AIAA SciTech 2020

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National Aeronautics and Space Administration

SBPW3: Propagation Workshop Results using sBOOM

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A Storied Legacy, A Soaring Future

Outline

- Summary of Cases Analyzed
- Boom Propagation Code Details
- Cases
  - Ground Signatures
  - Loudness metrics
- Highlights
- Summary

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- NASA trimmed low-boom concept - C25P
  - Required runs with measured atmospheric profiles
  - Lateral cut-off analysis
  - Optional focus boom simulations

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- NASA trimmed low-boom concept - C25P
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  - Lateral cut-off analysis
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- NASA-Lockheed Low-Boom Flight Demonstrator (LBFD): A variant of X-59 QueSST
  - Required runs with measured and standard atmospheres

Propagation Prediction Code: sBOOM

sBOOM

- Propagation based on lossy Quasi-1D Burgers equation

$$\frac{\partial p}{\partial \sigma} = \frac{\frac{\partial B}{\partial \sigma}}{B} p + \frac{\beta \Omega}{2\rho_0 c_0^3}\left(\frac{c_0}{v_g}\right)\frac{\partial p^2}{\partial \tau} + \frac{\delta \Omega^2}{2\rho_0 c_0^3}\left(\frac{c_0}{v_g}\right)\frac{\partial^2 p}{\partial \tau^2} + \sum_{\nu} \frac{m_\nu}{2c_0} \frac{t_\nu \Omega^2}{1 + t_\nu \Omega \frac{\partial}{\partial \tau}}\left(\frac{c_0}{v_g}\right)\frac{\partial^2 p}{\partial \tau^2}$$

$$B = \sqrt{\frac{\rho c S_0 D_0^2}{\rho_0 c_0 S D^2}\left(\frac{\frac{c v_{g0}}{D_0}}{\frac{c_0 v_g}{D}}\right)}\ ,\ v_g = \left| c\,.\,\bar{n} + \bar{w} \right|, \mathrm{D} = 1 + \frac{\bar{w}\,.\,\bar{n}}{c},\ \Omega = \frac{1}{D}$$

- Ray Path Equations:

$$\frac{dx}{dt} = \bar{w} + c^2 q D \qquad \frac{dq}{dt} = -\left[\frac{\nabla c}{cD} + \sum_{i=1}^{3} q_i \nabla w_i\right] \qquad q = \frac{\bar{n}}{c + \bar{w}\,.\,\bar{n}}$$

Propagation Prediction Code: sBOOM

sBOOM

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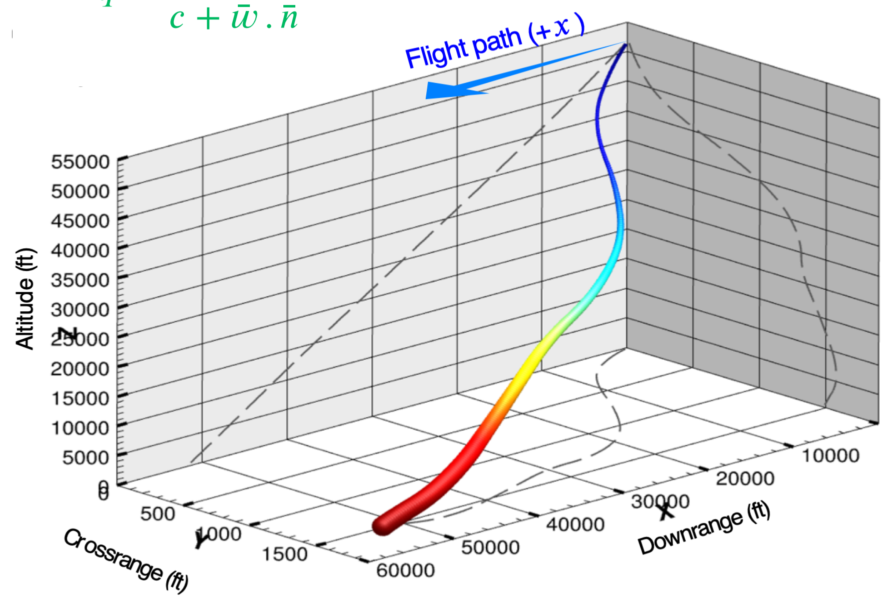
- **Features and capabilities**
  - Under-track, off-track signatures with winds
  - Acceleration, turn-rates, climb-rates, maneuvers and focus predictions by interfacing with Lossy Nonlinear Tricomi Equation (LNTE)
  - Design friendly sensitivities and adjoint error estimates

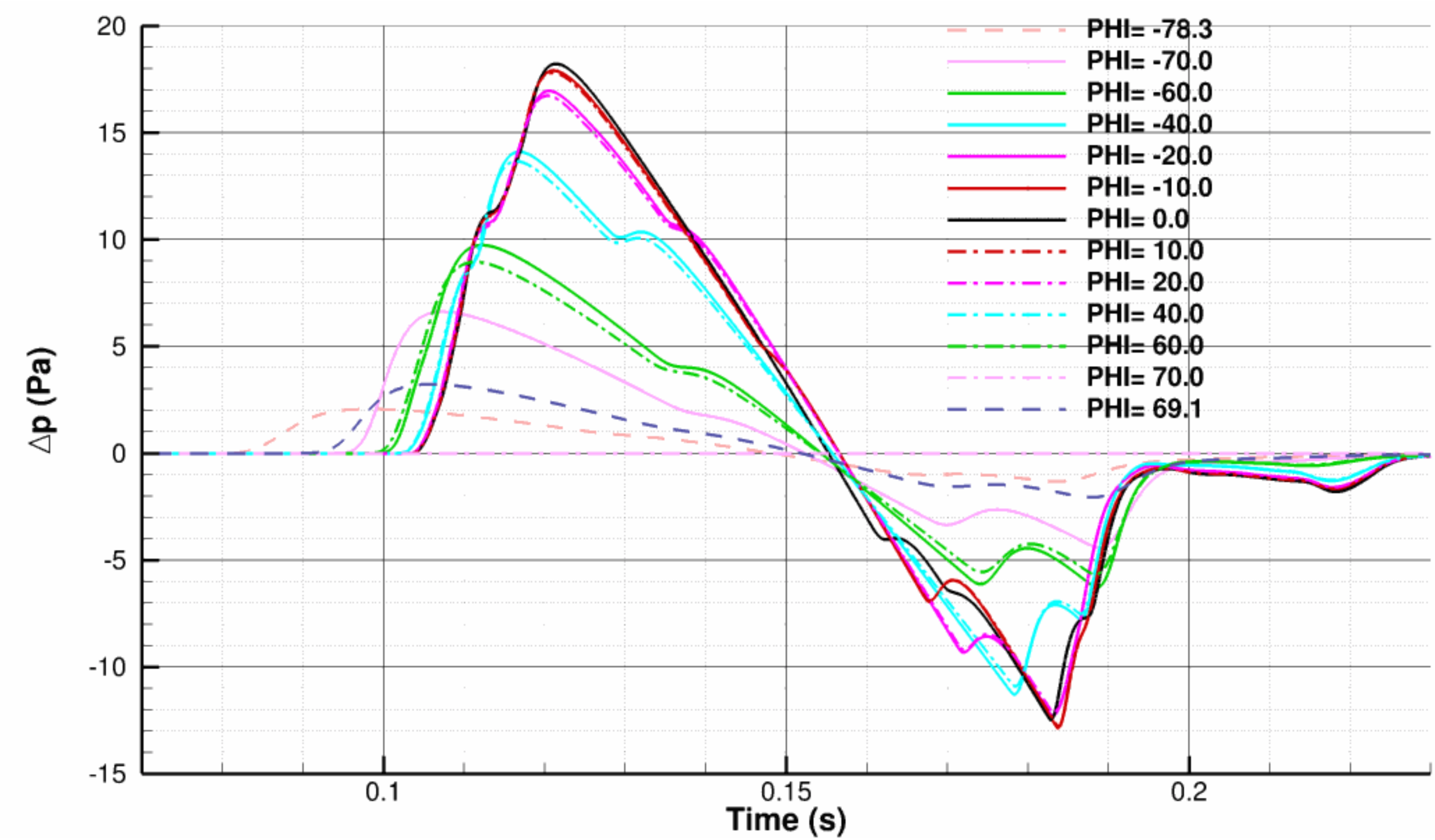


sBOOM is under active development. Contact Sriram.Rallabhandi@nasa.gov to get a copy of sBOOM

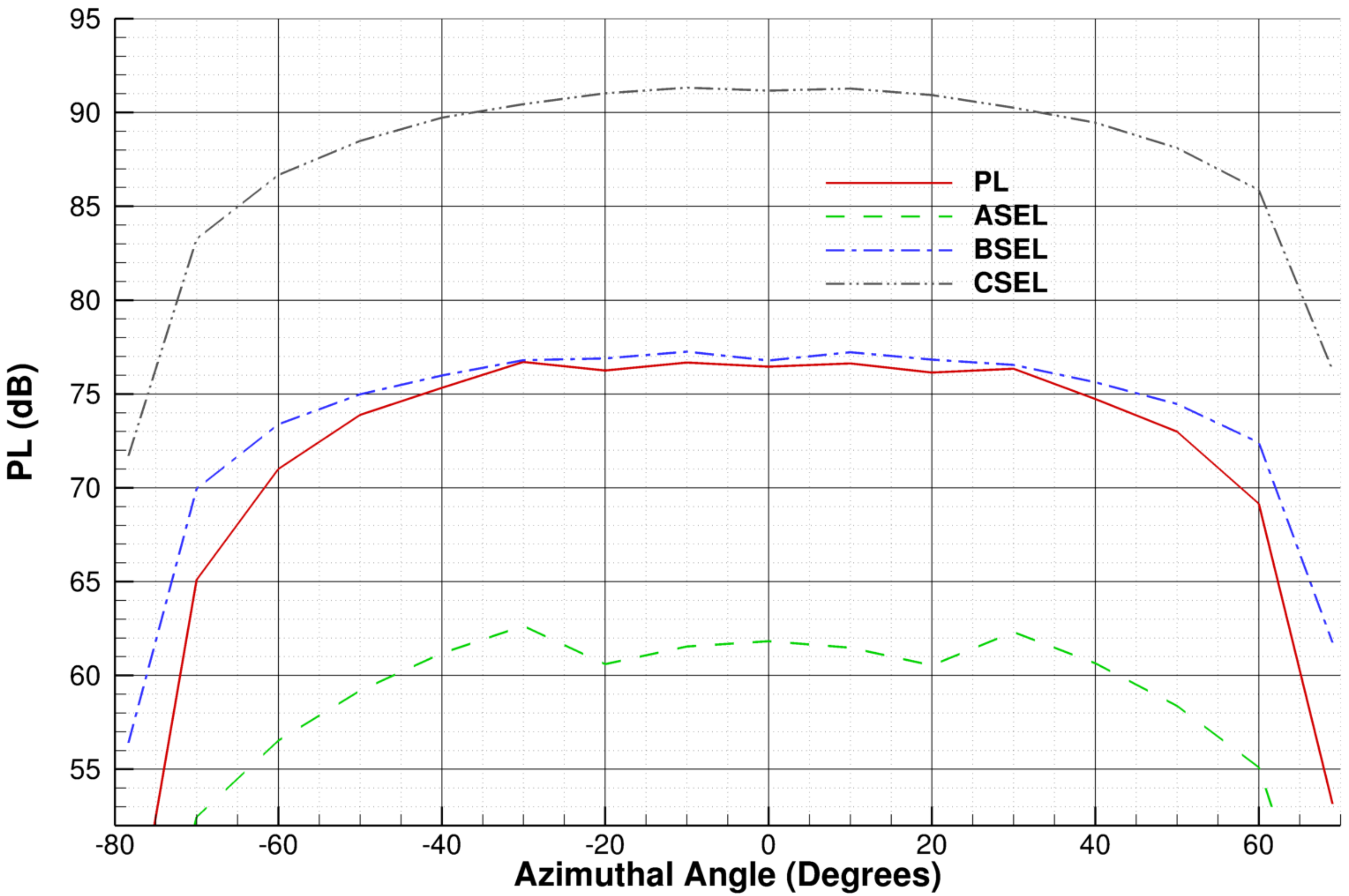
Run Parameters

- All azimuthal angles run in parallel
- Computing platform:
  - OSX running macOS Mojave (10.14.6)
    - CPU: 2.5 GHz i7
    - RAM: 16GB, 1600 MHz DDR3
  - NASA Langley mid-range computing facility
    - Single node of SGI ICE Altix Cluster
- No pre-processing of near-field data
- Computational run times
  - Typical run times for edge-to-edge carpet predictions
    - ~30 seconds wall-time @ sampling frequency = 100 KHz (16 azimuths)
    - ~130 seconds wall-time @ sampling frequency = 200 KHz (16 azimuths)
- Sampling frequency determined by adjoint-error correction approach by continuously embedding uniformly refined grid
  - 100 KHz sufficient to resolve loudness BSEL to within 0.1 dB
  - 400 KHz sufficient to resolve loudness BSEL to within 0.02 dB

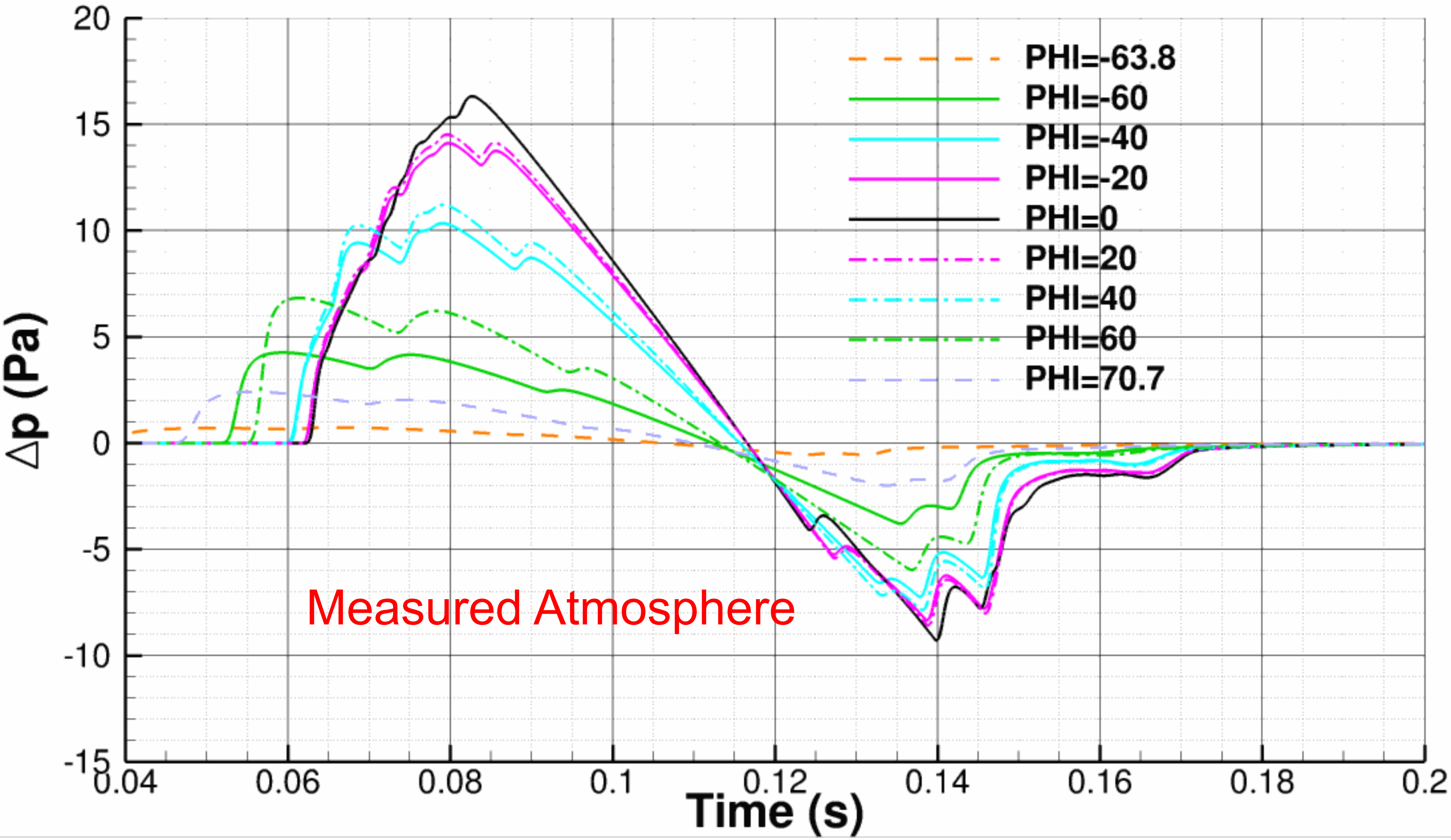
Case1: Ground Signatures



Case1: Loudness Metrics



Case2: Ground Signatures



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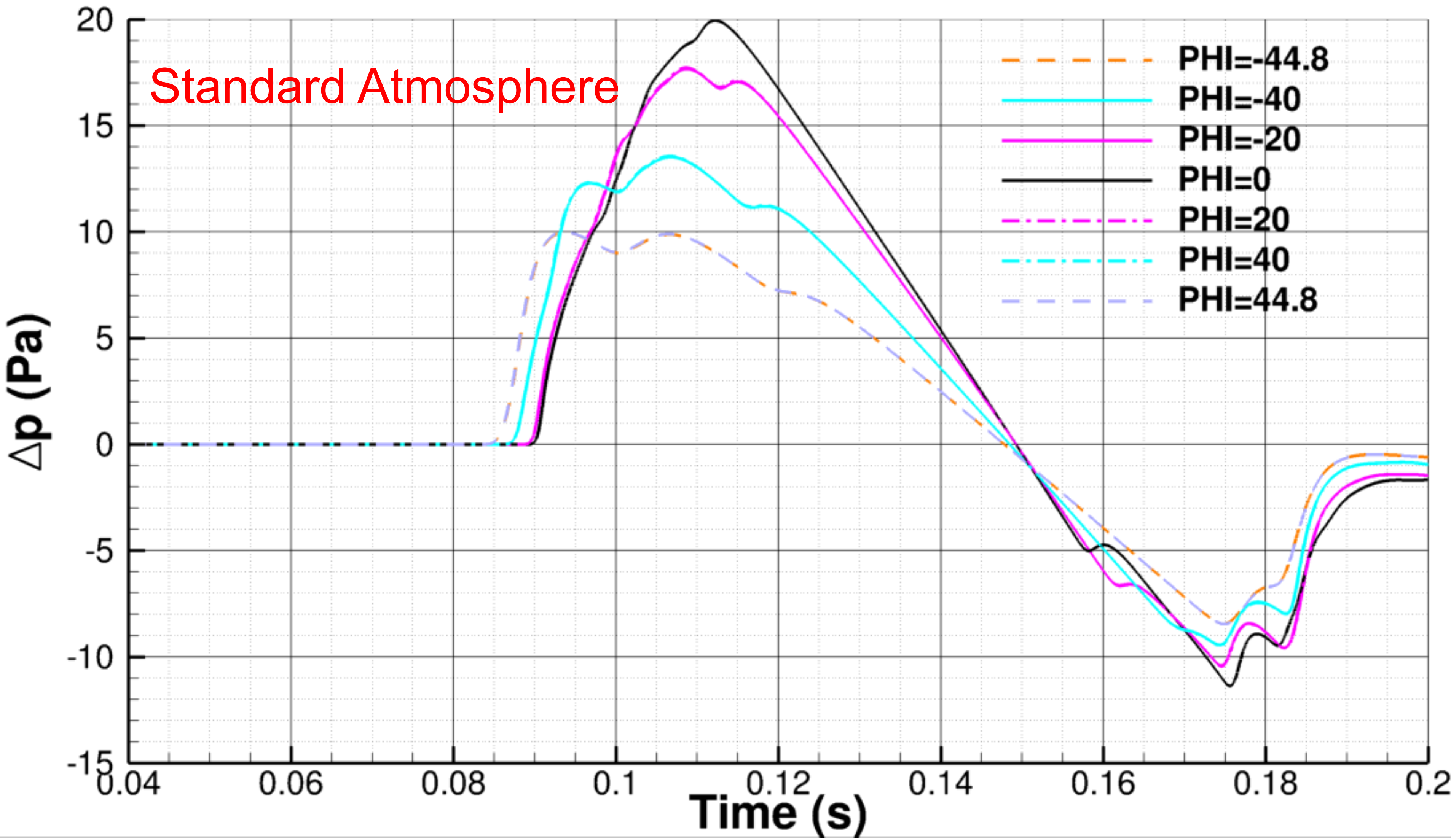

