4th Drag Prediction Workshop

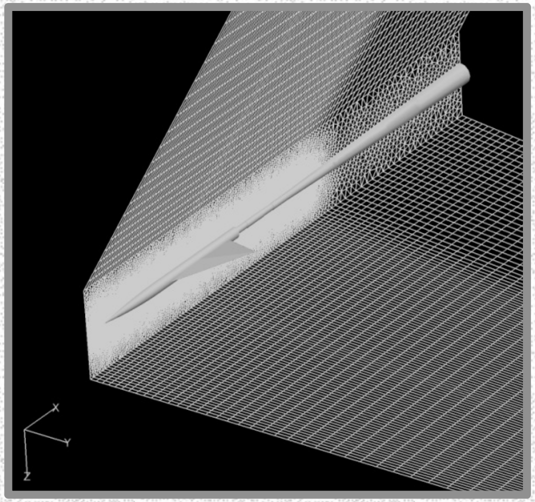
- Calculation conditions:
  - 64core@JSS(JAXA Supercomputer System)
  - Inviscid calculation
  - HLLEW scheme with 2nd order MUSCL interpolation with Hishida's van Leer type limiter
  - LU-SGS time integration with local time stepping
  - CFL number is set to 10.

GIVEN GRID ANALYSES

Summary of Grids and Convergence Histories

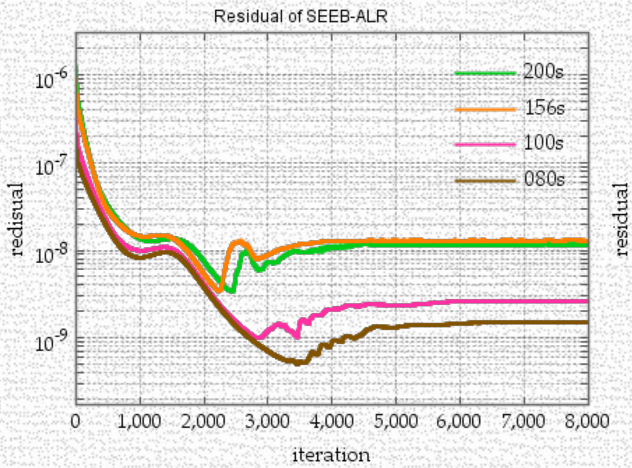
- ✓ Mixed element type were chosen as given grids.
- ✓ Convergence histories indicate that thousands of iteration needs to be converged.

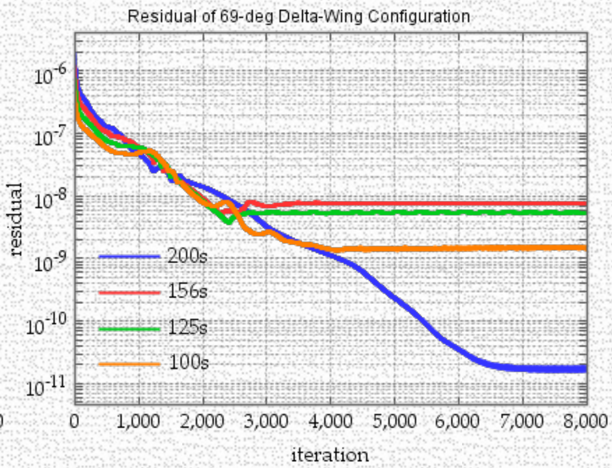




Summary of the given grid

	SEEB-ALR	69deg. Delta
Coarse	200s	200s
Medium	156s	150s
Fine	100s	125s
Very fine	080s	100s

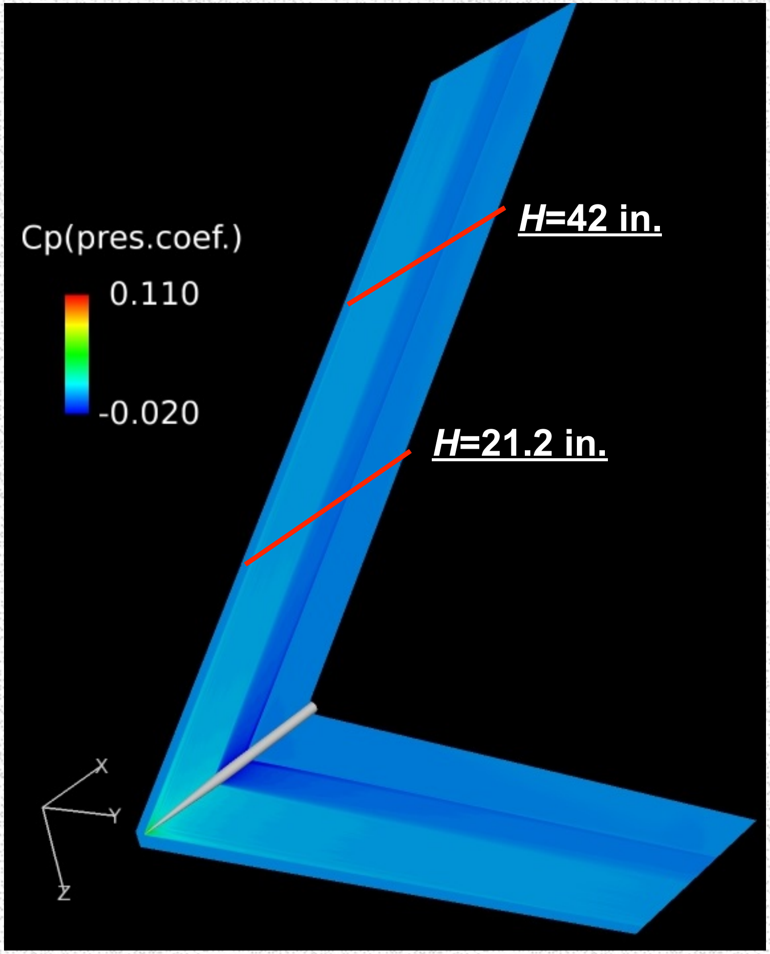


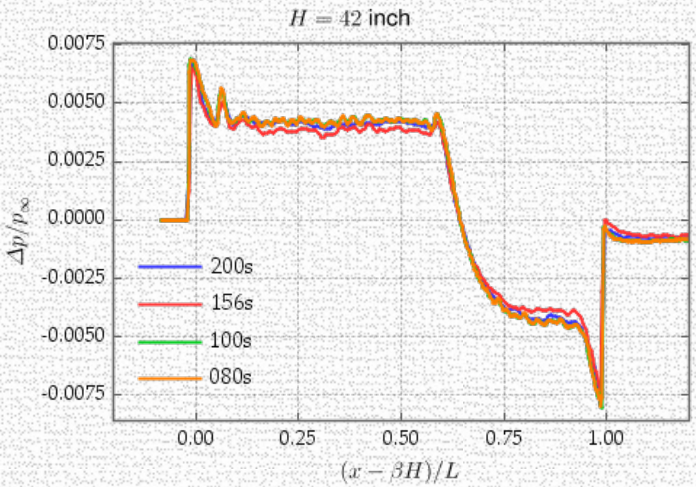


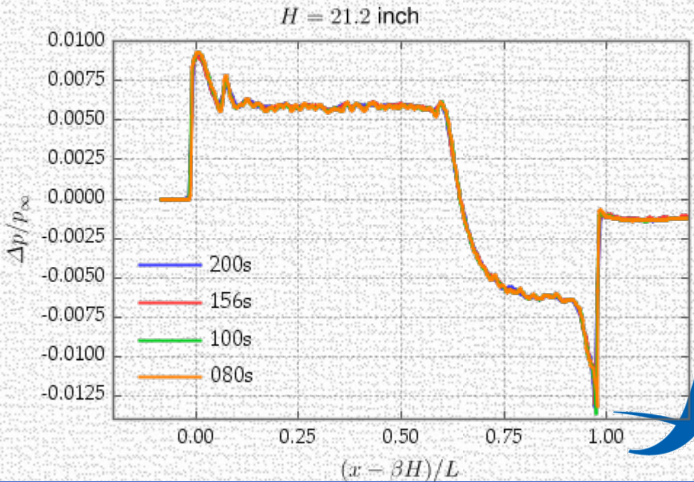
- ✓ Calculation stops when the residual reaches the plateau.
- ✓ Time to converge is about 1 to 1.5 hours.

Results of SEEB-ALR

- ✓ Signatures from the result of different resolution show good convergence.
- ✓ Only the signature of 156s at 42 in. is different from others.

