Sonic Boom Prediction Using a Multi-Block Structured CFD Solver - ADCS

Prof. Zhong Lei

Tokyo University of Science, Suwa, Japan

Dr. Yoshikazu Makino

Japan Aerospace Exploration Agency

Outline

Cases analyzed

- SEEB-ALR Body of Revolution
  provided grid
- 69-Degree Delta Wing Body
  grid modified from the provided one

Flow solver / Computing platform

- ADCS (Aero-Dynamic Computational System)
- An in-house CFD Code developed at JAXA
- Multi-block, structured grid

Results

- Pressure countours
- Near field signature

Highlights

Conclusions

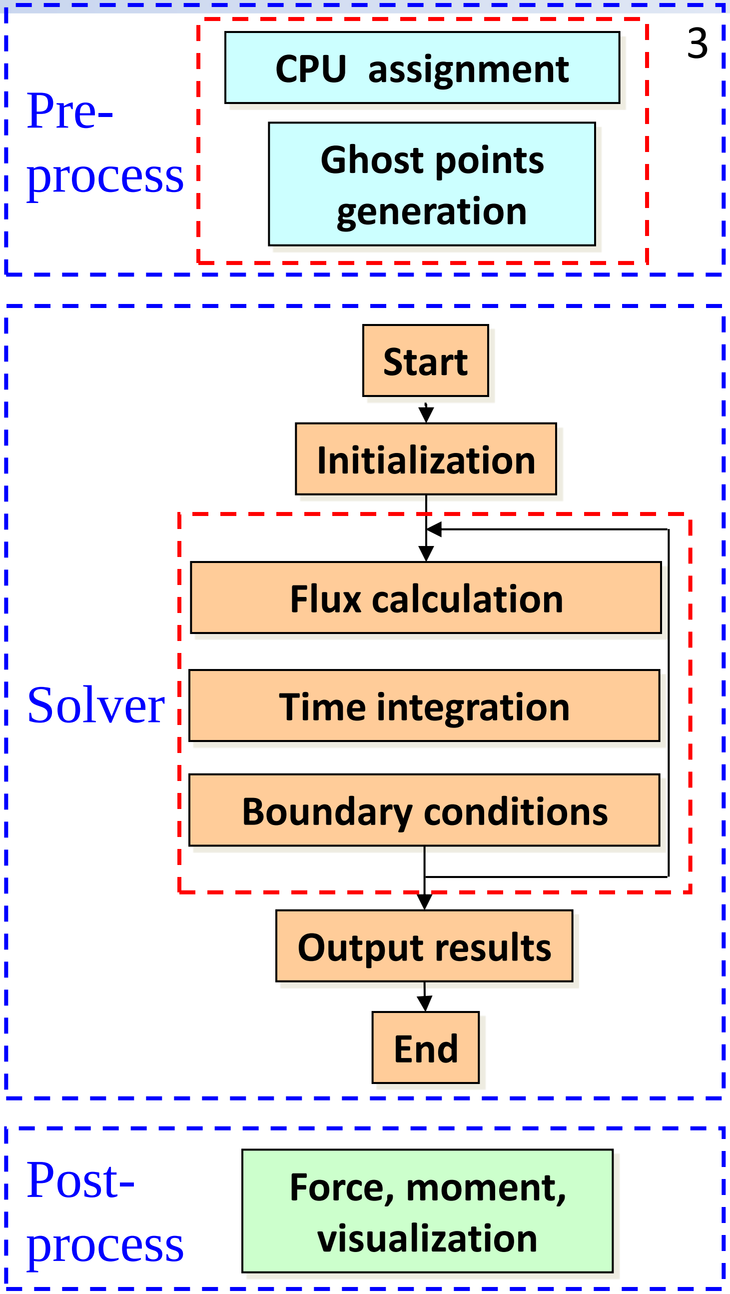
Flow solver / Computing platform

ADCS (Aero-Dynamic Computational System)

An in-house CFD Code developed at JAXA

fundamental research | aerodynamic design

- Large scale simulation, complex configuration
- Reynolds-averaged Navier-Stokes equations
- Turbulence models
  - Spalart-Allmaras model
  - Menter's SST k-ω model
  - Some k-ε models
- Discrete method
  - Finite difference method
- Multi-block grids
- Domain decomposition
- Fortran90 parallel programming with MPI
- conducted at JAXA Supercomputer System



Flow solver / Computing platform

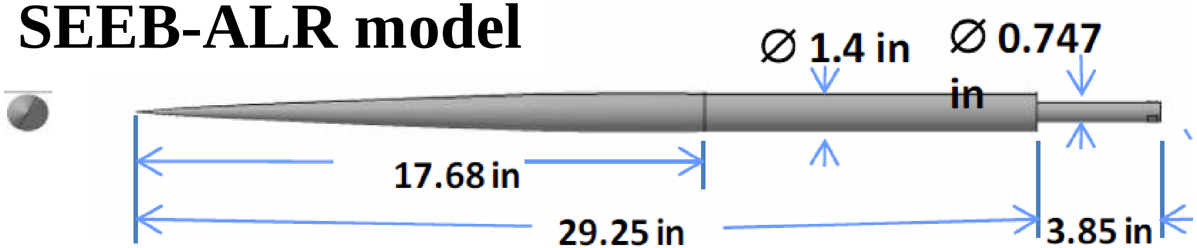
ADCS（Aero-Dynamic Computational System）

Sonic Boom Prediction in this study

Governing Equations	**Euler equations** for the inviscid compressible flow
Turbulence model	No
Mesh	genralized coordinates, multi-block technique
Discrete method	finite difference method
Inviscid flux	Chakravarthy-Osher TVD、MUSCL interpolation, 3rd-order
Viscous flux	No
Time integral	LU-ADI
Boundary condition file	generic boundary condition file of ***Gridgen***
File format	***Plot3d***
Post-process	***FIELDVIEW, Tecplot***

SEEB-ALR Body of Revolution

SEEB-ALR model



Input data

- CFL=1.0
- Angle of attack = 0 degree
- Mach number =1.4

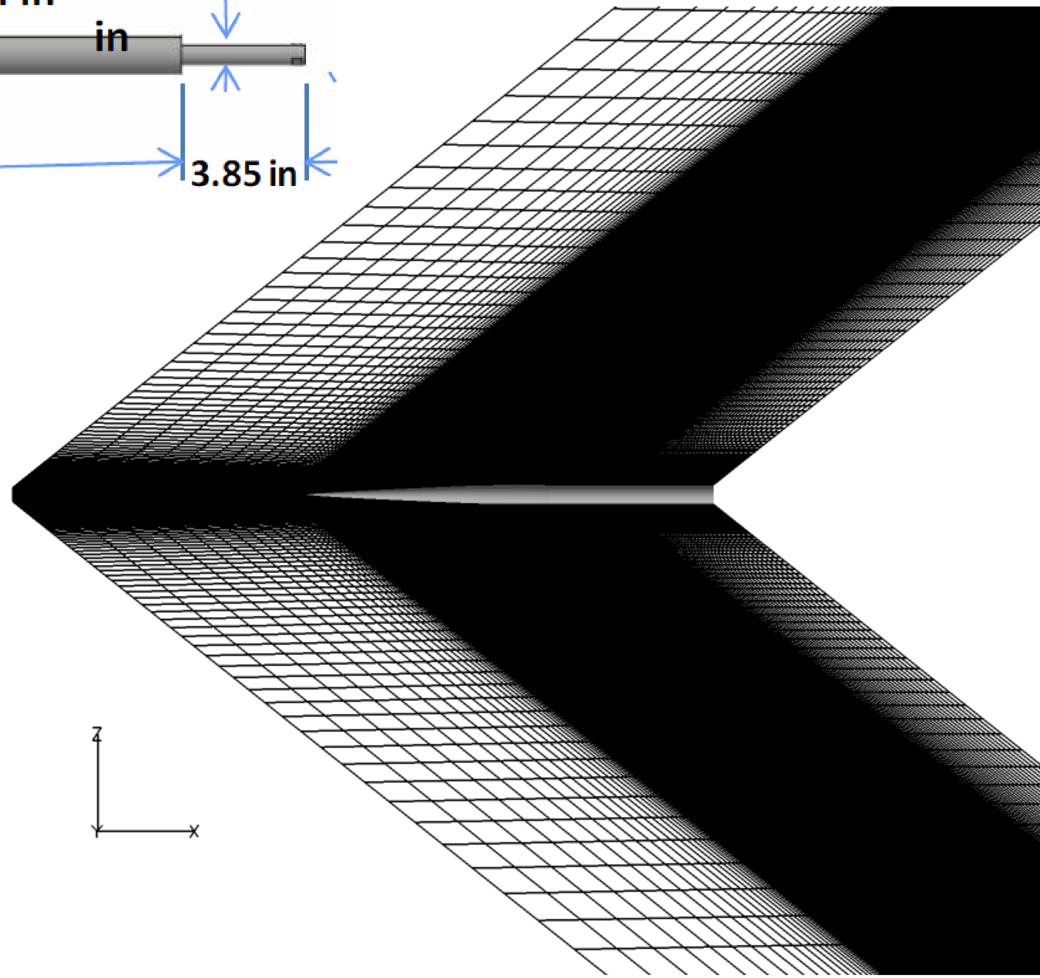
Workshop provided grid

- Multi-block, 75blocks
- Grid points: 7,986,107

Used Resource

- Number of CPU = 15, node x 4 = 60
- Total Normal Page Memory = 6.7GB

Fig. Provided grid

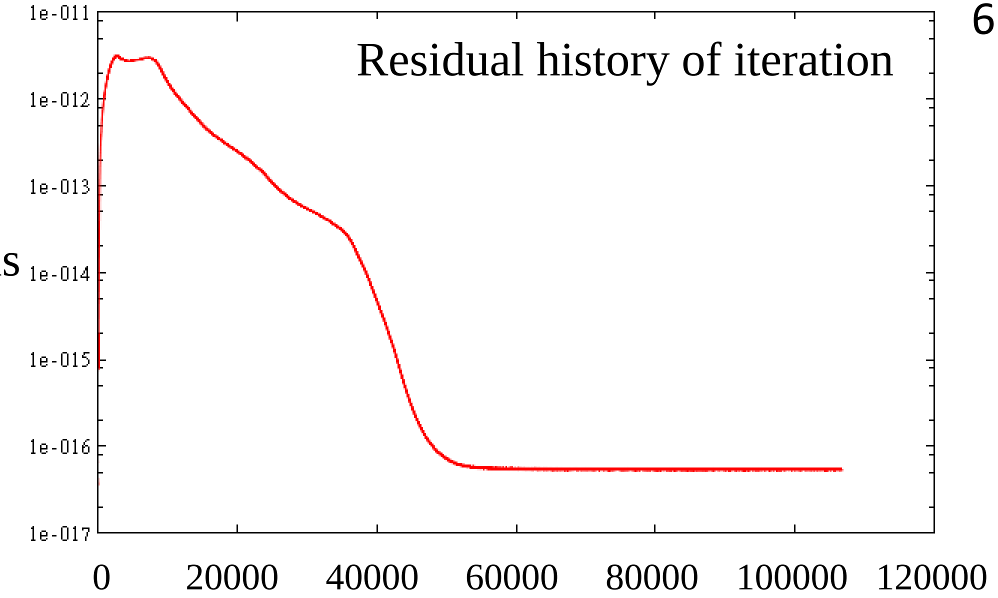


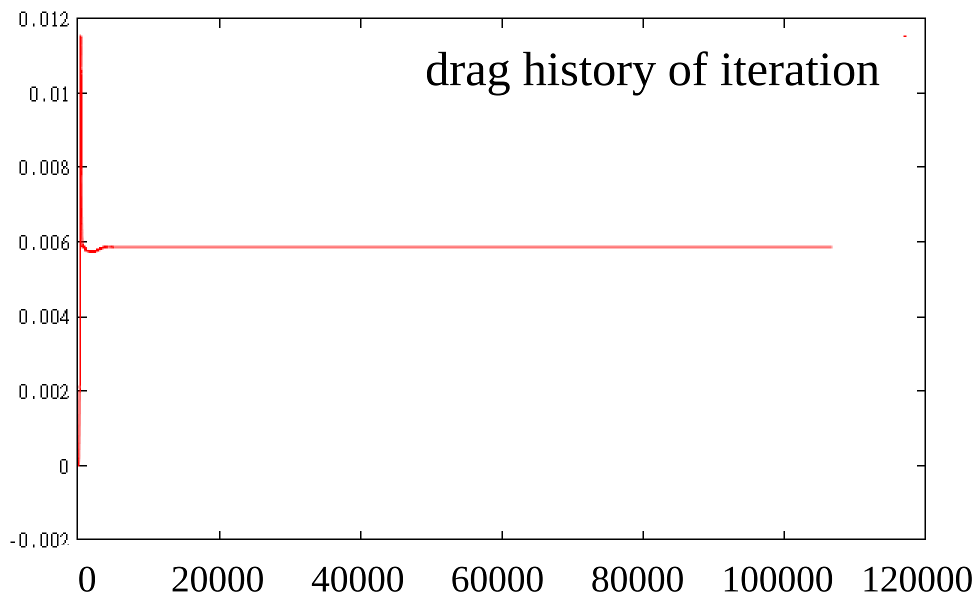
Ref.: Carlson, H., Mack, R., and Morris, O., "Wind-Tunnel Investigation of the Effect of Body Shape on Sonic-Boom Pressure Distributions," NASA TN D-3106, NASA Langley Research Center, 1965.