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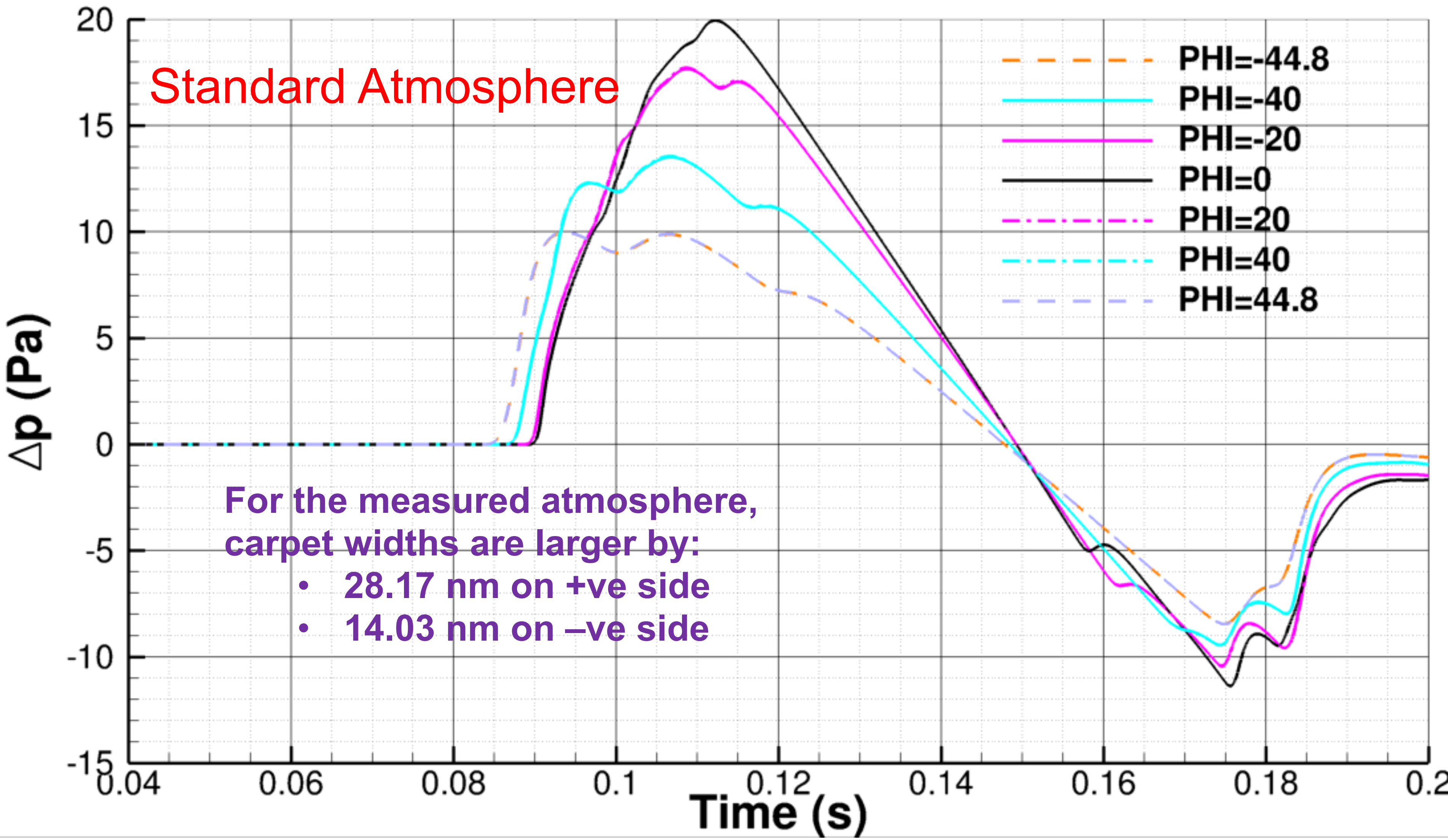

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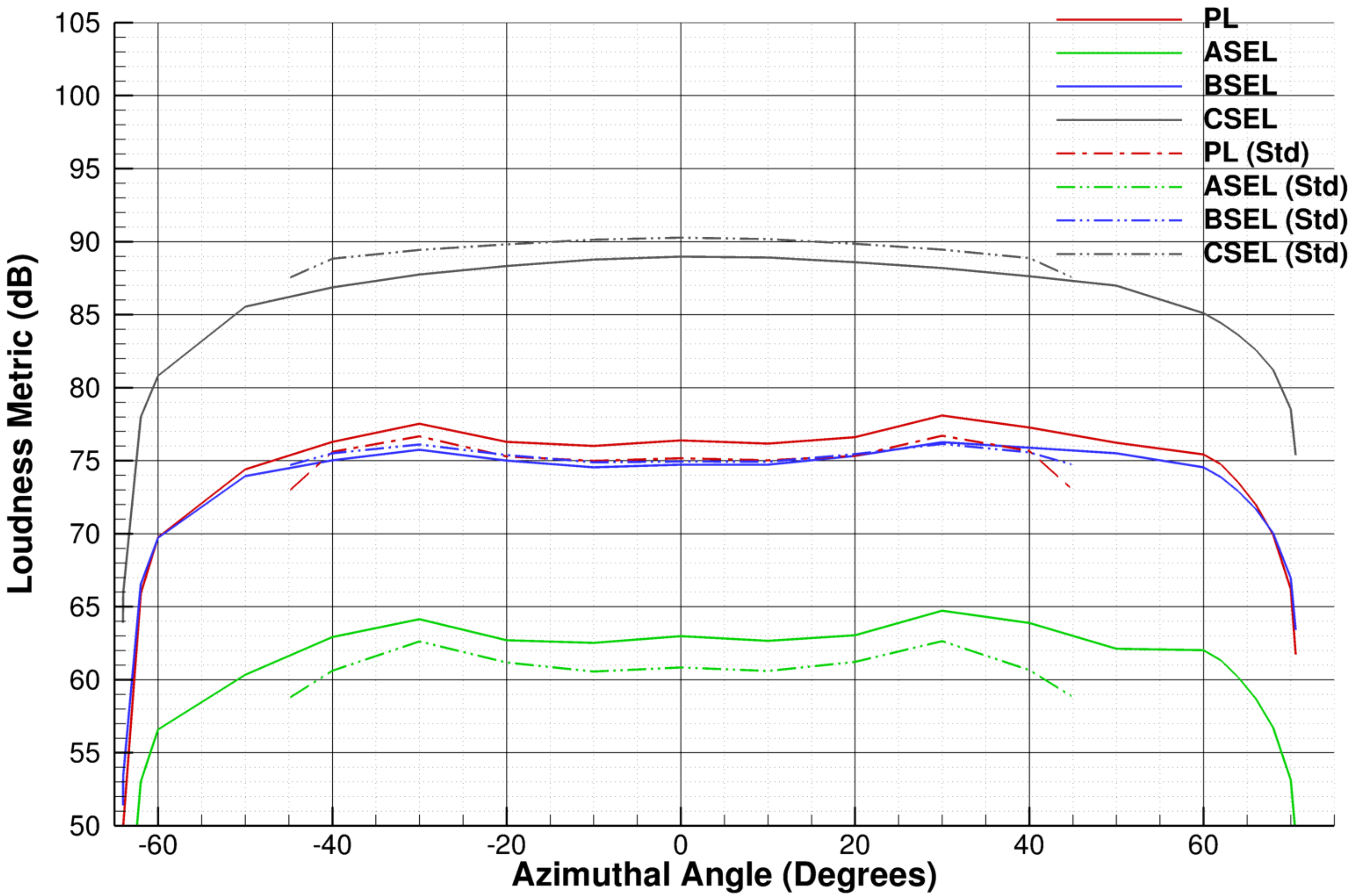
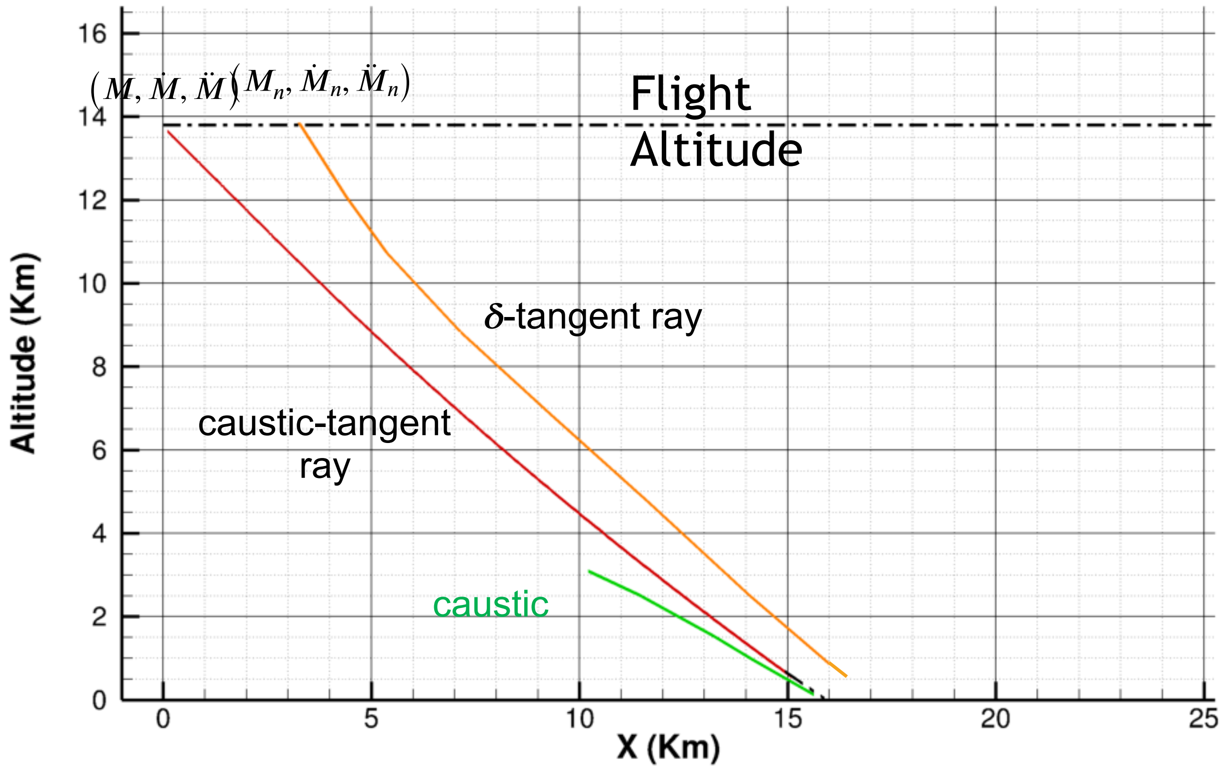


Case1: Optional Focus Analysis

- $\left(M, \dot{M}, \ddot{M}\right)$ = (1.4121, 0.015681, 0.000359)
- Diffraction boundary layer thickness (δ) = 682.45m



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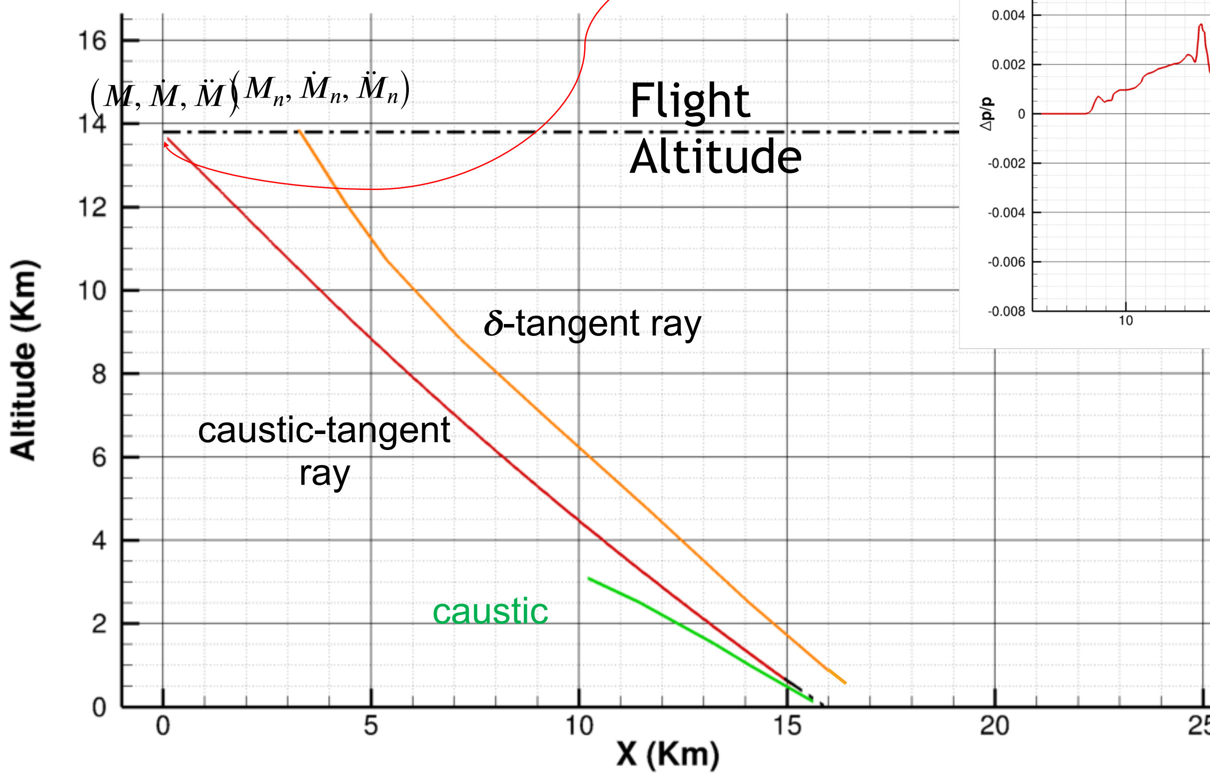

