Simulation for Shock-Plume Interaction Model from 3rd Sonic Boom Prediction Workshop

January 4, 2020

Zhonghua Han, Jianling Qiao, Yulin Ding, Liwen Zhang, Ke Song

qiaojianling@163.com

Supersonic Transport Research Center
National Key Laboratory of Aerodynamic Design and Research
School of Aeronautics
Northwestern Polytechnical University (NPU)
Xi'an, China

Outline

- Flow Solver and Computing Platform
- Summary of cases analyzed
- Geometry Modification and Grids Generation
- Flow Solver Convergence
- Simulation Results
- Summary and Conclusions

Flow Solver and Computing Platform

➢PMNS3DR

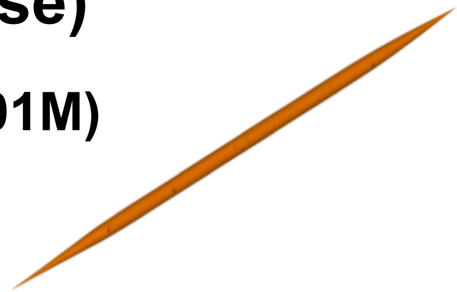
- In-house structured grid based solver
- Cell-center finite-volume method
- JST scheme and upwind schemes(AUSM+-up, Roe)
- LU-SGS, Runge-Kutta
- Minmod limiter

➢National Super Computer Center in Tianjin

- Parallel based on MPI and OpenMP
- 28 cores per computing node
- 2.93 GHz
- Distributed memory
- Red Hat Enterprise 5.3

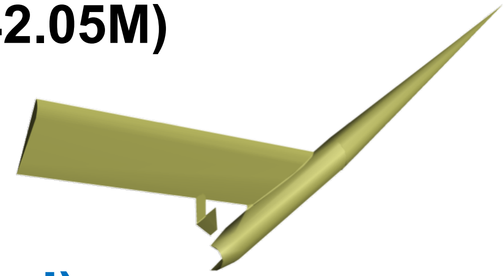
Summary of cases analyzed

➢AXIE model (Nearfield Notice of Intent Case)



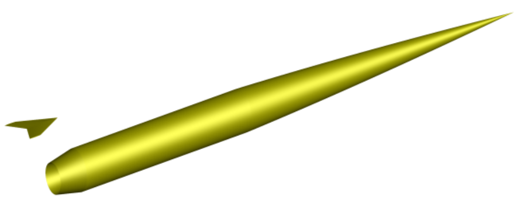
- Four structured grids (1.78M, 5.72M, 13.26M, 19.01M)
- Euler

➢Biconvex model



- Four structured grids (5.60M, 10.89M, 21.17M, 42.05M)
- Euler
- Engine plenum

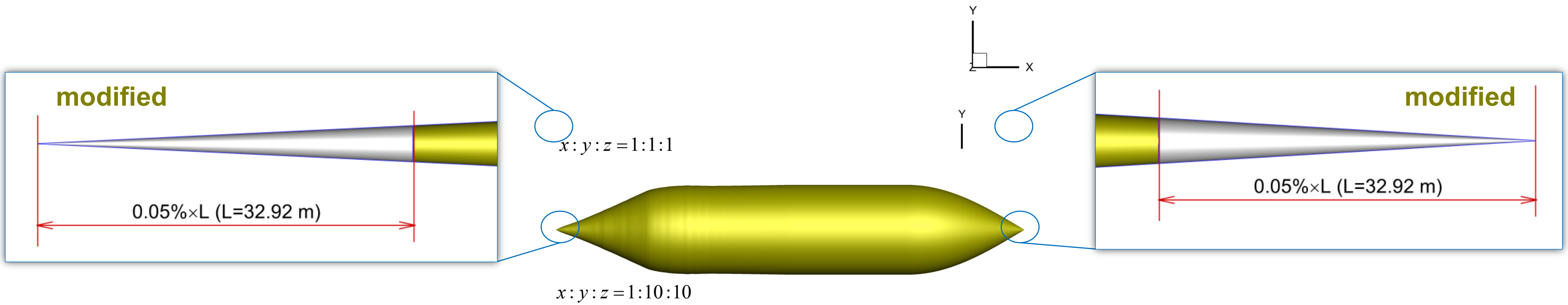
➢Biconvex model without “sting” (modified)

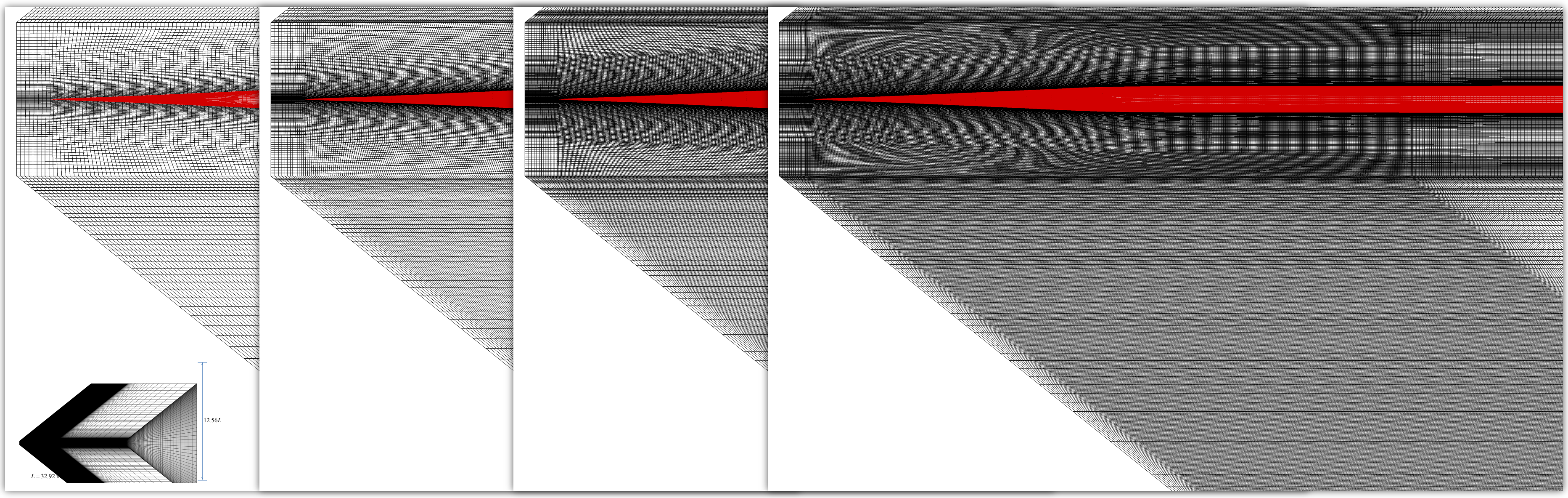


- Structured grid (21.17M)
- Euler
- Engine plenum / No engine plenum

Geometry Modification and Grids Generation

AXIE model (Nearfield Notice of Intent Case and Validation)