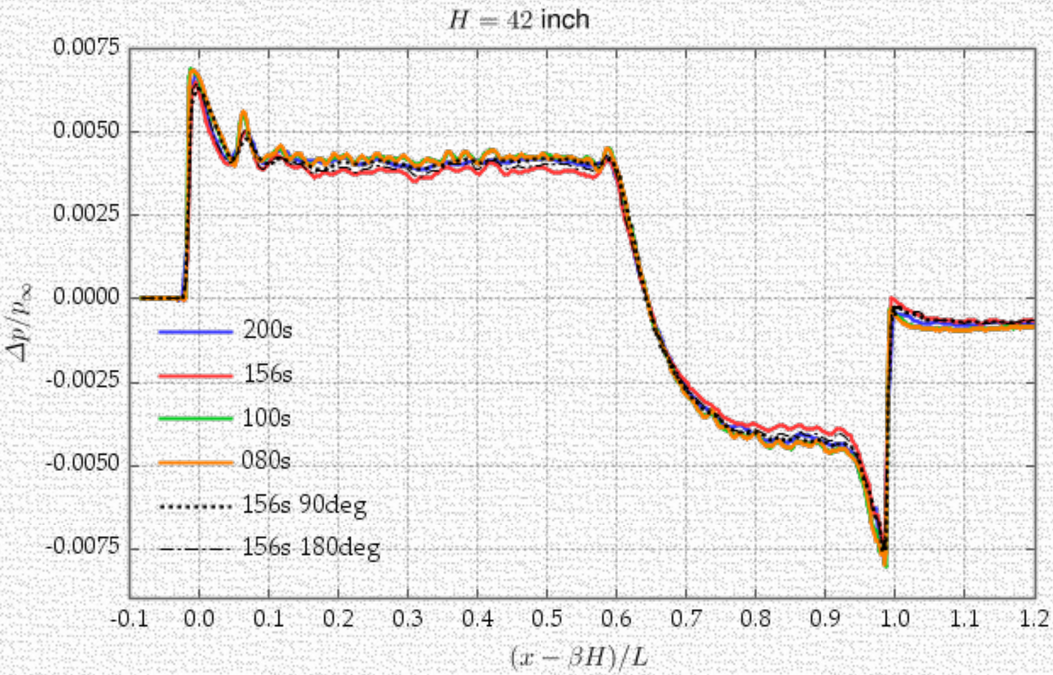


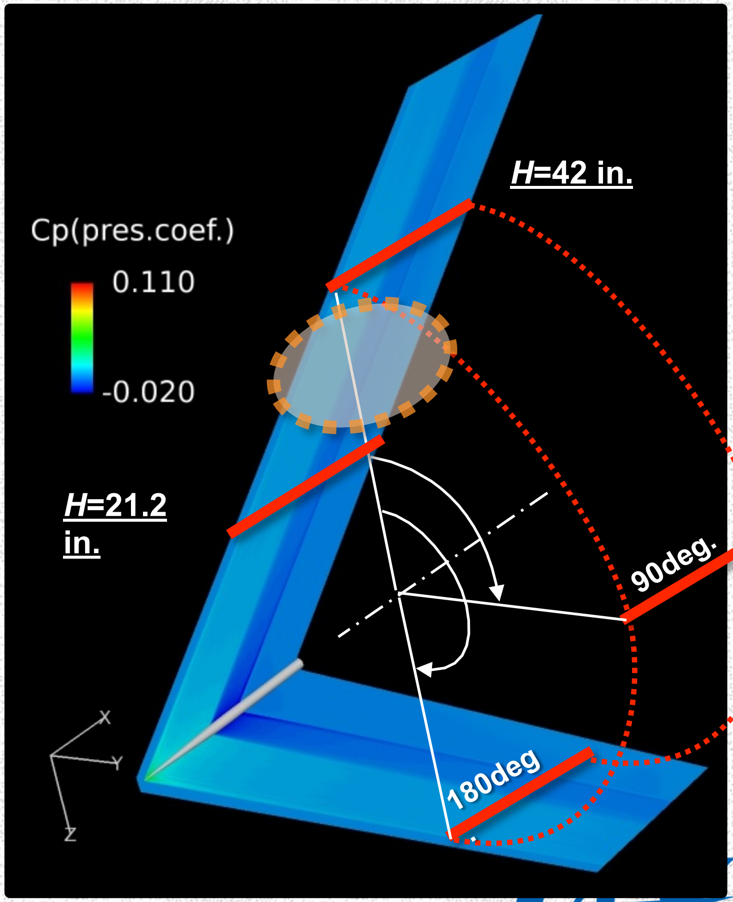




Difference on Signature at H=42 in.

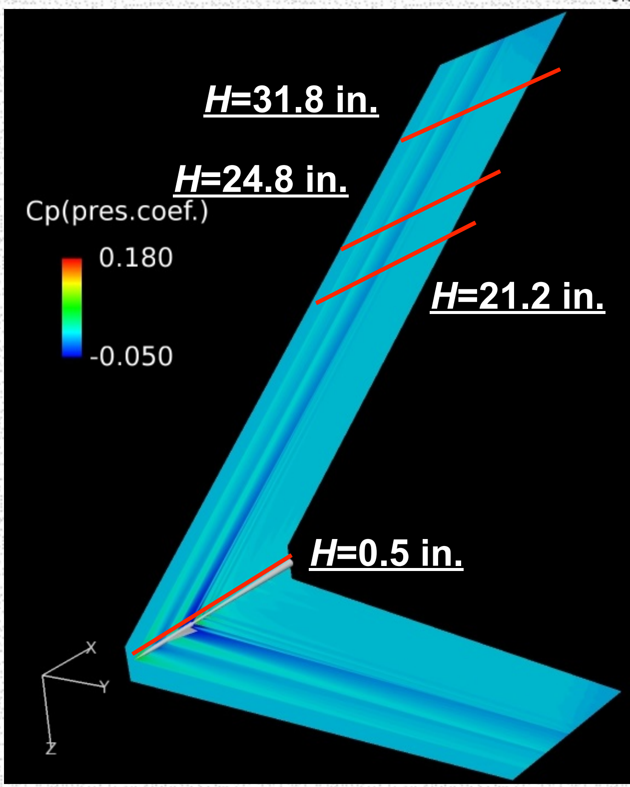
- ✓ Something is wrong with the signature of 156s at 42 in., not with that at 21.2in.
- ✓ Compared with the signatures at different azimuthal angles, namely 90 and 180 deg., such a discrepancy is not observed.
- ✓ This indicates that problematic cells are located between H=21.2in. and 42in.

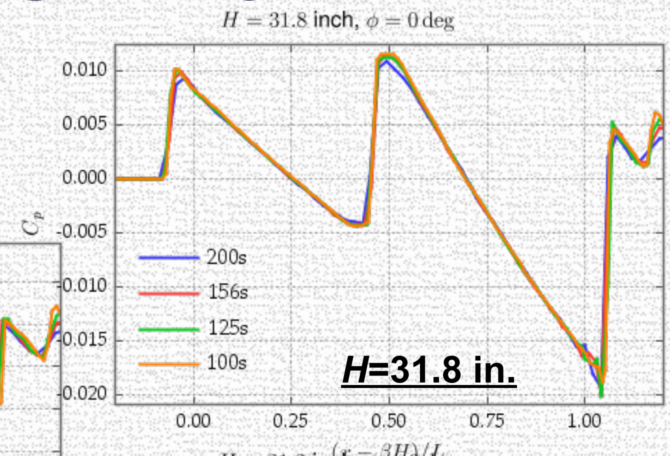


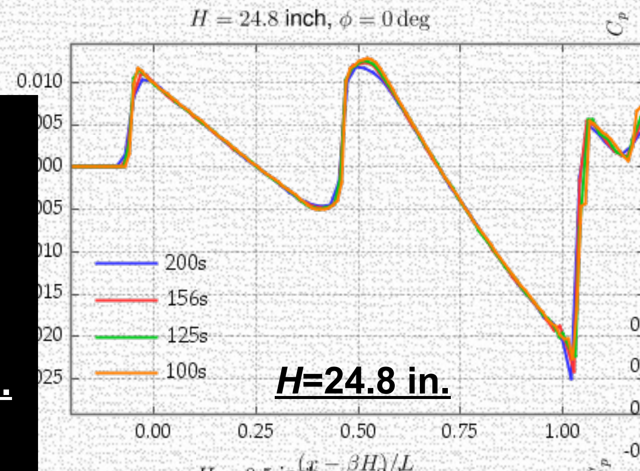


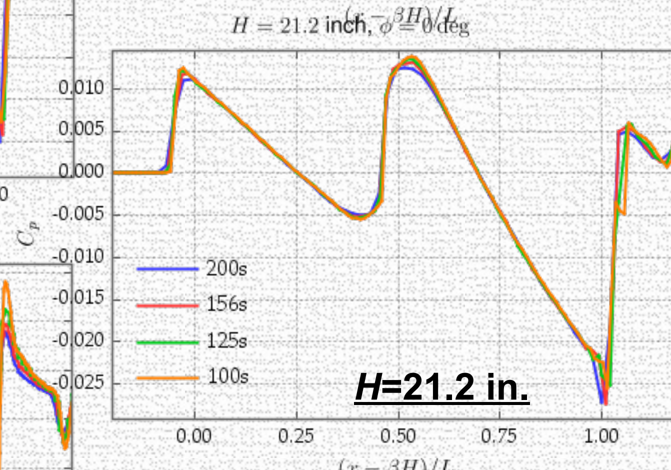
Results of 69-Degree Delta Wing Body

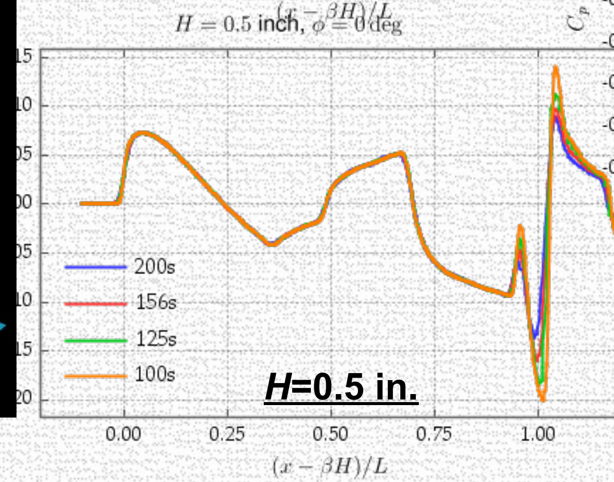
- ✓*H*-variations
  - ✓ shows good grid convergence.
  - ✓ includes nothing suspicious unlike SEEB-ALR.