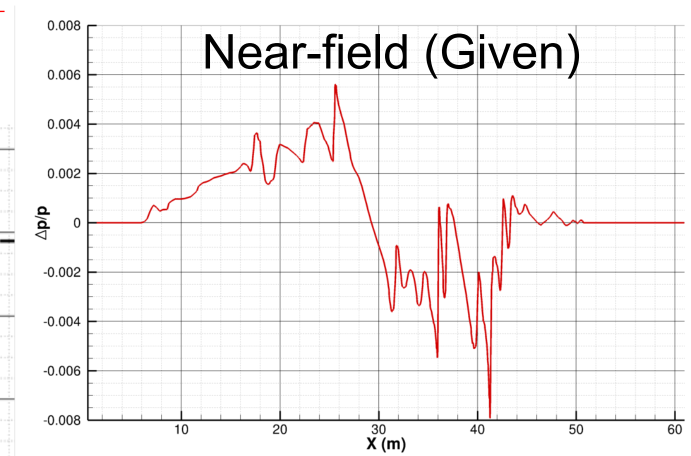

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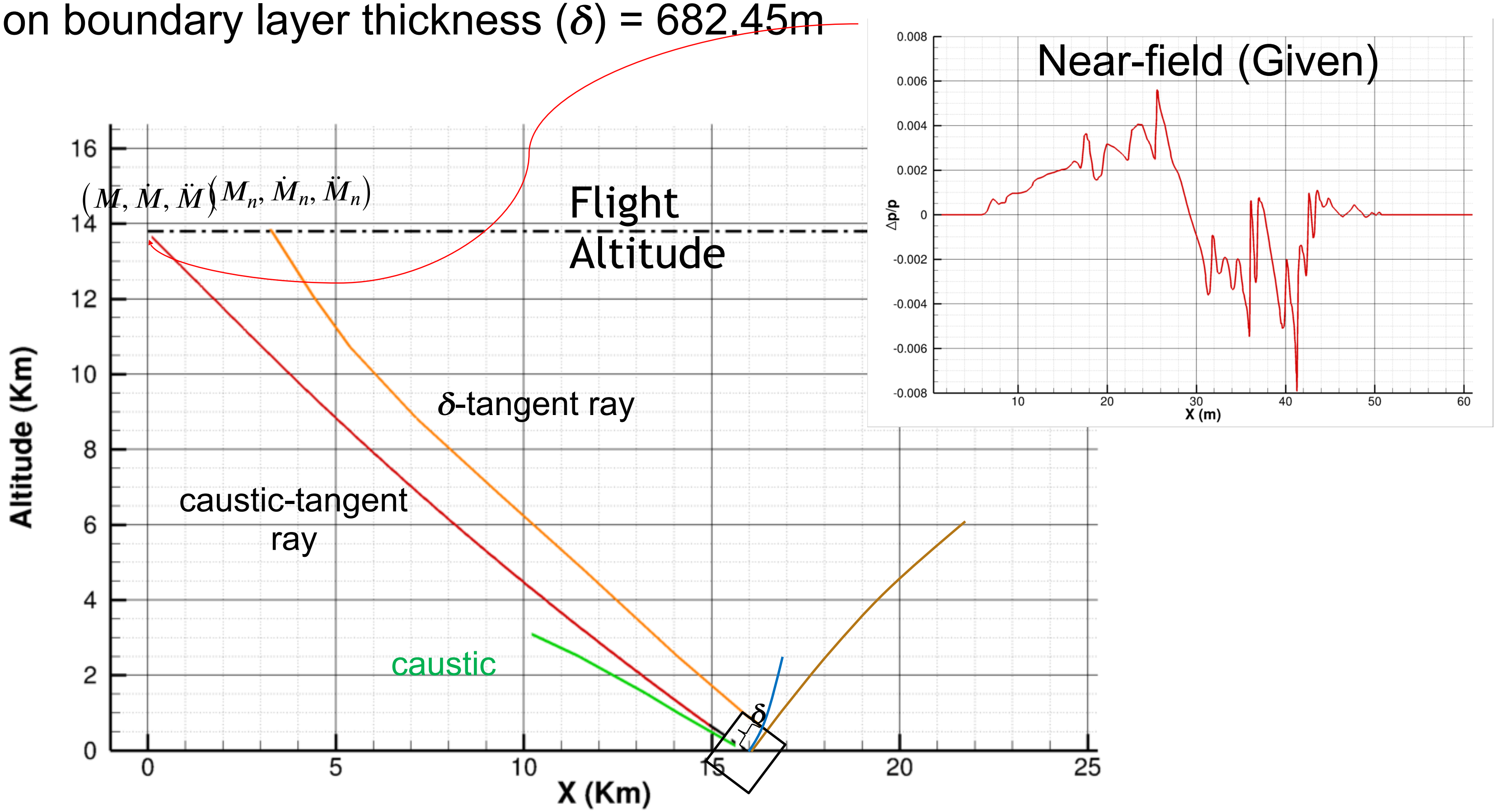

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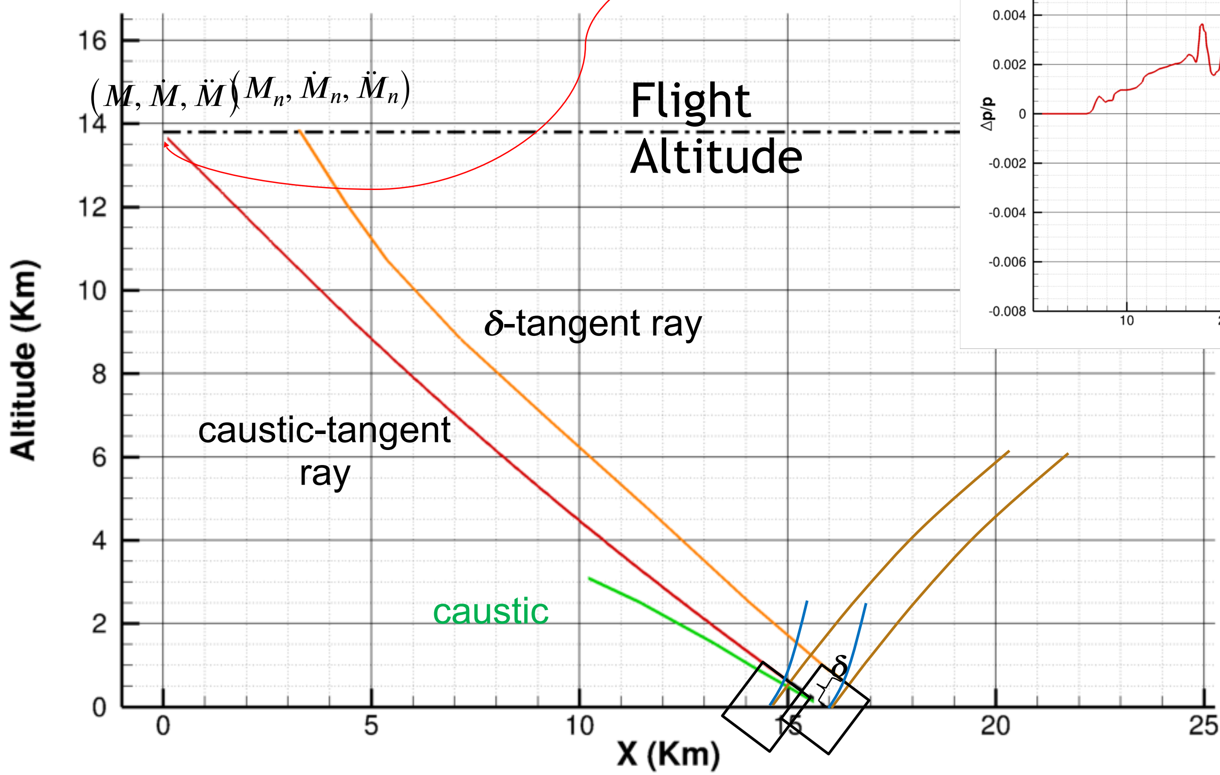

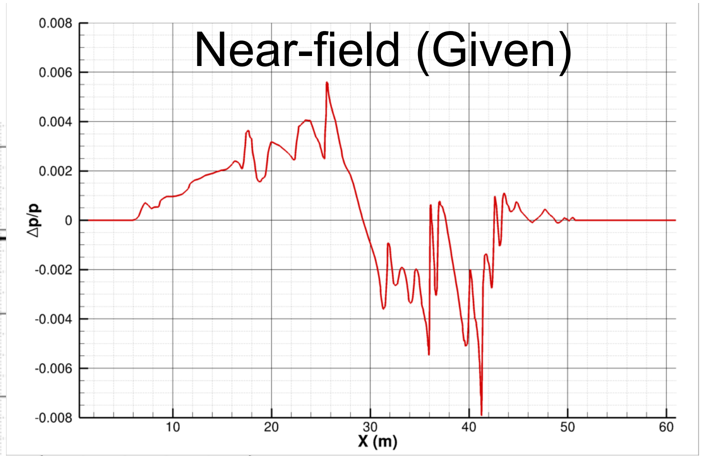

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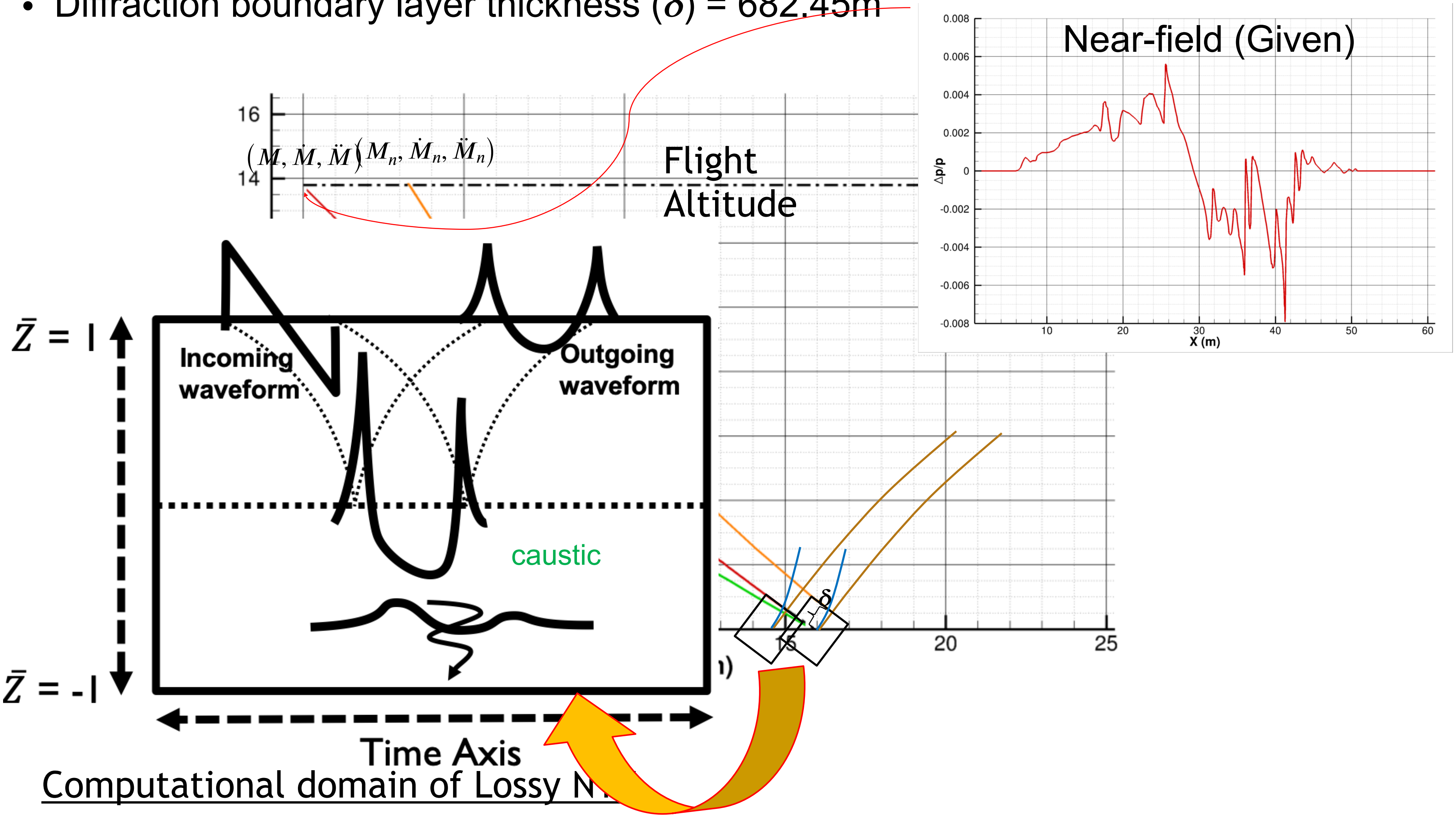

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$$\frac{\partial^2 P}{\partial \bar{Z}^2} - \bar{Z}\frac{\partial^2 P}{\partial \tau^2} + \frac{\mu}{2}\frac{\partial^2 P^2}{\partial \tau^2} + \left[\frac{\alpha}{\varepsilon^2} + \sum_{\nu} \frac{\theta_\nu/\varepsilon^2}{1+\tau_\nu \partial/\partial\tau}\right]\frac{\partial^3 P}{\partial \tau^3} = 0$$

Lossy NTE Model Equation as developed by Joe Salamone for the NASA Scamp Project

$$\mu = 2\beta\frac{P_{ac}}{\rho_0 c_0^2}\left(\frac{R_{tot} f_{ac}}{2c_0}\right)^{2/3} \qquad \varepsilon = \left(\frac{2c_0}{R_{tot} f_{ac}}\right)^{2/3} \qquad R_{tot} \approx R_{cau} = \frac{2\delta^3 f_{ac}^2}{c_0^2}$$

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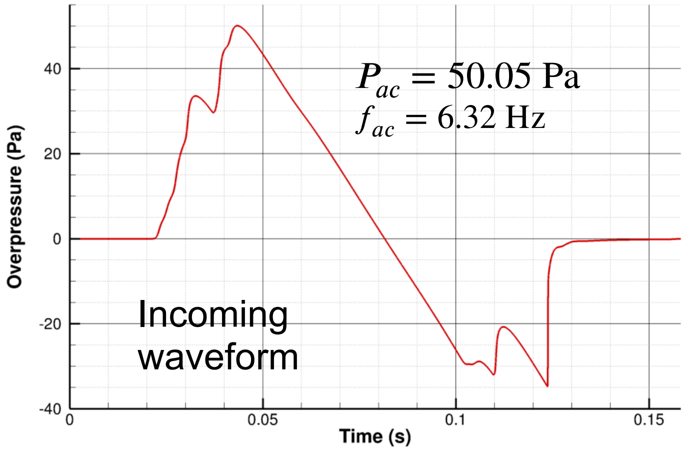

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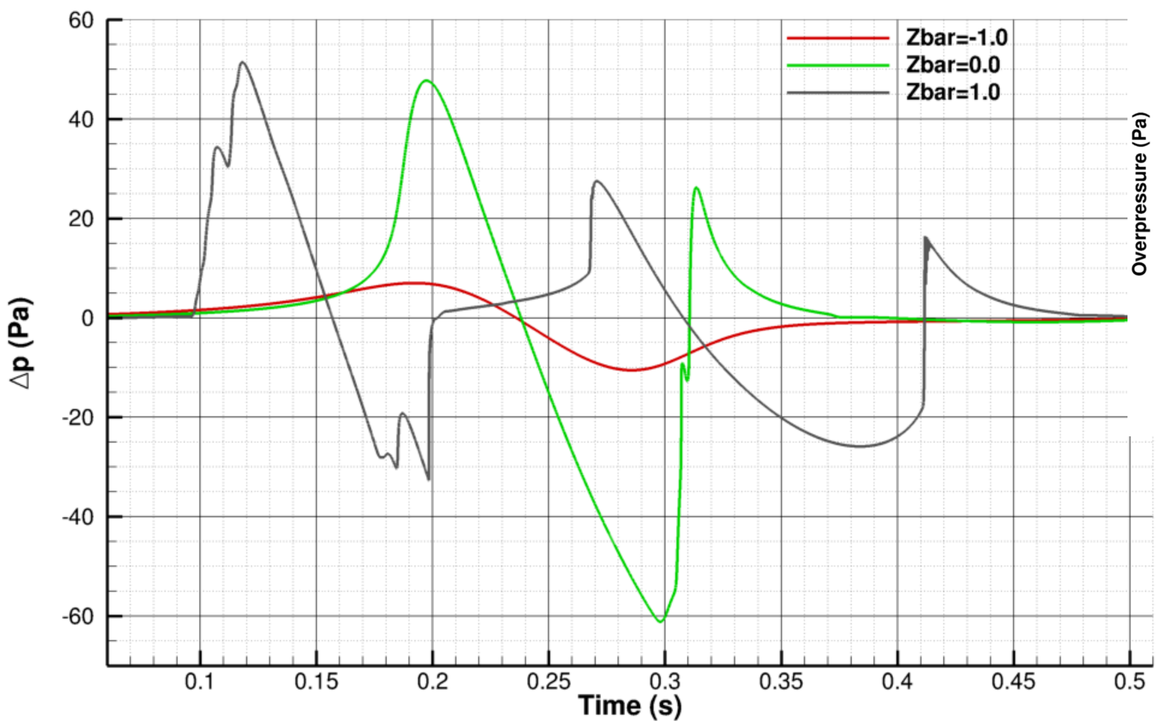

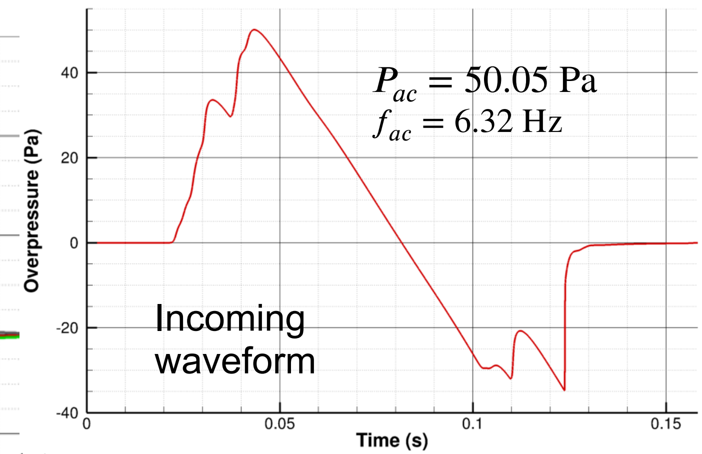

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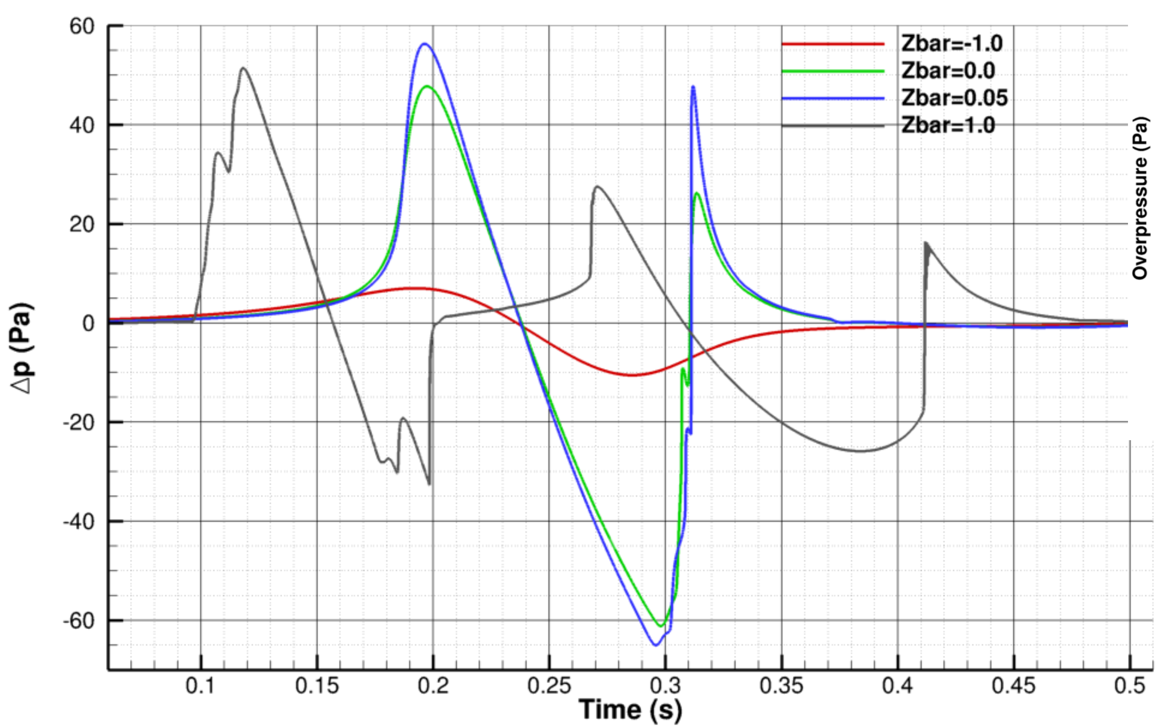