Convergence of computation

Convergence criteria:

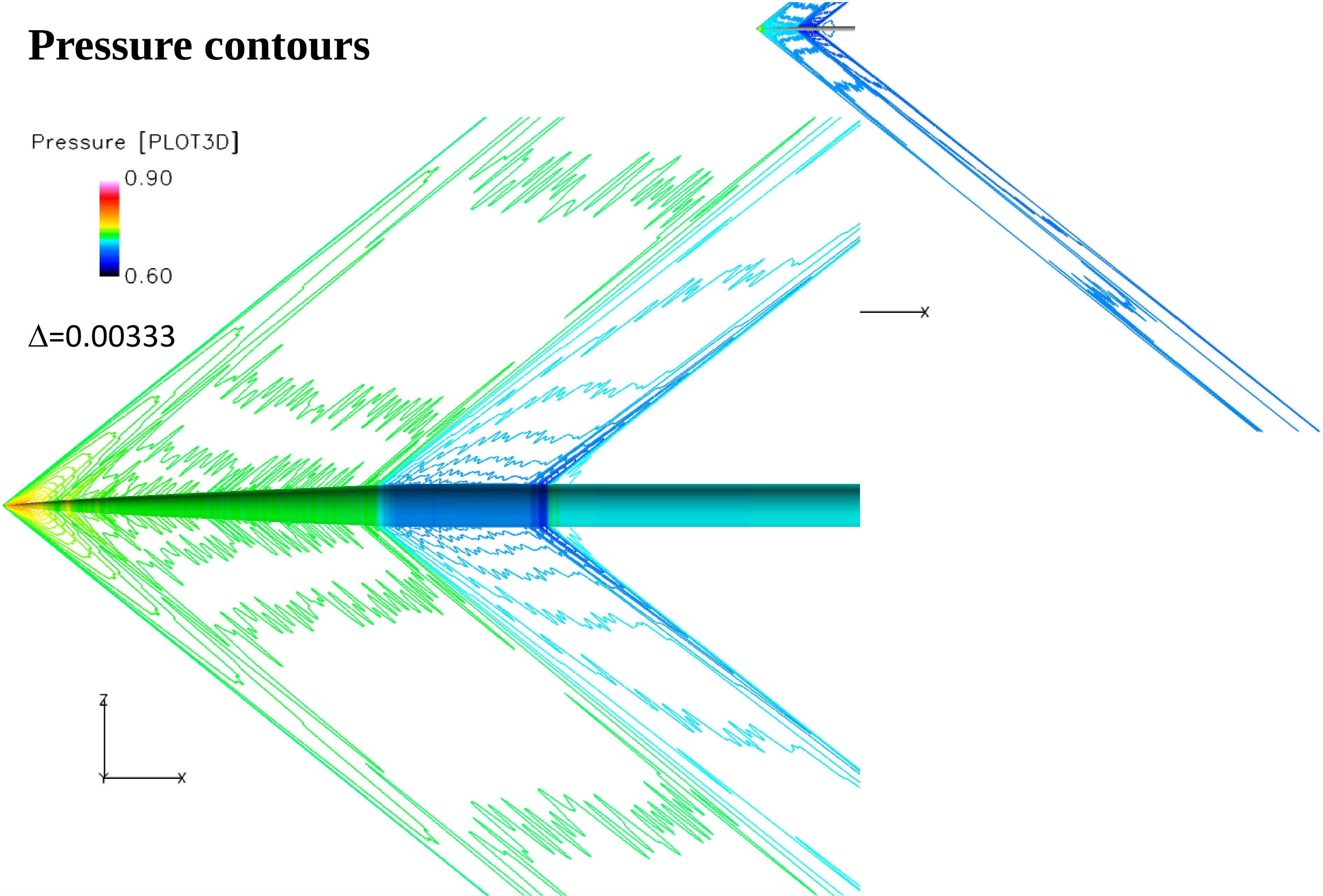
- RMS of the residual of the Euler equations
- Also check the lift and drag coefficients
- Converged sufficiently



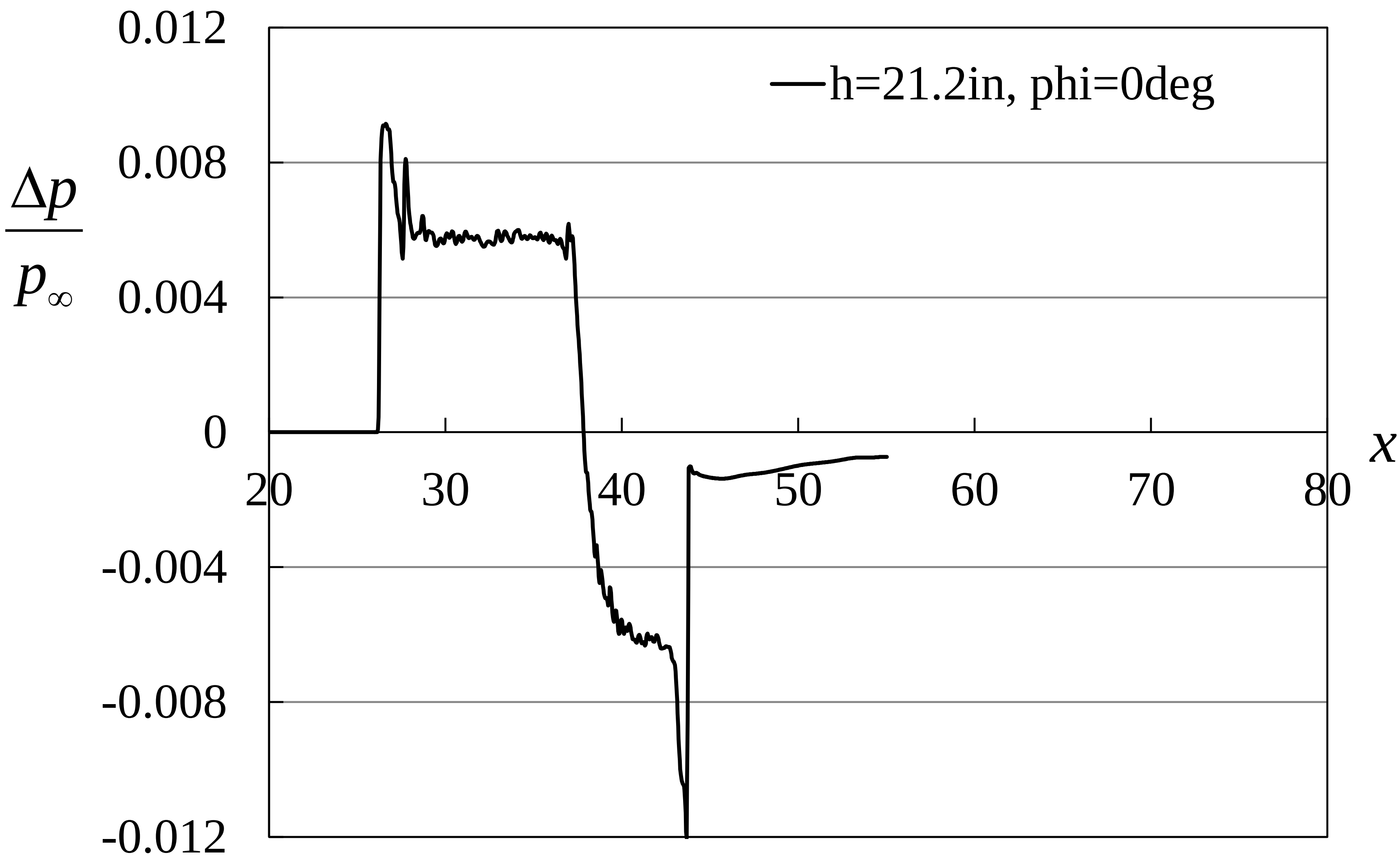


SEEB-ALR Body of Revolution

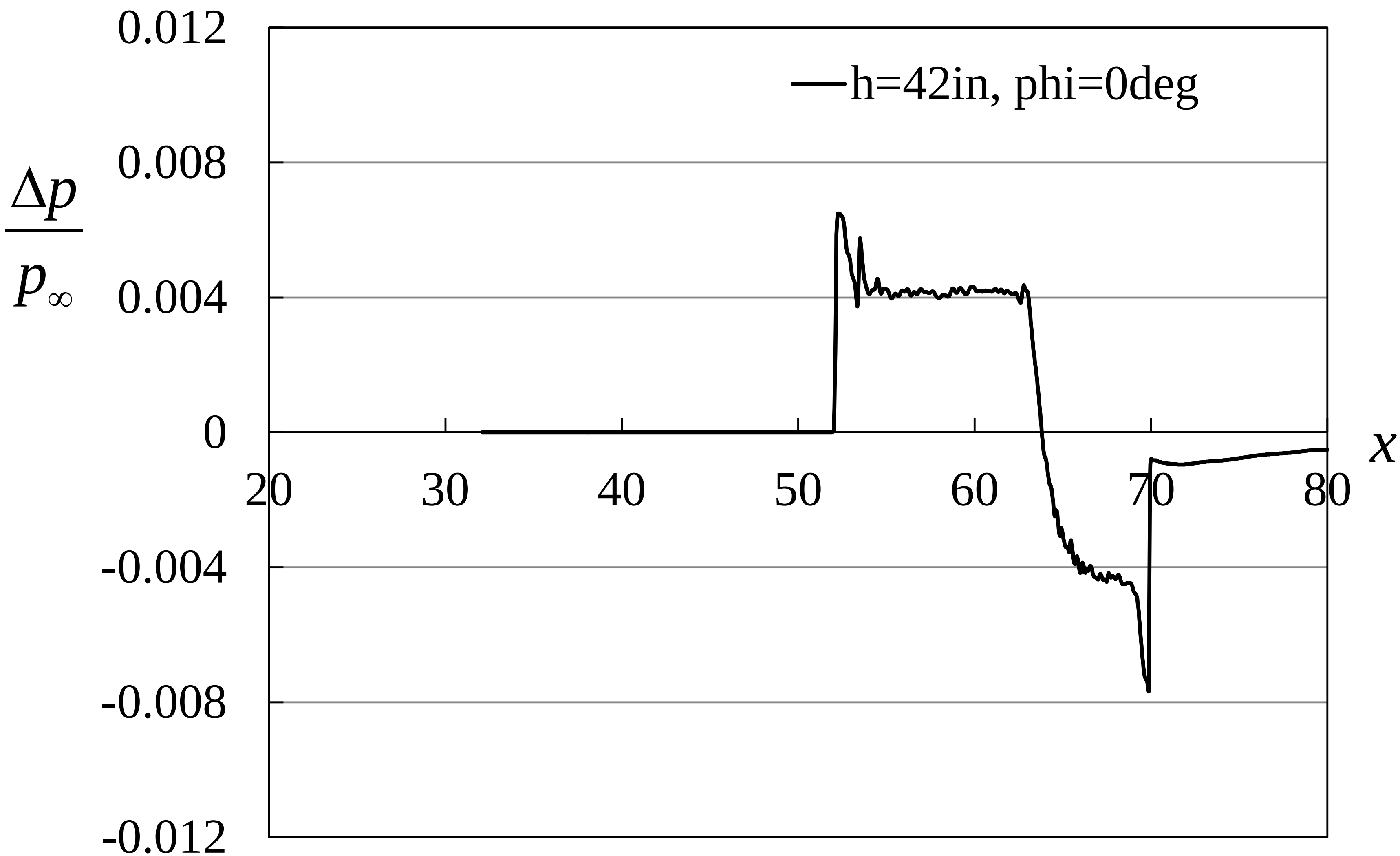
Pressure contours



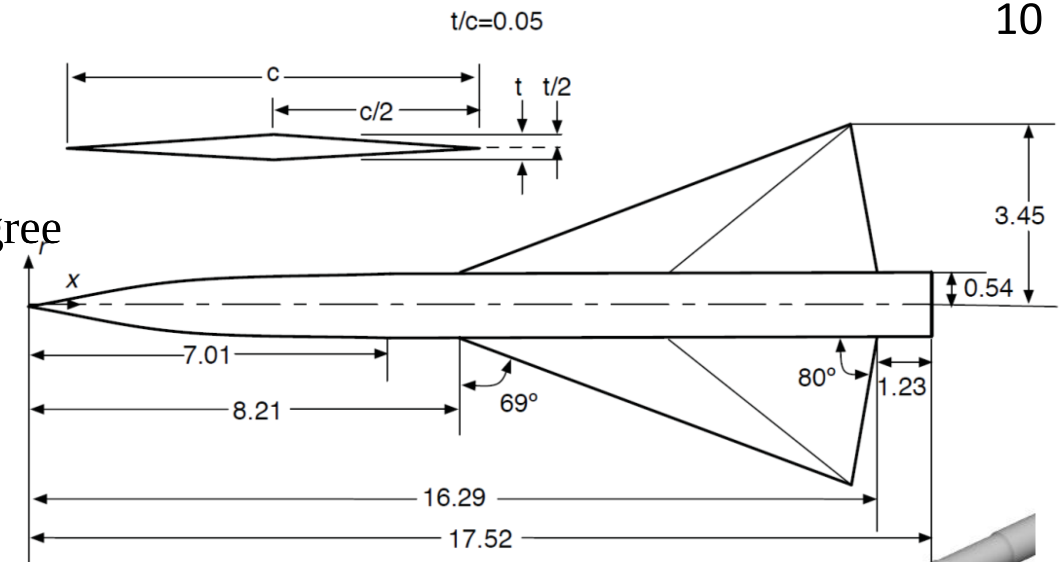
near field signatures



near field signatures



69-Degree Delta Wing Body

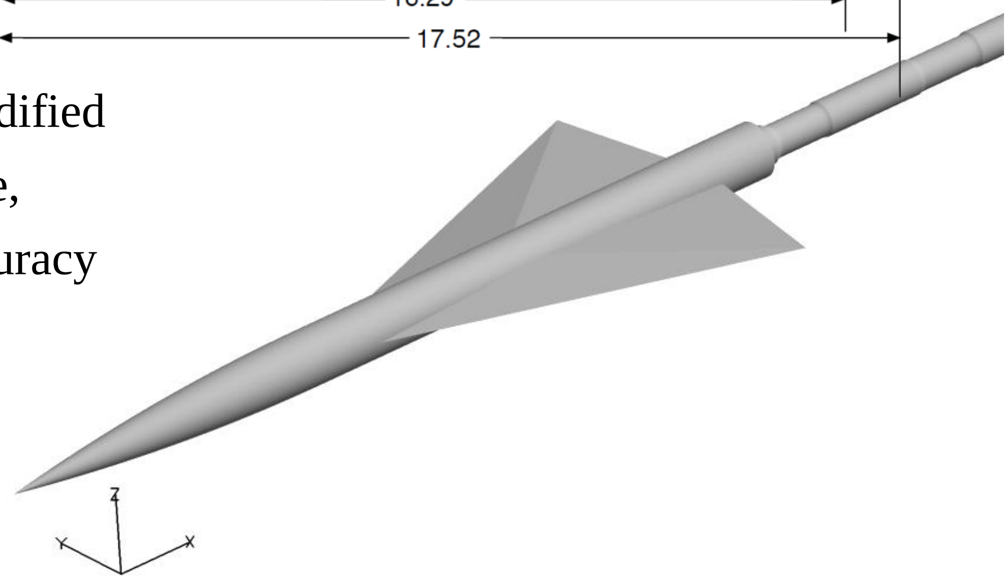


Input data

- CFL=1.0
- Angles of attack = 0, 2.079, 3.588 degree
- Mach number =1.70

Modified from the workshop grid

- Multi-block: changed to 20 blocks
- Grid points: 10,141,696
- **normal spacing** on the surface was modified at the sting step to improve convergence, and on the wing surface to improve accuracy