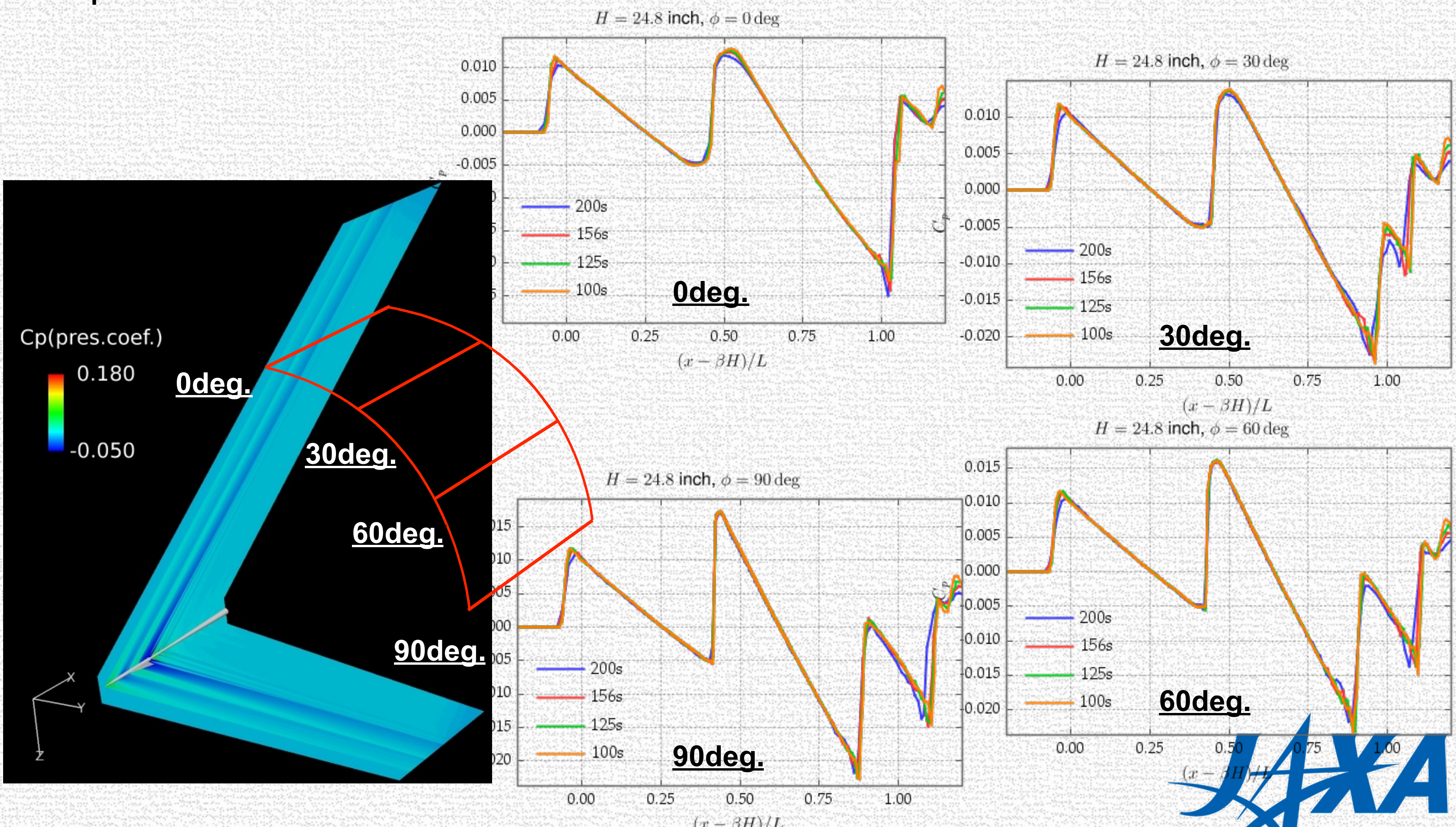






Results of 69-Degree Delta Wing Body Cont'd.

✓ φ-variations for H = 24.8 in.



Results of 69-Degree Delta Wing Body Cont'd.

- ✓φ-variations for H = 31.8 in.

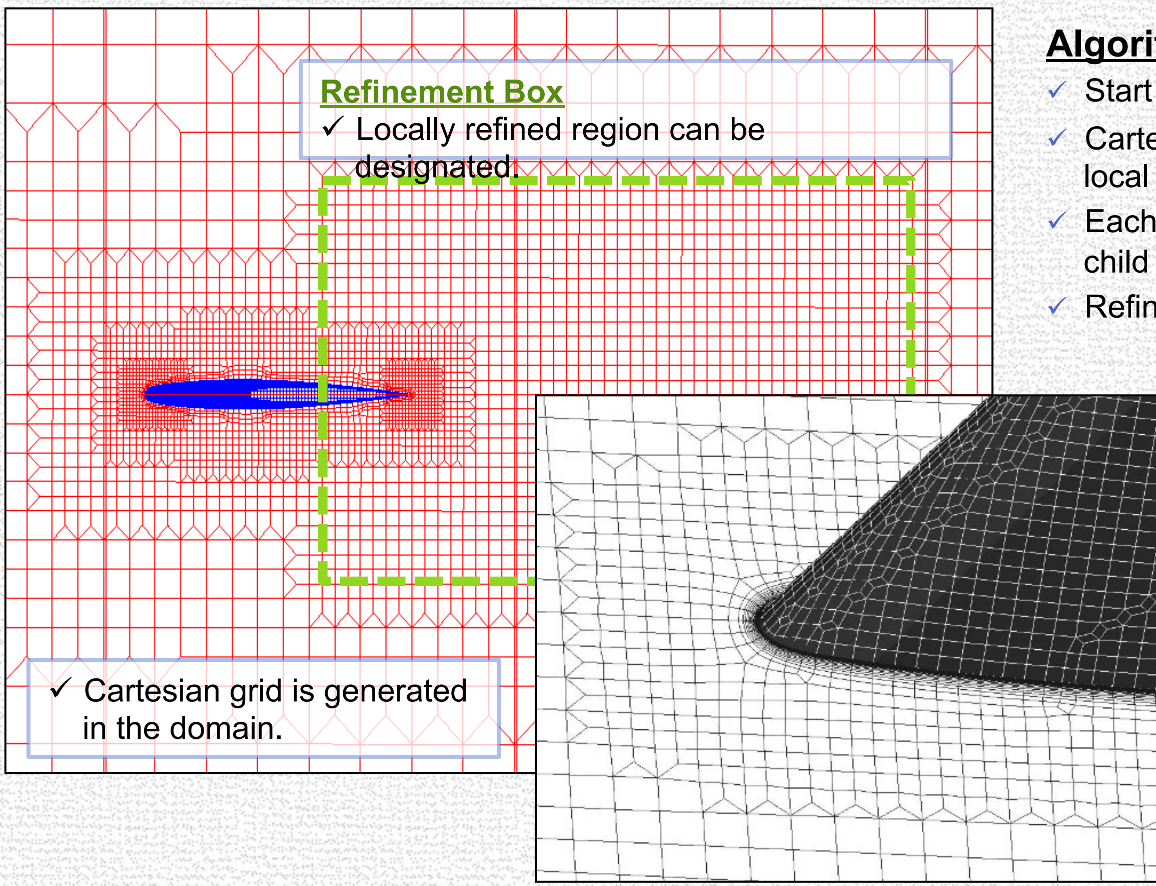
OWN GRID ANALYSES

HexaGrid – Full Automatic Grid Generator –

Full Automatic grid generation using a few control parameters

- ✓ Domain (max and min of x, y, z)
- ✓ Max and min cell sizes on the surface
- ✓ Layer parameter (thickness of first layer, expansion factor)

+ CAD data
  (STL format)



Algorithm of HexaGrid

- ✓ Start with one big element(= computational domain)
- ✓ Cartesian grid is generated by means of successive local refinement
- ✓ Each refinement divides a cell isotropically into eight child cells
- ✓ Refine the element using 3 criteria

Body-fitted layer grid is generated near the solid surface
(Layer grid is hexahedral)