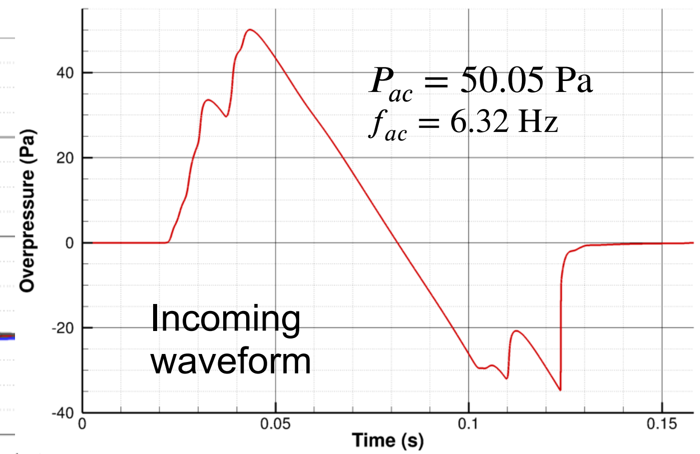

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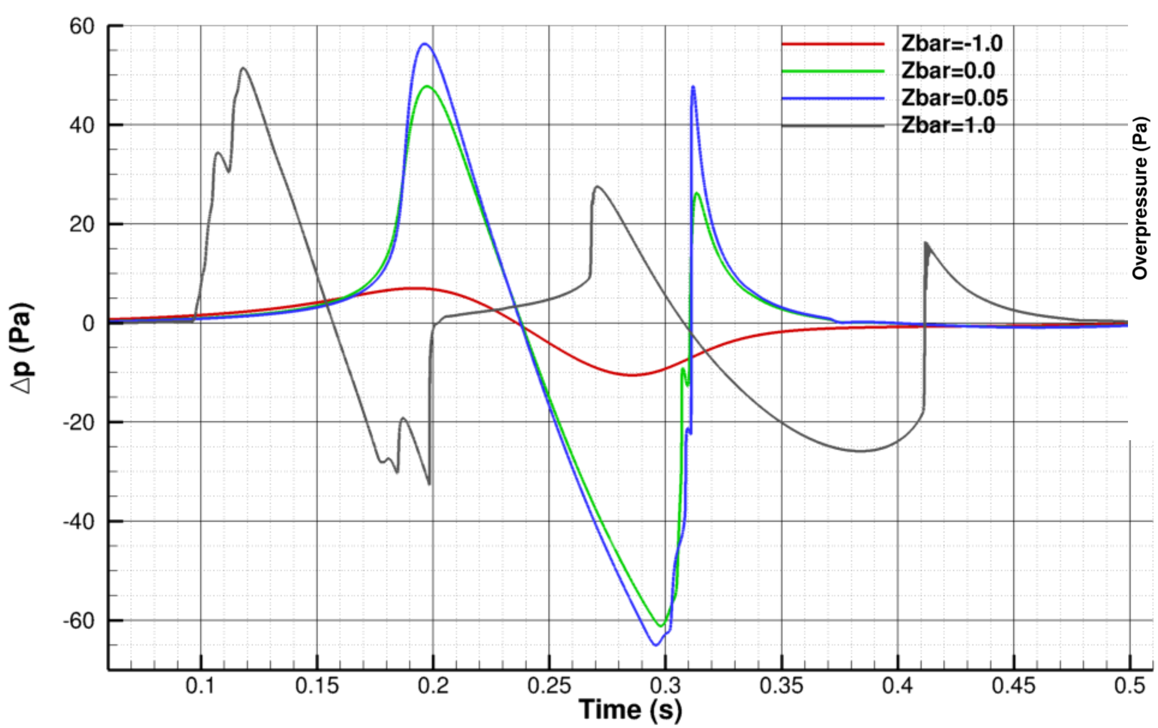

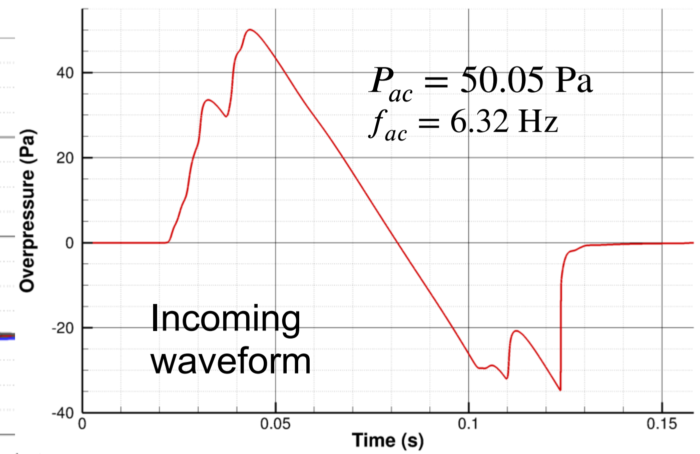

Zbar=0.0: PL = 97.8 dB

Zbar=0.05: PL = 106.8 dB

Zbar=1.0: PL = 101.0 dB

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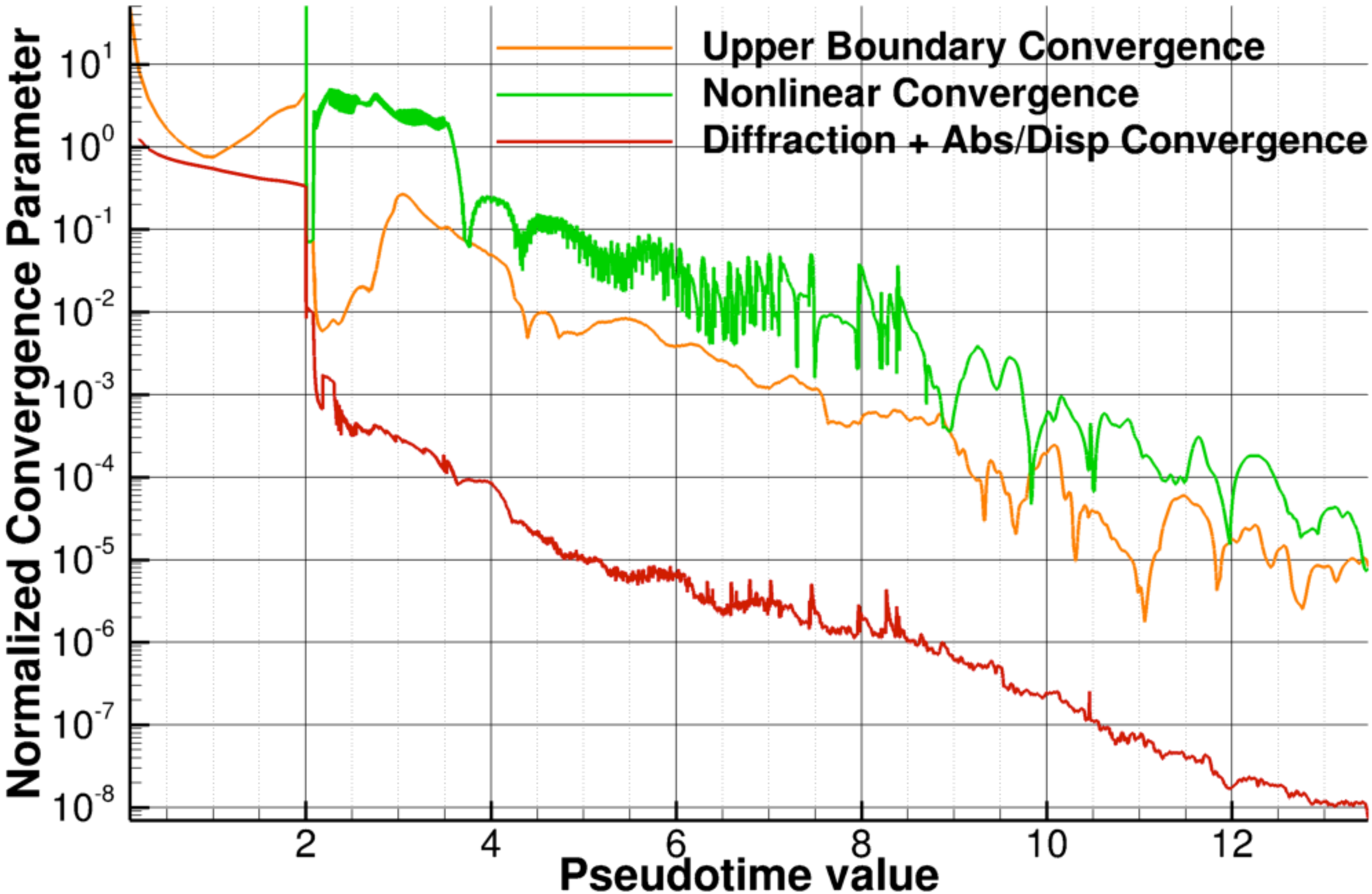
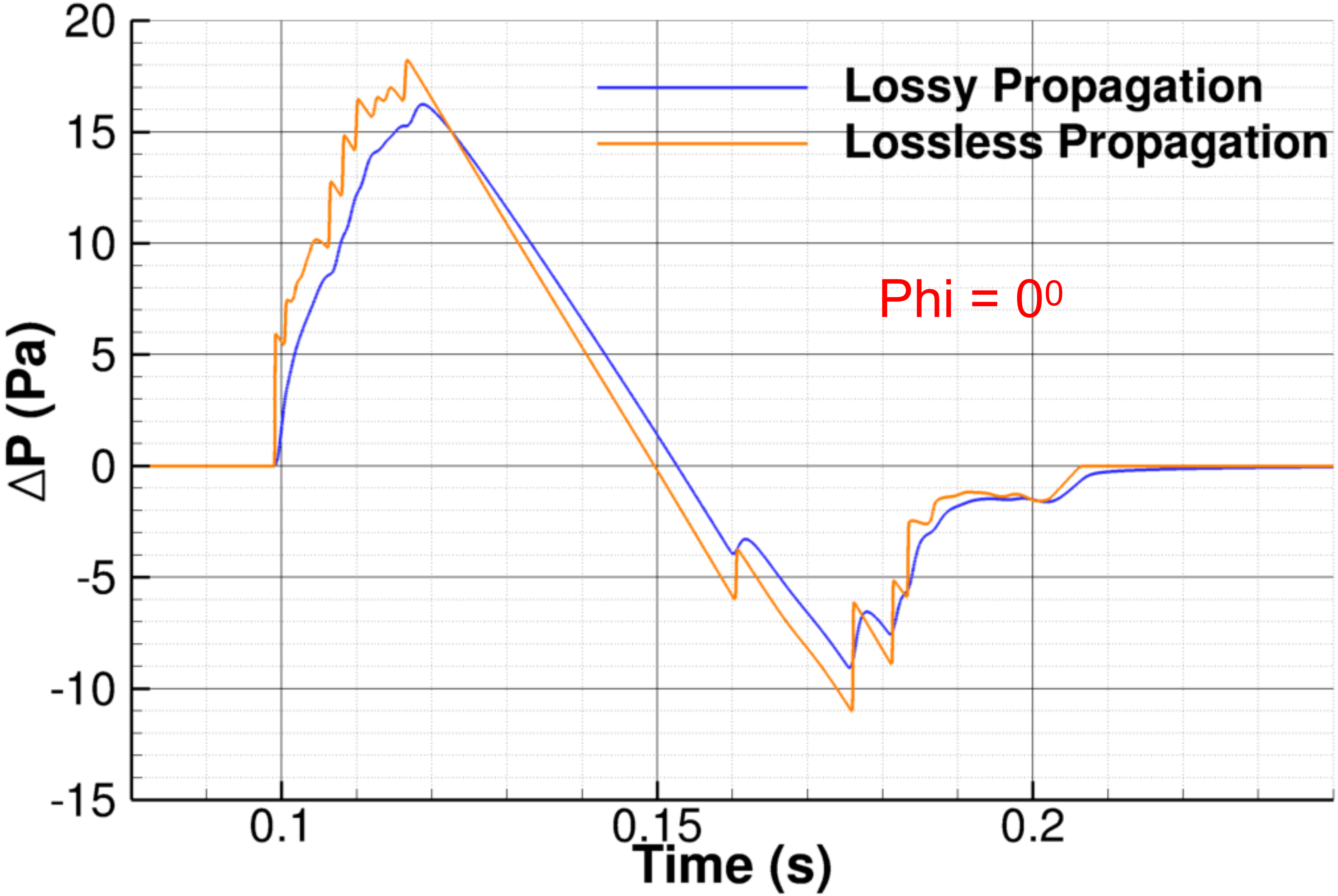


Highlights

- Lossy vs Lossless propagation
- Signature Evolution
- Modeling Non-linearity
- Loudness build-ups
- Loudness Gradients

Highlights: Lossless vs Lossy



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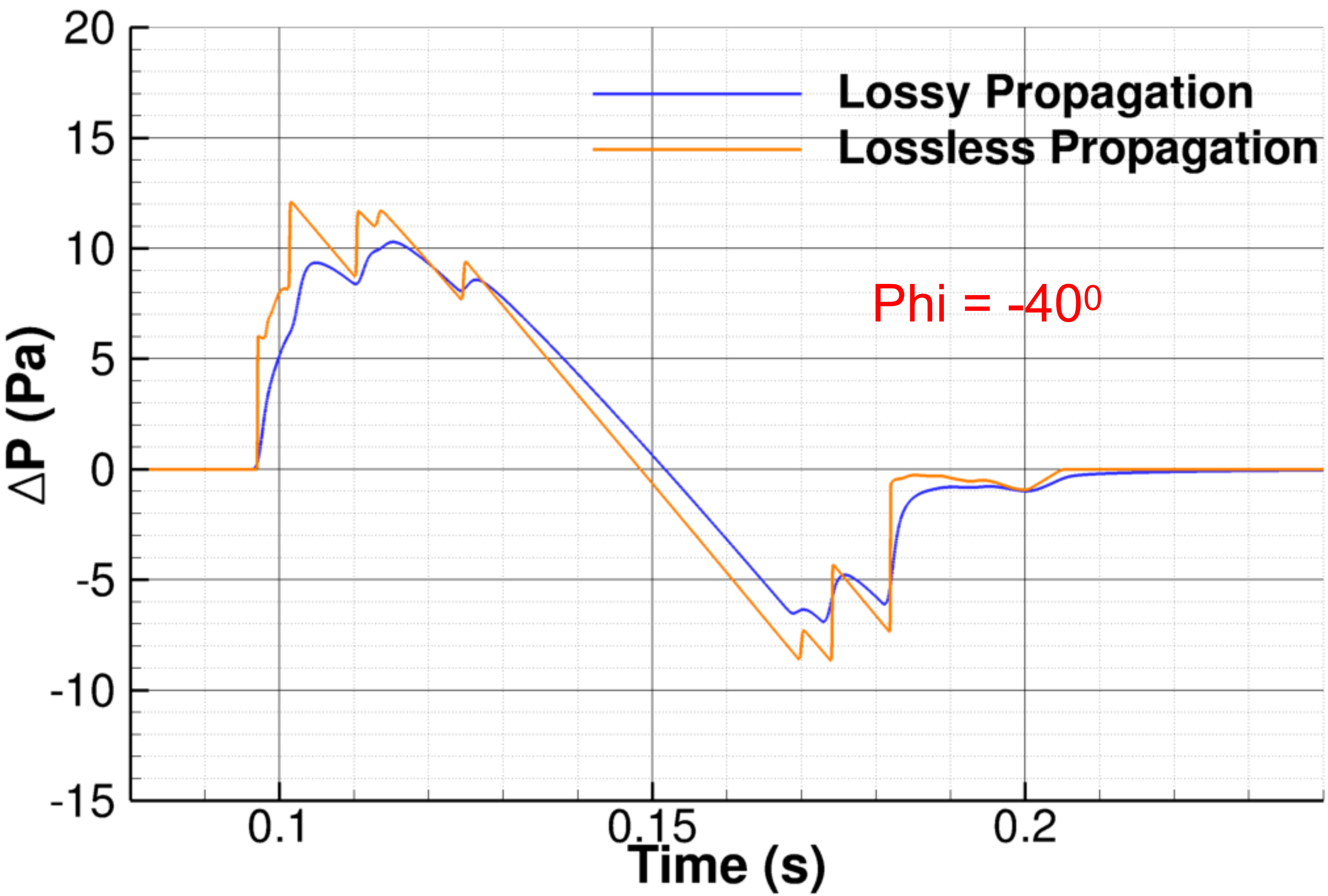