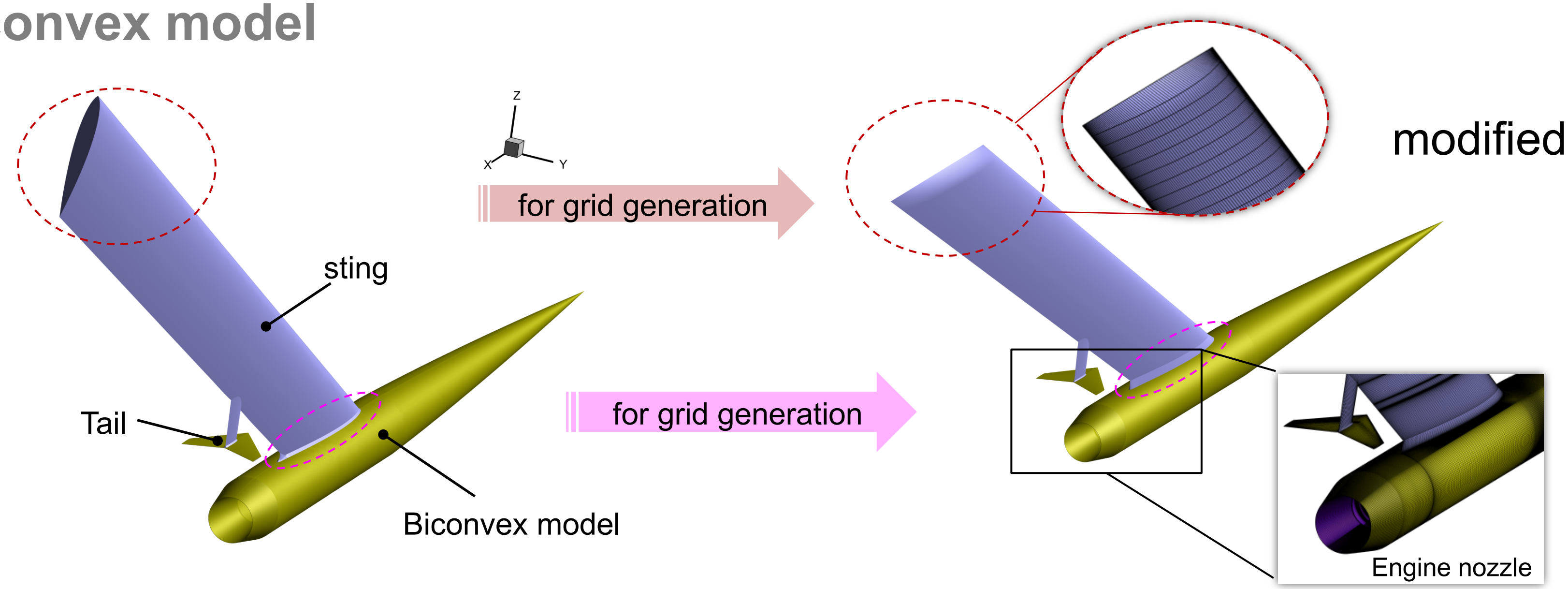


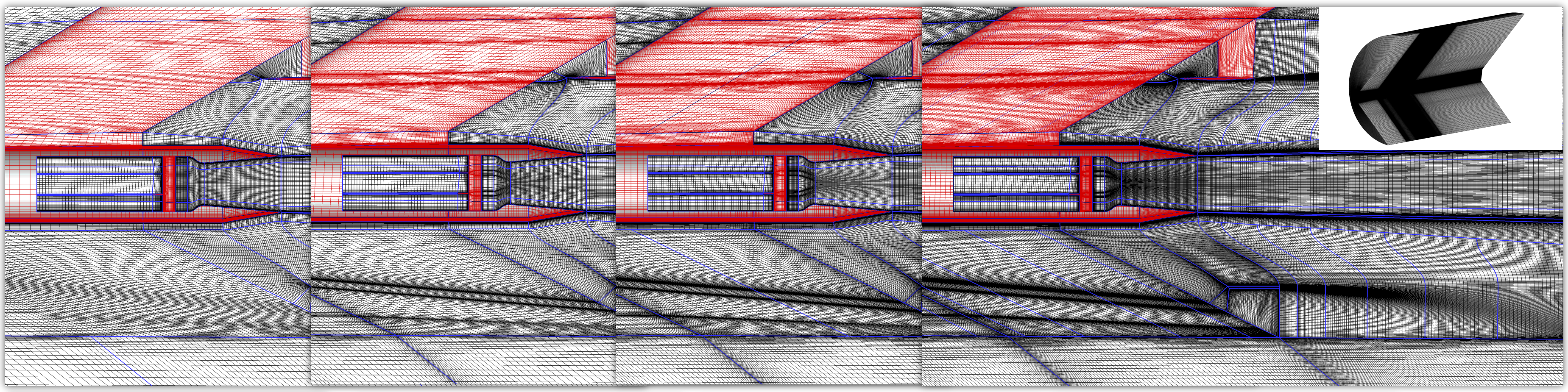


total cells: 1,779,456 body points: 145	total cells: 5,721,696 body points: 289	total cells: 13,264,896 body points: 433	total cells: 19,012,608 body points: 577

Geometry Modification and Grids Generation

Biconvex model

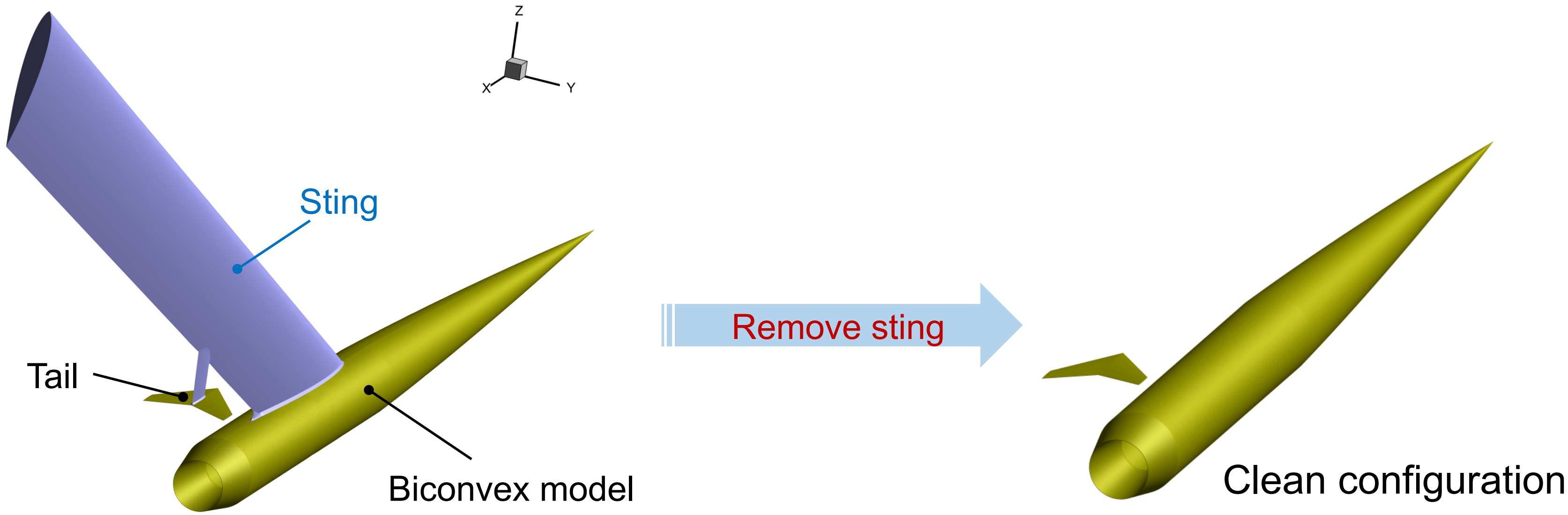


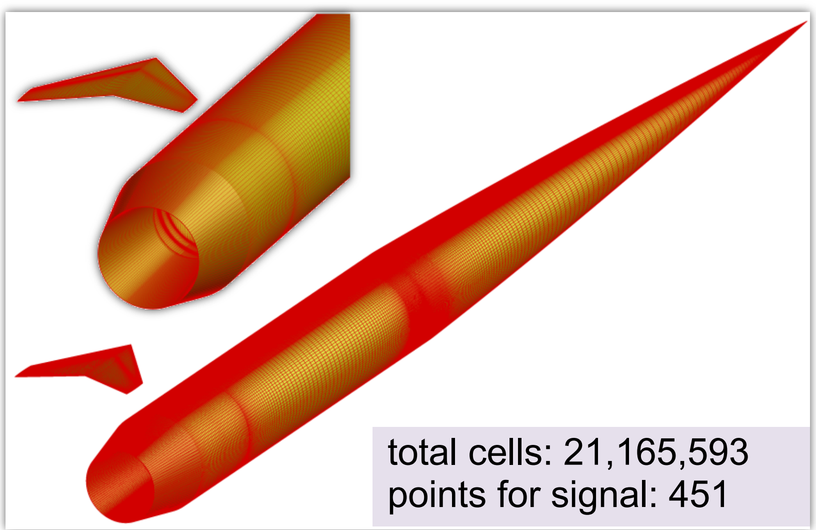


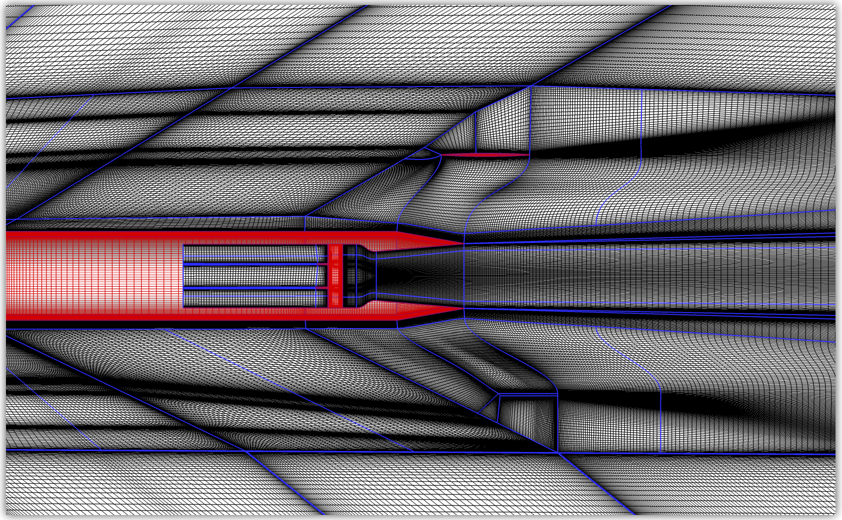
total cells: 5,599,702 points for signal: 281	total cells: 10,890,245 points for signal: 357	total cells: 21,165,593 points for signal: 451	total cells: 42,047,360 points for signal: 569

Geometry Modification and Grids Generation

Biconvex model without “sting”