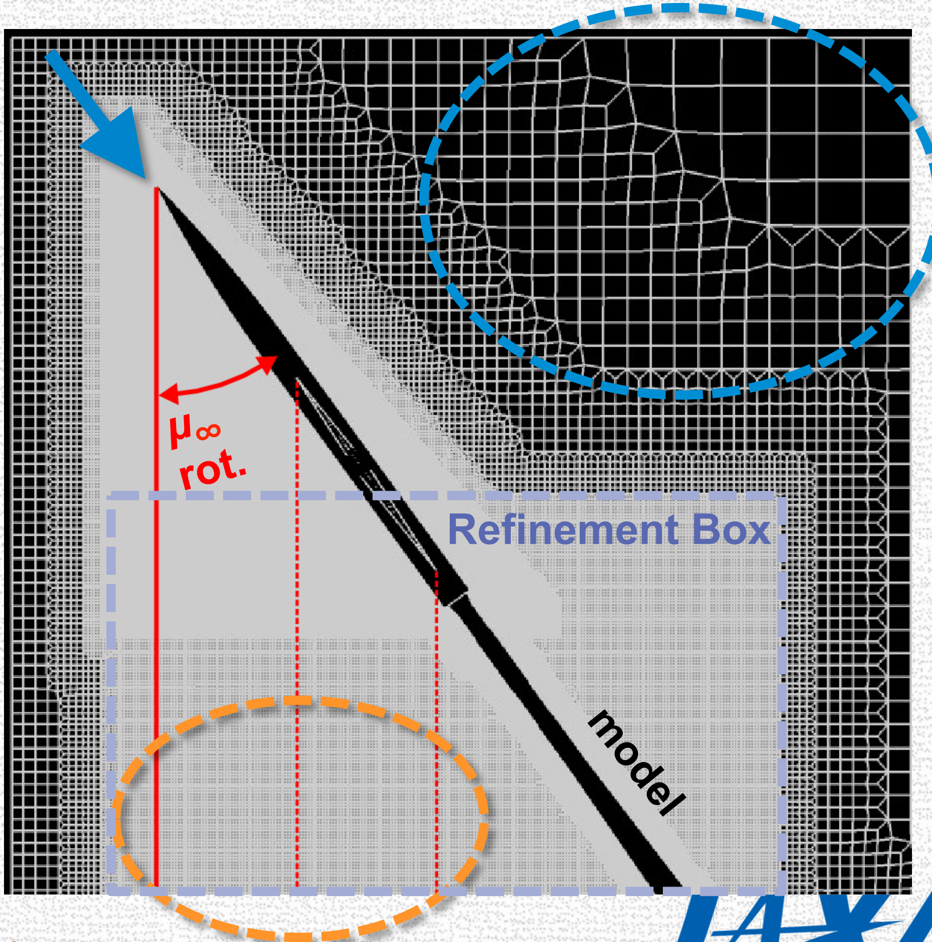
Outline for Own Grid Analyses

Our Strategy

- ✓ The model is rotated by Mach angle μ_∞ so that the grid lines become parallel to the shock waves.
- ✓ Refinement box, or locally refined region is designated along shock propagation path, which guarantees a sufficient resolution for predicting near-field signatures.
- ✓ Only the signatures
  - ✓ for 69-degree delta wing body
  - ✓ on the plane of symmetry

  are considered in this presentation.

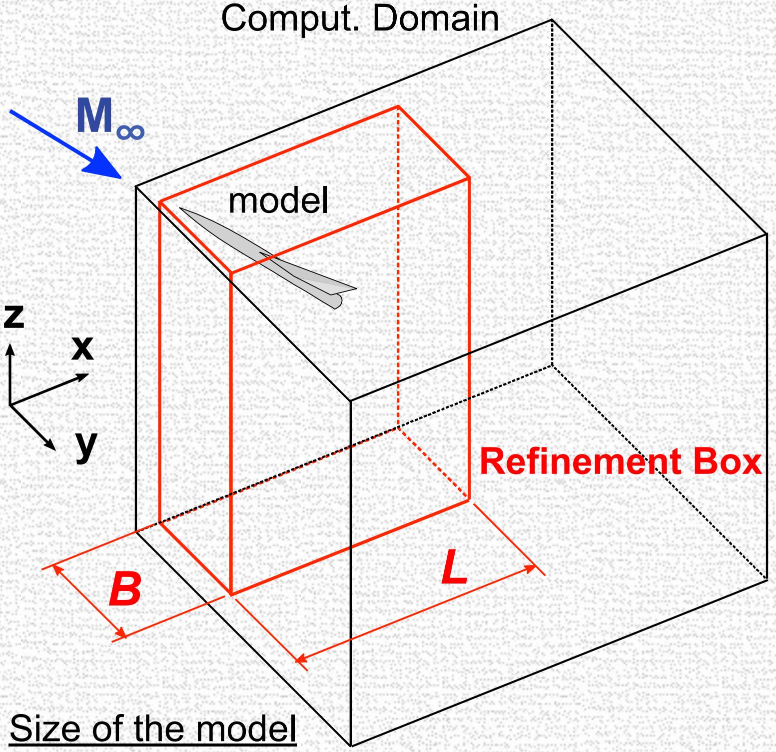
Cartesian grid away from the model



Grid lines parallel to the shock waves

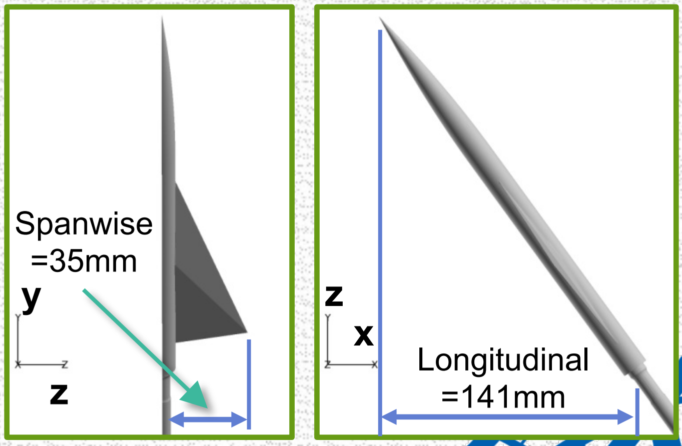
Parametric Study Settings

- ✓ The sensitivity of the nearfield signature is investigated by changing the size of Refinement Box parametrically:
  - ✓ longitudinal length *L*
  - ✓ spanwise length *B*
- ✓ *L*=150mm is about the size of the model in x direction.
- ✓ *B*=70mm is twice of the span of the model.
- ✓ The number of grid point: min. 20M, max. 90M