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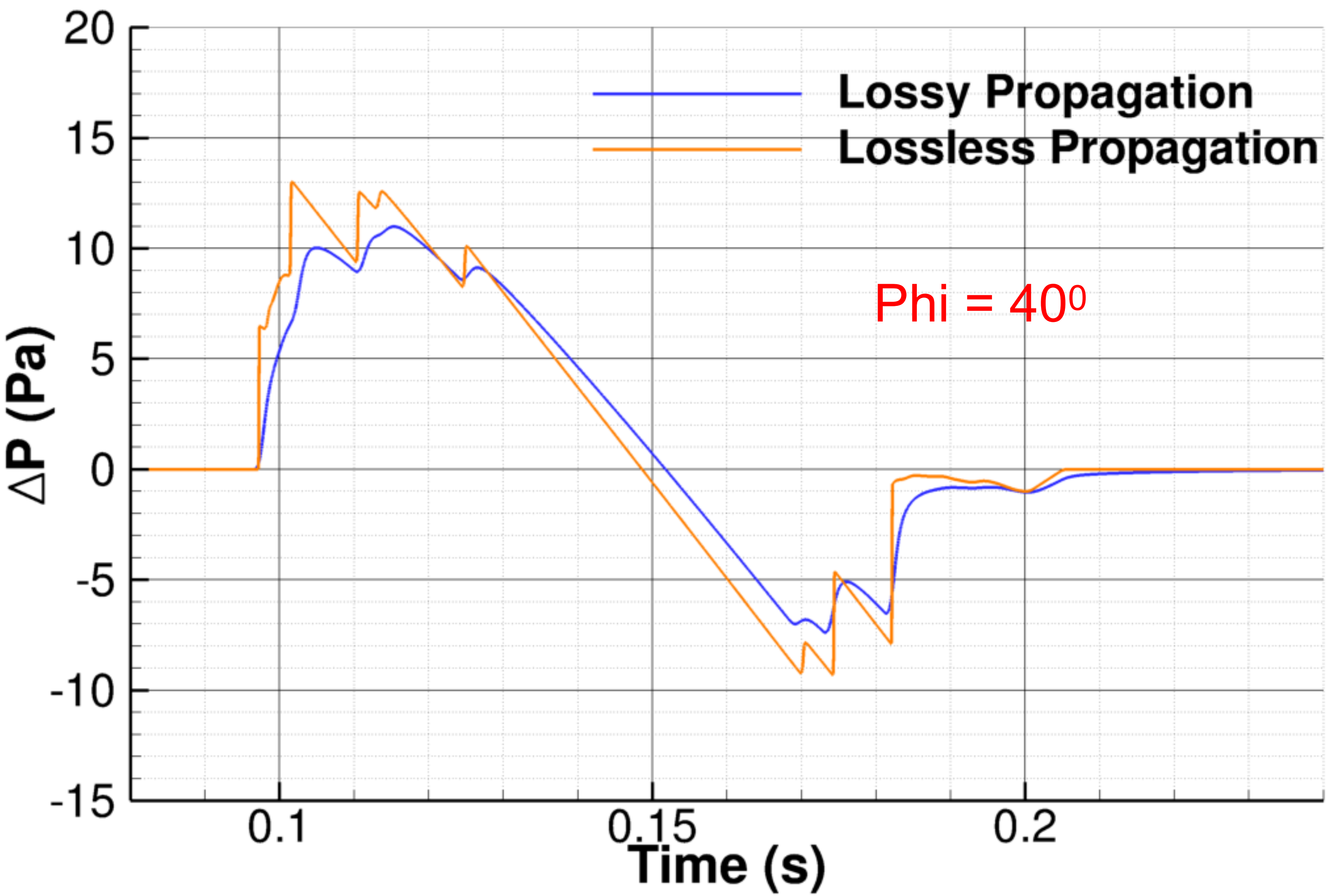

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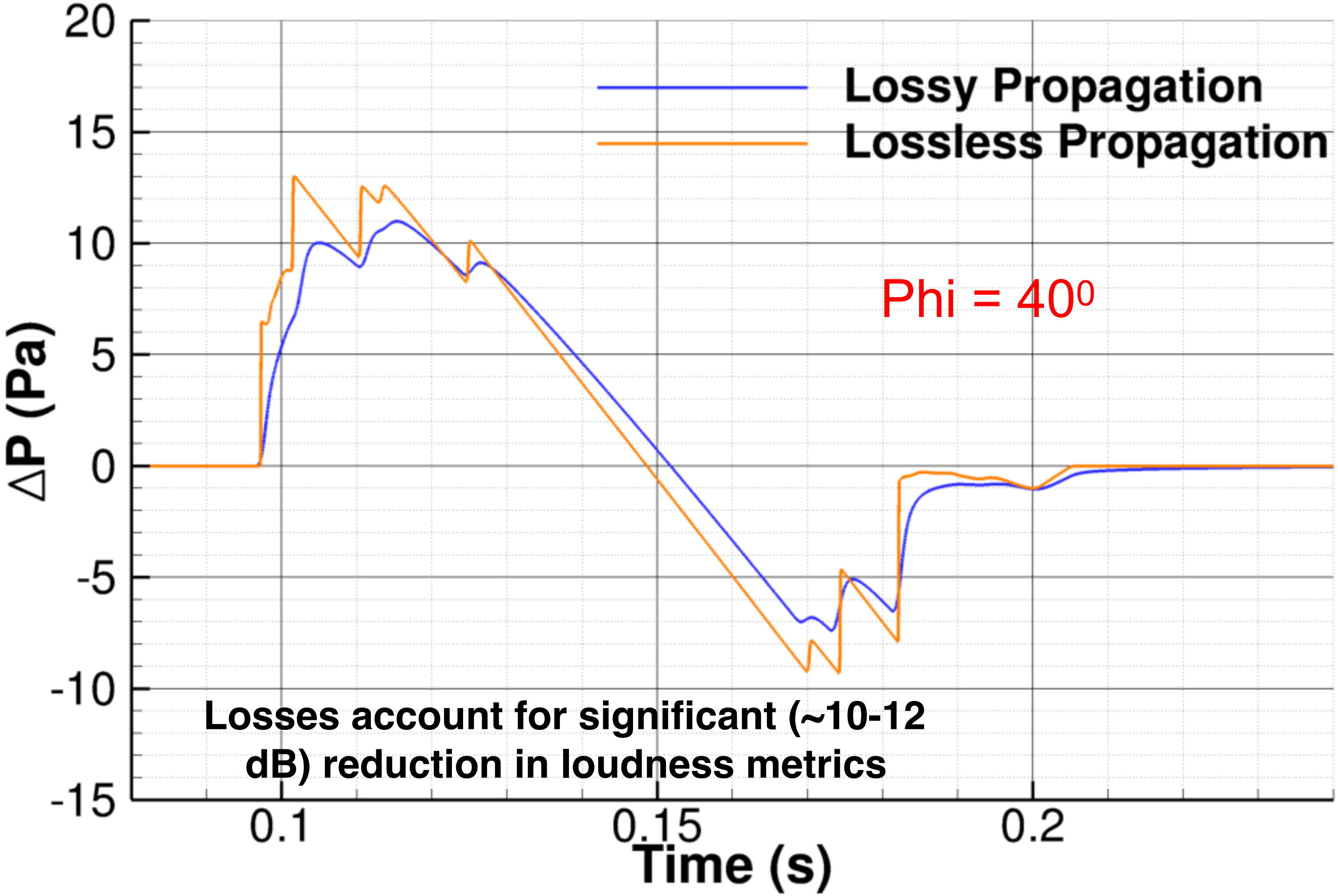

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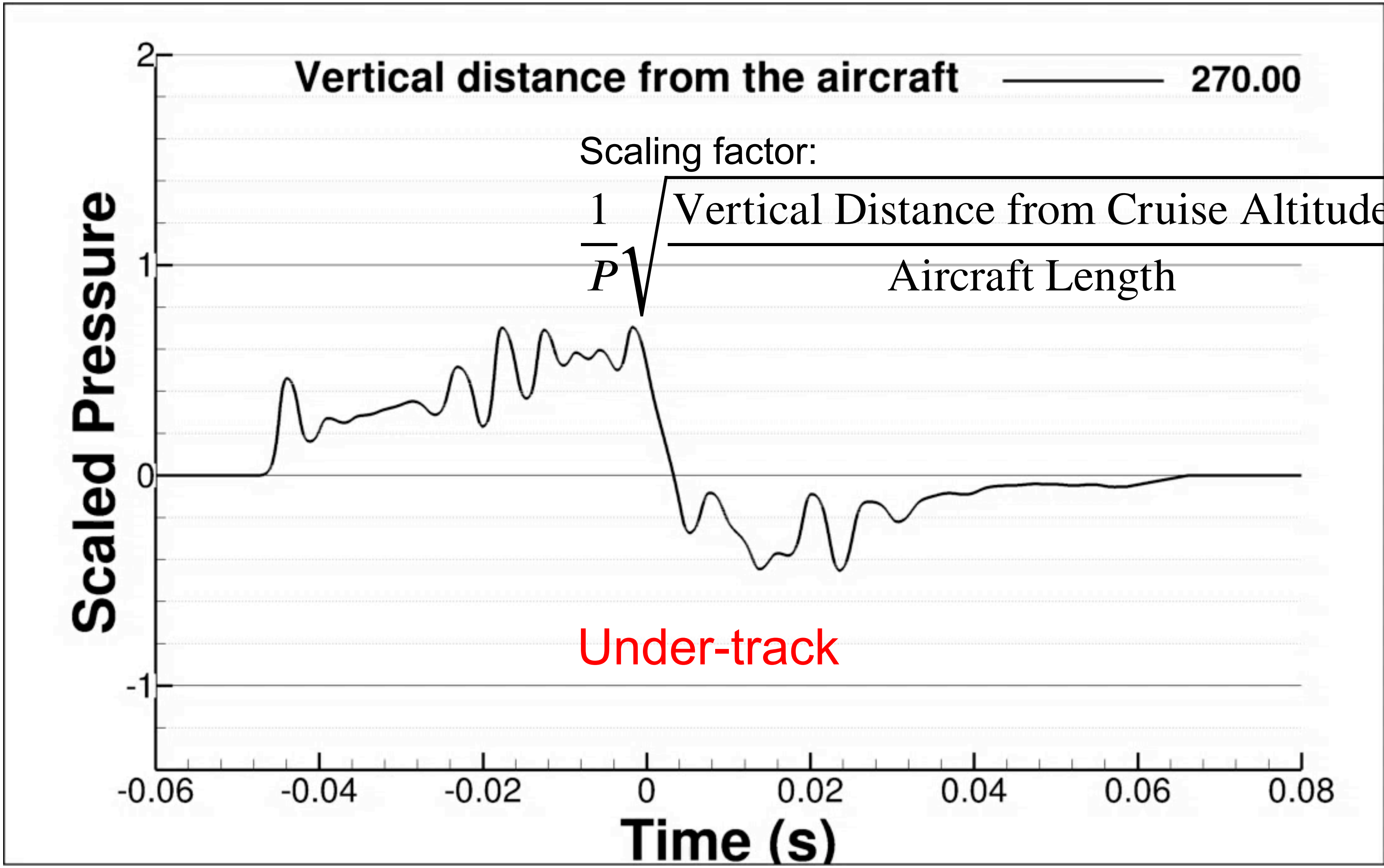

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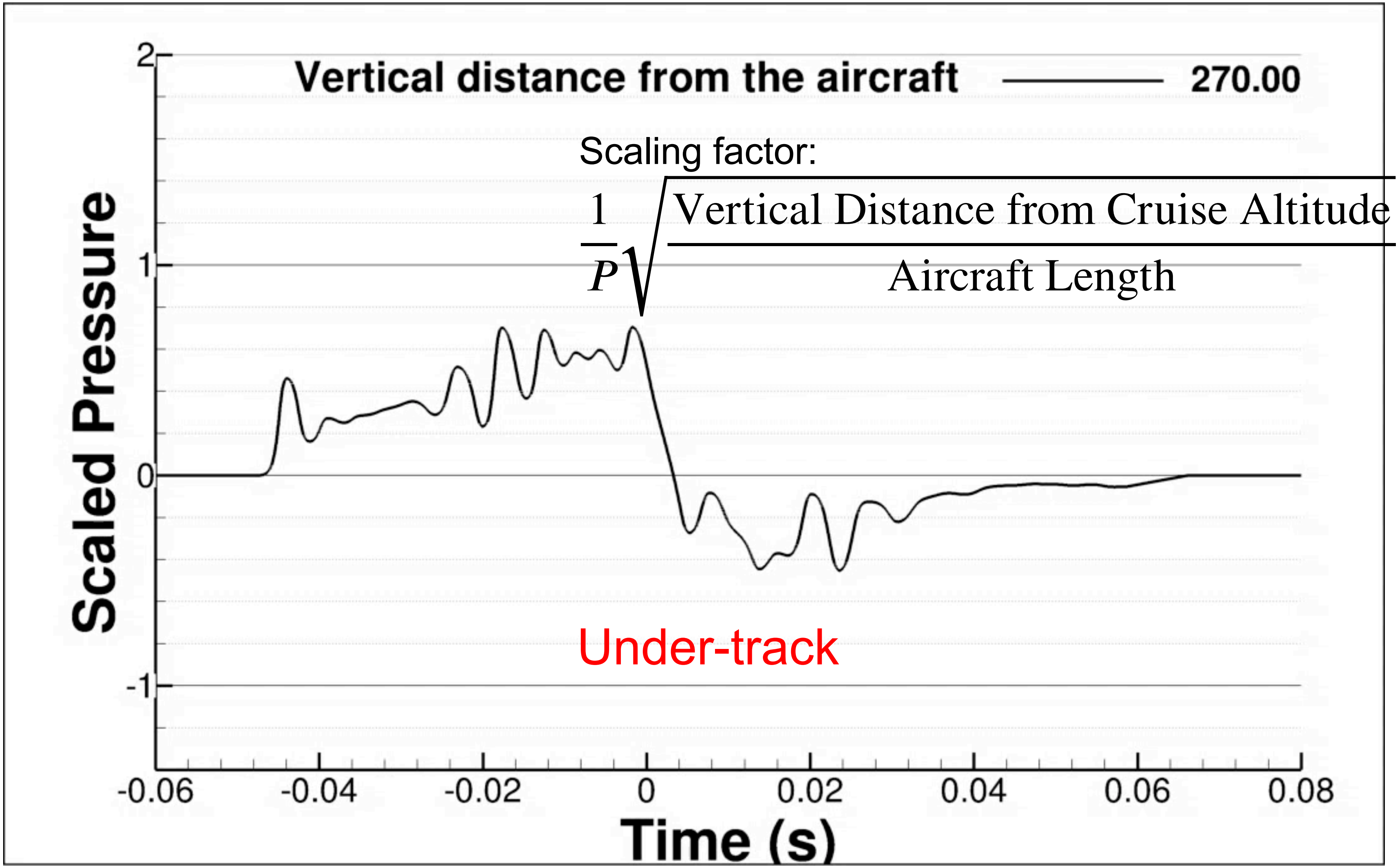

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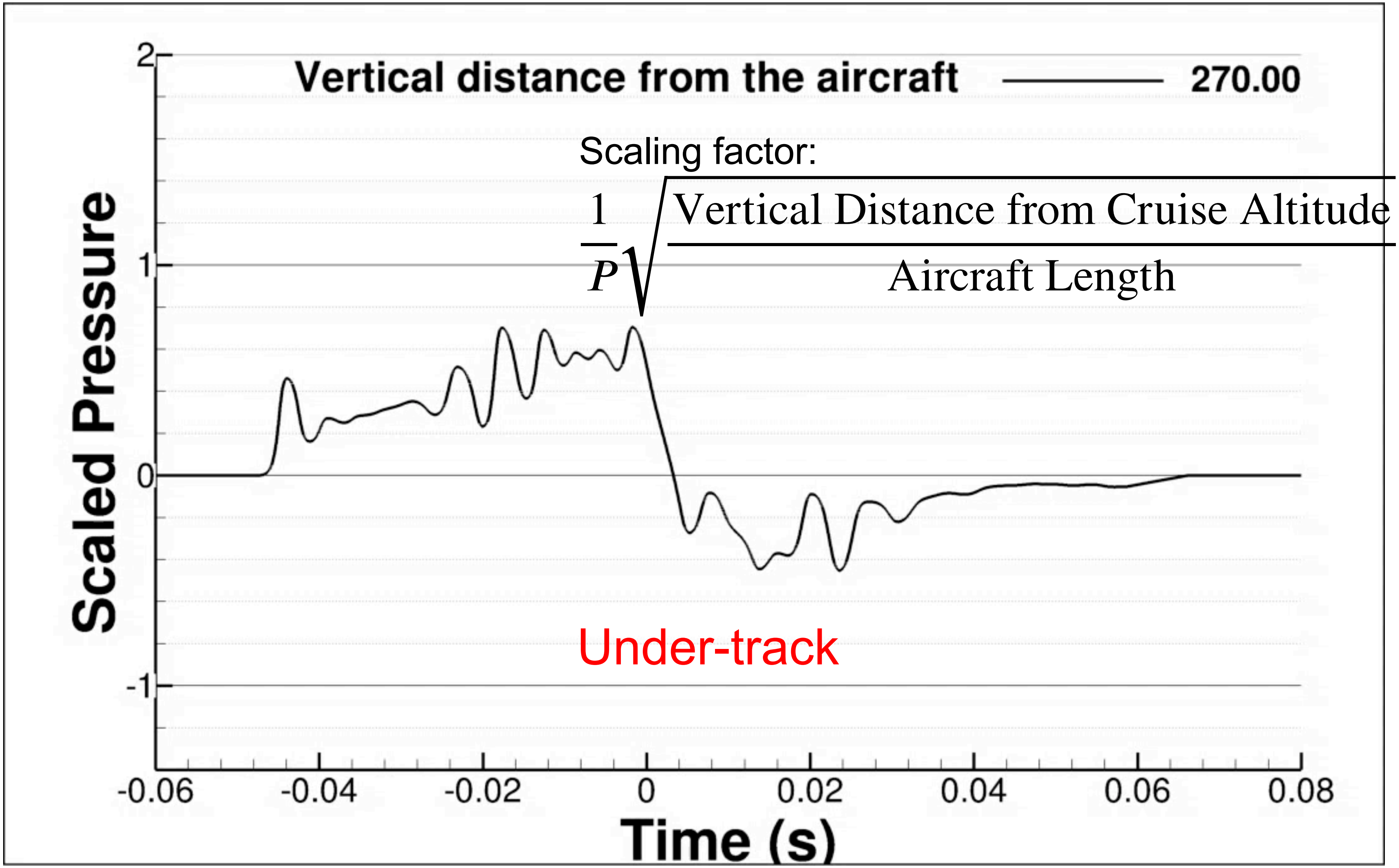