Used Resource

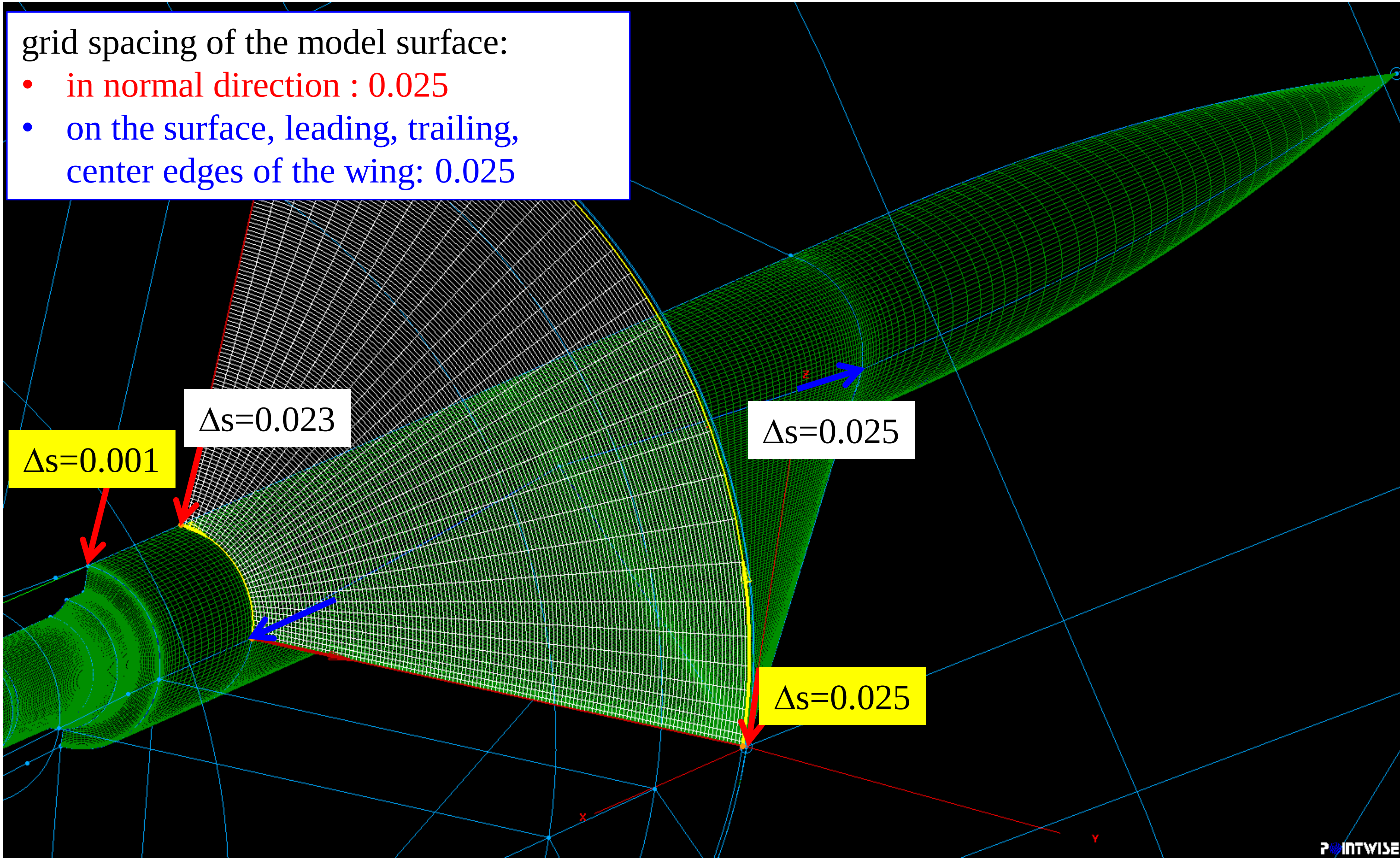
- Number of CPU = 20 node x 4 = 80
- Total Normal Page Memory = 9.4GB

Ref.: Originally described as Model 4 in Lynn W. Hunton, Raymond M. Hicks, and Joel P. Mendoza, "Some Effects of Wing Planform on Sonic Boom," NASA TN D-7160, 1972.

Modification of grid: normal spacing was modified.

grid spacing of the model surface:

- in normal direction : 0.025
- on the surface, leading, trailing, center edges of the wing: 0.025



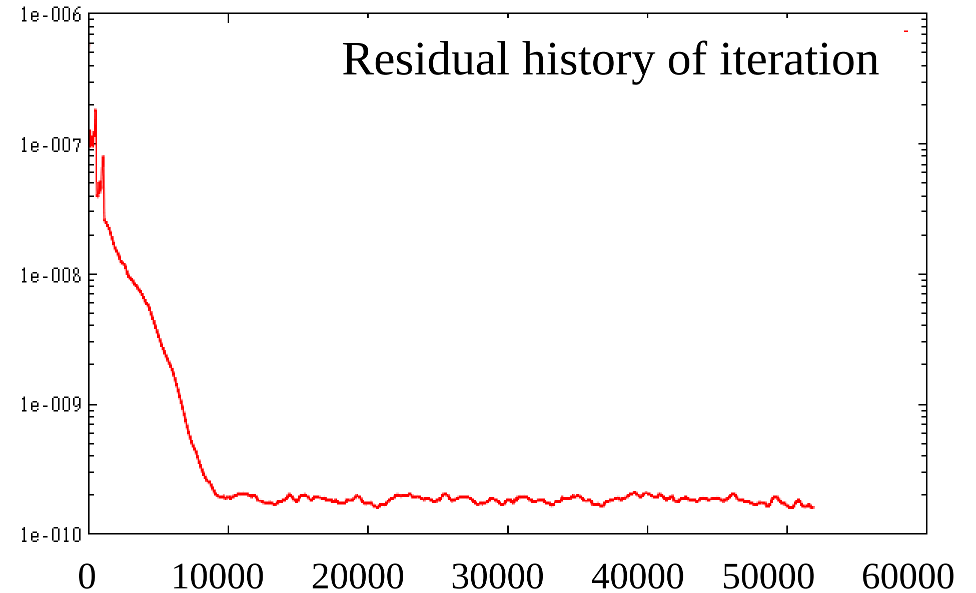
69-Degree Delta Wing Body

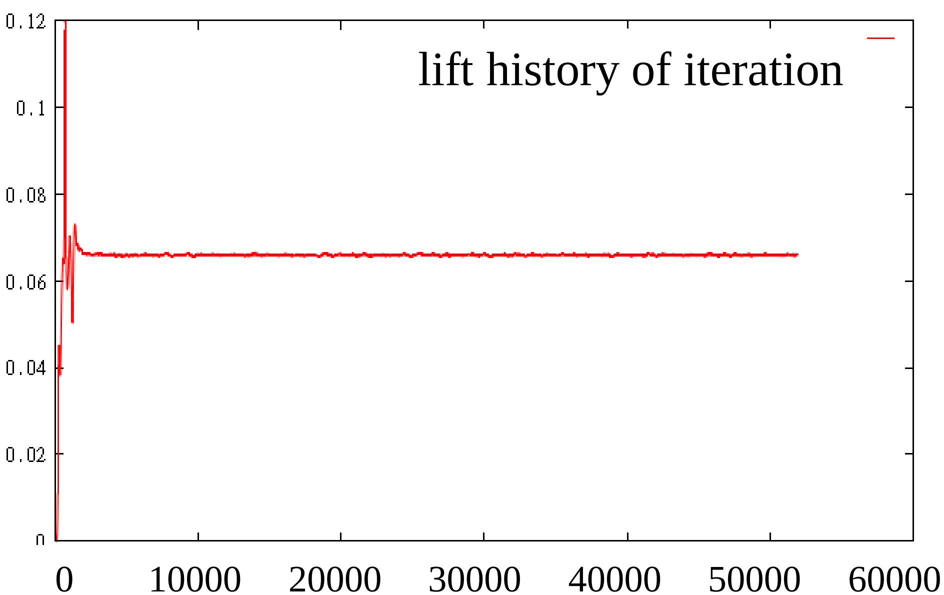
Convergence of computation

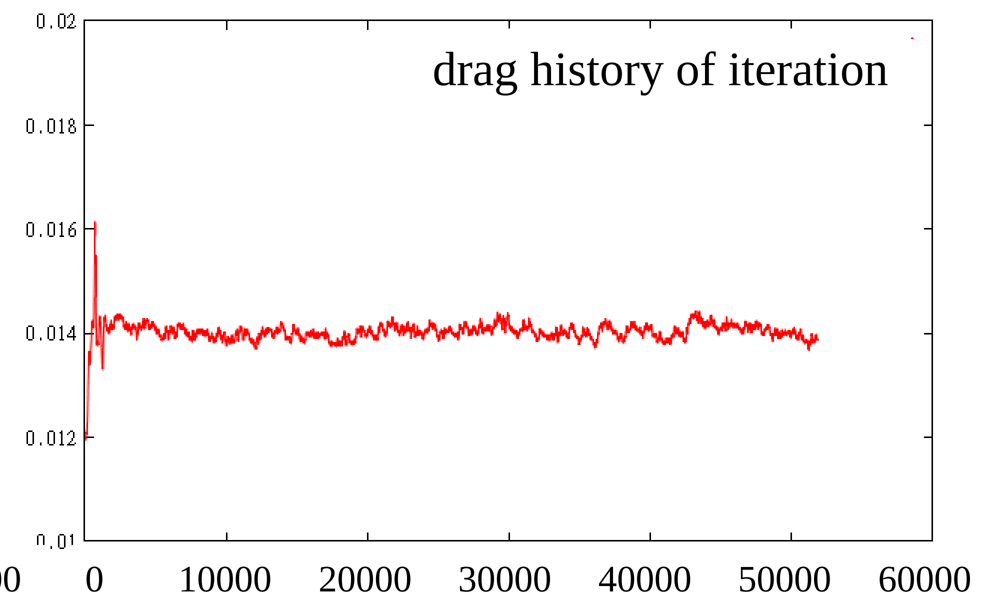
Mach number = 2.079

Convergence criteria:

- RMS of the residual of the Euler equations
- Also check the lift and drag coefficients
- Converged sufficiently