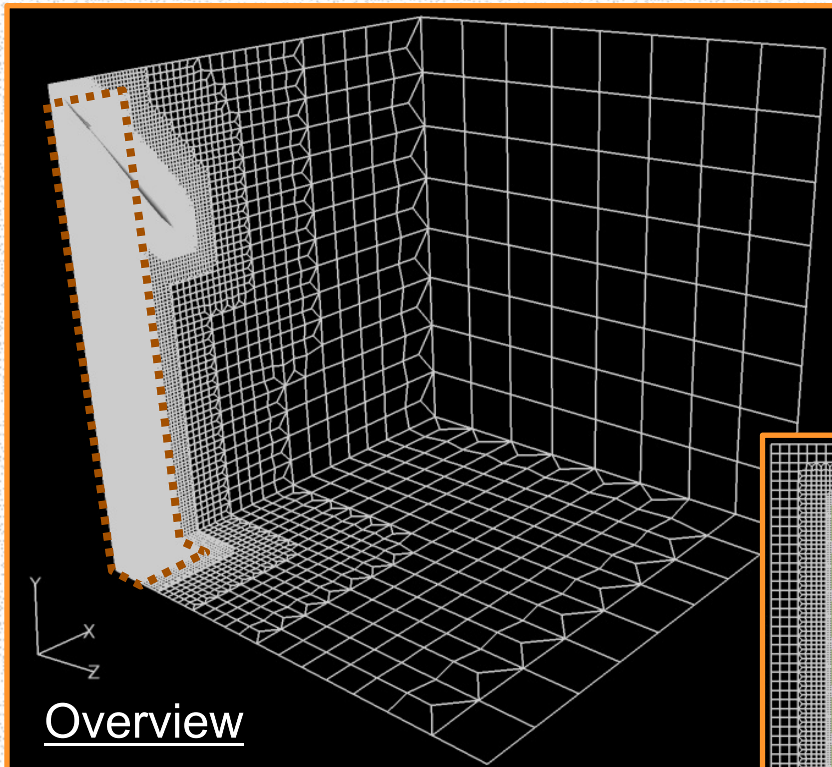


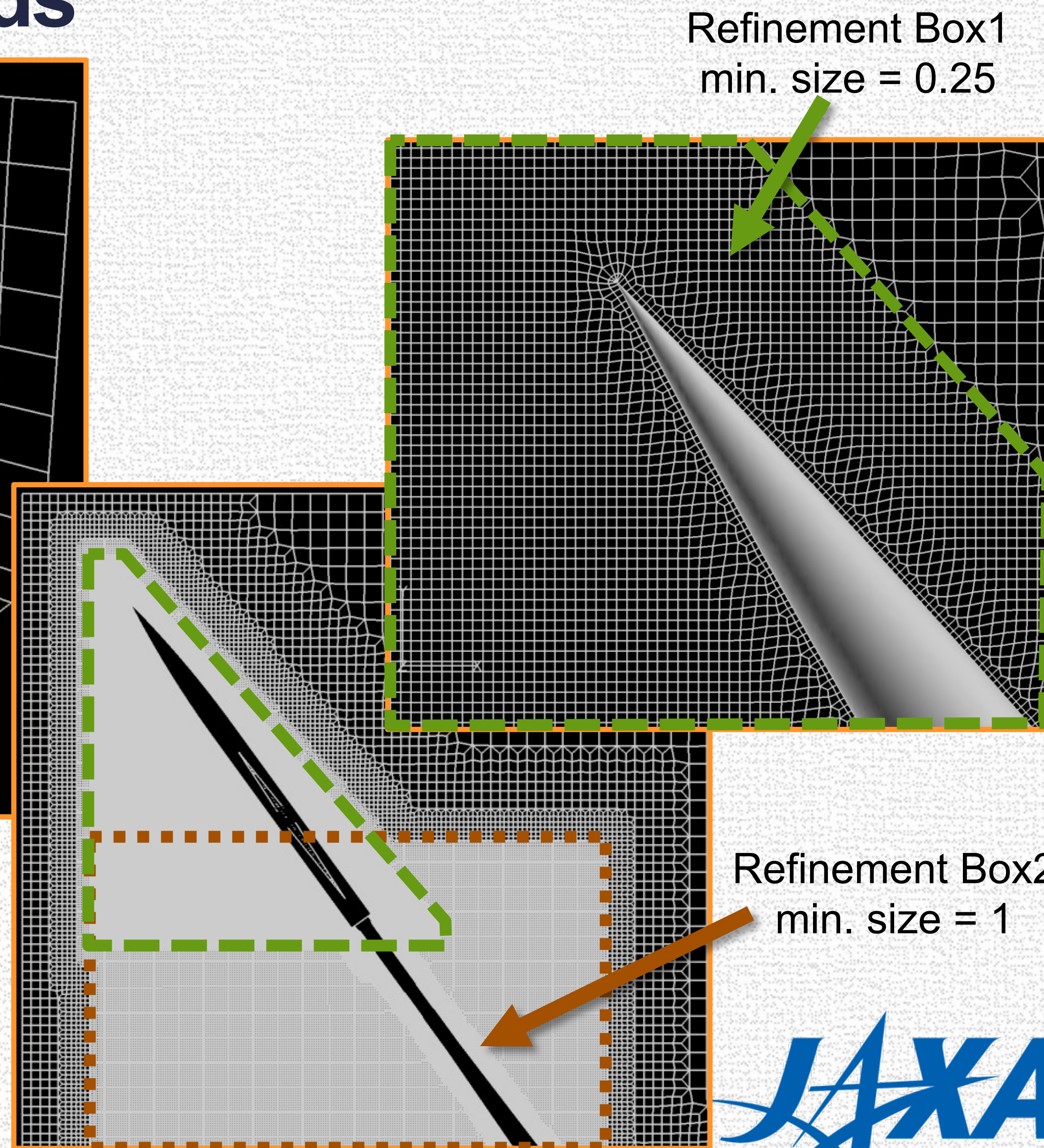
Longitudinal *L* / Spanwise *B*	150mm	200mm	250mm
70mm	case 1	case 2	case 3
100mm	case 4	case 5	case 6
150mm	case 7	case 8	case 9

Size of the model



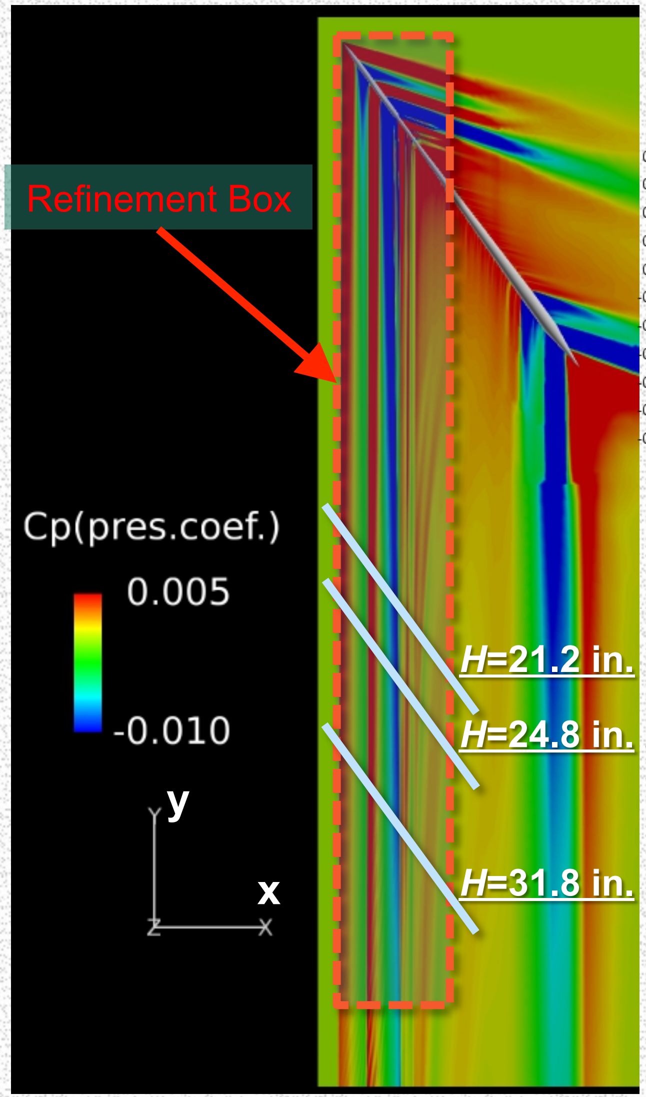
Example of Own Grids



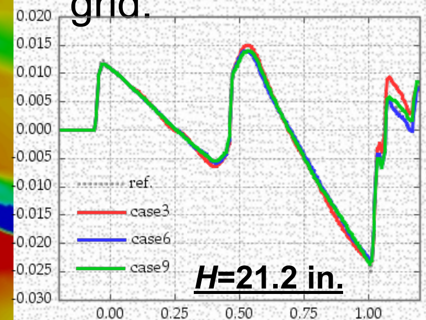


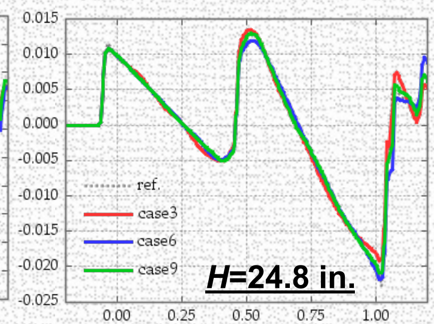
- ✓ Body-fitted grid around the body and Cartesian, cubic cell elsewhere
- ✓ Resolution (=Min. size of the cell) is fixed as shown in this slide.

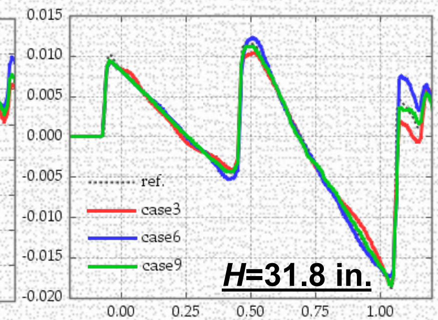
Example of the Result

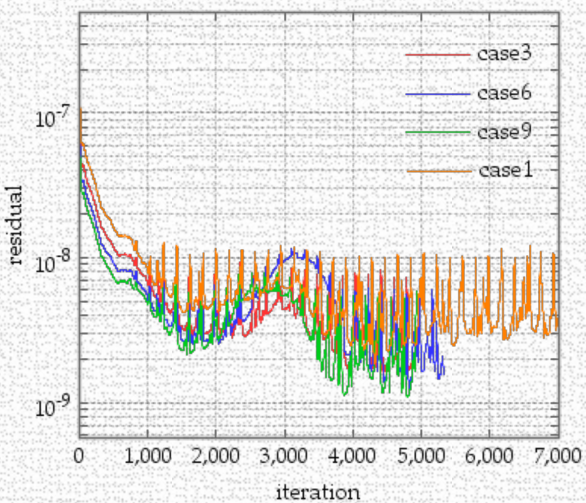


- Highly accurate signatures can be obtained by the combination of model rotation and local refinement of the grid.









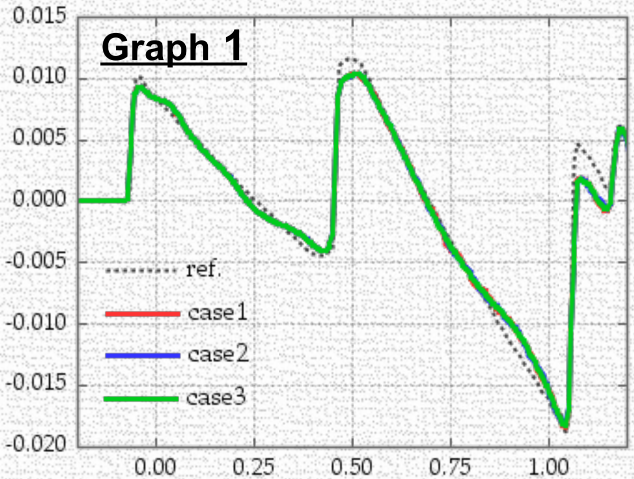
Convergence history

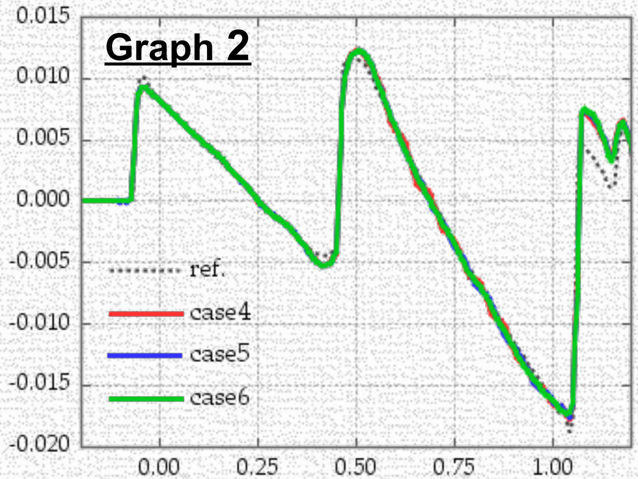
- looks wavy because of the relation between shock waves and grid lines.
- connection of the cells of different level also causes the waviness.
- computation stops when the moving average becomes flat.