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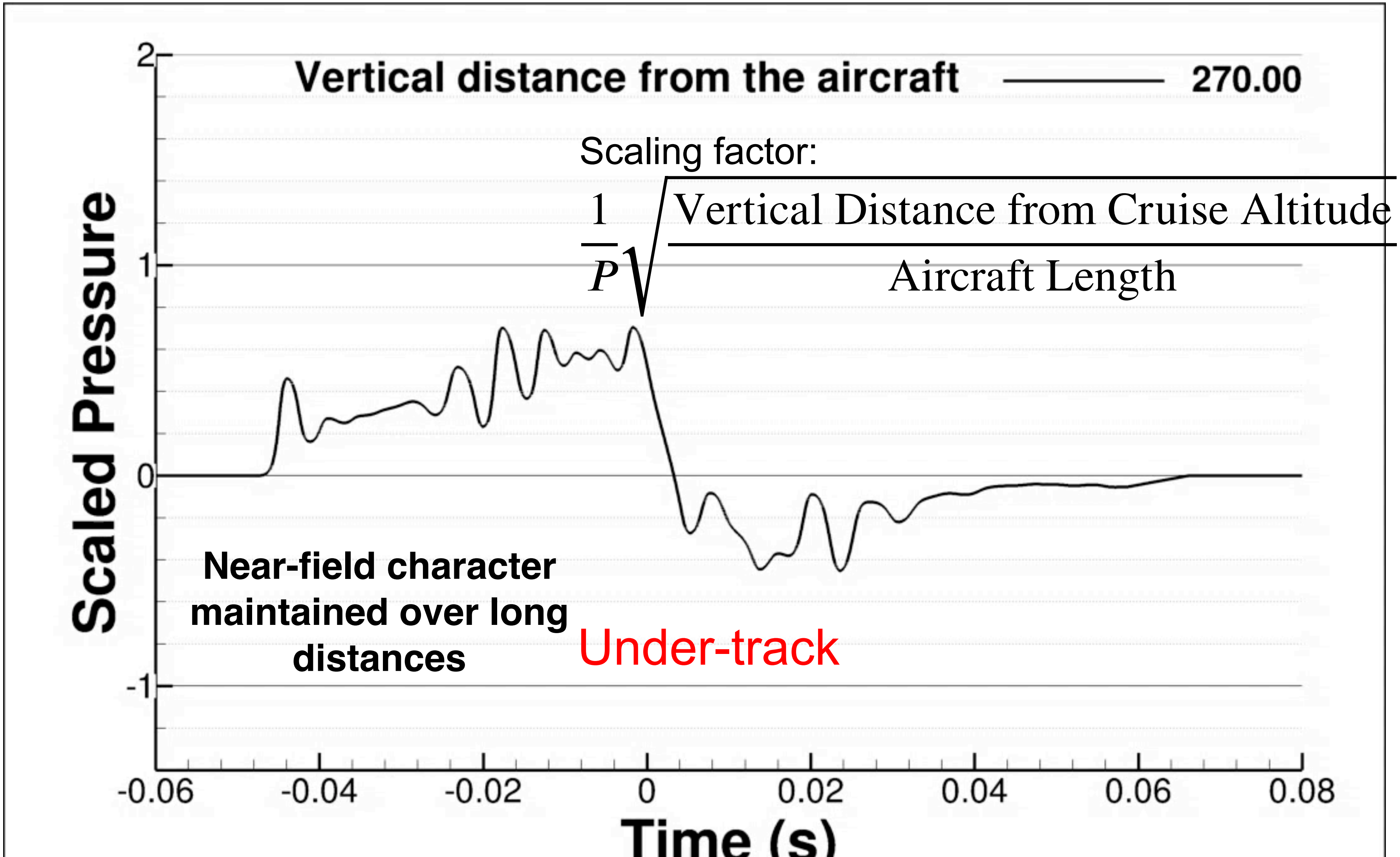

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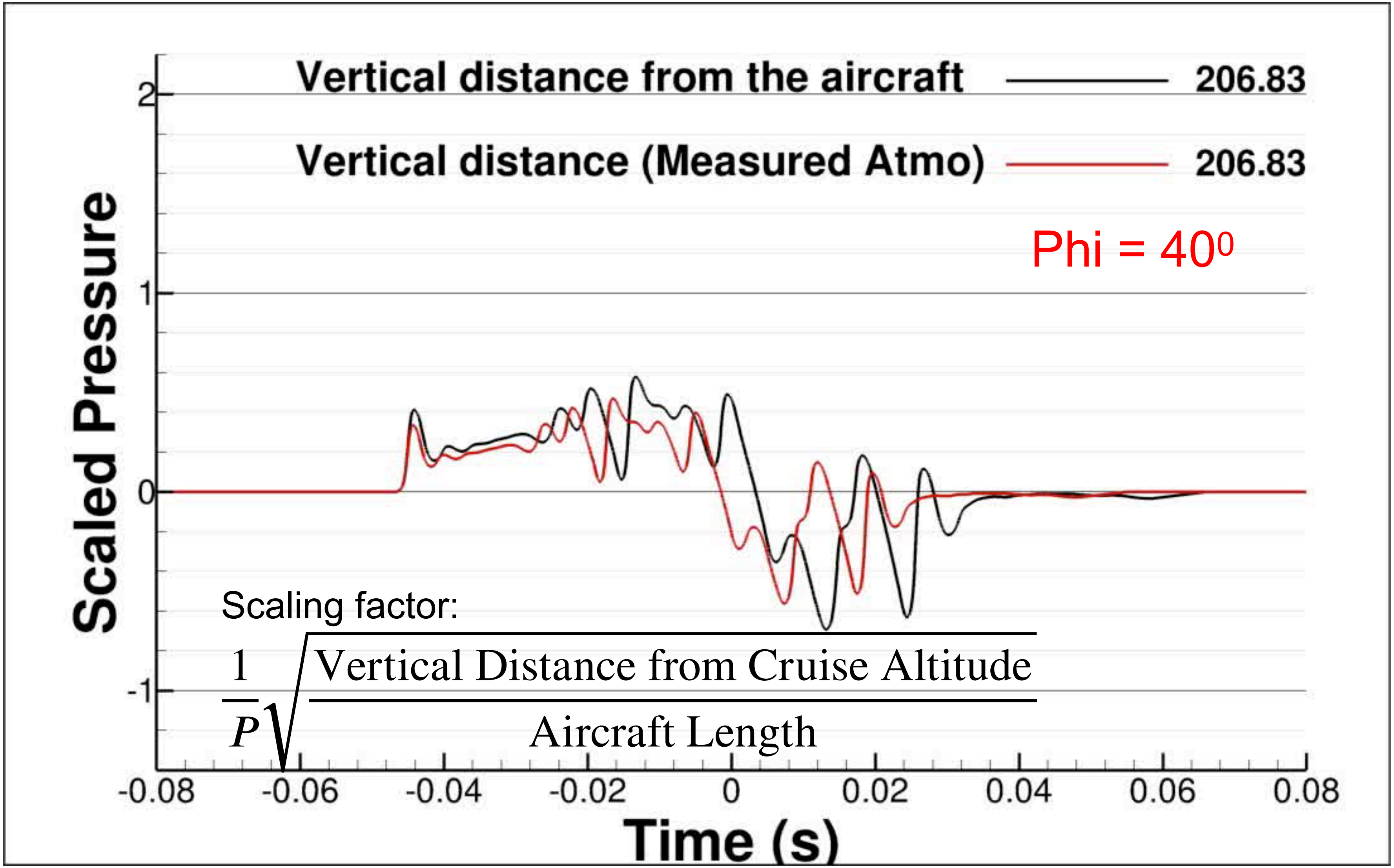

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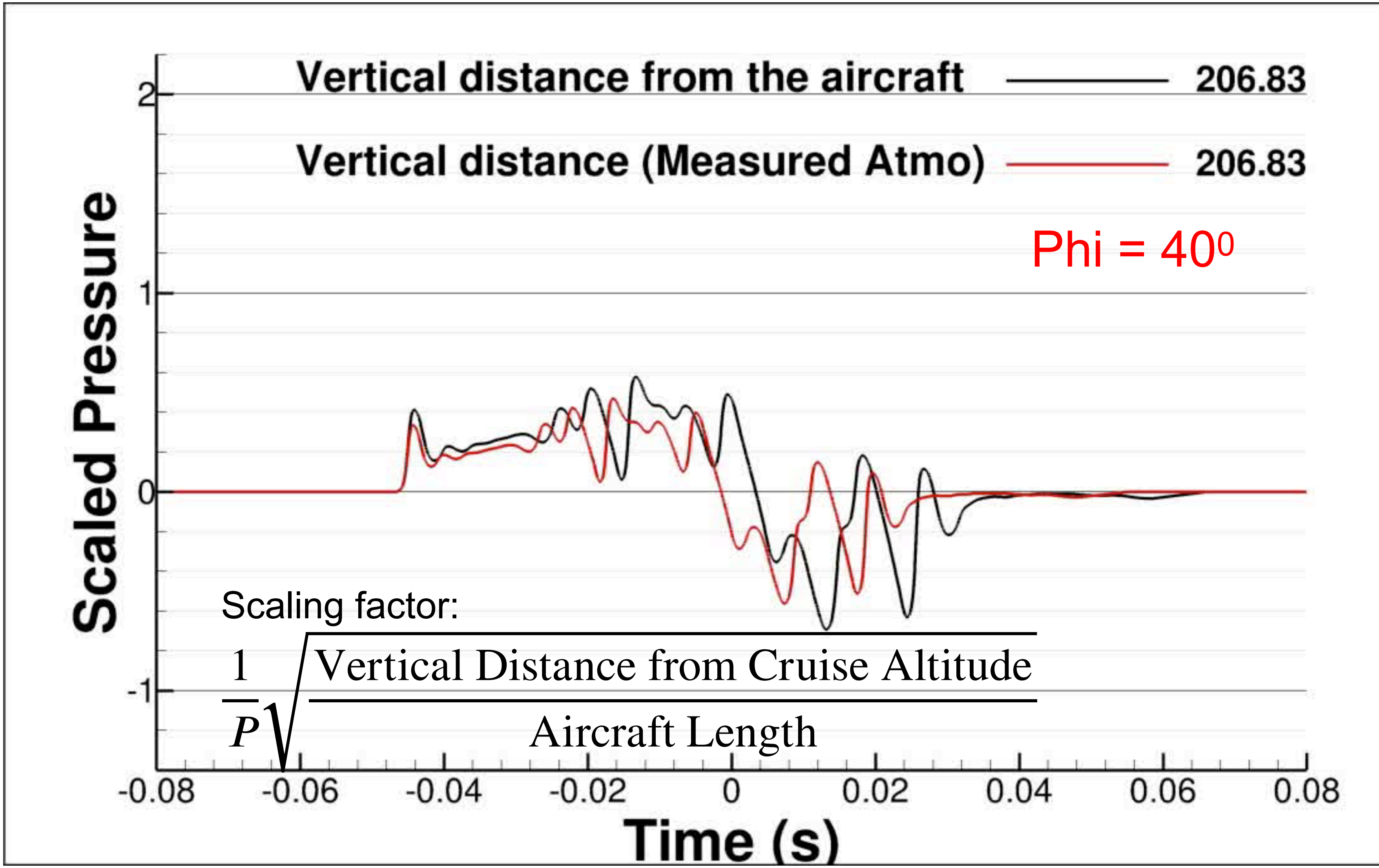

$$\frac{1}{P}\sqrt{\frac{\text{Vertical Distance from Cruise Altitude}}{\text{Aircraft Length}}}$$

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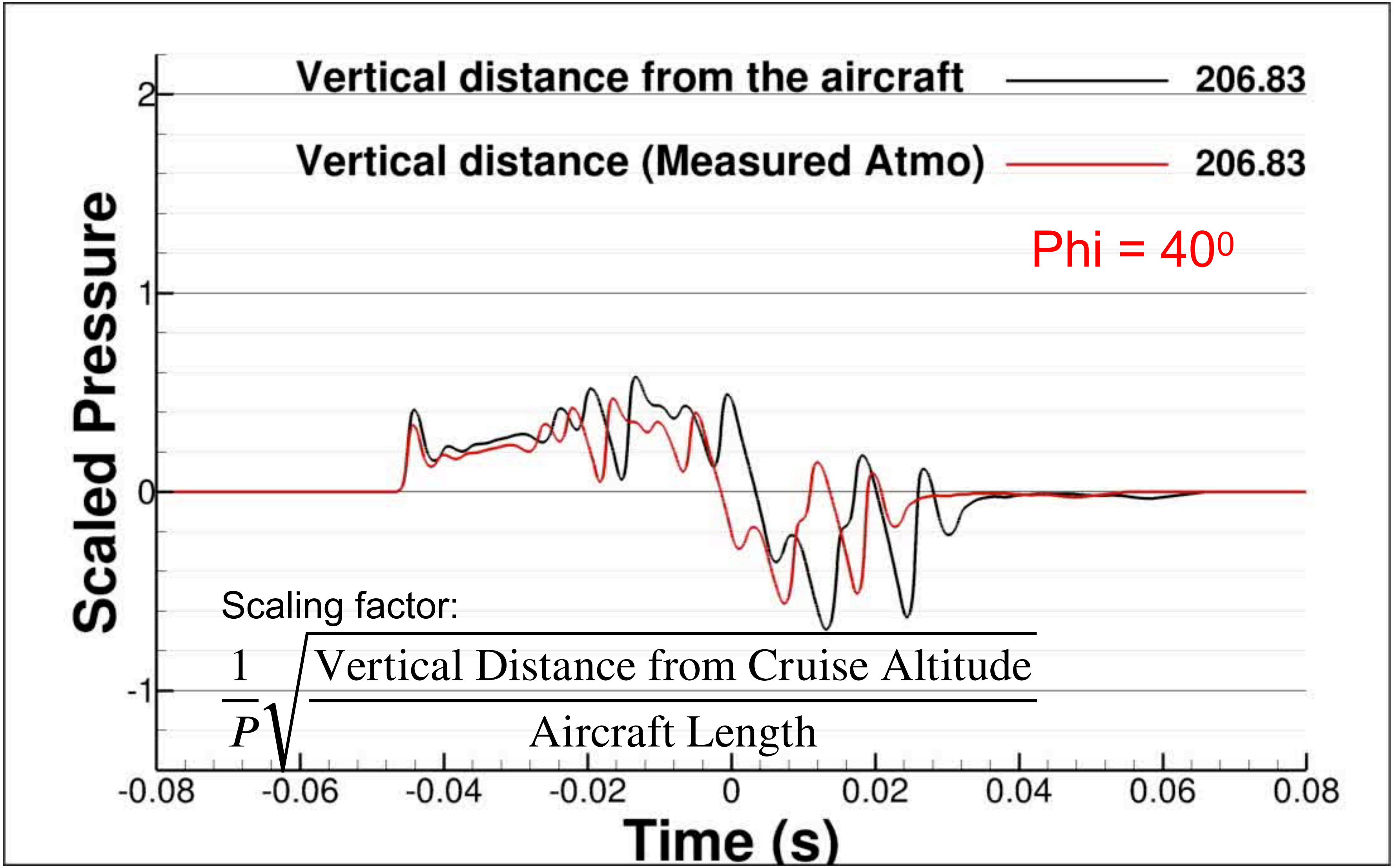

Highlights: Modeling Non-linearity

Acoustic Potential formulation vs Poisson Implementation

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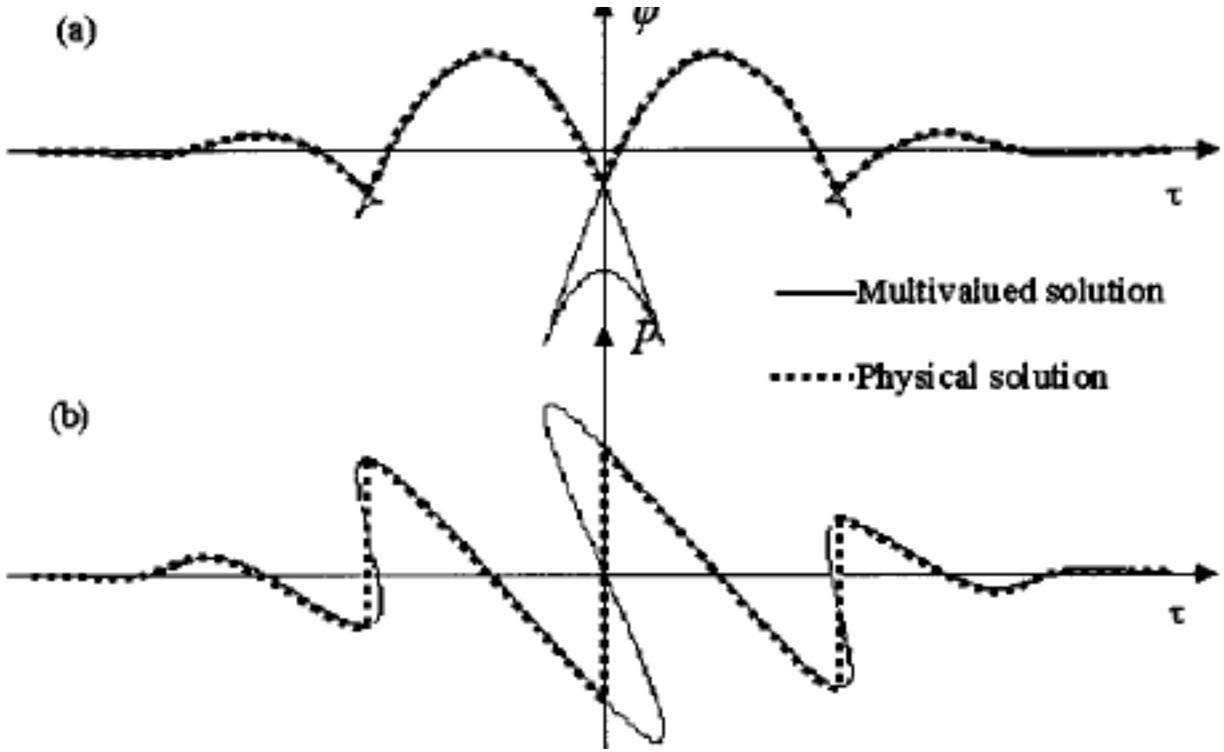
Acoustic Potential formulation vs Poisson Implementation

$$\phi(t,\tau)=\phi_0(\theta)-\frac{\mu t}{2}(p_0(\theta))^2.$$

$$\phi(t,\tau)=\max\left\{\phi_0(\theta)-\frac{\mu t}{2}(p_0(\theta))^2\right\}.$$



"Numerical Simulation of Shock Wave Focusing at Fold Caustics, with application to Sonic Boom", Marchiano, R., Coulouvrat, F., Grenon, R., JASA, 114, 1758 (2003), doI: 10.1121/1.1610459