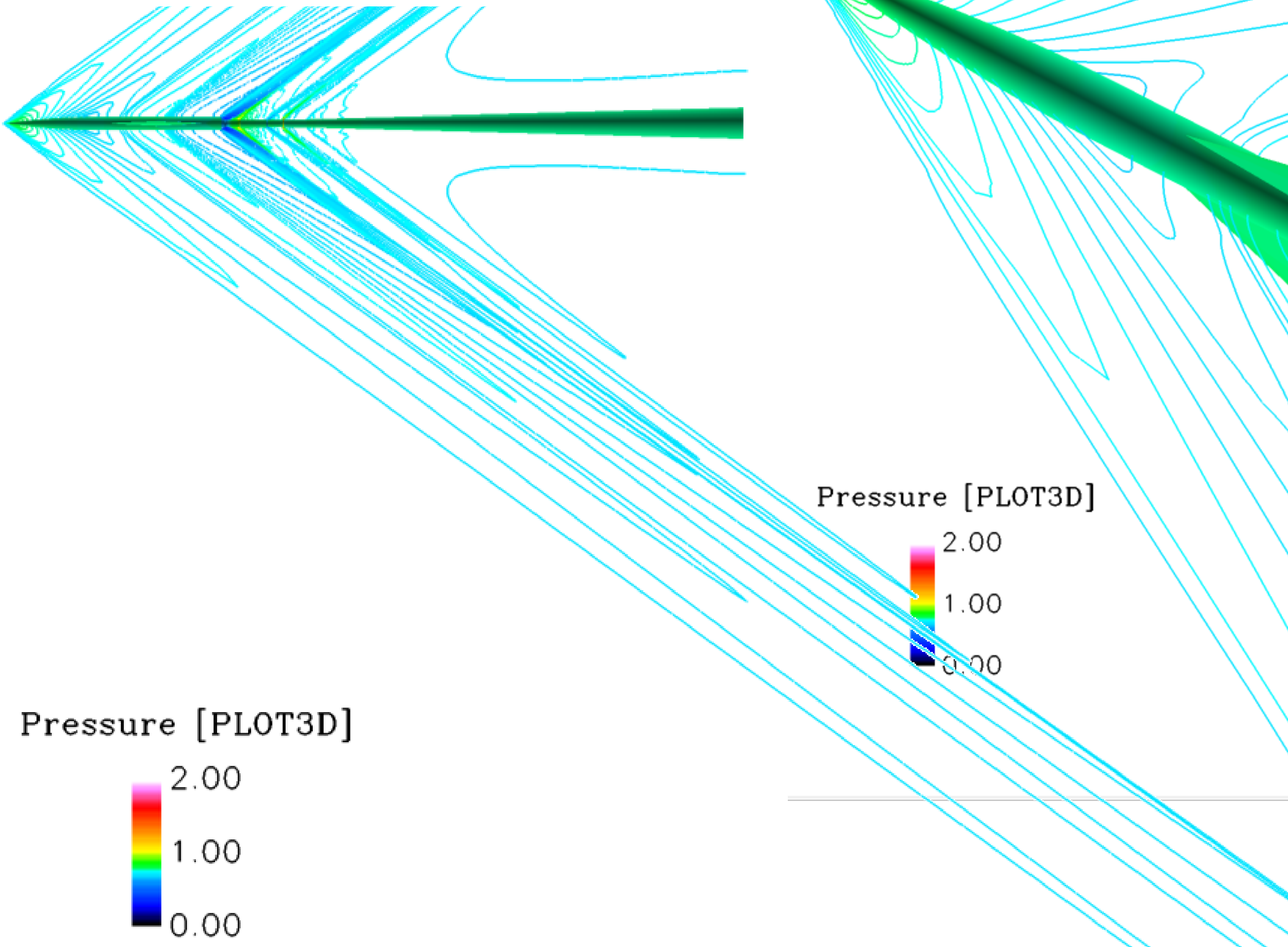




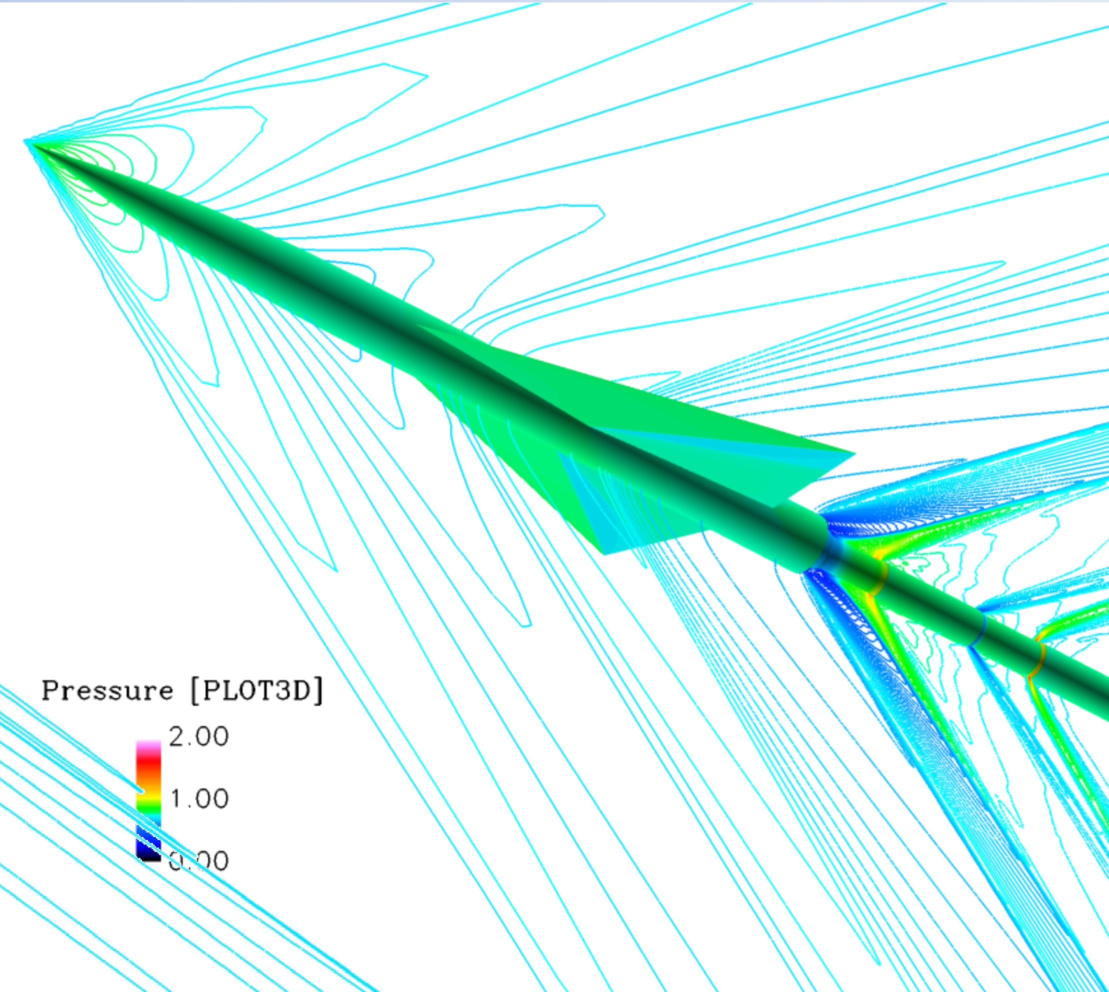
69-Degree Delta Wing Body

Pressure contours

Angle of attack = **0.0**deg



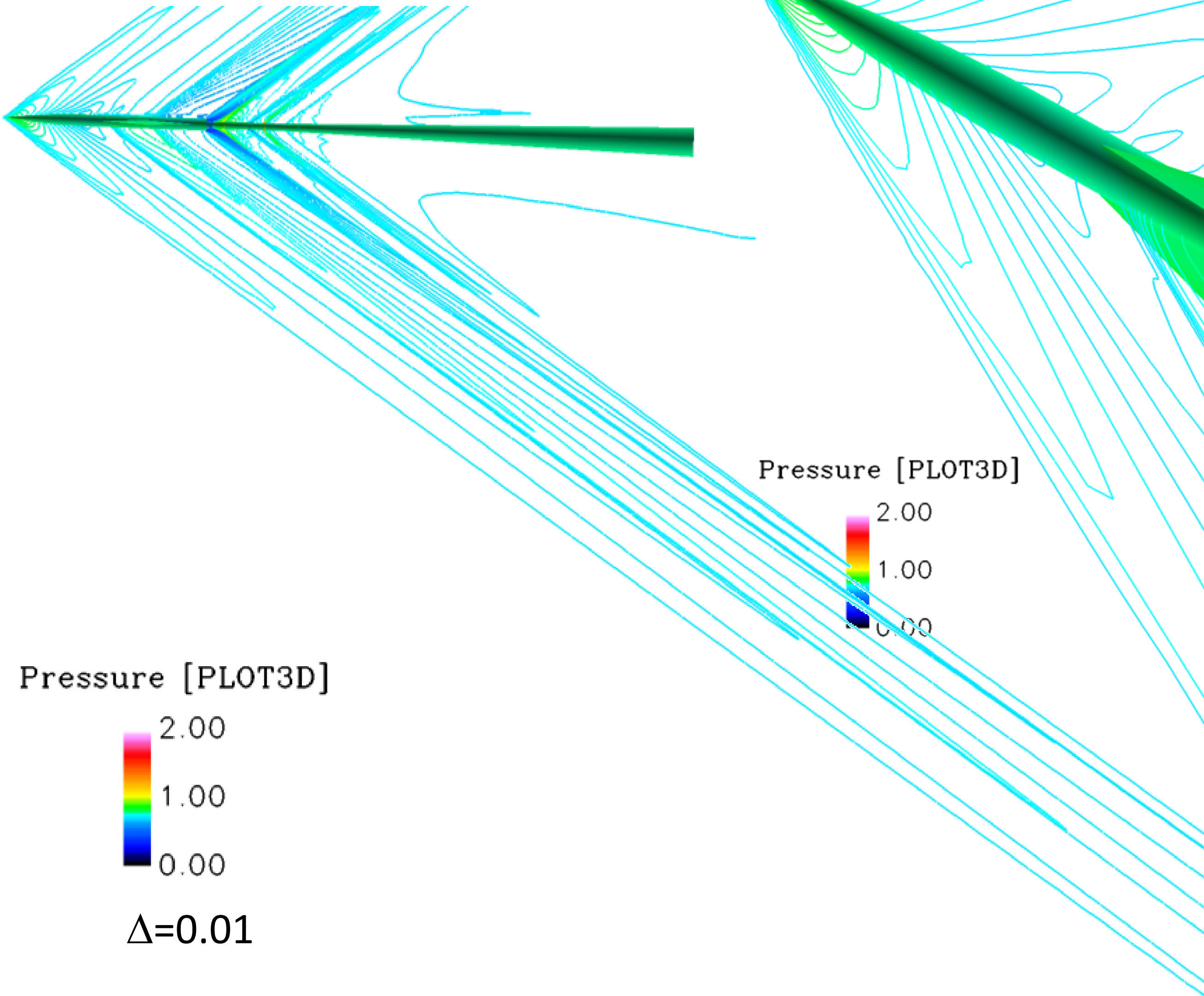
Δ=0.01

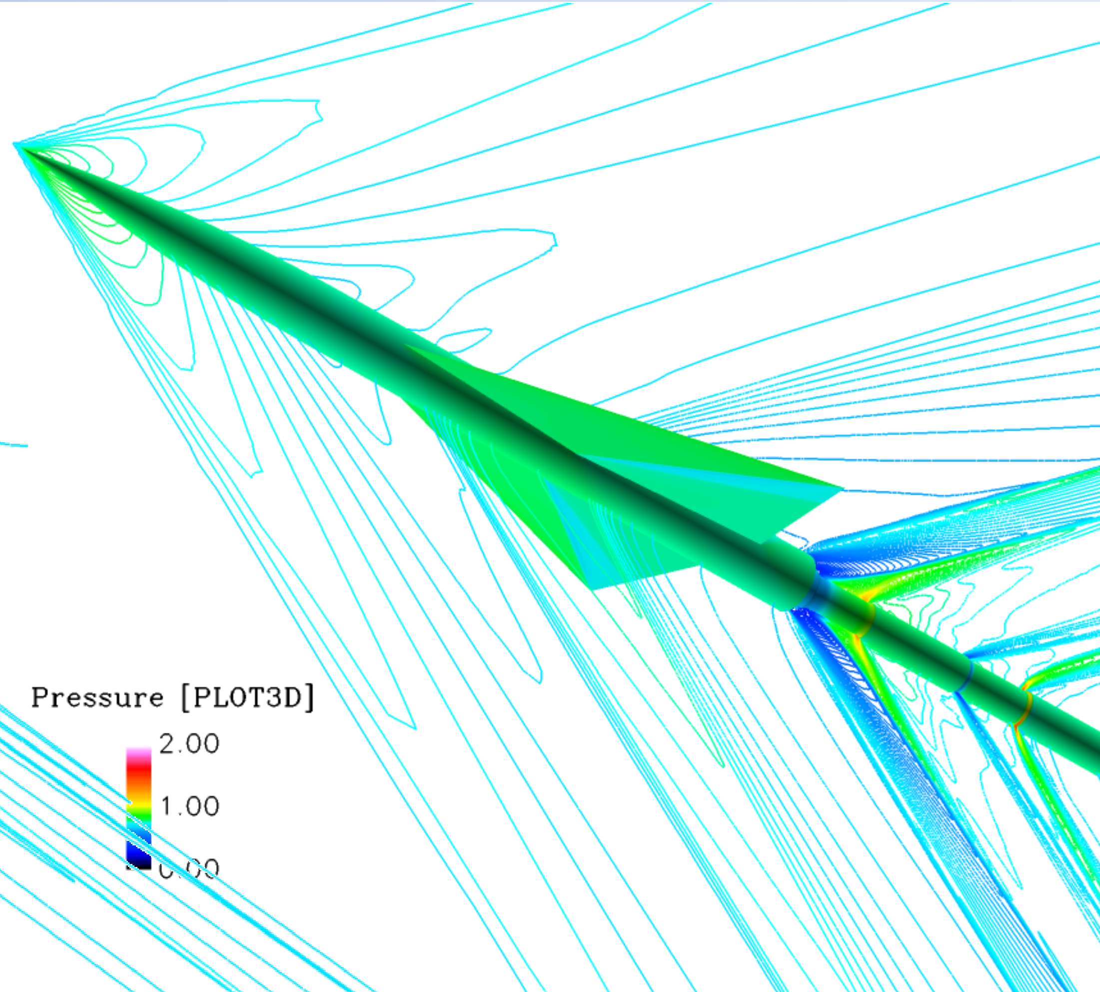


69-Degree Delta Wing Body

Pressure contours

Angle of attack = **2.079**deg