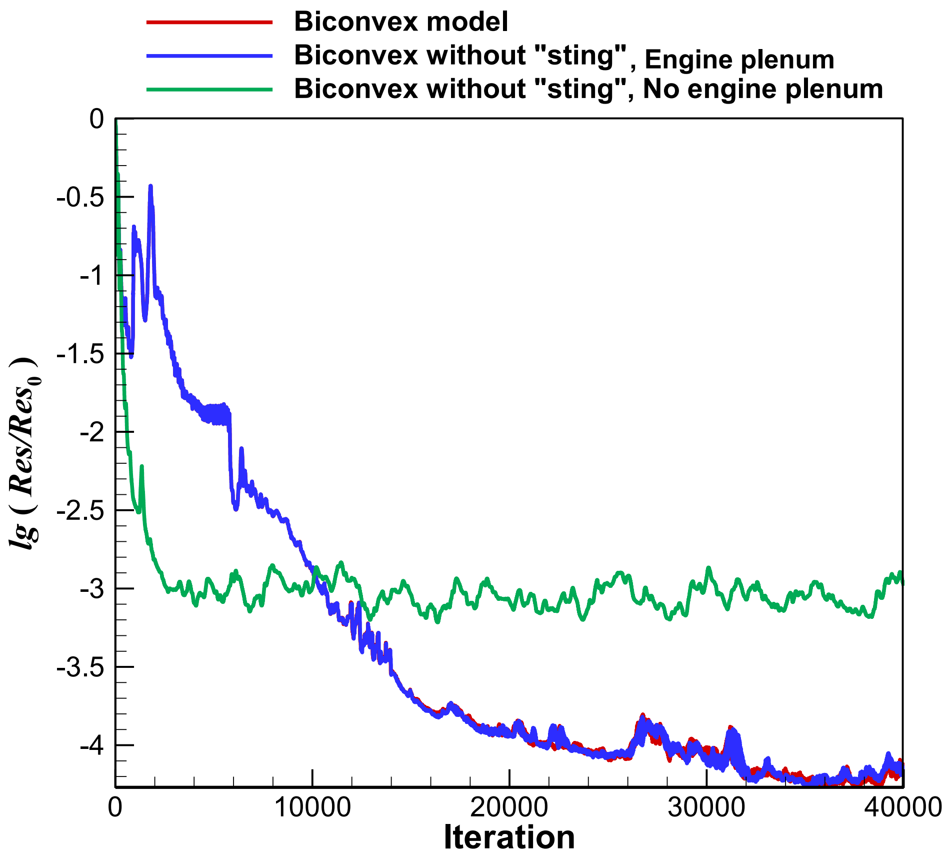


Flow Solver Convergence

Typical convergence history

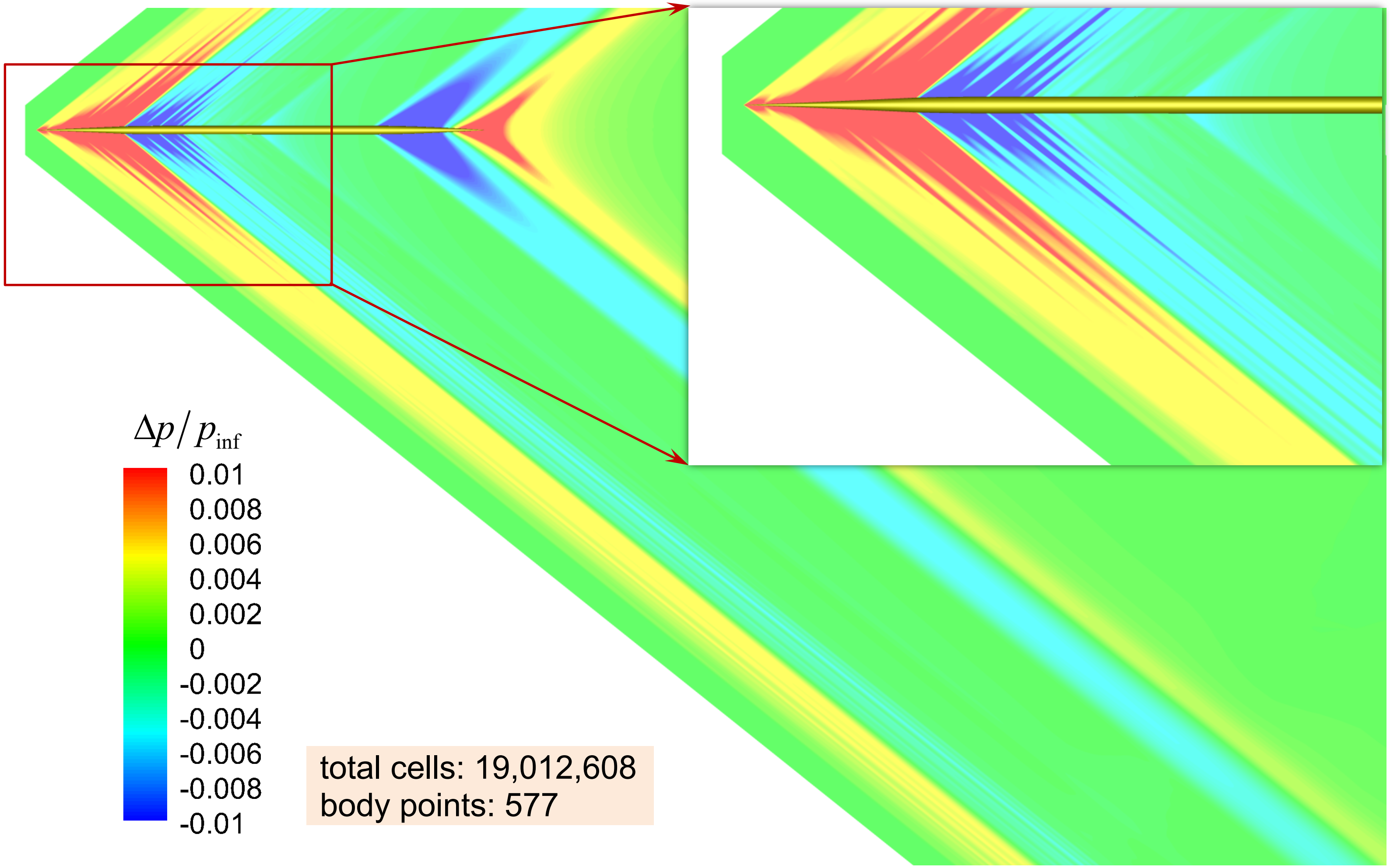
- **Convergence Criteria**
  - 40,000 Iterations
  - Average density residual value dropped by 5 orders of magnitude

- Grid size: 21.17M
- 3 computing nodes
- 35.55 hours



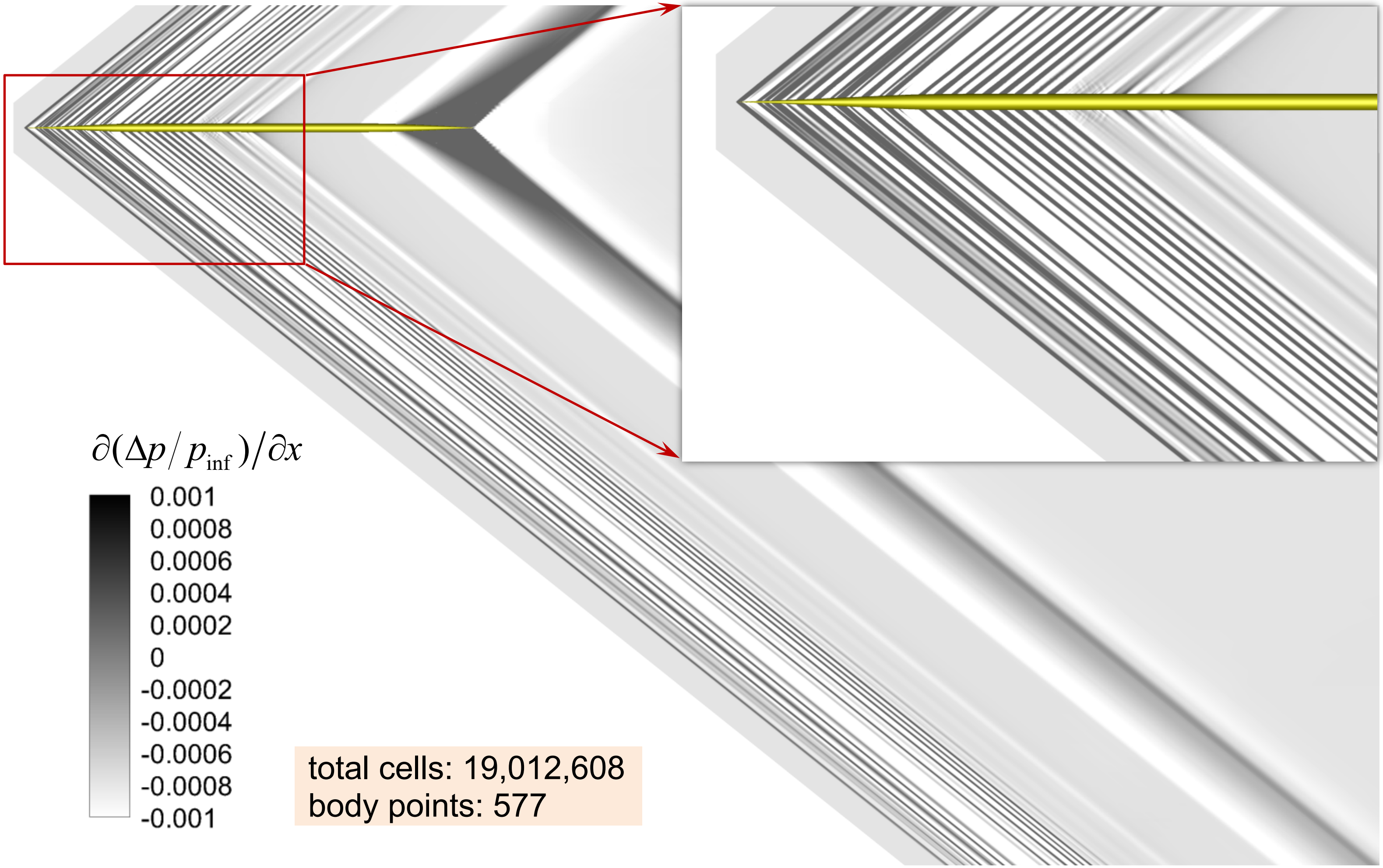
Simulation Results: AXIE Model for Validation

Overpressure contour and shock-expansion waves



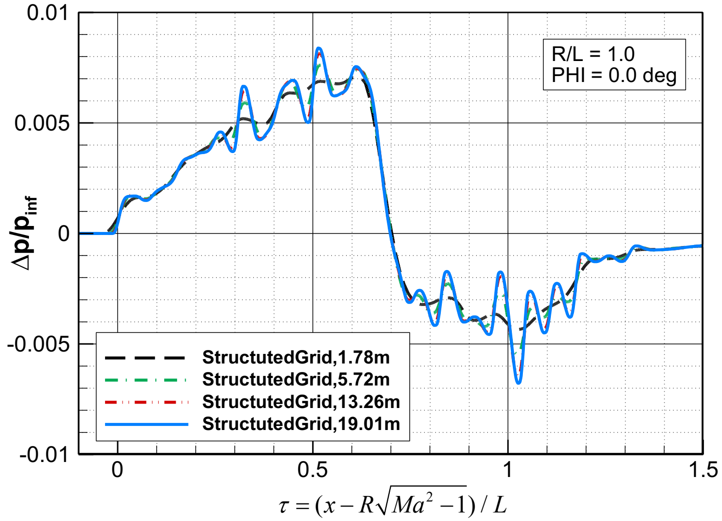
Simulation Results: AXIE Model for Validation