Highlights: Modeling Non-linearity

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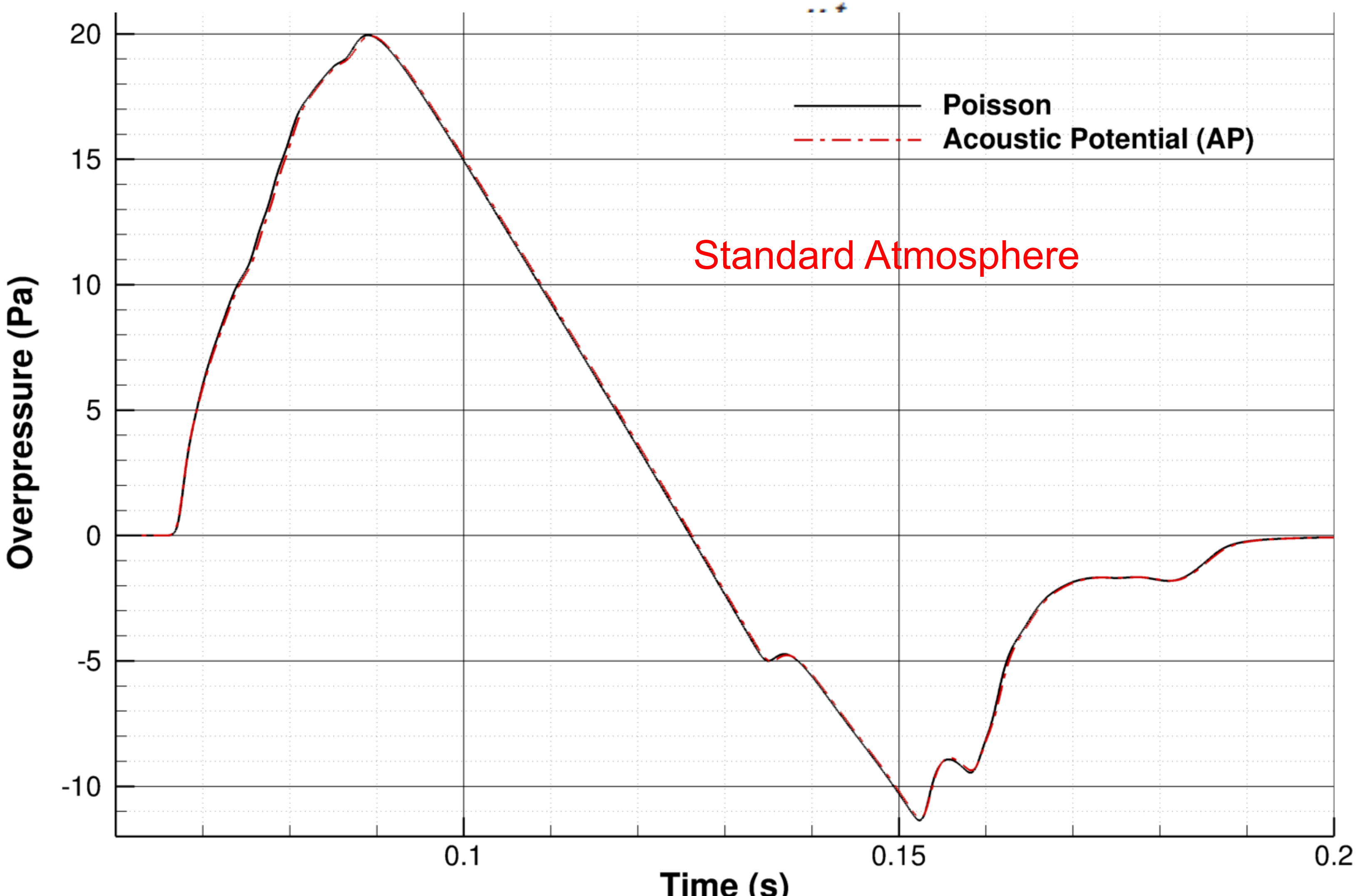

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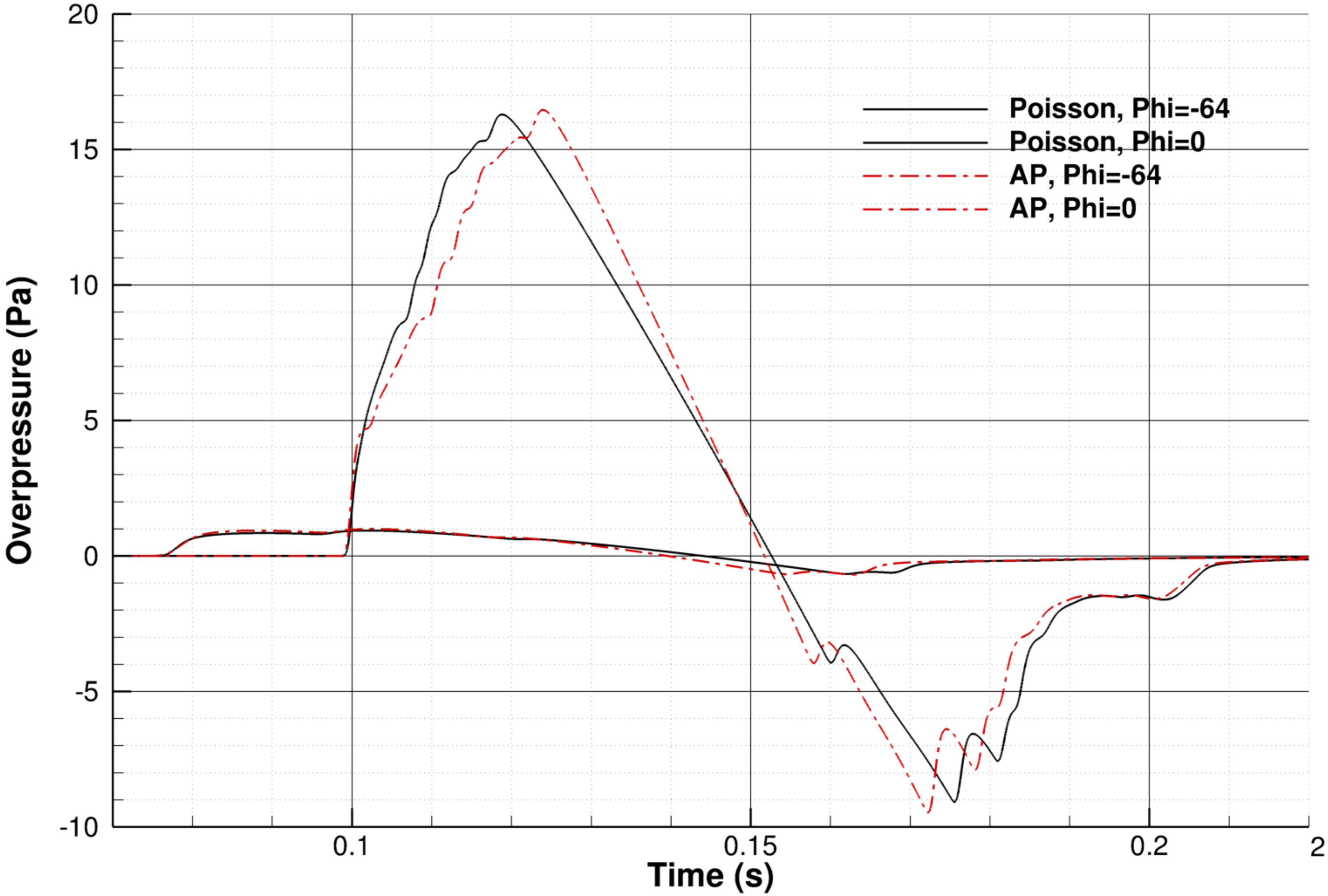

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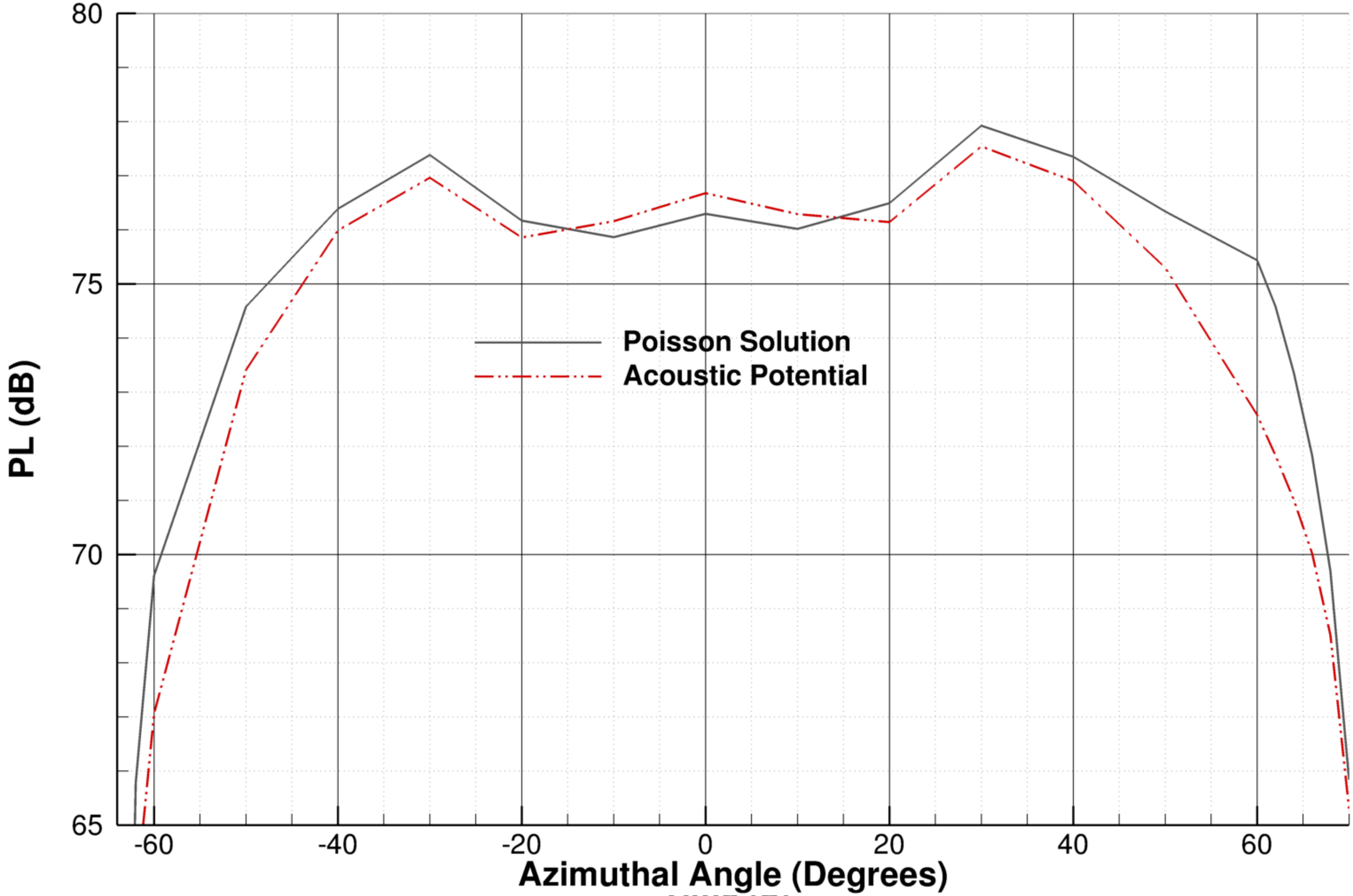

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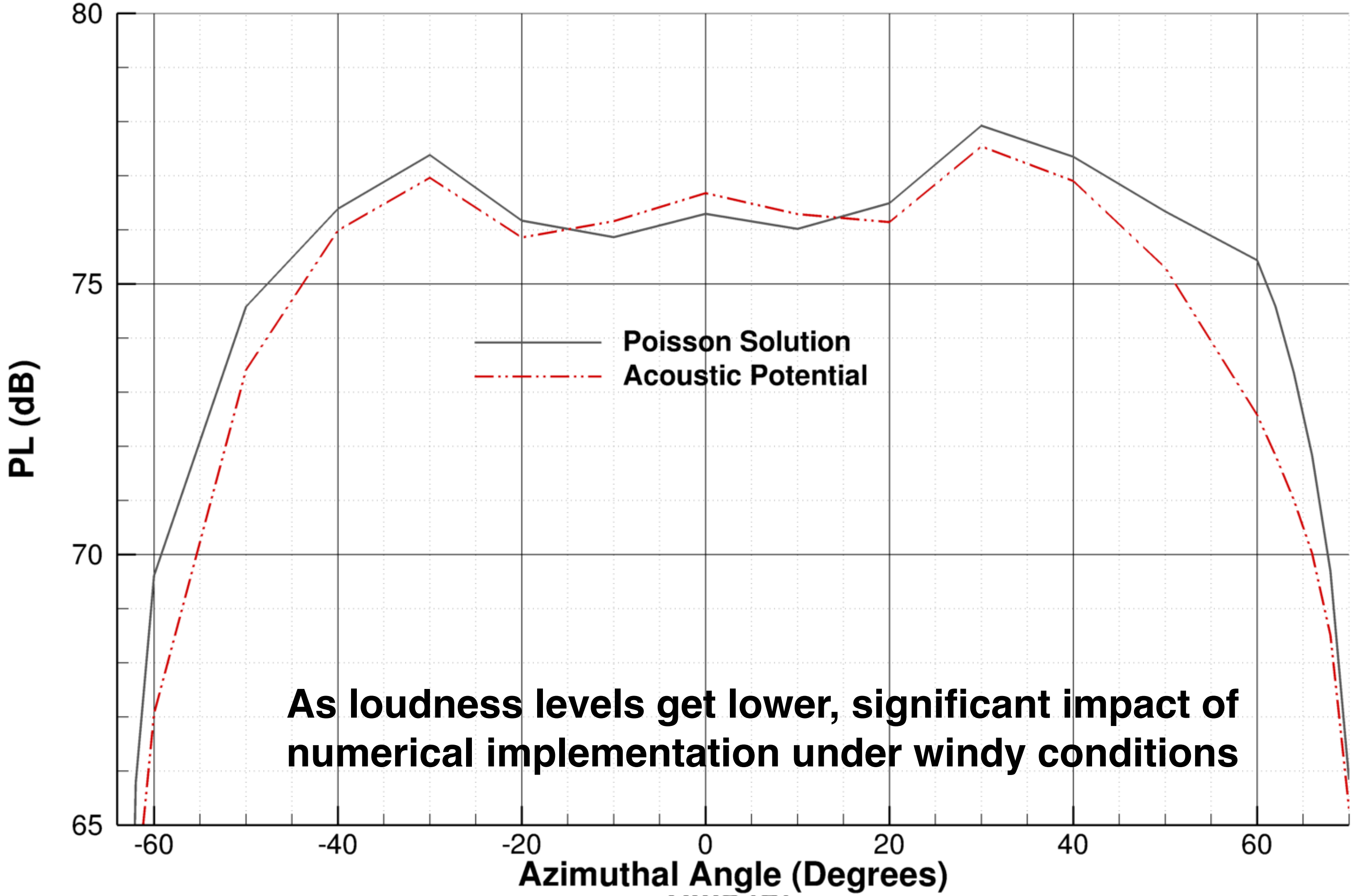

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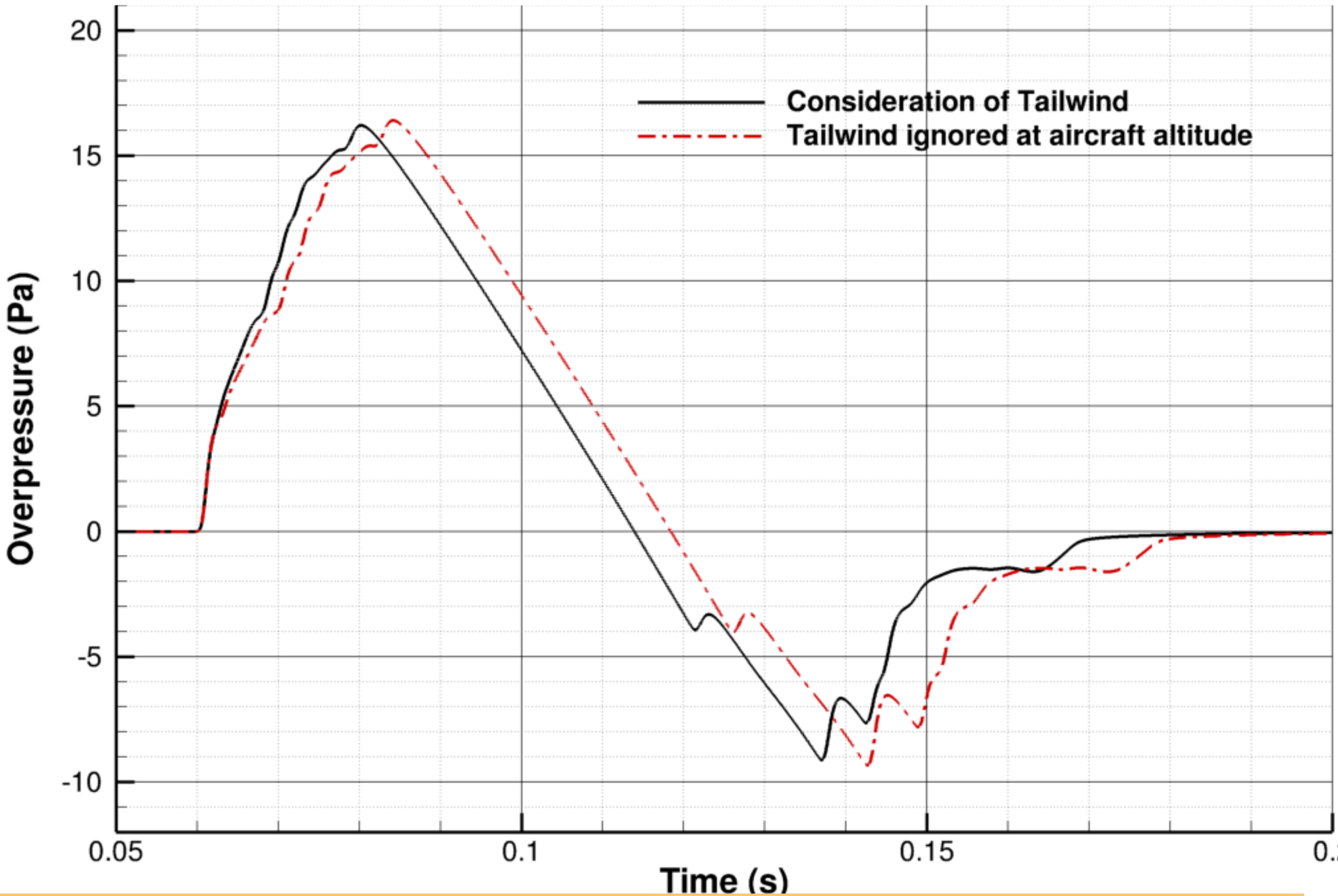
Highlights: Modeling Wind

- Based on provided data, there is a large tailwind at the cruise altitude
  - Tailwind accounts for almost 10% of the speed of sound