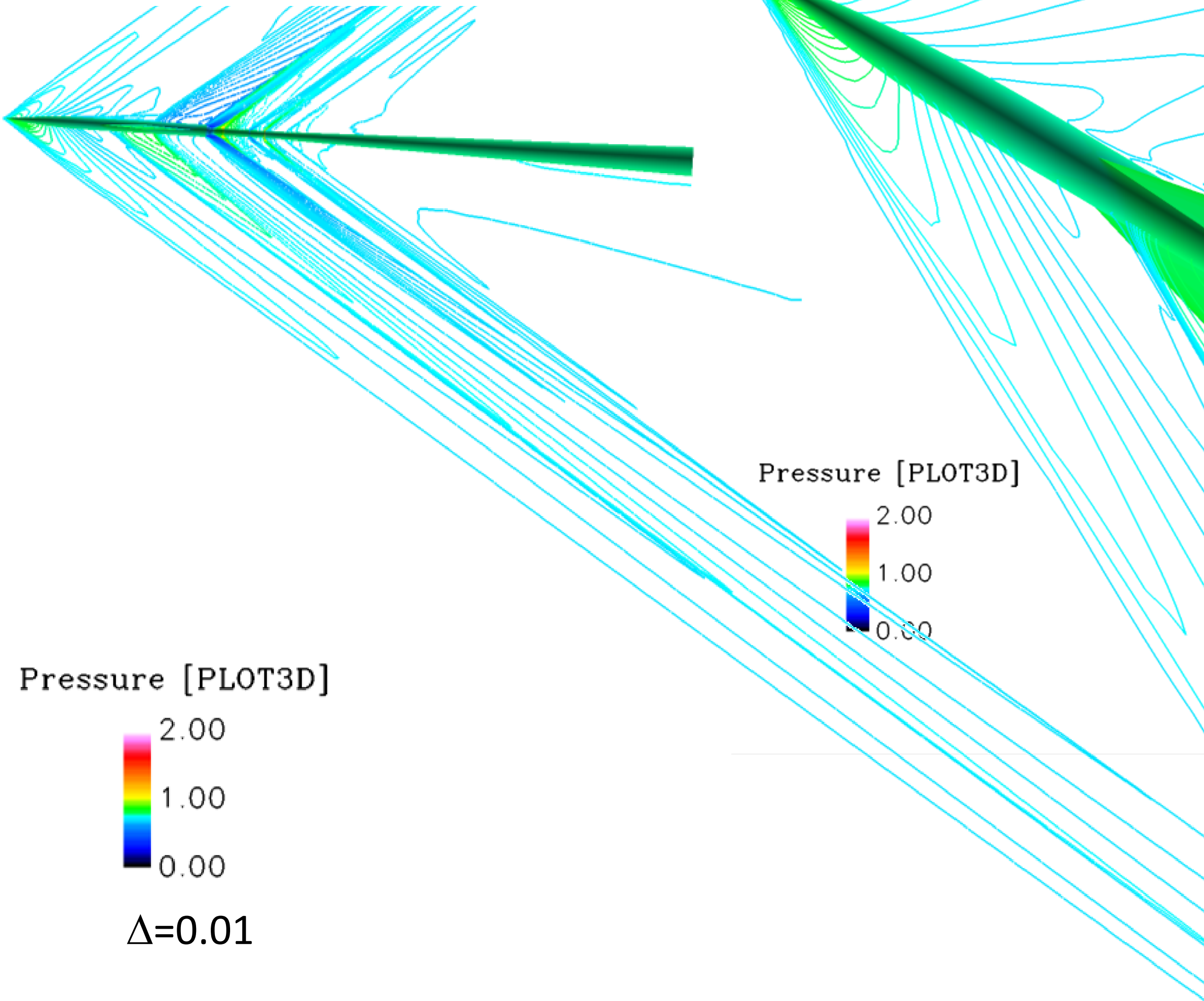


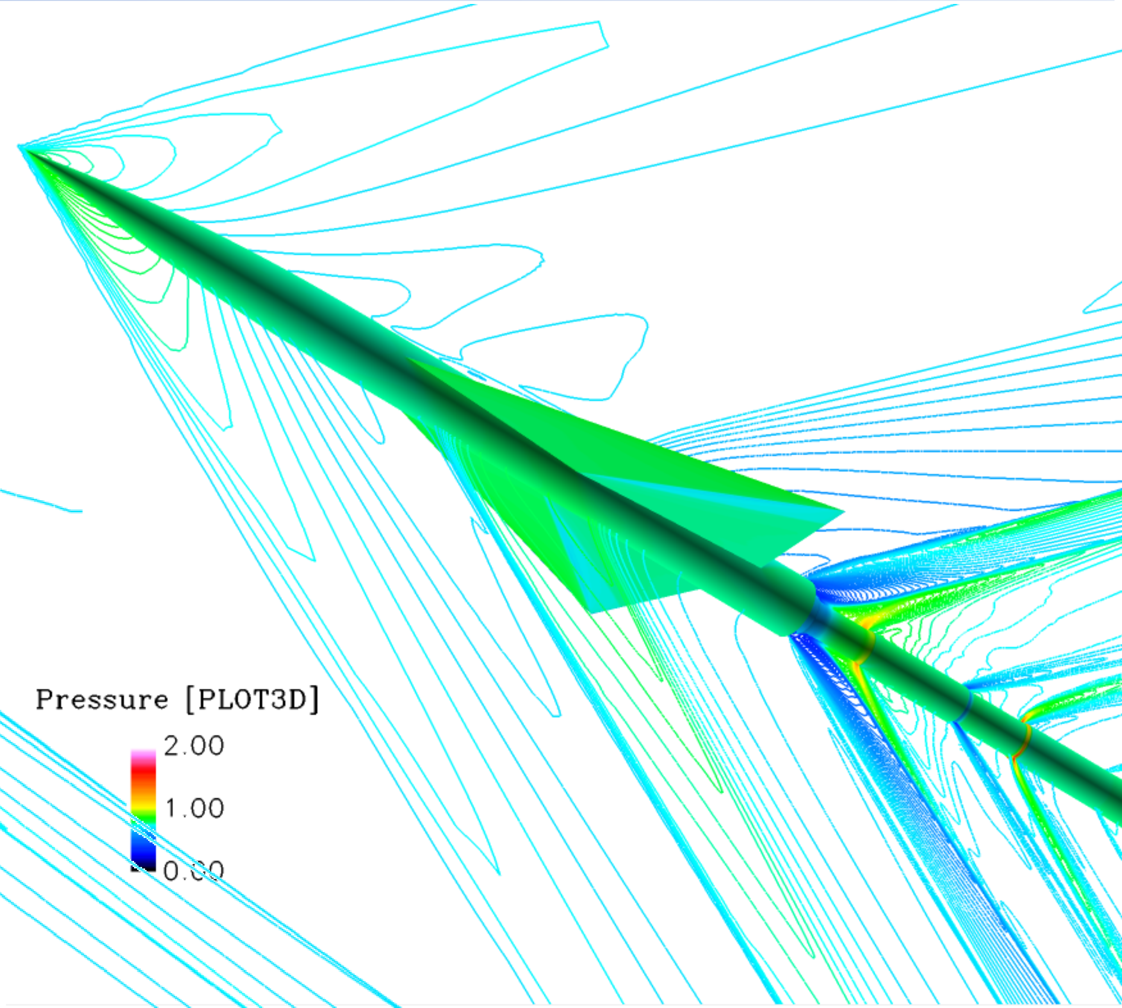


69-Degree Delta Wing Body

Pressure contours

Angle of attack = **3.588**deg



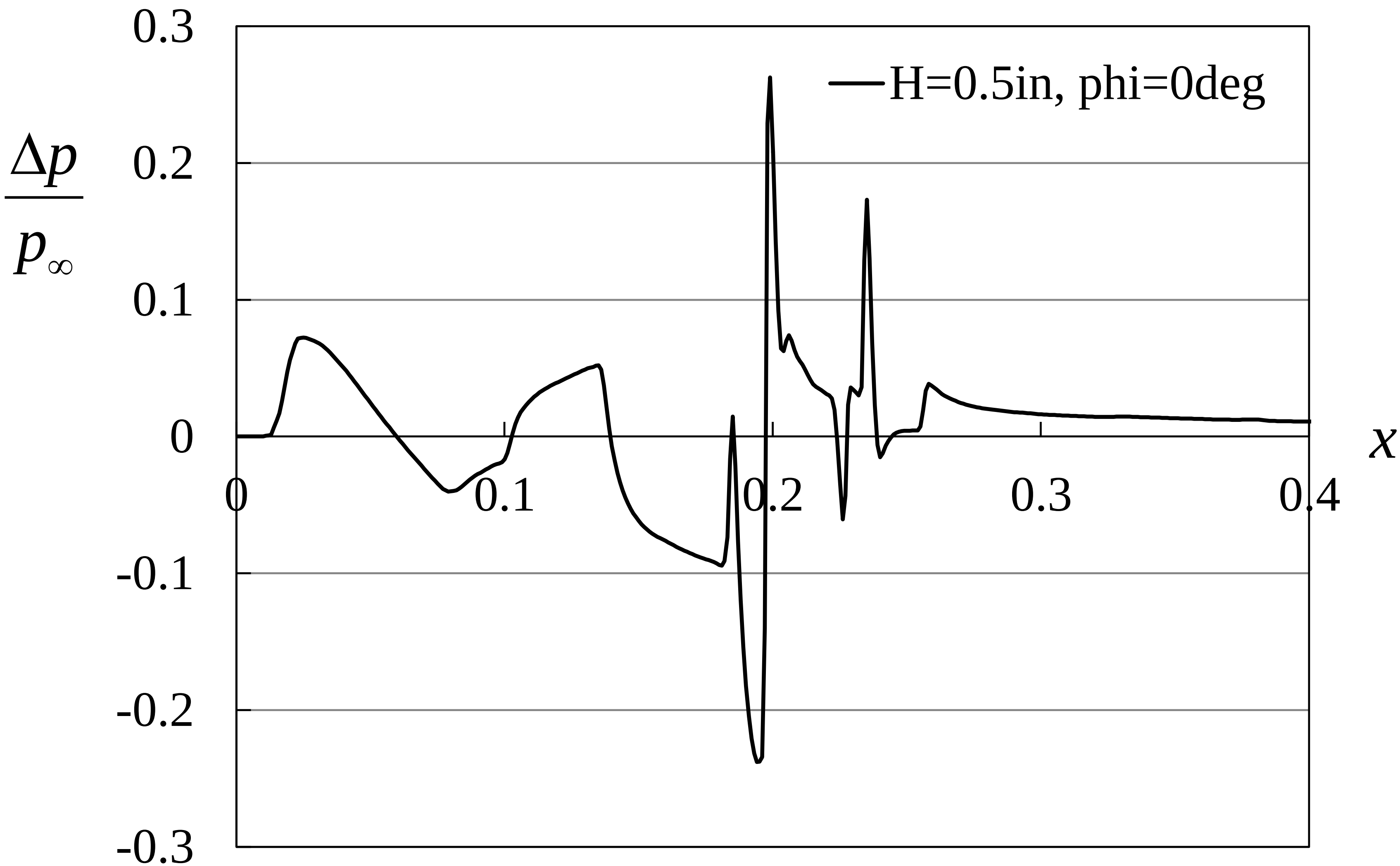


Δ=0.01

69-Degree Delta Wing Body

near field signatures

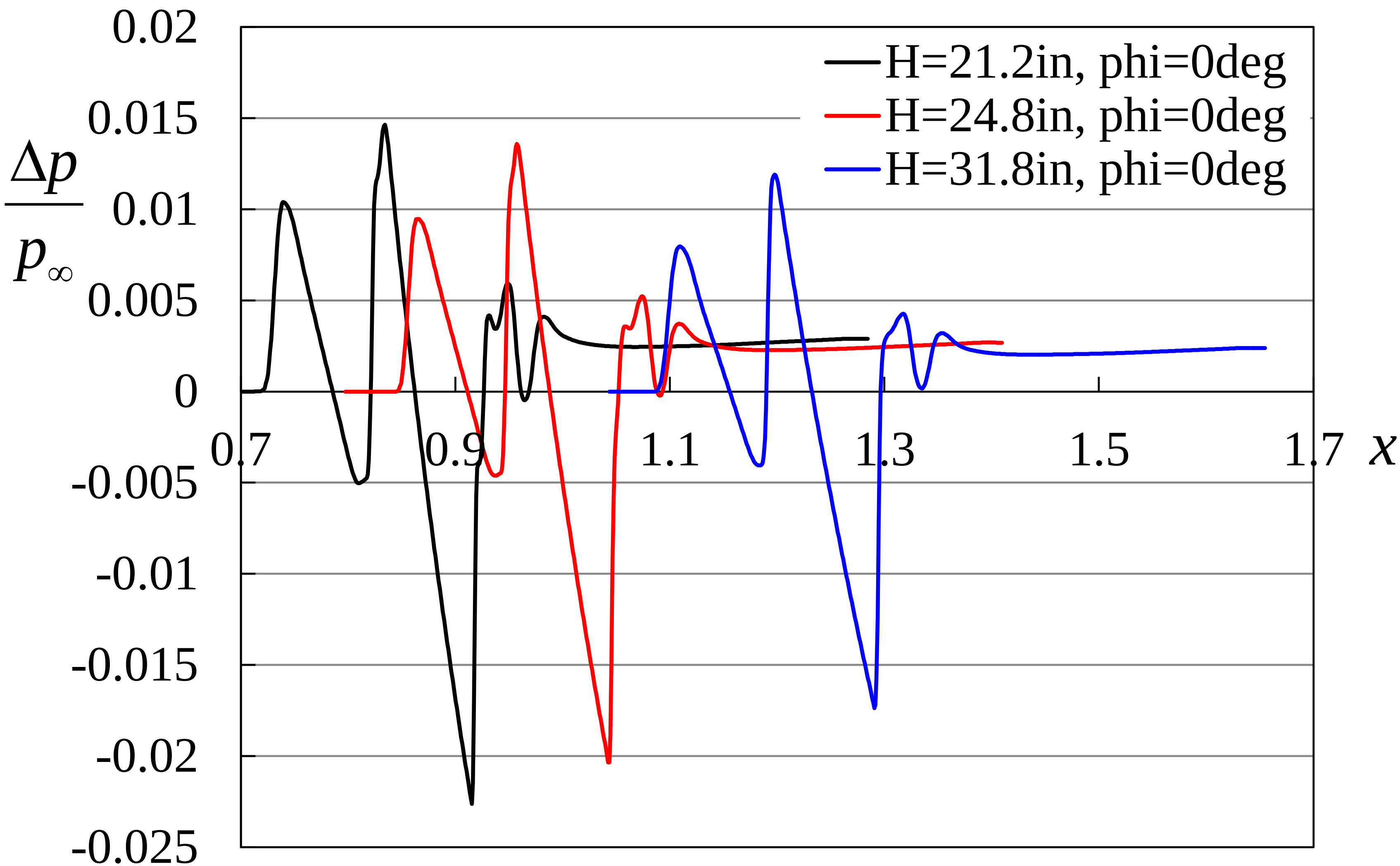
Angle of attack = **0.0**deg, phi=**0**deg