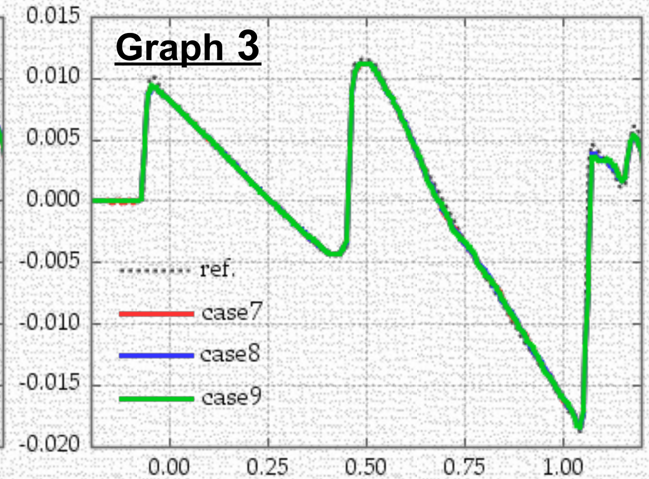
Effect of Longitudinal Resolution

Longitudinal *L* / Spanwise *B*	150	200	250
70		Graph 1	
100		Graph 2	
150		Graph 3	

- ✓ Signatures obtained at H=31.8in.
- ✓ *L* variation with fixed *B*
- ✓ Compared with three signatures for fixed *B*, the resolution along longitudinal direction is not so sensitive.
  → Setting *L*=(size of the model in the x direction) is sufficient for predicting nearfield signatures.
- ✓ Such a trend is observed at the other locations.





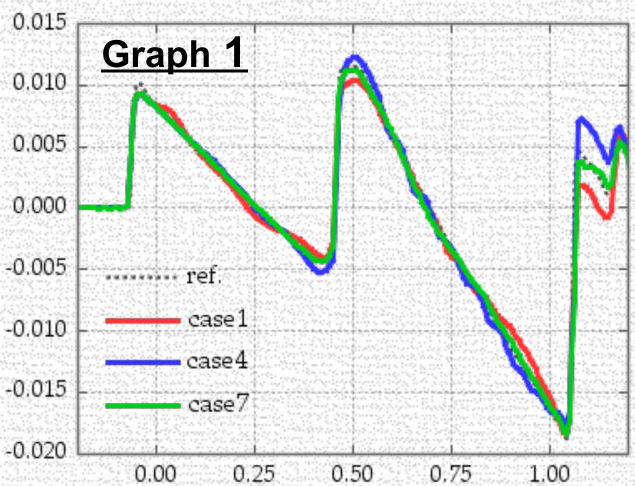


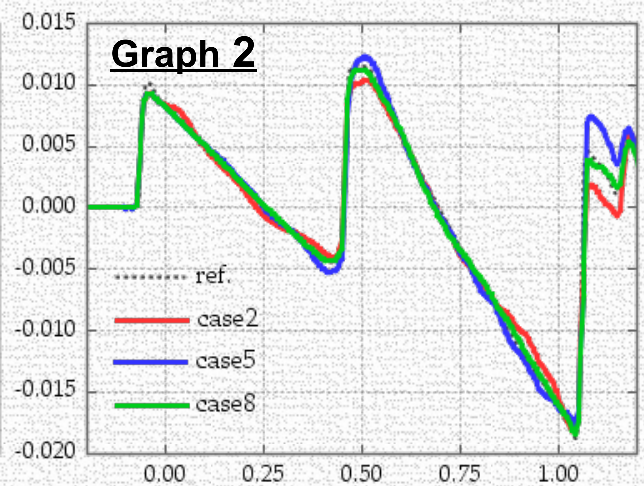
※ ref. = Obtained from given grid (100s)

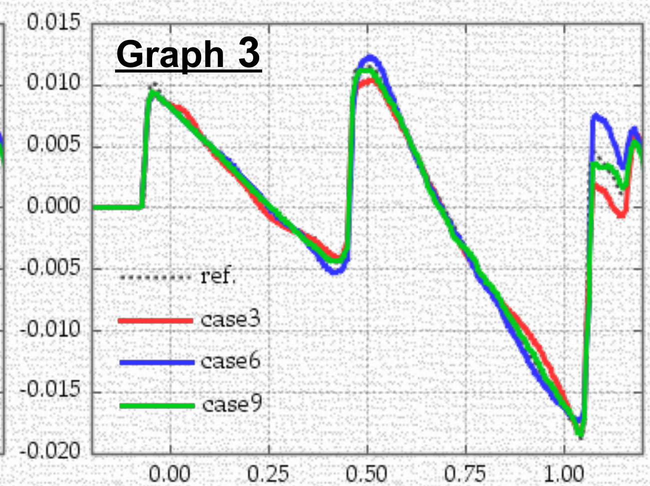
Effect of Spanwise Resolution

Longitudinal *L* / Spanwise *B*	150	200	250
70			
100	Graph 1	Graph 2	Graph 3
150			

- ✓ Signatures obtained at H=31.8in.
- ✓ *B* variation with fixed *L*
- ✓ Signatures corresponding to large B show good agreements with the reference result.
  →Large span is necessary for accurate prediction of the nearfield signatures.
- ✓ Such a trend is observed at the other locations.

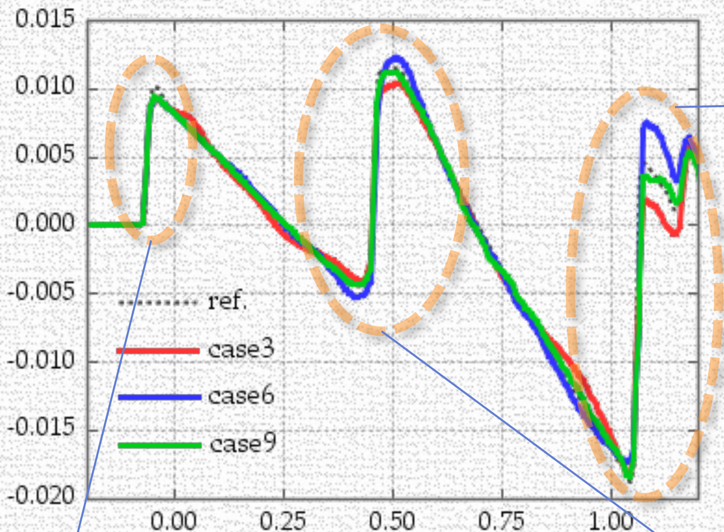


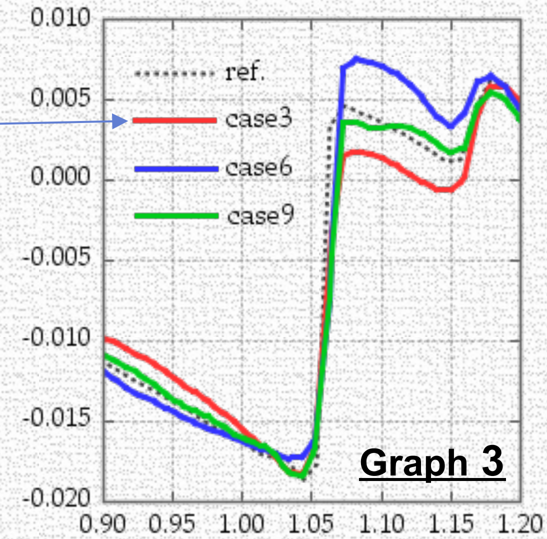


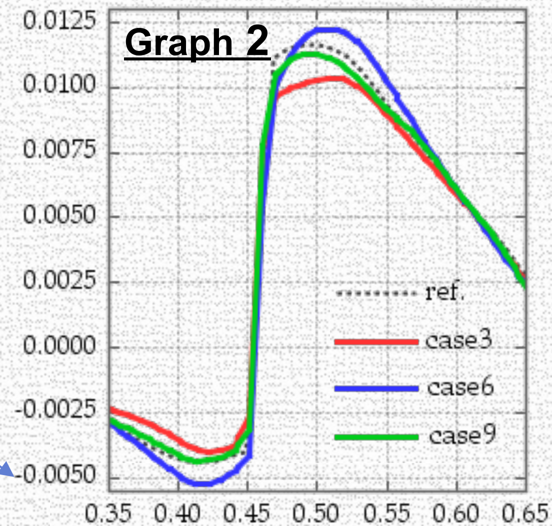


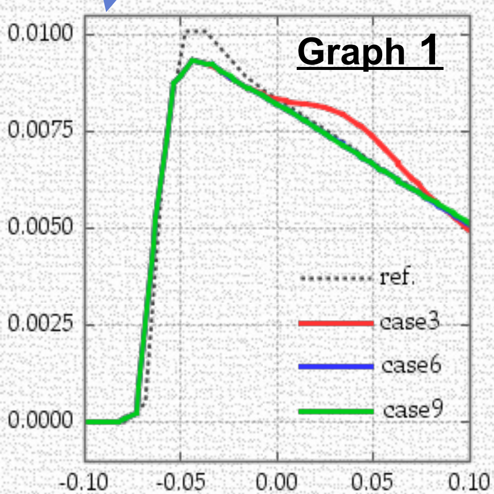
※ ref. = Obtained from given grid (100s)