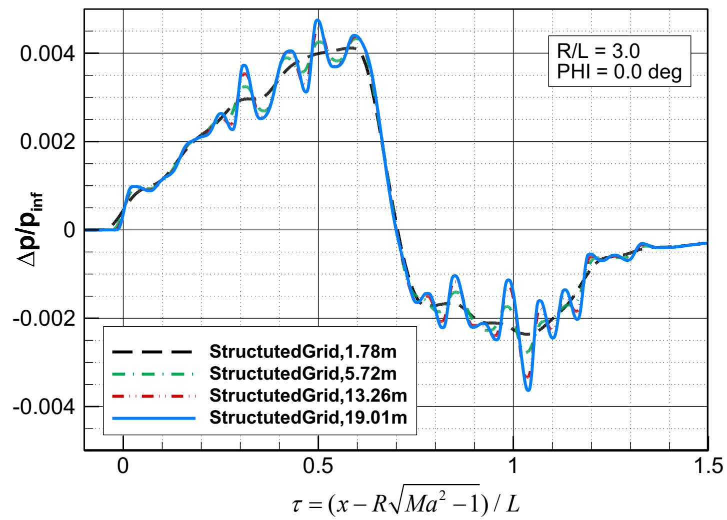
Overpressure contour and shock-expansion waves

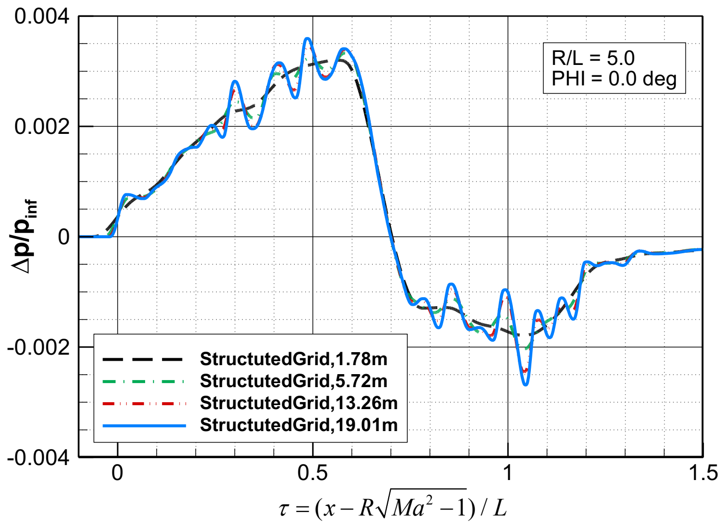


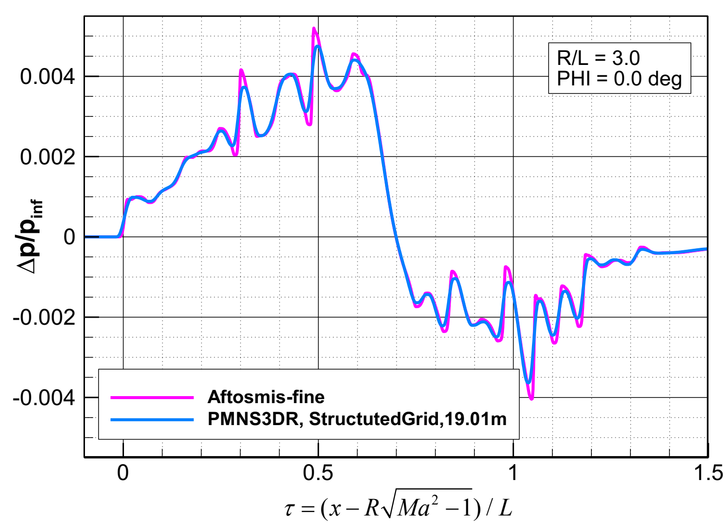
Simulation Results: AXIE Model for Validation

Nearfield signatures







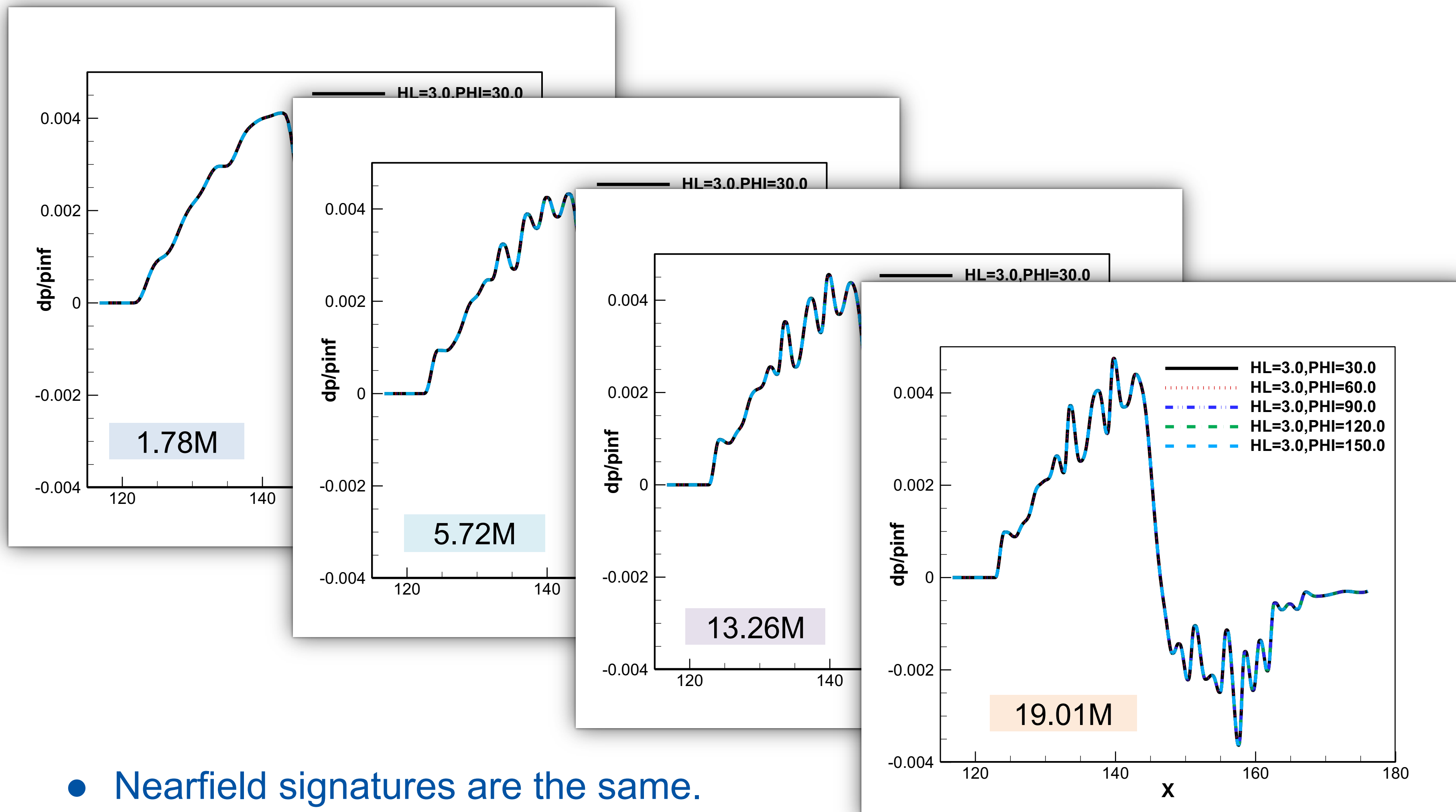


[1] Anderson G R, Aftosmis M J, and Nemec M. Cart3D Simulations for the Second AIAA Sonic Boom Prediction Workshop. *Journal of Aircraft*, 2019, Vol. 56,No.3, pp.896-911.

Simulation Results: AXIE Model for Validation

Nearfield signatures

- Optional：$H = 3L$ ($\phi = 30°, 60°, 90°, 120°, 50°$)