69-Degree Delta Wing Body

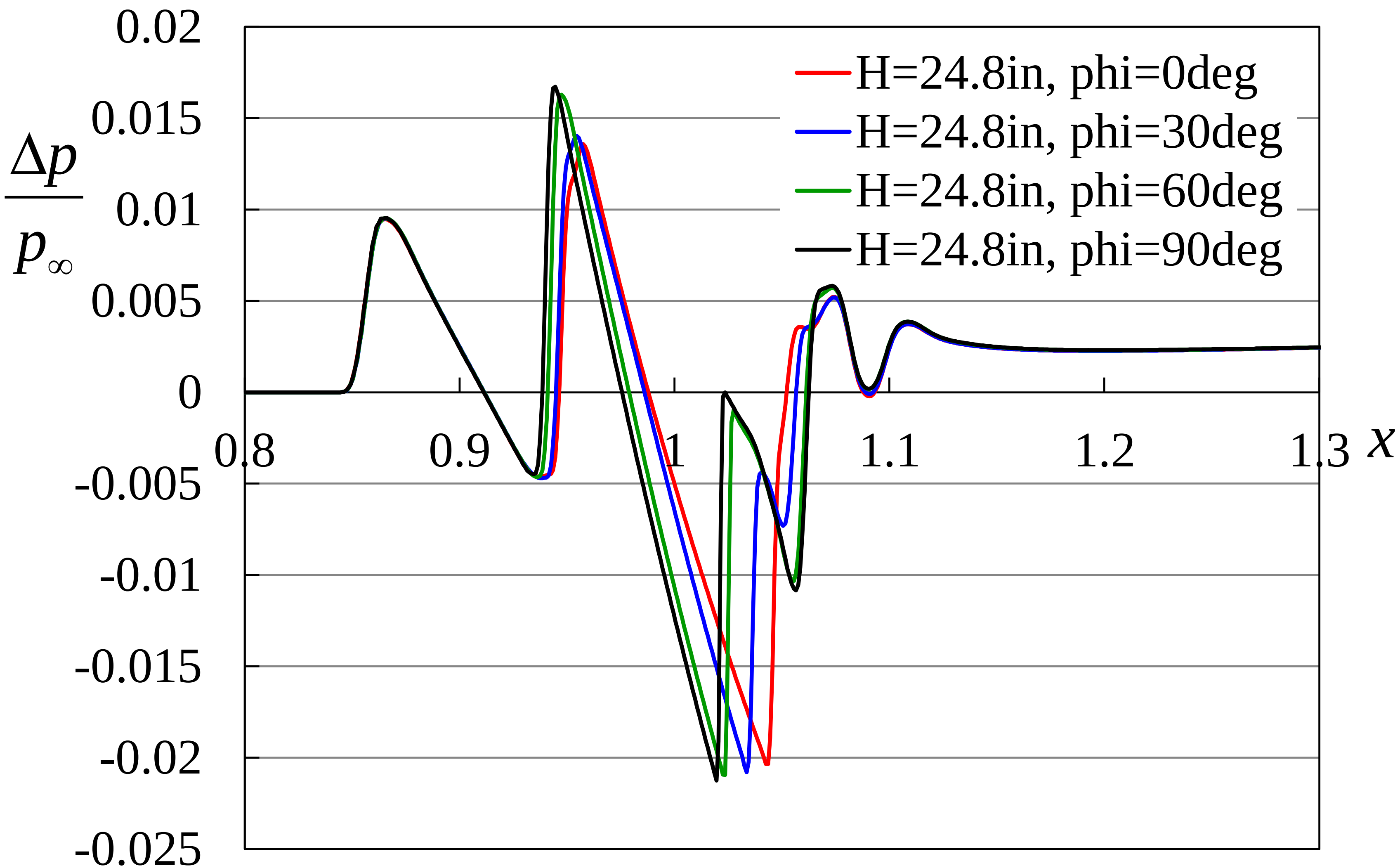
near field signatures

Angle of attack = **0.0**deg, phi=**0**deg



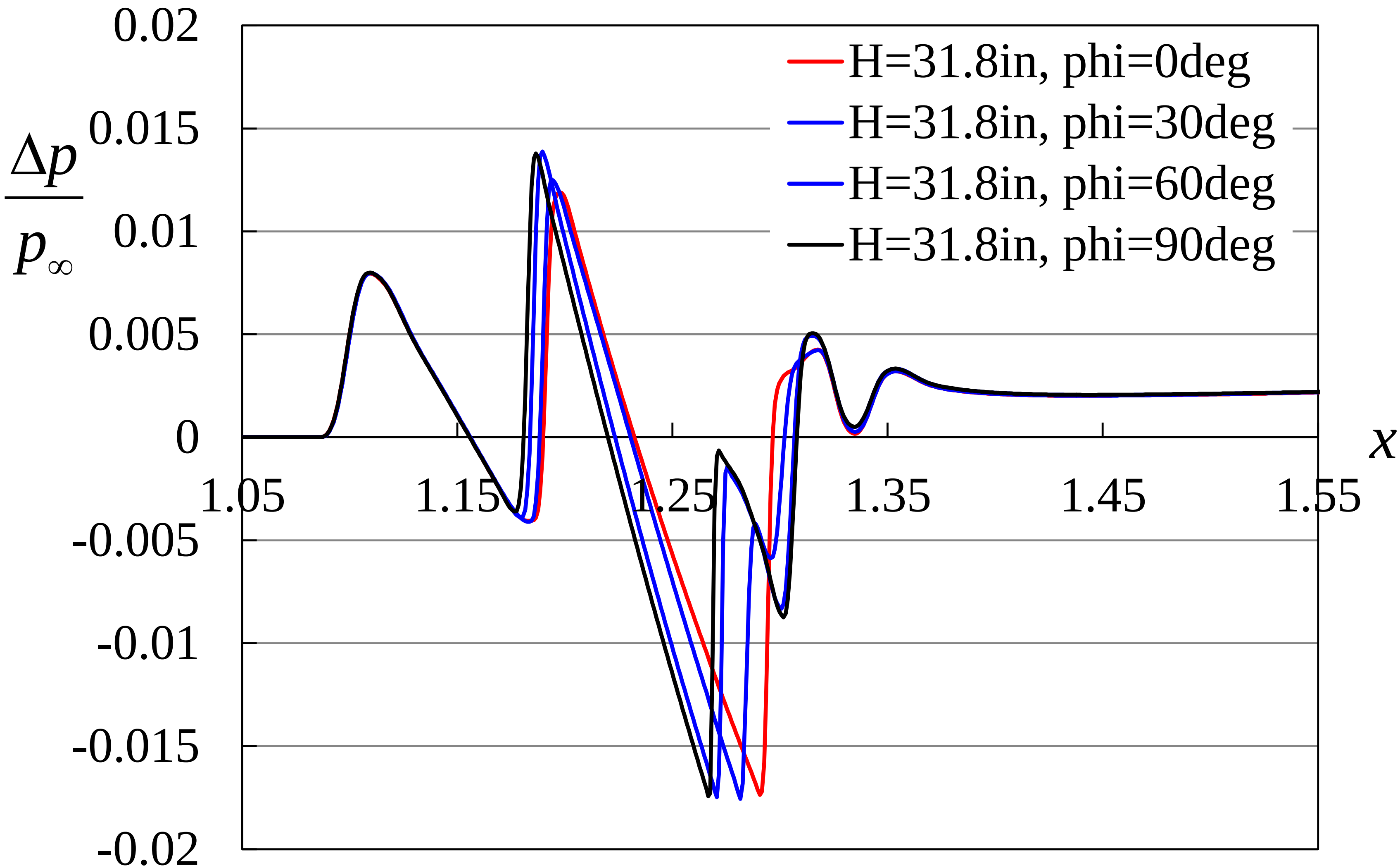
near field signatures

Angle of attack = **0.0**deg, H=**24.8**in



near field signatures

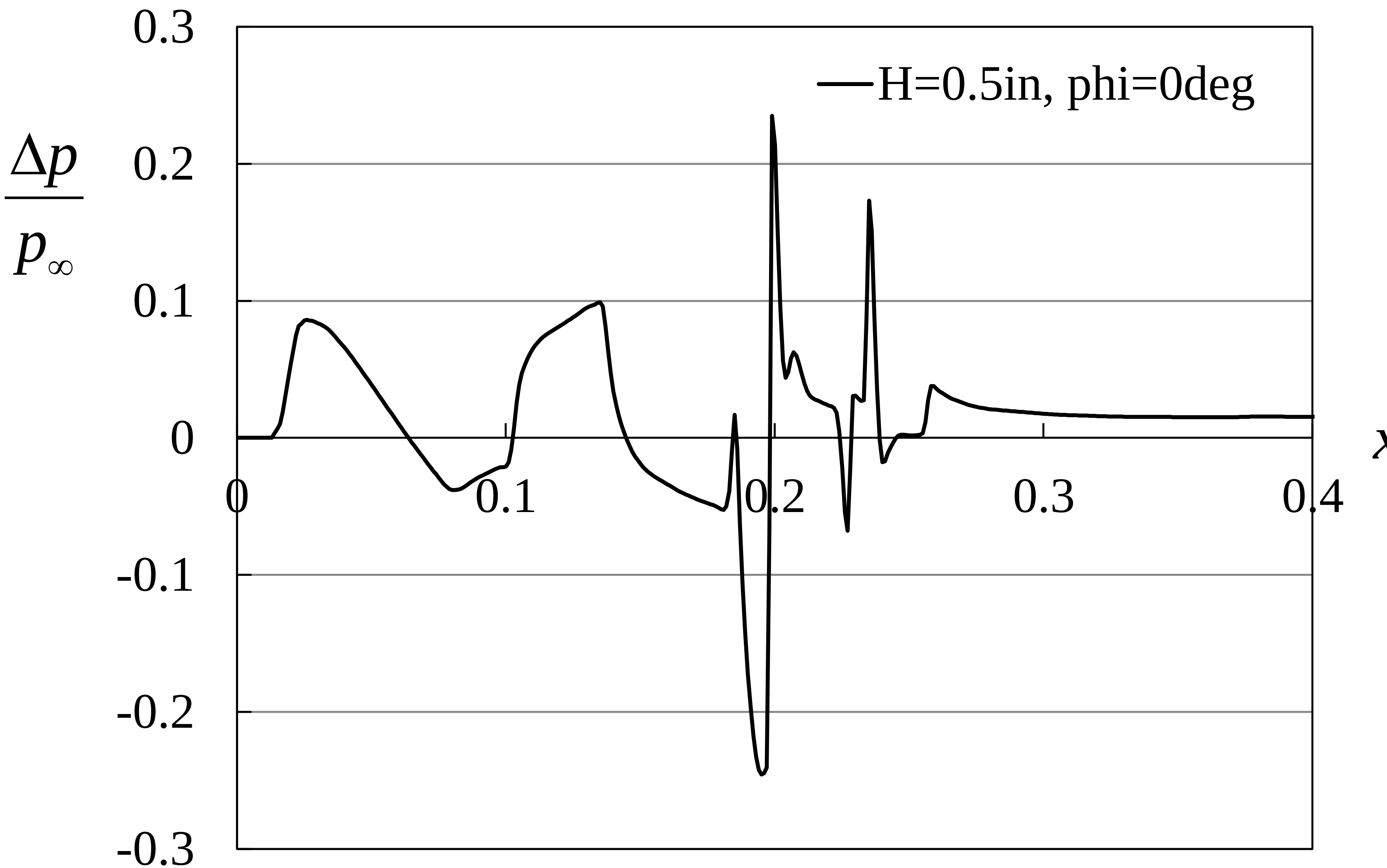
Angle of attack = **0.0**deg, H=**31.8**in