Effect of Spanwise Resolution Cont'd



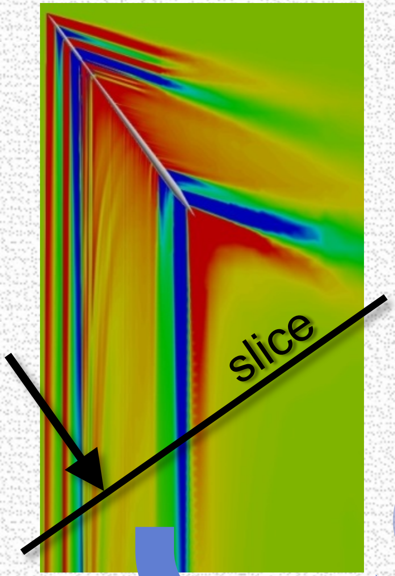




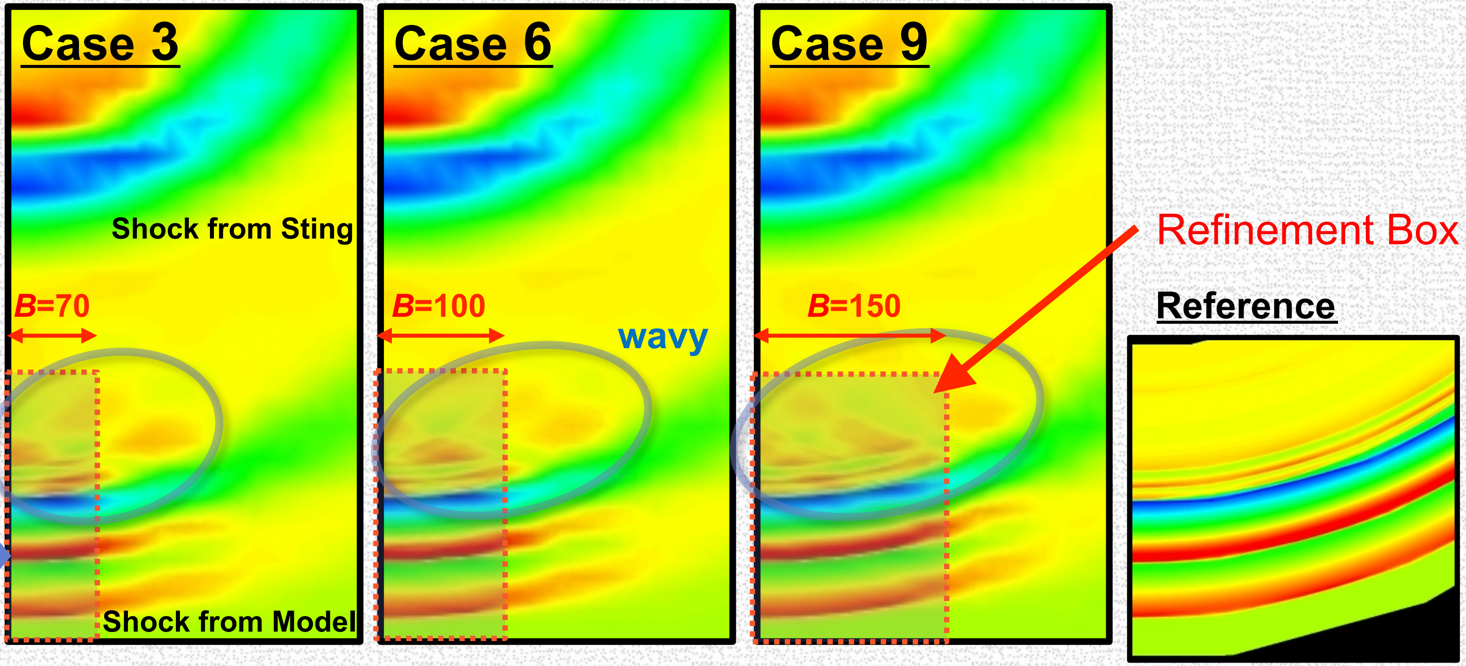


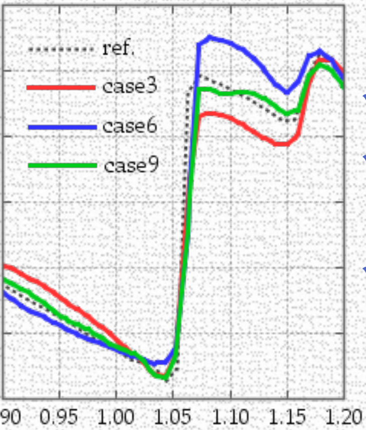
- ✓ Pressure rise at the front shock is not sensitive to the spanwise resolution, but finer grid is necessary to capture the peak (Graph1).
- ✓ Pressure rise at middle and tail shock are highly affected by the variation of *B*. (Graph 2 and 3)
  → Circumferential effect
- ✓ Wide Refinement Box will result in the correct nearfield signatures.

Circumferential Distribution of Pressure Signal



C_P Distribution on sliced plane





- ✓ Signatures are somewhat wavy in the circumferential direction.
- ✓ Waviness still remains even in case 9, but is not sensitive to the signature itself. → *B*=150 (case9) is sufficient for this model.
- ✓ The width of the Refinement Box *B* becomes more than 4 times larger than that of the model !

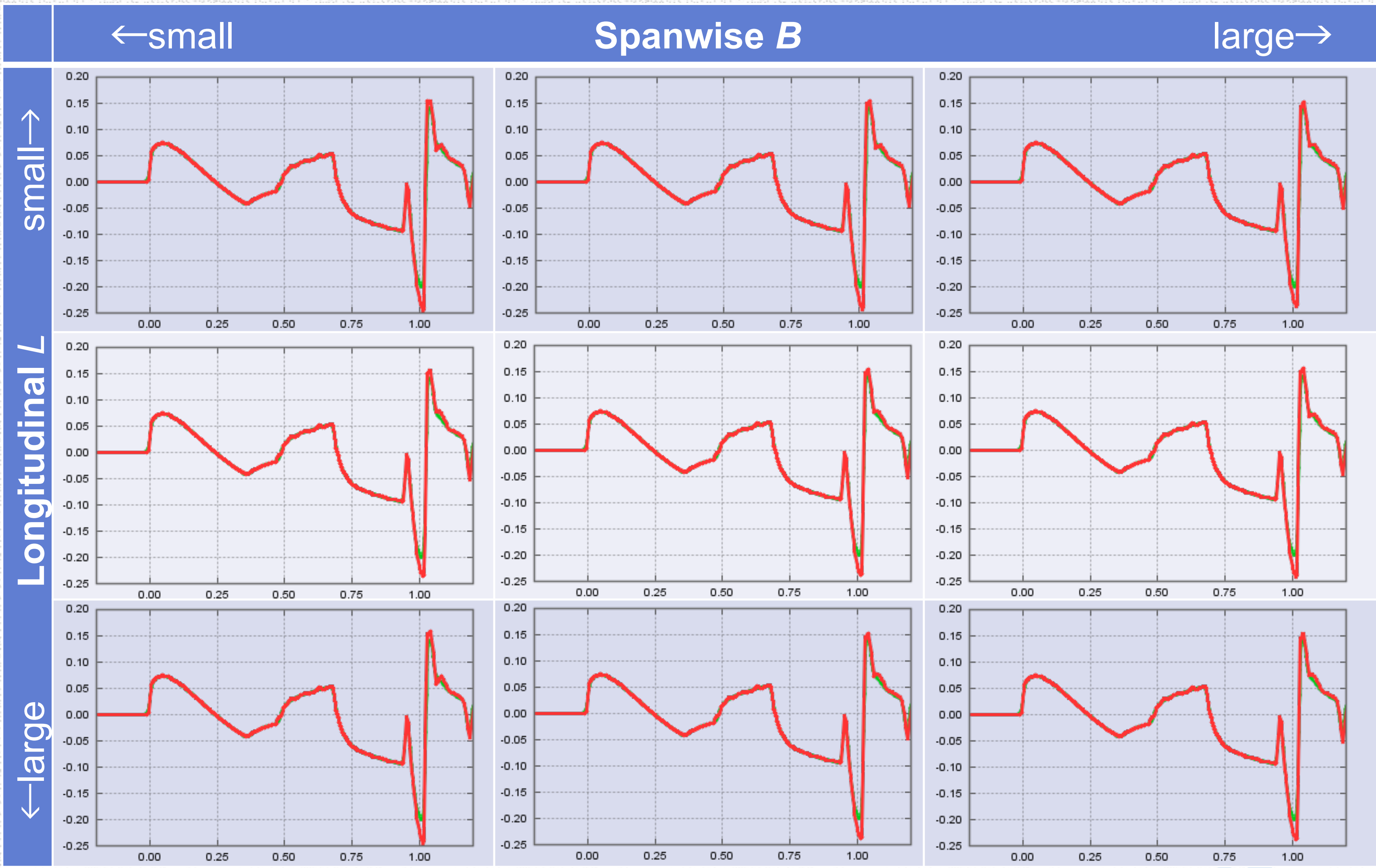
Concluding Remarks

- ✓Predictions of nearfield signatures are conducted with FaSTAR.
  - ✓ SEEB-ALR and 69-degree Delta Wing Body are calculated.
- ✓For given grids,
  - ✓ extracted signatures show good convergence against grid resolution.
  - ✓ only the result of SEEB-ALR has some different tendency compared with other results, which is mainly due to the grid itself rather than the flow solver.
- ✓For own grids,
  - ✓ With HexaGrid, or automatic grid generation tool, nearfield signatures are predicted correctly by the combination of model rotation and local grid refinement.
- ✓The effect of refined region on the nearfield signature is investigated.
  - ✓ longitudinal length is not important.
  - ✓ sufficiently large spanwise resolution is important for the prediction of nearfield signatures.