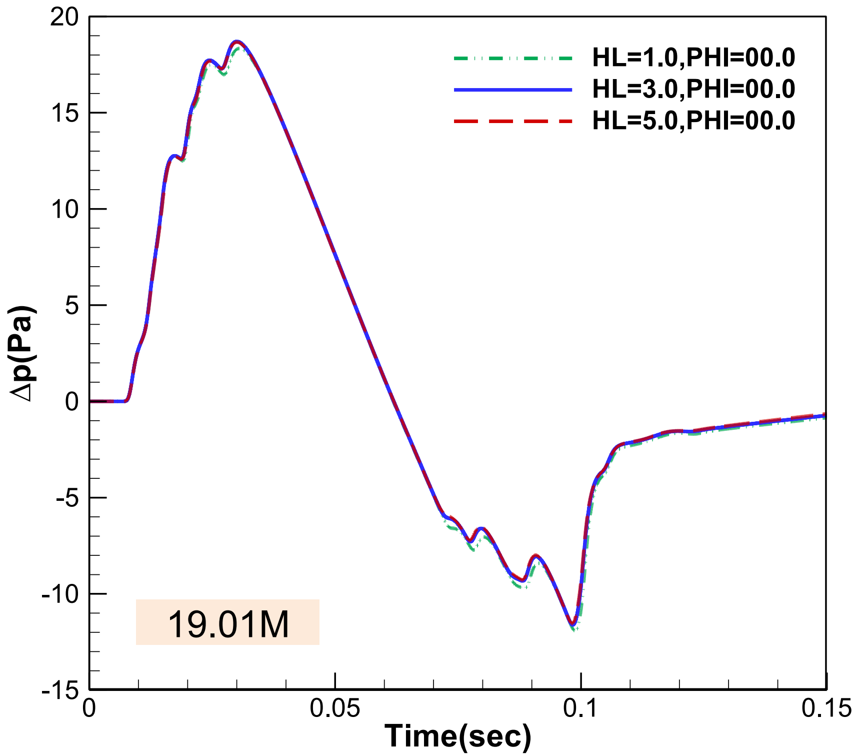


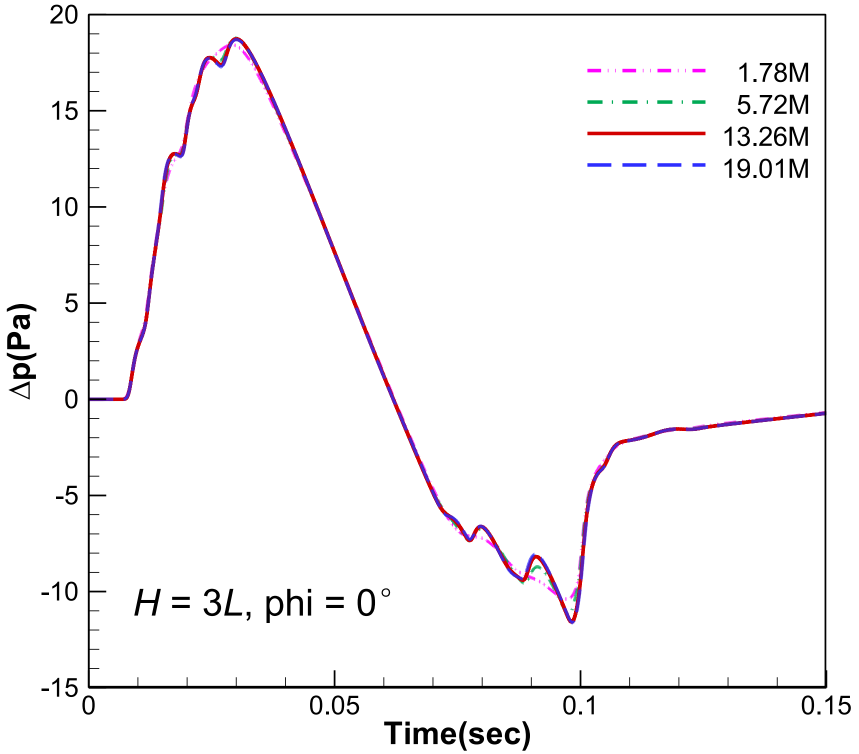
- Nearfield signatures are the same.

Simulation Results: AXIE Model for Validation

Propagation to the ground

- In-house far-field propagation code[1]
- Standard atmosphere
- Ground reflection factor: 1.9
- Sampling frequency: 500kHz
- Dimensionless space step: 0.05

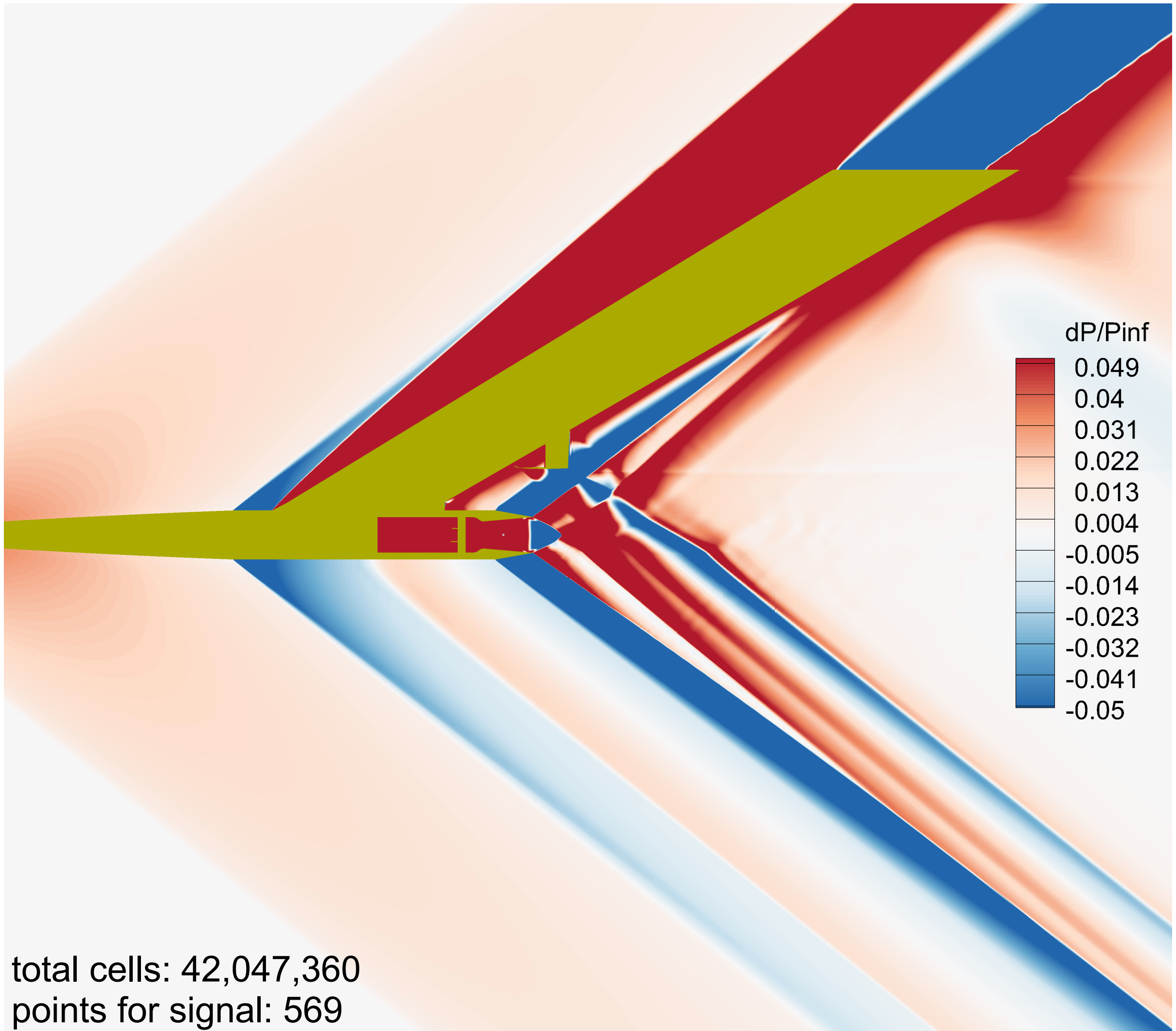




[1] Qiao J L, Han Z H,Song W P, et al. Development of Sonic Boom Prediction Code for Supersonic Transports Based on Augmented Burgers Equation. AIAA-2019-3571, 2019.

Simulation Results: Biconvex Model

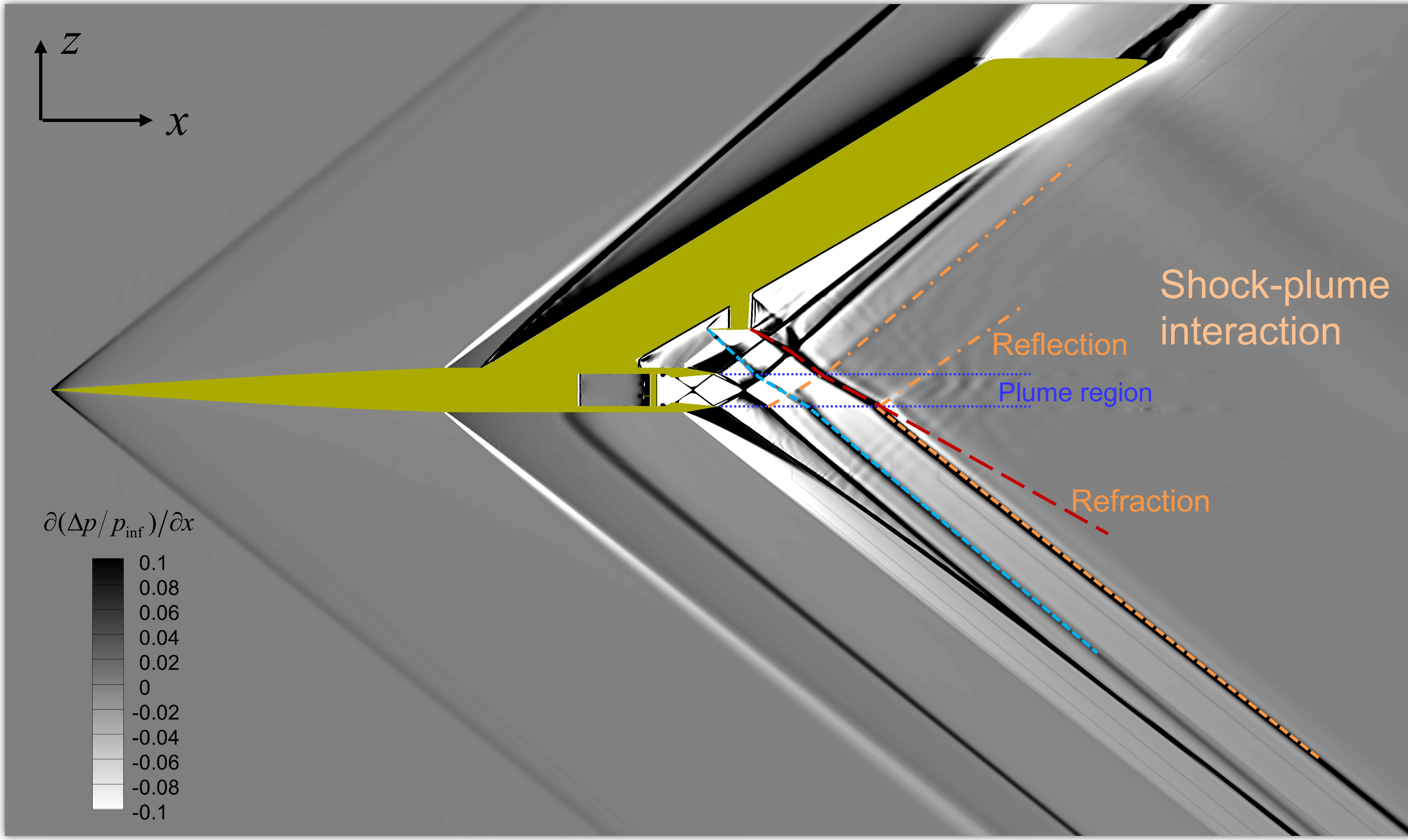
Overpressure contour in different size grids



- The finer the grid size is, the sharper the shock from tail is.