69-Degree Delta Wing Body

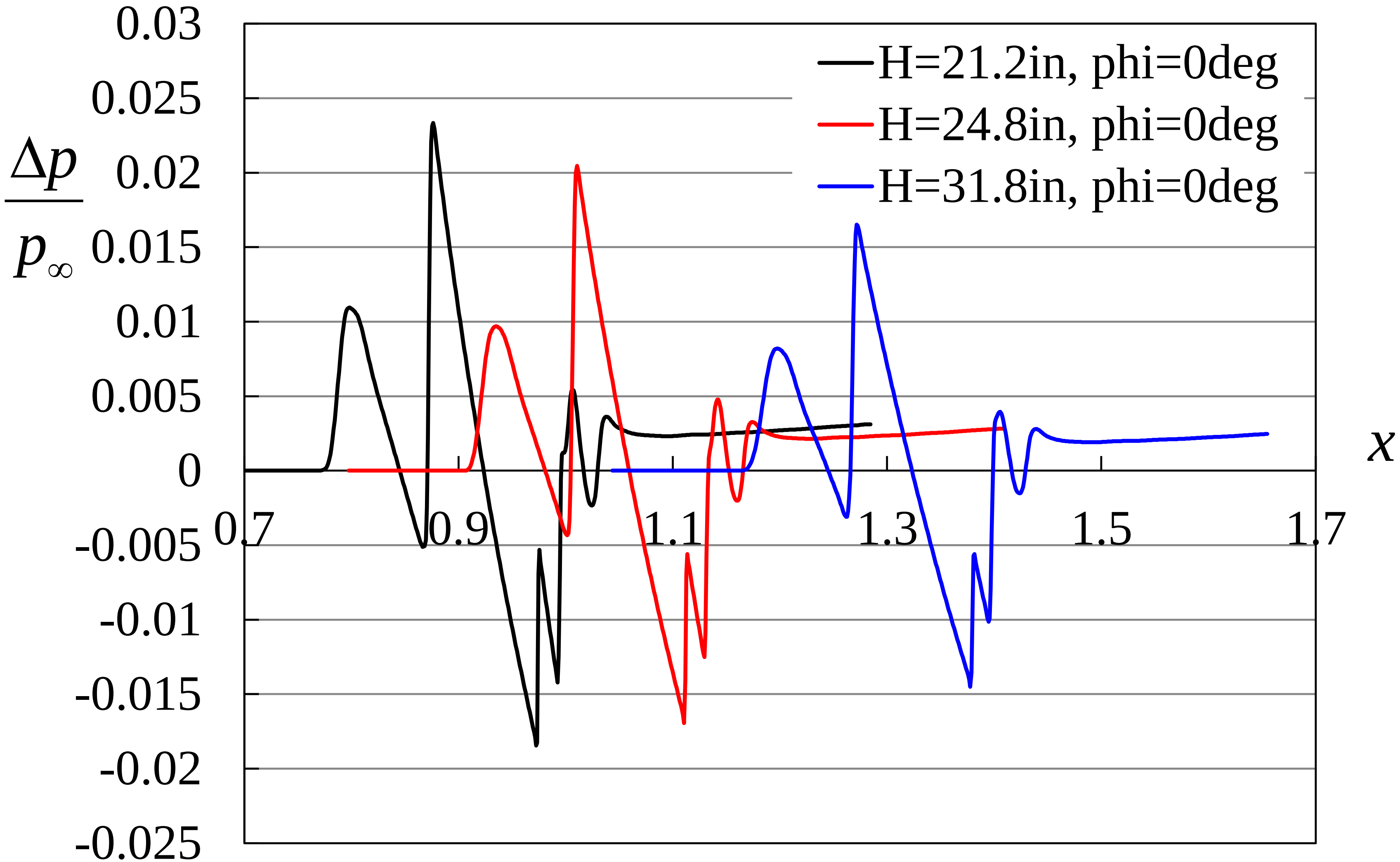
near field signatures

Angle of attack = **2.079**deg, phi=**0**deg



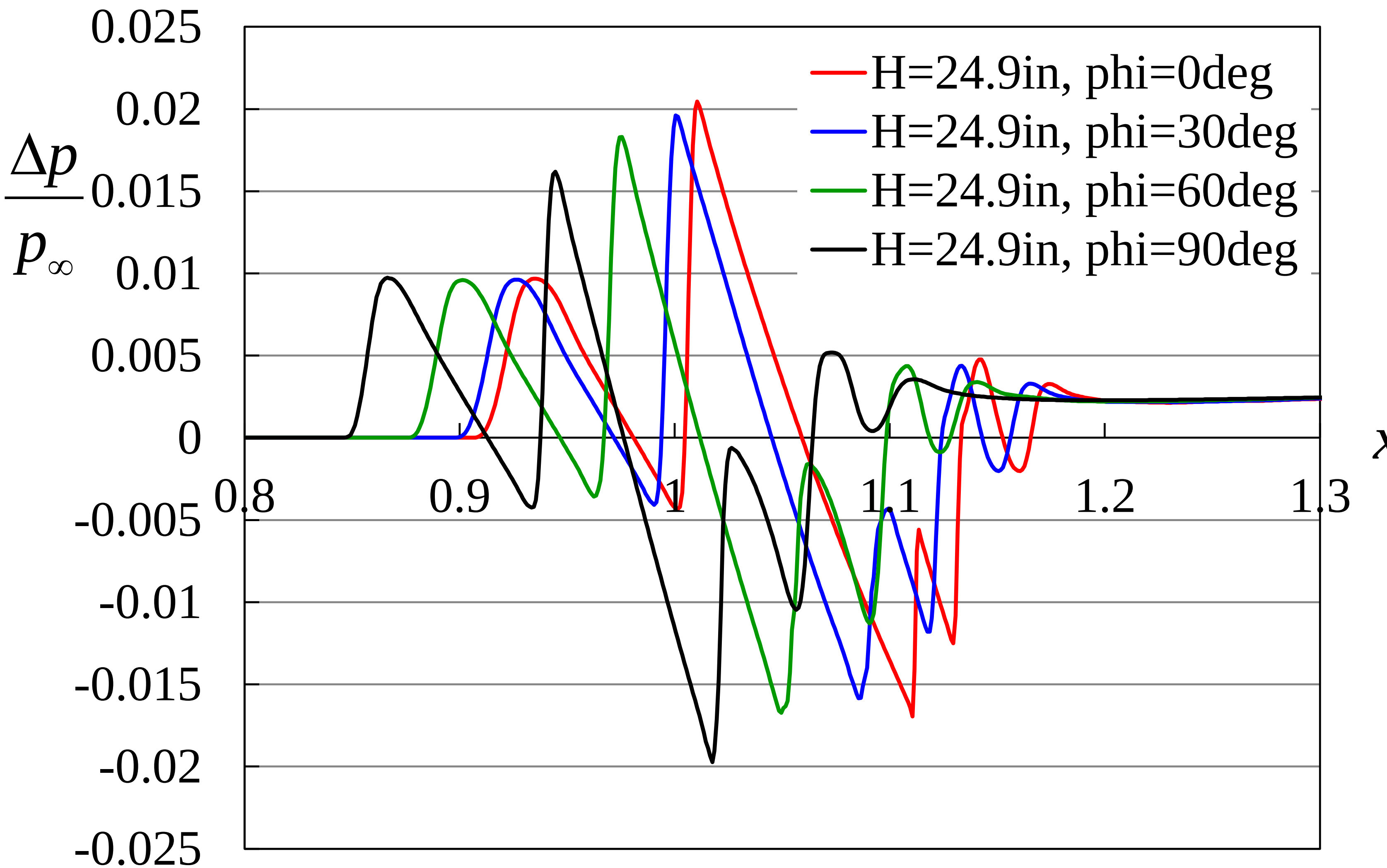
near field signatures

Angle of attack = **2.079**deg, phi=**0**deg



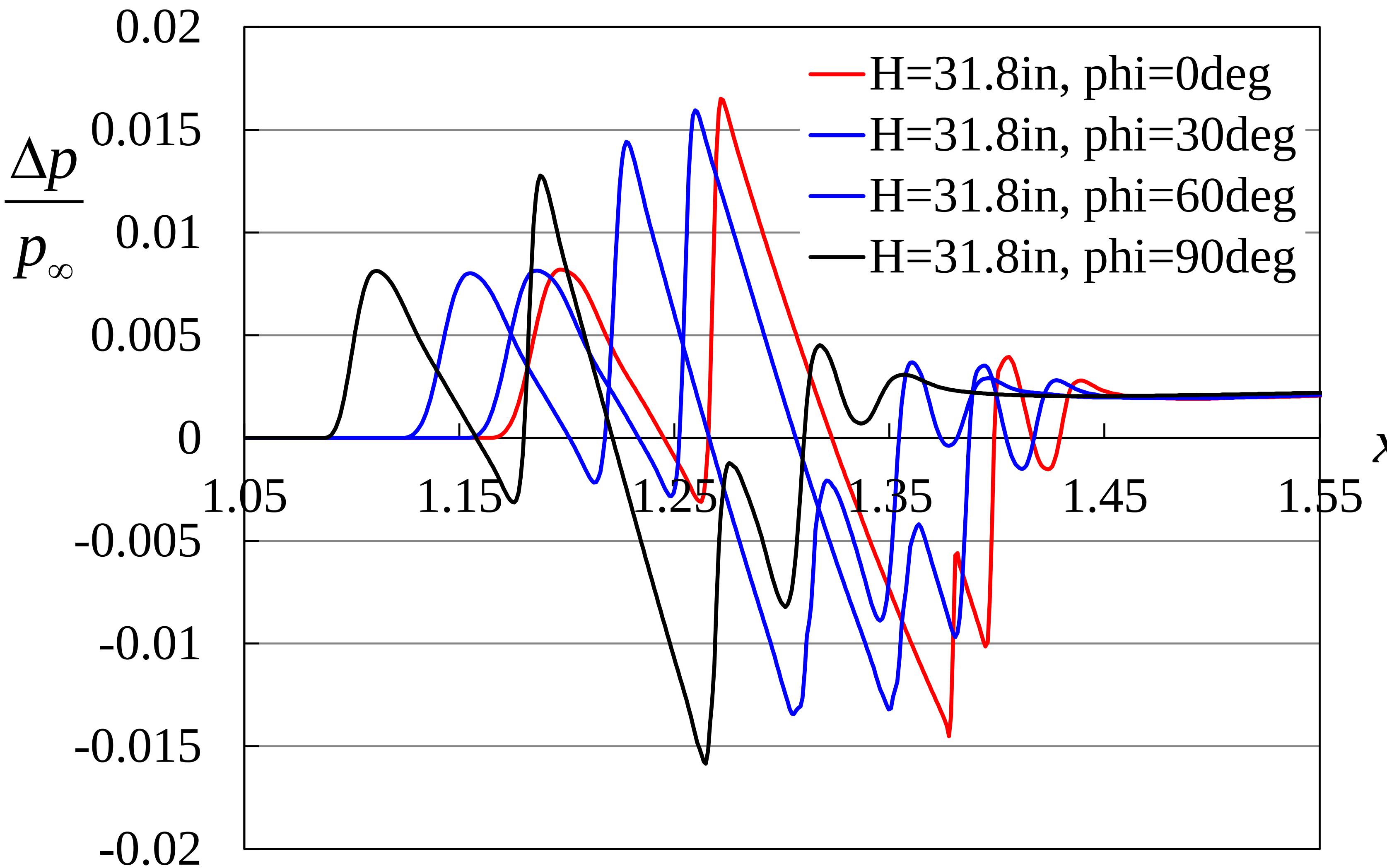
near field signatures

Angle of attack = **2.079**deg, H=**24.8**in



near field signatures

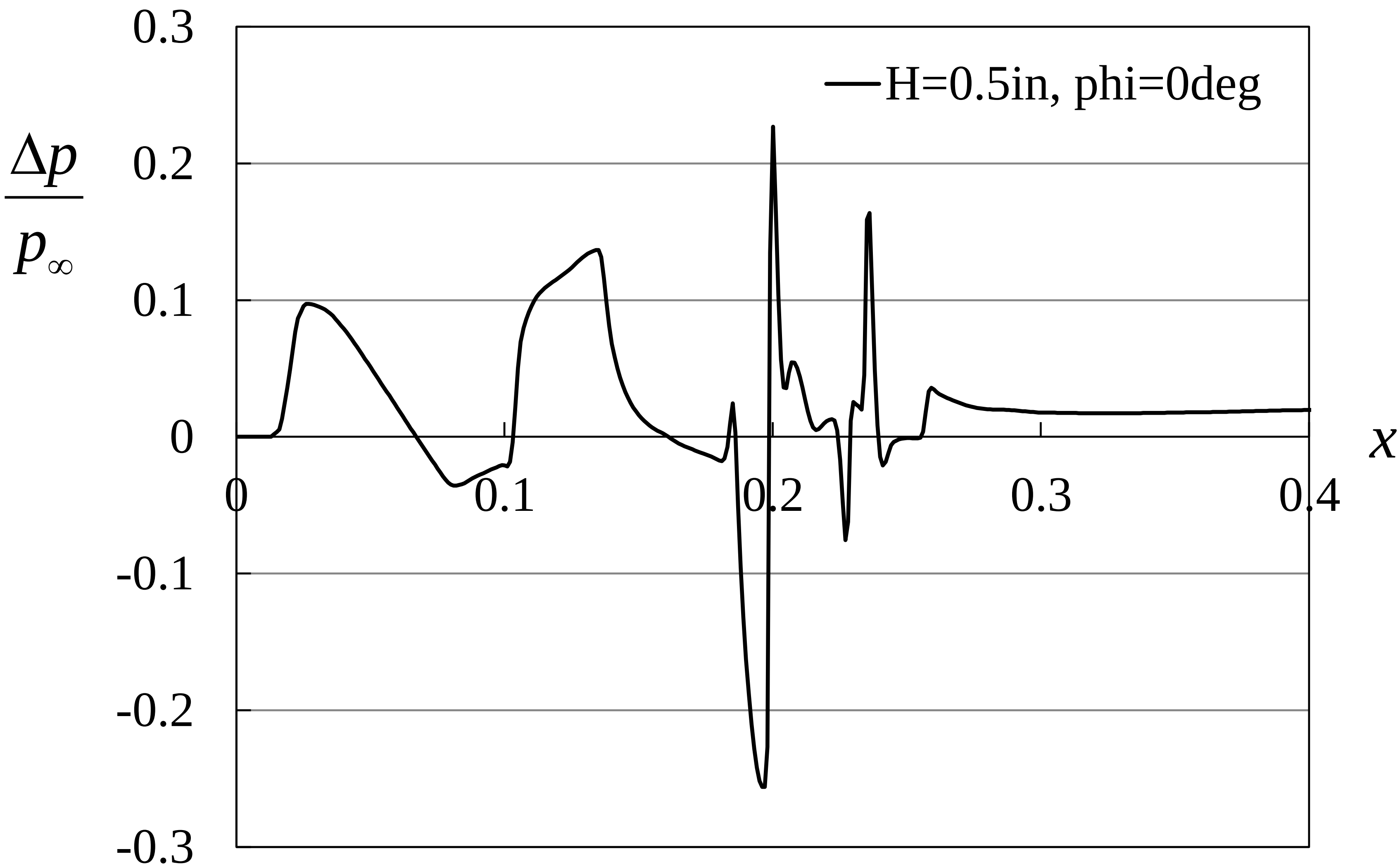
Angle of attack = **2.079**deg, H=**31.8**in



69-Degree Delta Wing Body

near field signatures

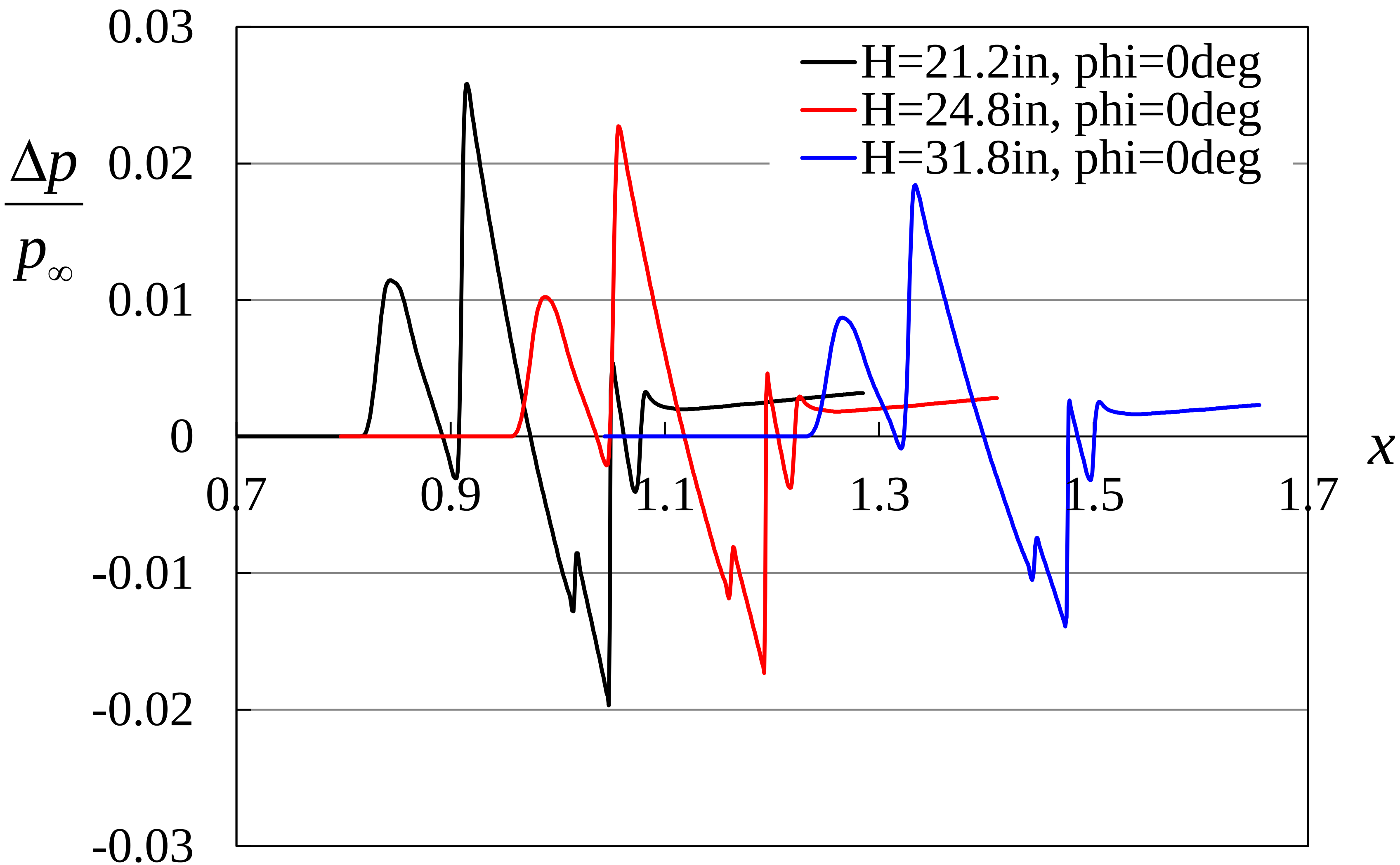
Angle of attack = **3.588**deg, phi=**0**deg