Thank you for your attention!

APPENDIX

Signatures at Location 1

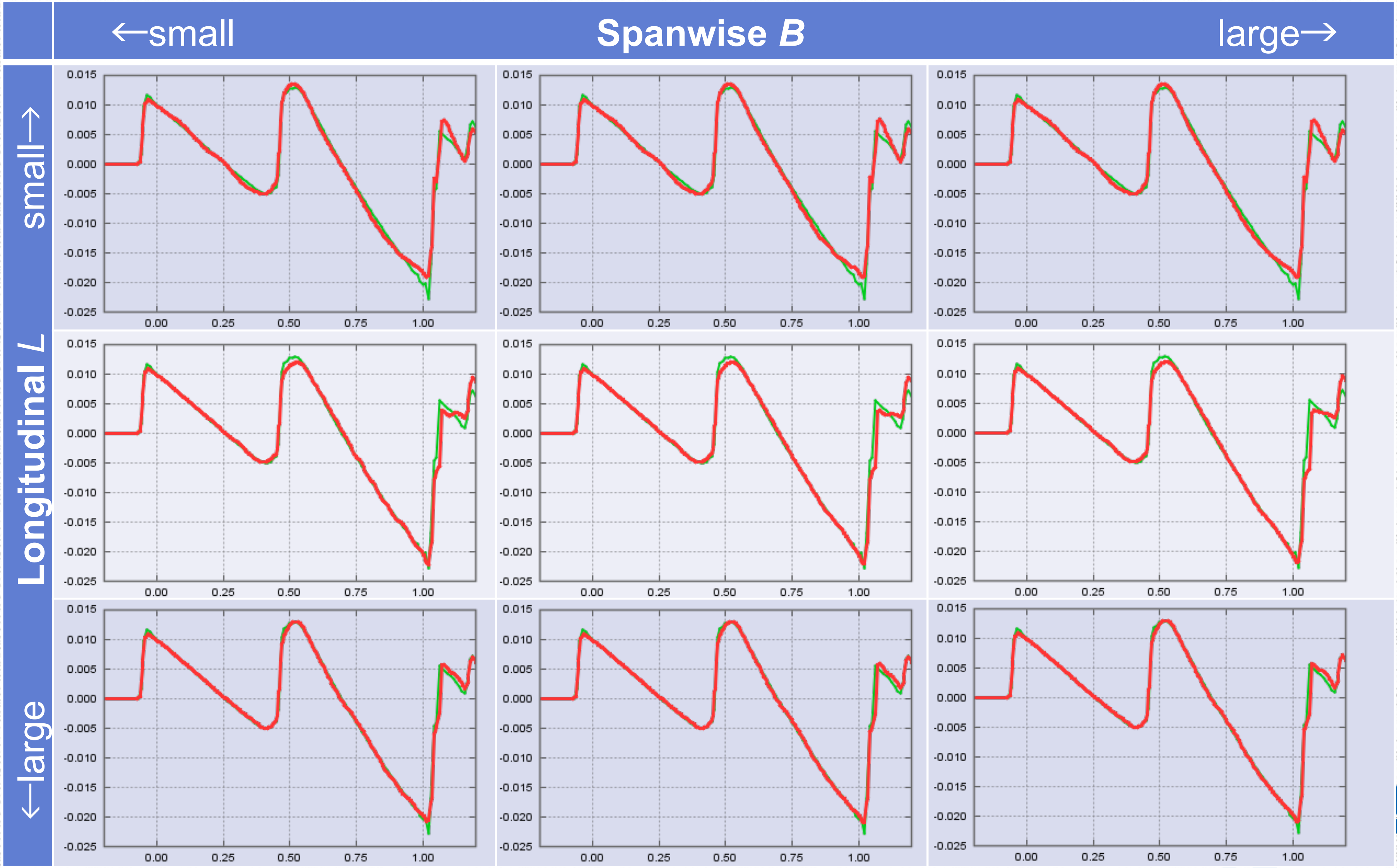


Signatures at Location 2

←small **Spanwise *B*** large→

small→ **Longitudinal *L*** ←large

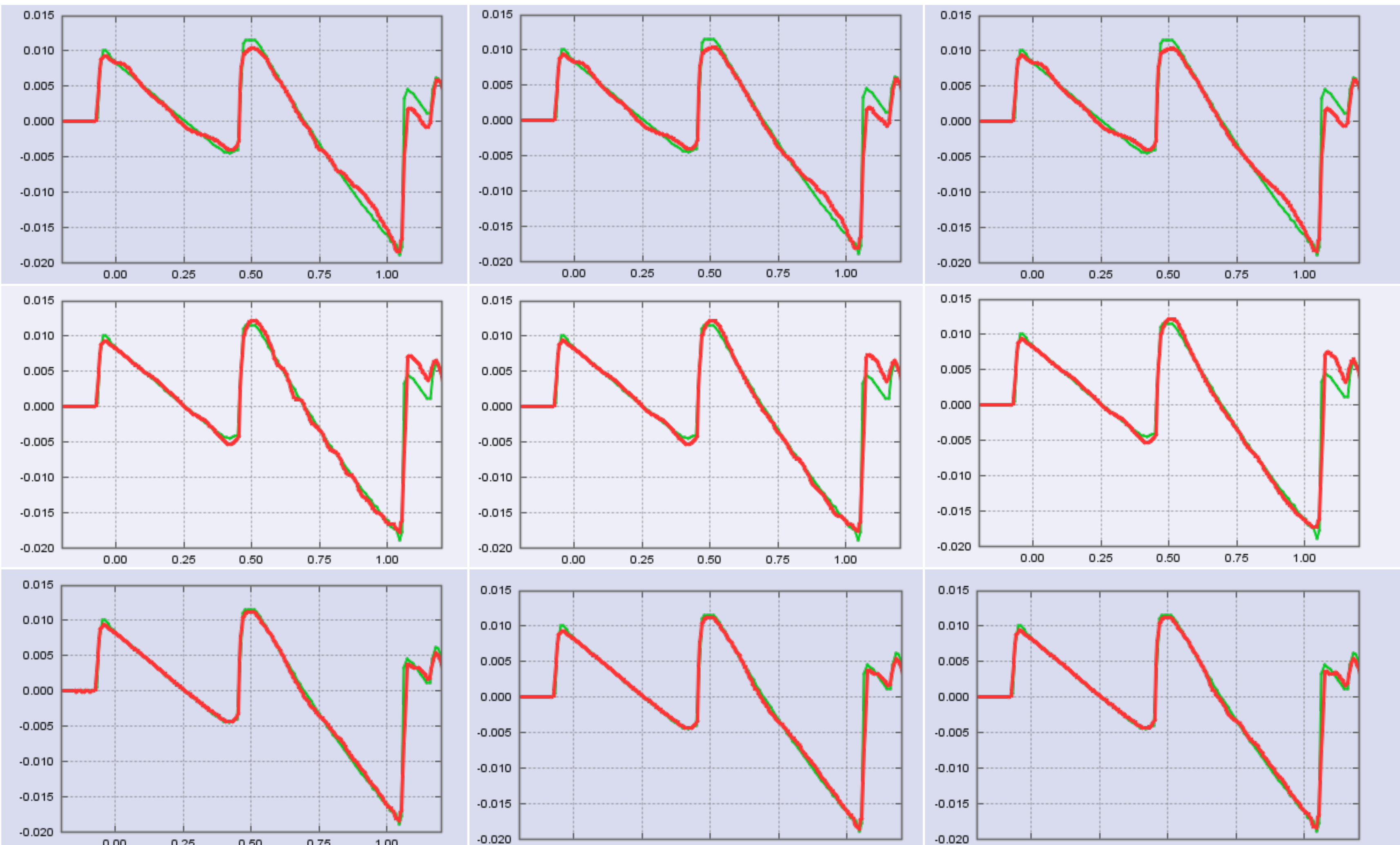
Signatures at Location 3



Signatures at Location 7

←small **Spanwise *B*** large→

small→ **Longitudinal *L*** ←large



Pressure Contours for 69deg. Delta-Wing

- ✓ Waves emanating from wing causes a generation of disturbances in the circumferential direction.
- ✓ Capturing such disturbances is important to predict nearfield waveform correctly, which will be discussed later.