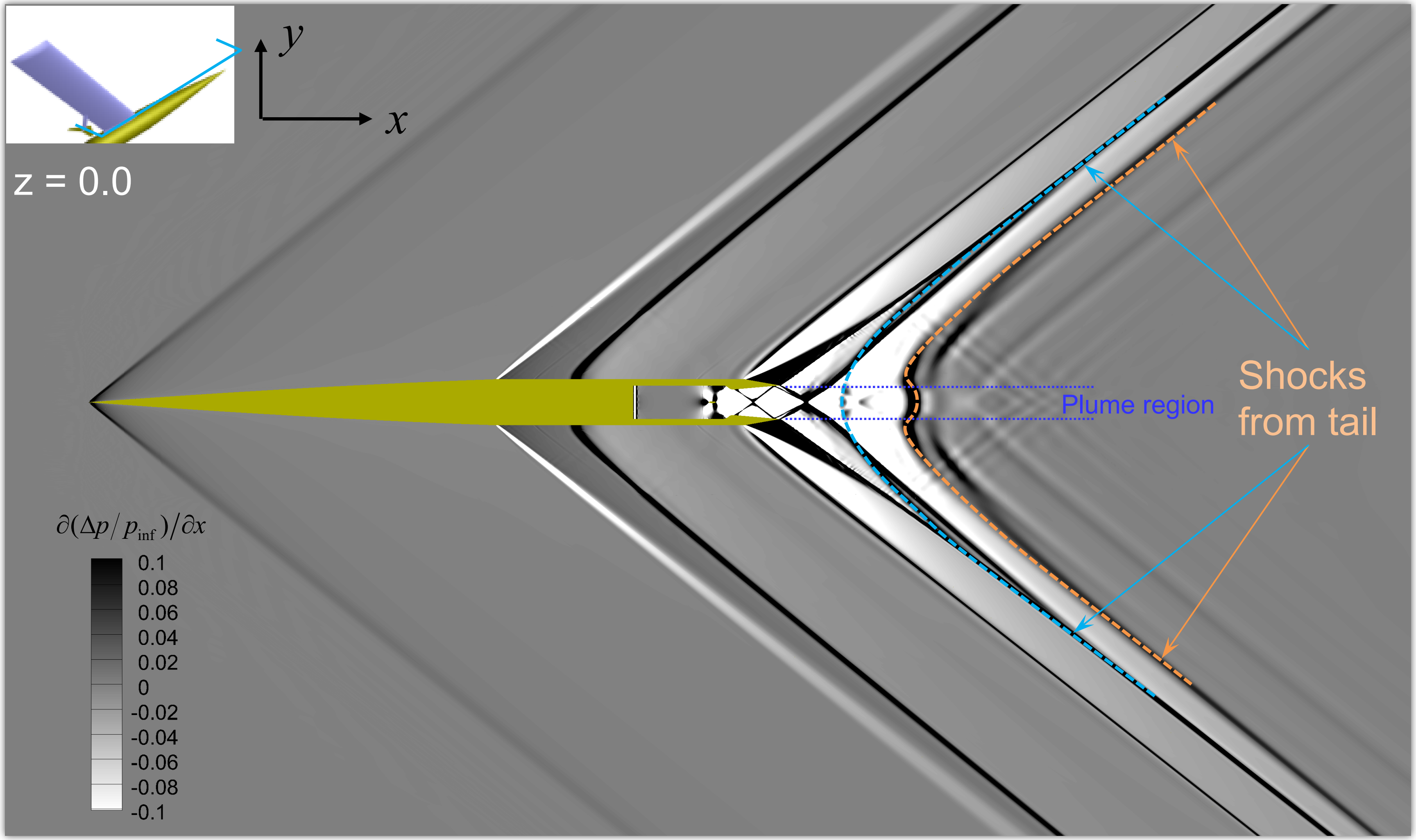
Simulation Results: Biconvex Model

Shock-expansion waves on finest grid



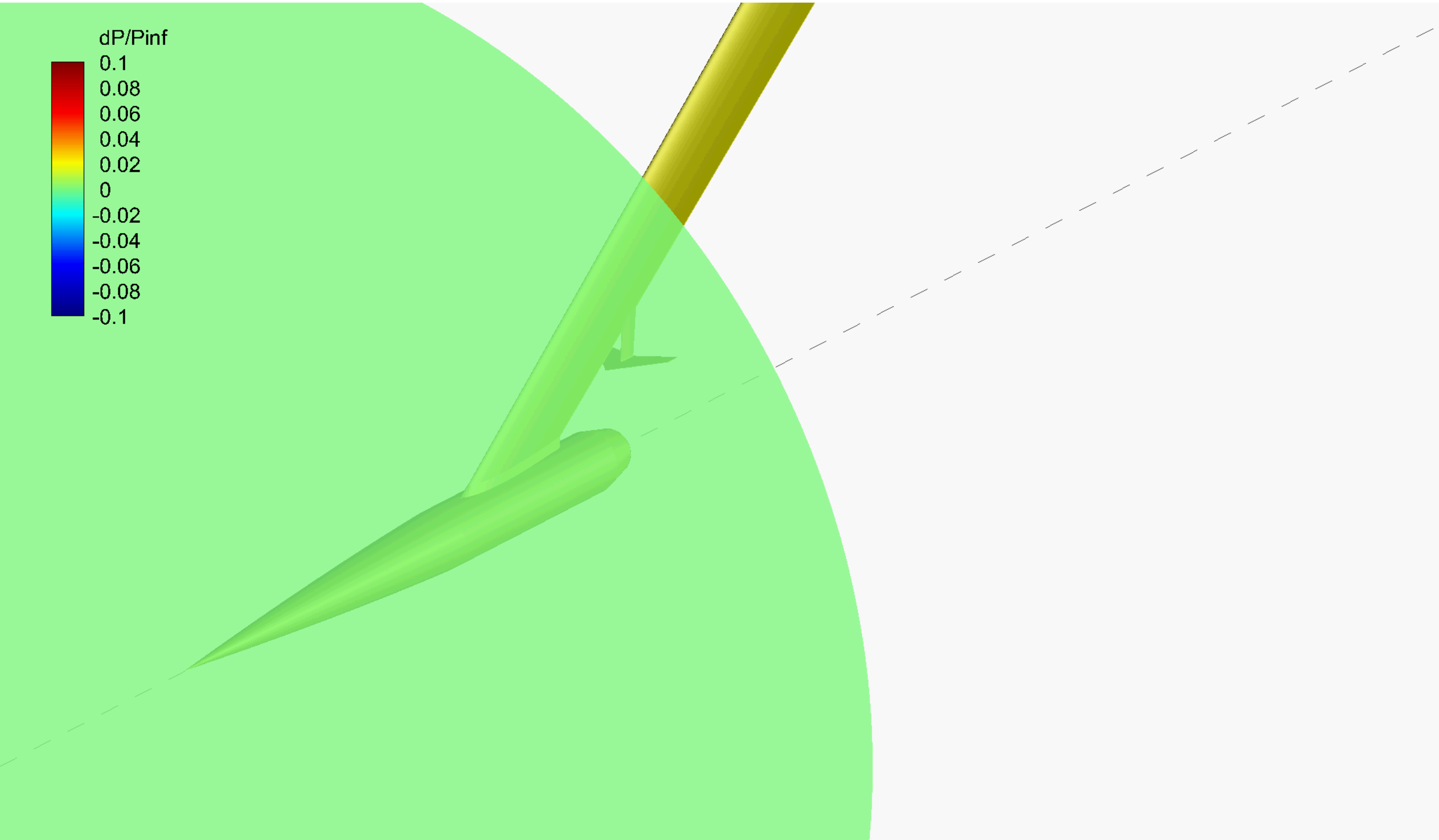
Simulation Results: Biconvex Model

Shock-expansion waves on finest grid



Simulation Results: Biconvex Model

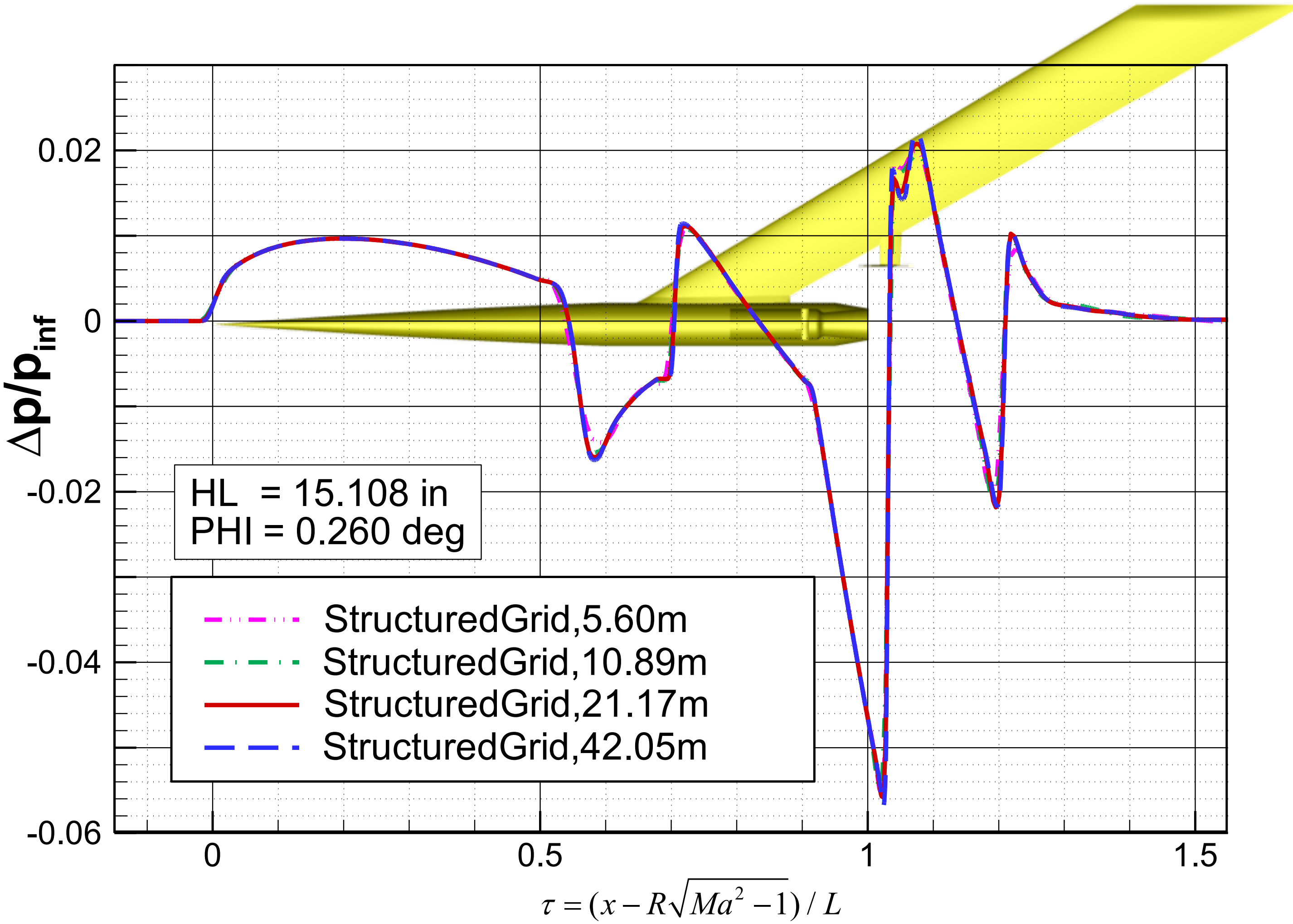
Generation of the shock-expansion waves



Simulation Results: Biconvex Model

Nearfield signatures

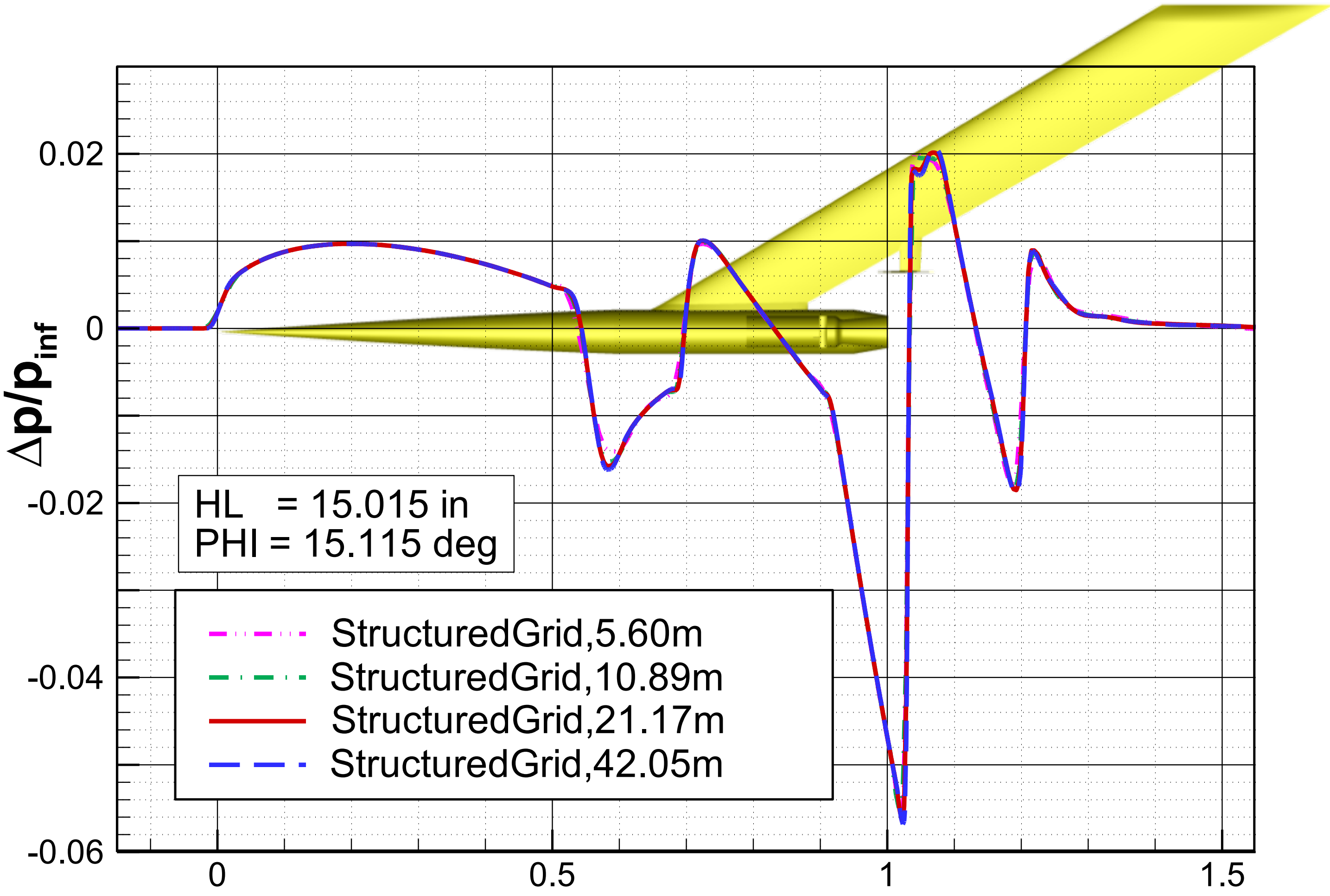
- HL=15.108 in, PHI=0.260 deg



Simulation Results: Biconvex Model

Nearfield signatures

- HL=15.015 in, PHI=15.115 deg

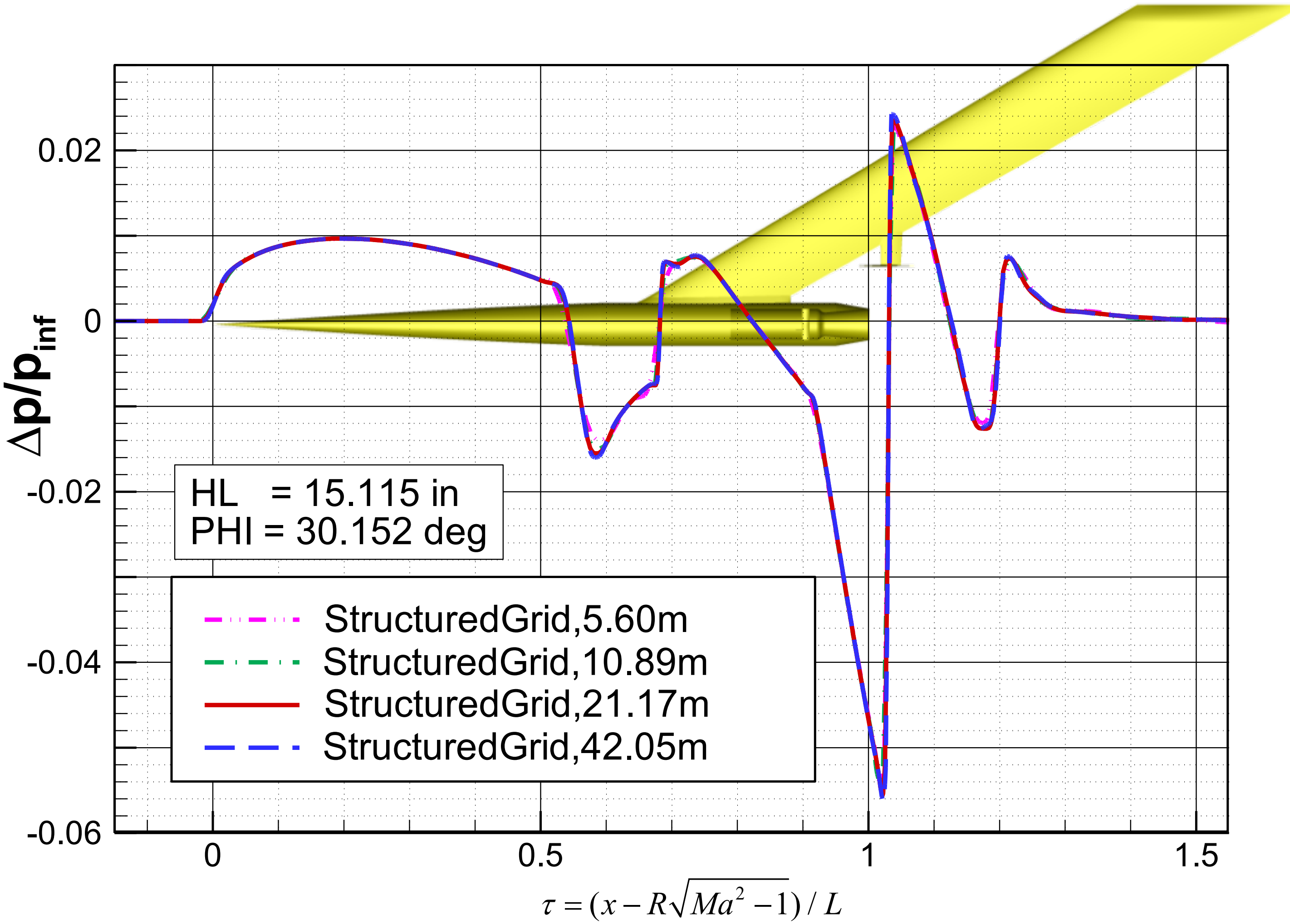


$\tau = (x - R\sqrt{Ma^2 - 1}) / L$

Simulation Results: Biconvex Model

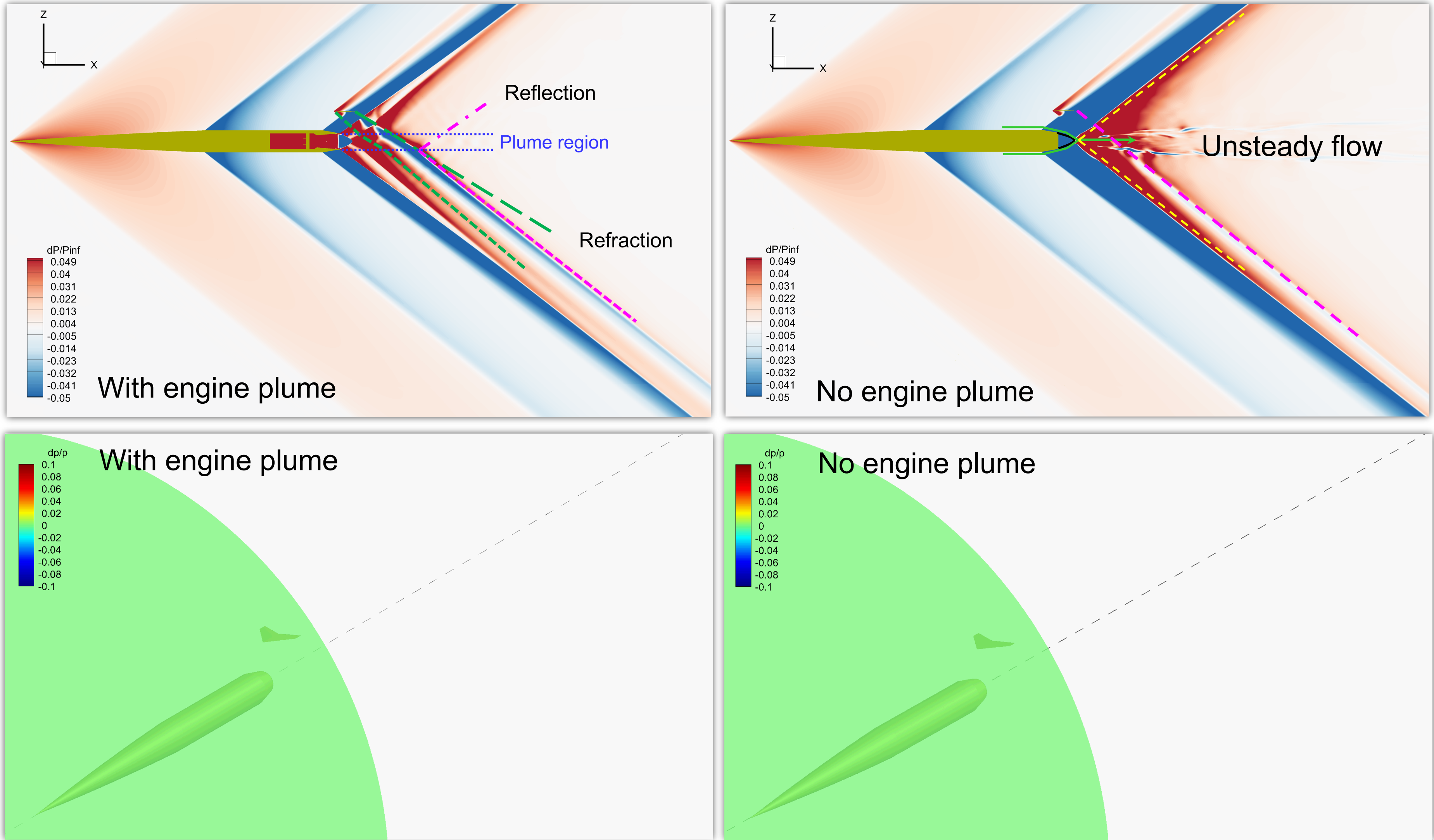
Nearfield signatures

- HL=15.115 in, PHI=30.152 deg



Simulation Results: Biconvex (no “sting”)

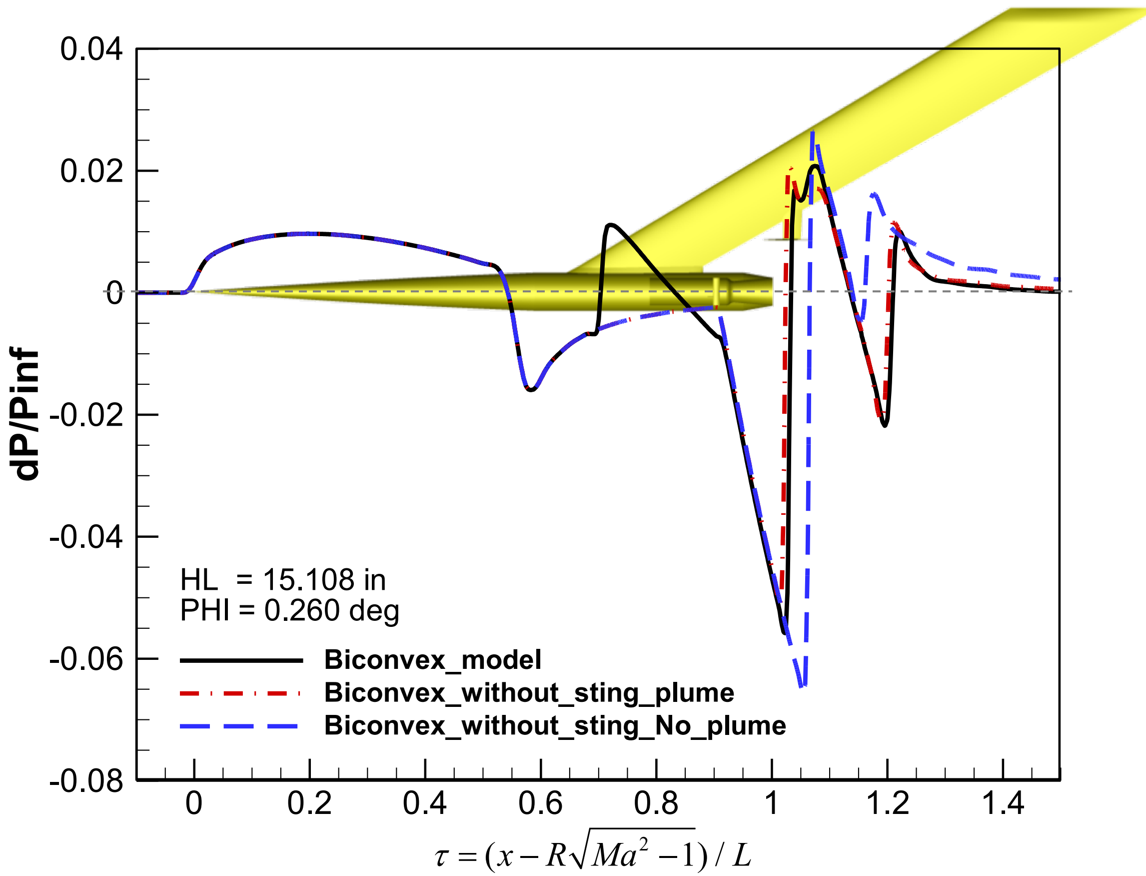