69-Degree Delta Wing Body

near field signatures

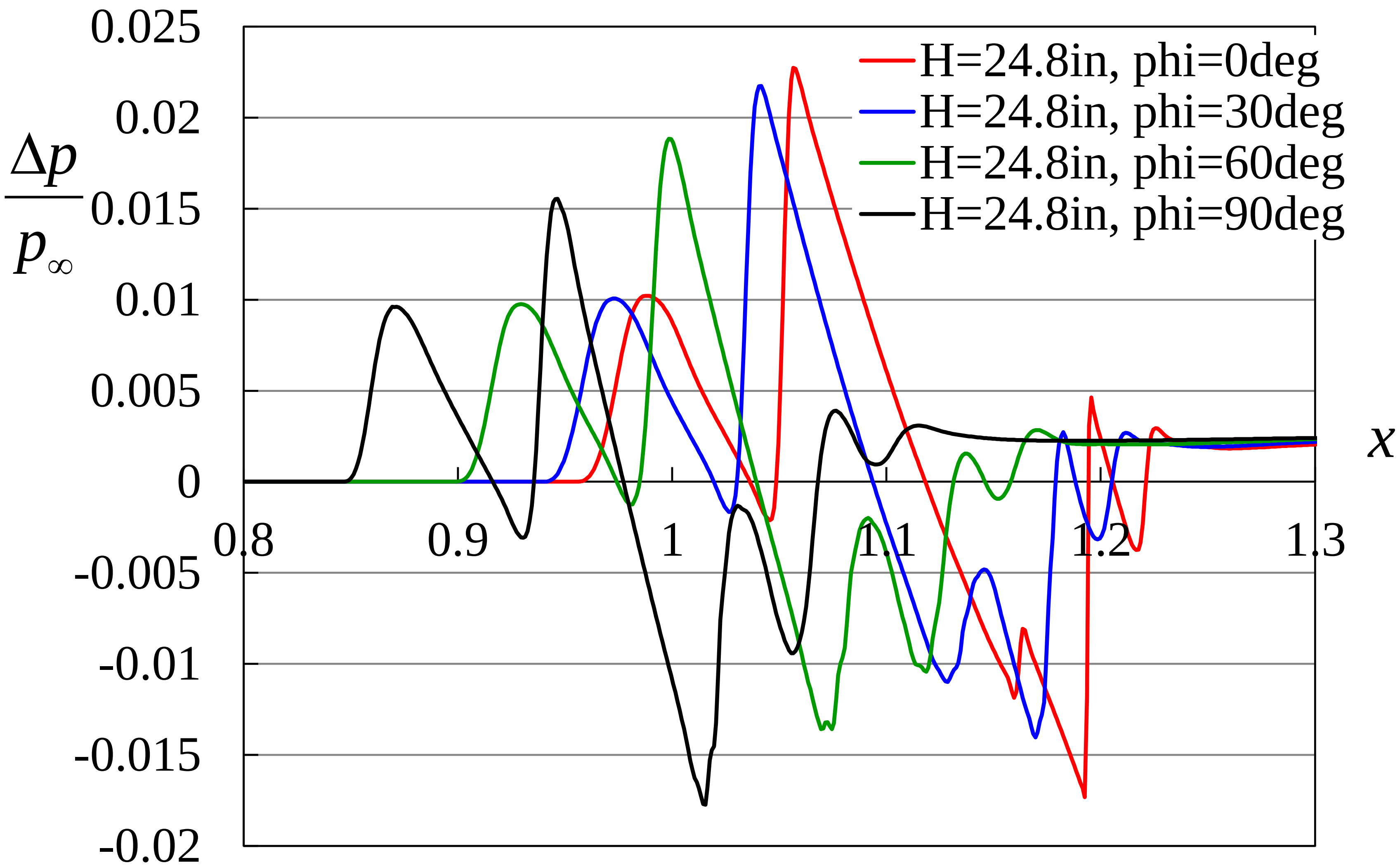
Angle of attack = **3.588**deg, phi=**0**deg



69-Degree Delta Wing Body

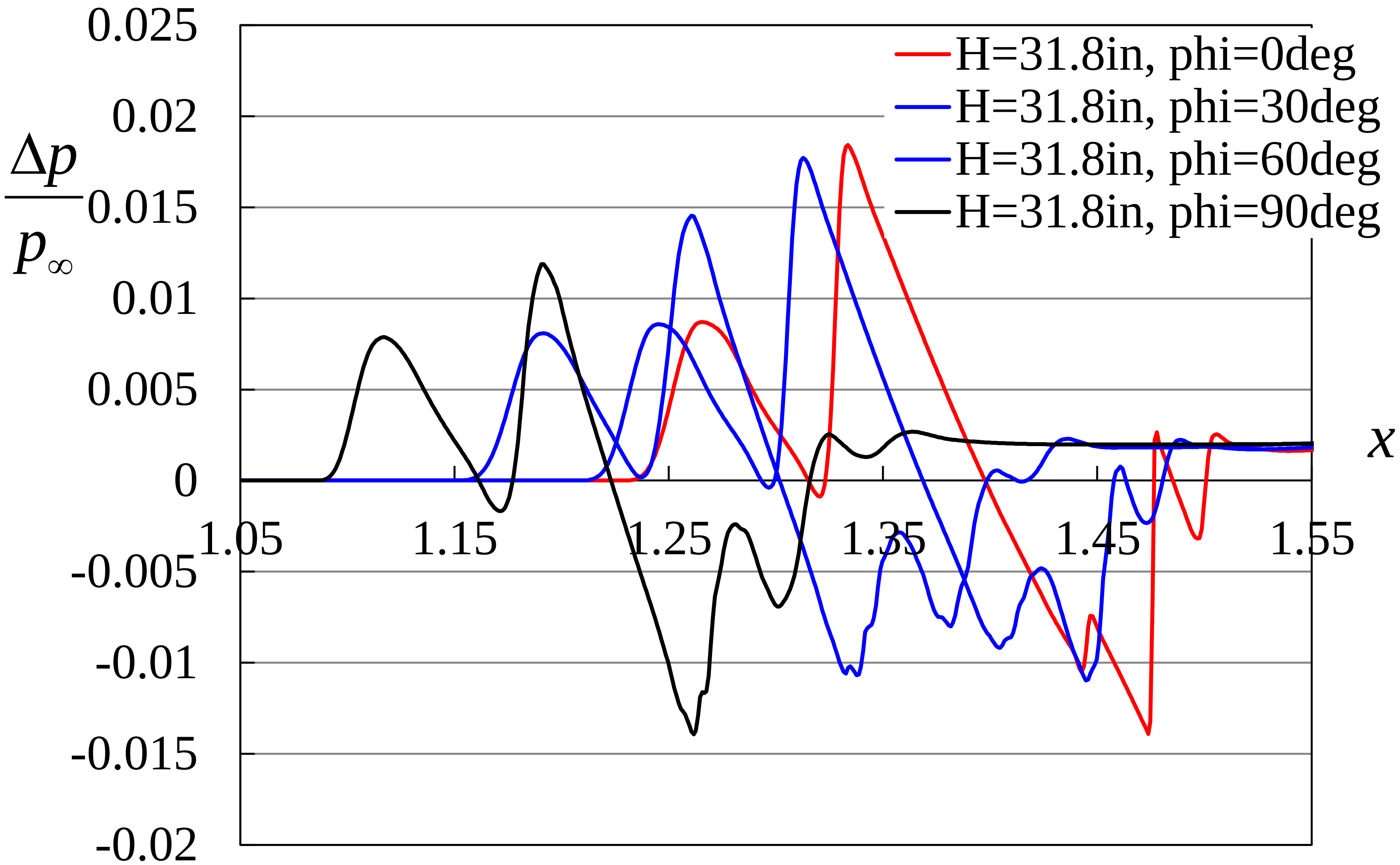
near field signatures

Angle of attack = **3.588**deg, H=**24.8**in



near field signatures

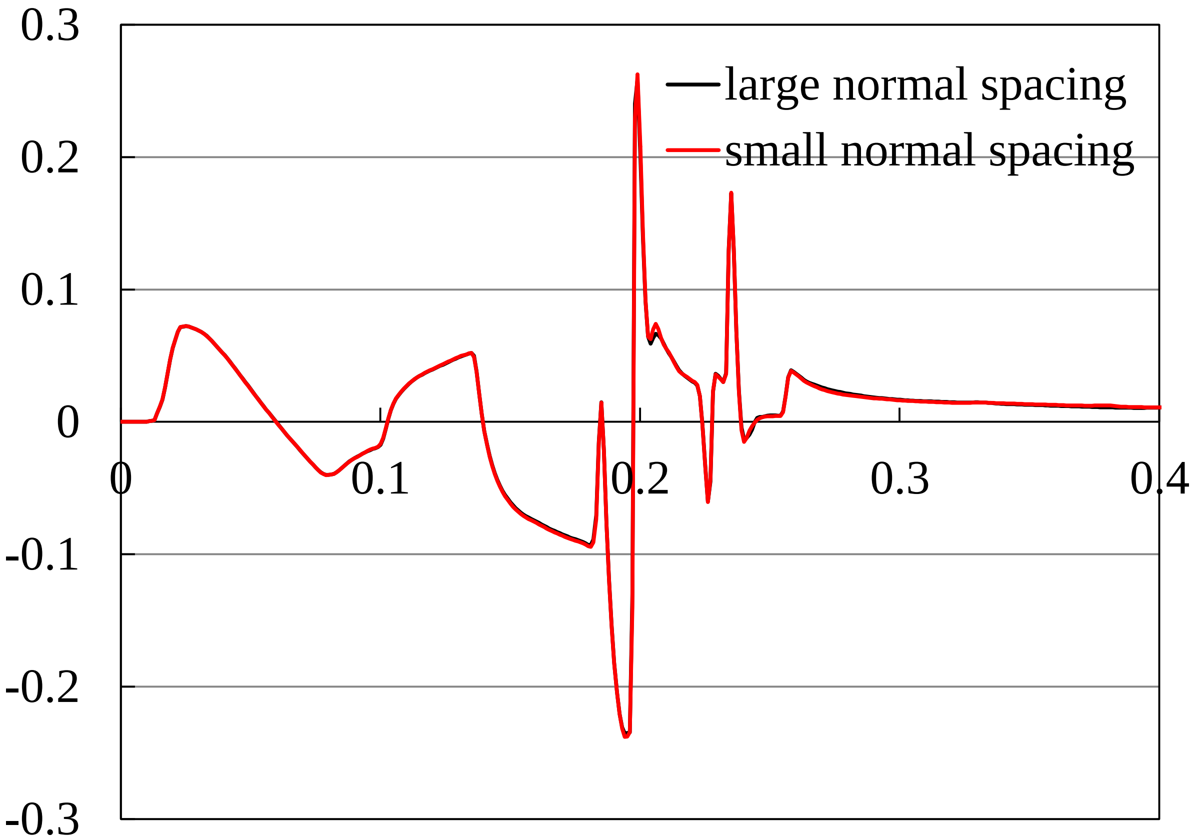
Angle of attack = **3.588**deg, H=**31.8**in



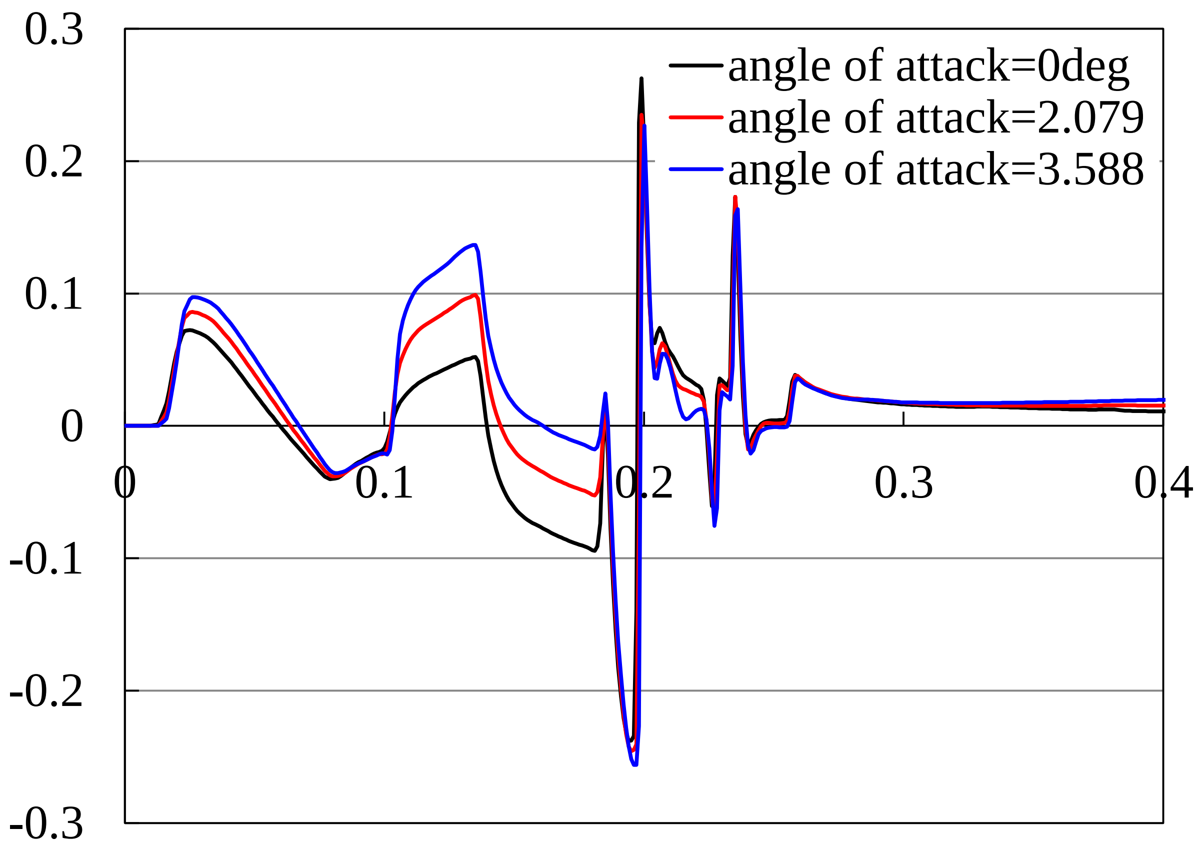
Highlights

Grid: Spacing in normal direction of the model surface did not have significant effect on the numerical accuracy of the sonic boom.

Convergence: generally good for Euler equations



Angle of attack: The level of sonic boom was strongly dependent on the angle of attack.



Conclusions

Convergence: was generally good for Euler equations, but should be careful of the sting step.

Accuracy: pressure signatures were generally well as compared with experiments.

Normal grid spacing had some influence on numerical accuracy on the model surface, but little on near field.