Influence of engine plume



Simulation Results: Biconvex

Nearfield signature comparison

- HL=15.108 in, PHI=0.260 deg



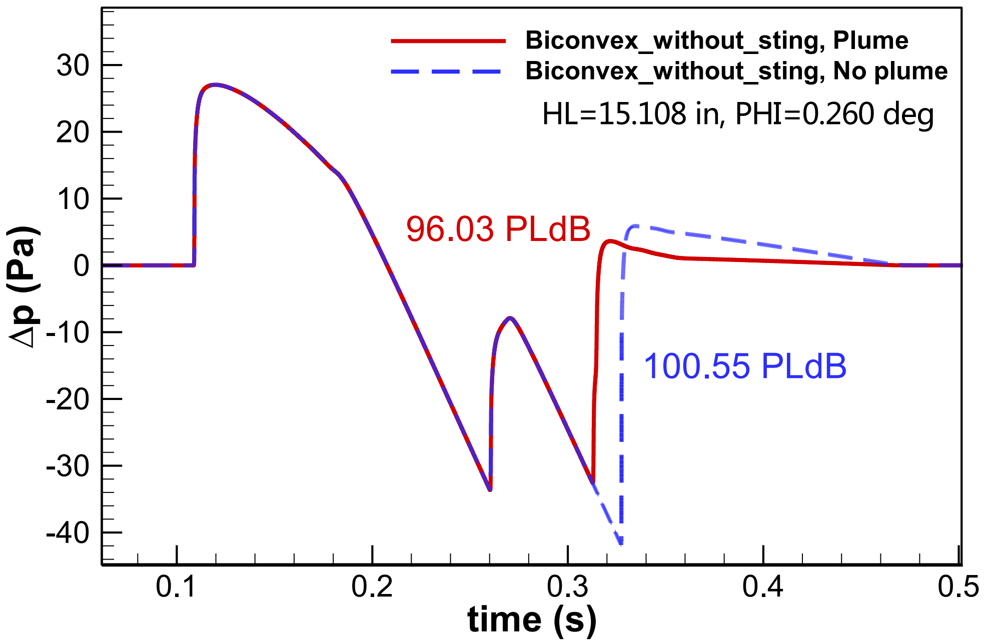
- Shock wave from the tail will be delayed on the biconvex model with “sting”.
- Shock wave of the tail will be weakened by plume from engine.

Simulation Results: Biconvex (no "sting")

Propagation to the ground from near field

➢ Flight condition assumption of "full scale"

- Full scale: 71.12 m (LM-1021)
- Cruise altitude:16.764 km (LM-1021)
- Standard atmosphere
- Ground reflection factor: 1.9
- Sampling frequency: 500kHz
- Dimensionless space step: 0.05



- Sonic boom is reduced by 4.5 PLdB in the situation with engine plume.

Summary and Conclusions

- **Validation of the flow solver PMNS3DR is carried out.**
  - Nearfield pressure signatures of AXIE model are captured on four grids.
  - The shock is more and more distinct with the size of grid increasing.
- **The shock-plume interaction model is analyzed.**
  - Four structured grids are generated for computation based on Euler equations.
  - Shock-expansion distributions in different grids are similar.
  - Shocks will be refracted and reflected through the plume from engine.
  - We remove the sting for wind tunnel and the effect of plume is studied. Shock wave of the tail will be weakened by plume from engine. Sonic boom on the ground can be reduced in the situation with engine plume. This encourages us to study the plume from engine on reducing boom next.

Thank you for your attention!

Zhonghua Han, Jianling Qiao, Yulin Ding, Liwen Zhang, Ke Song

If you have any further questions regarding our work, please email to :

qiaojianling@163.com

hanzh@nwpu.edu.cn