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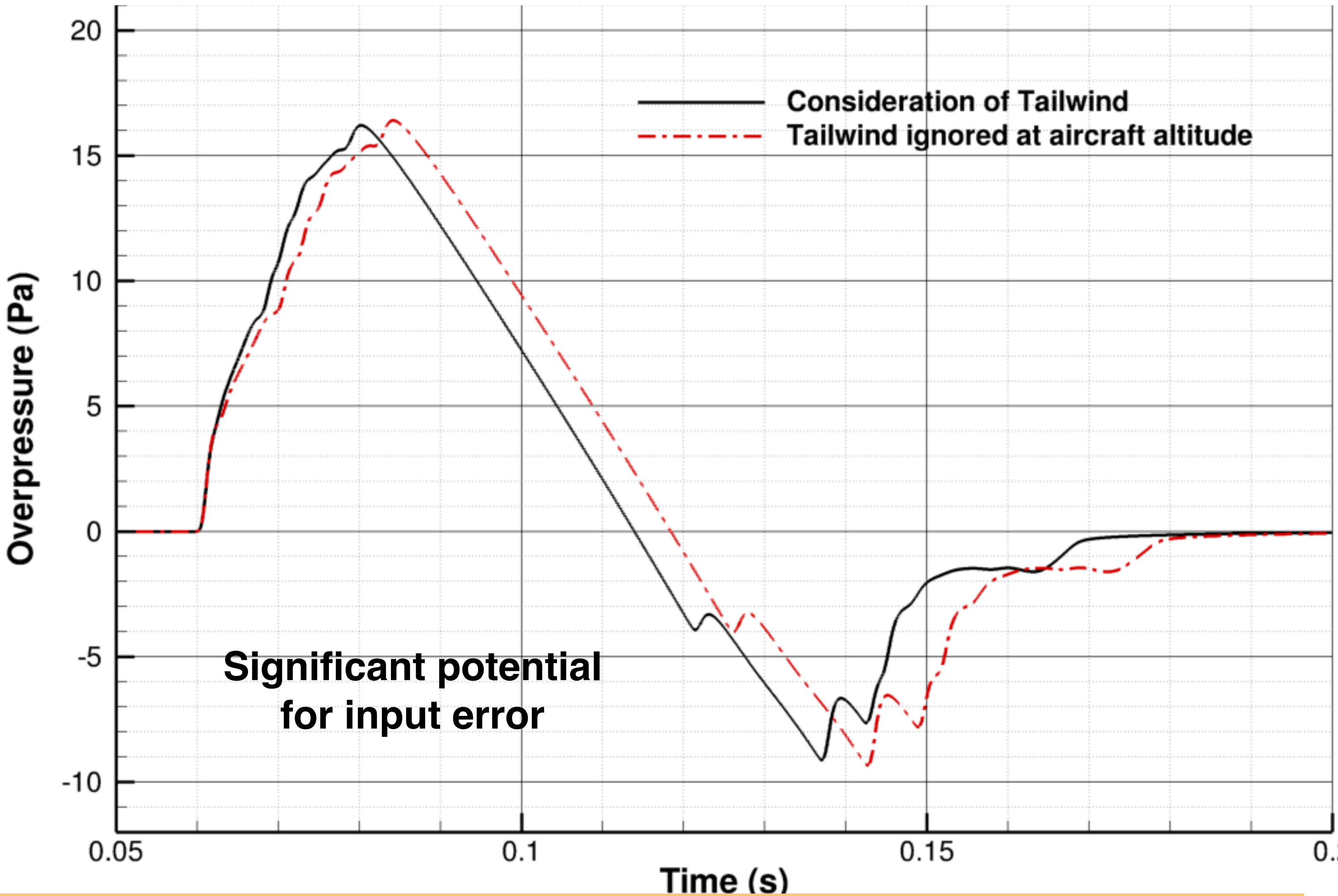
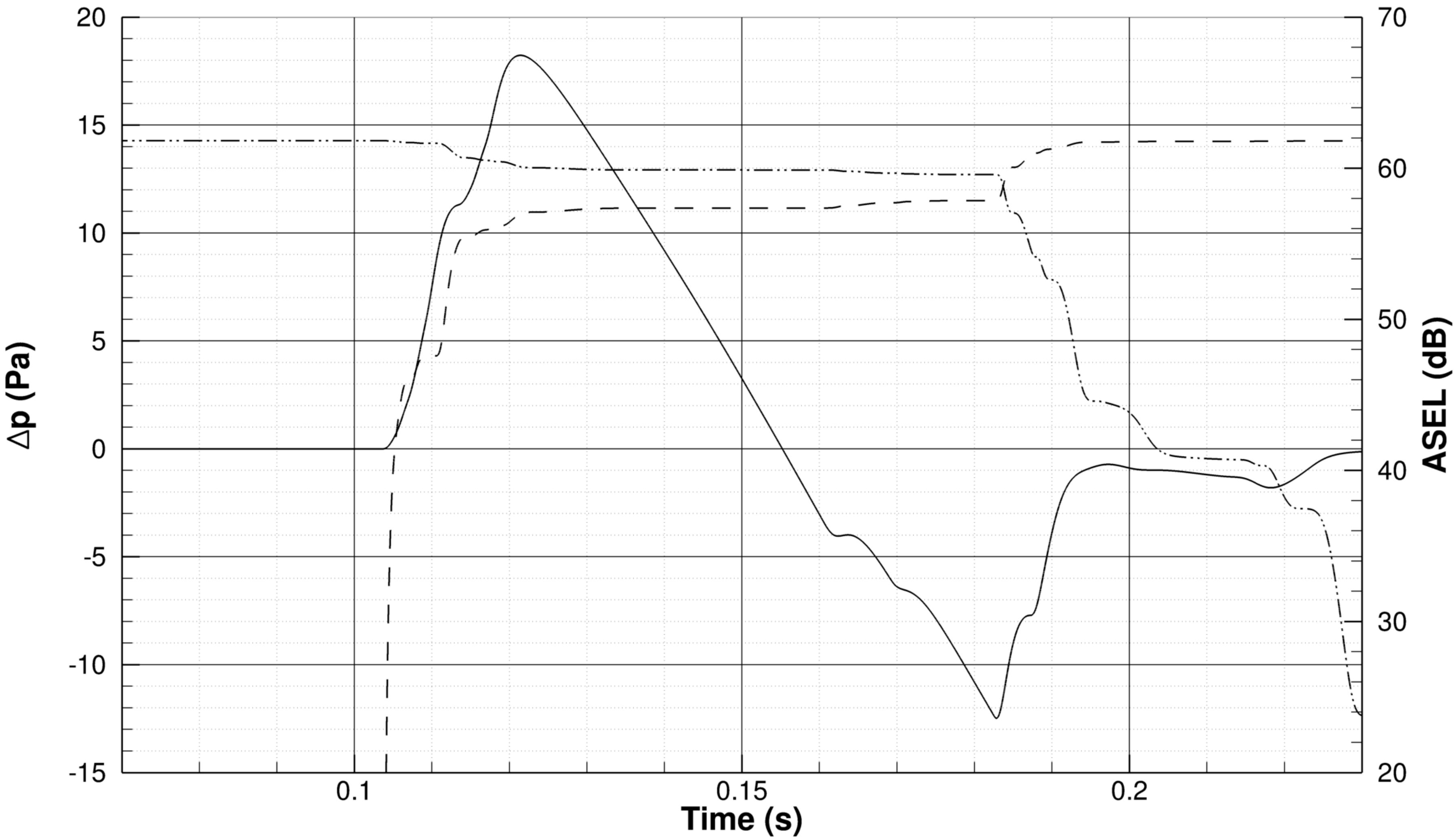
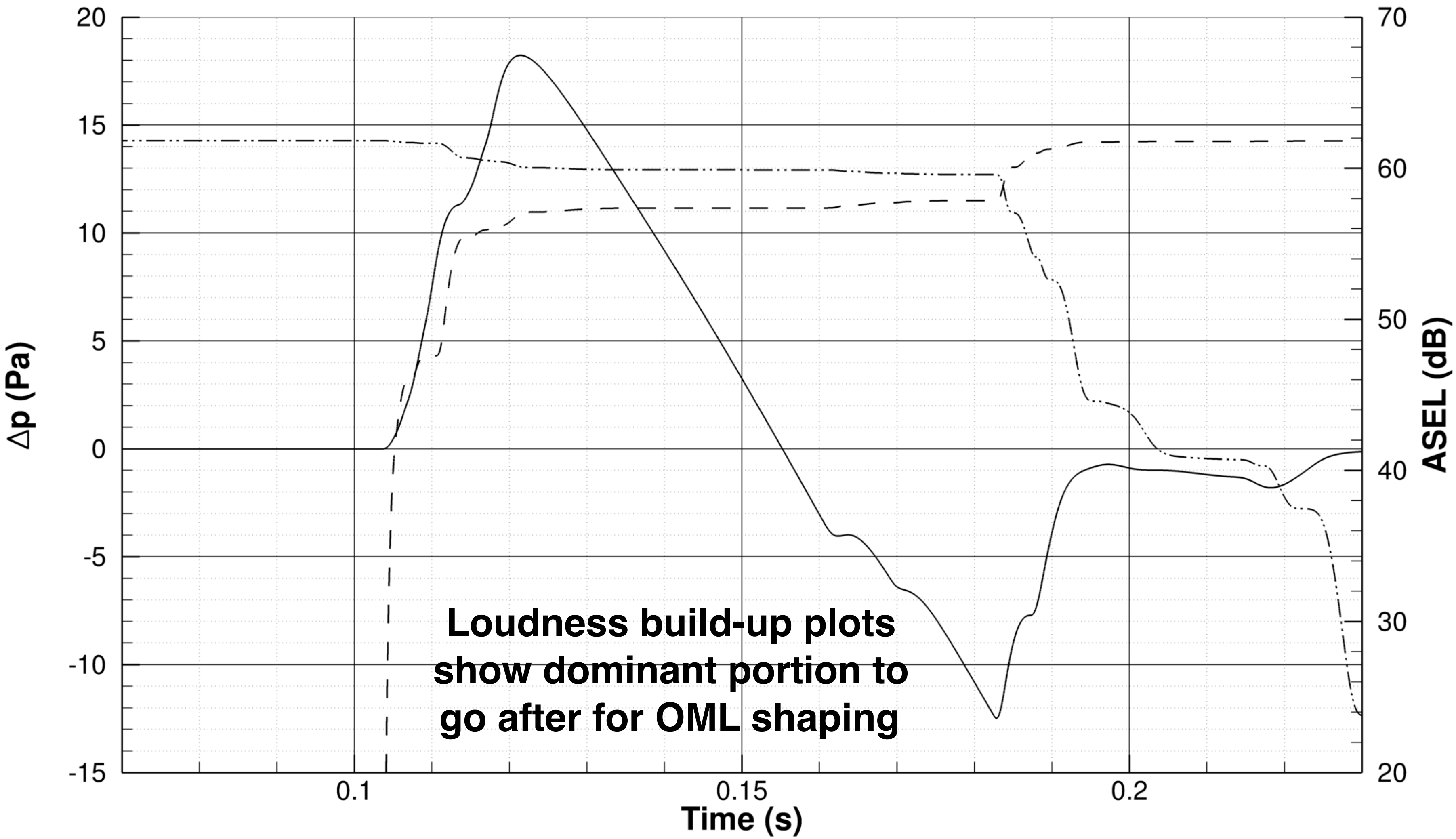


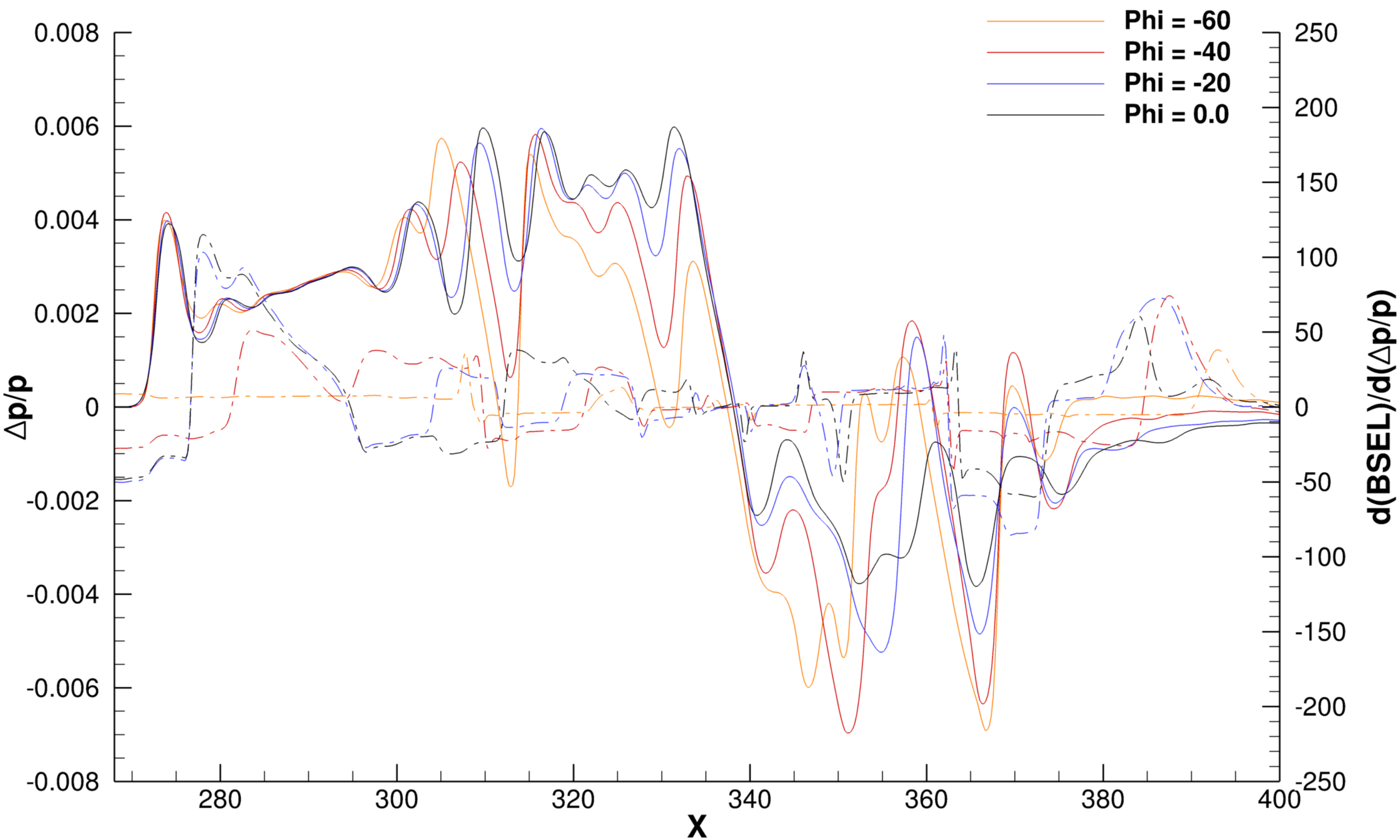
Highlights: Loudness Build-up



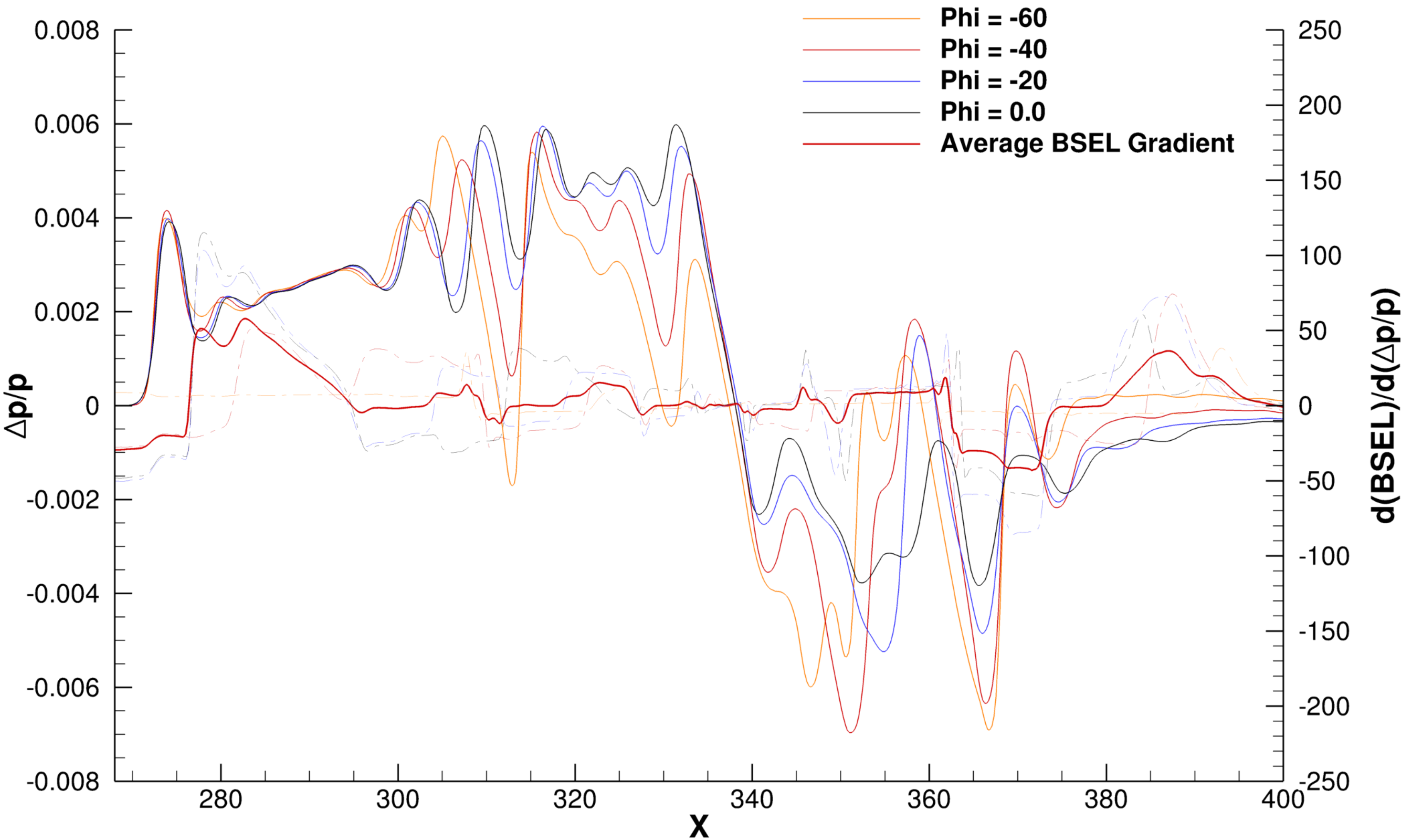
Highlights: Loudness Build-up



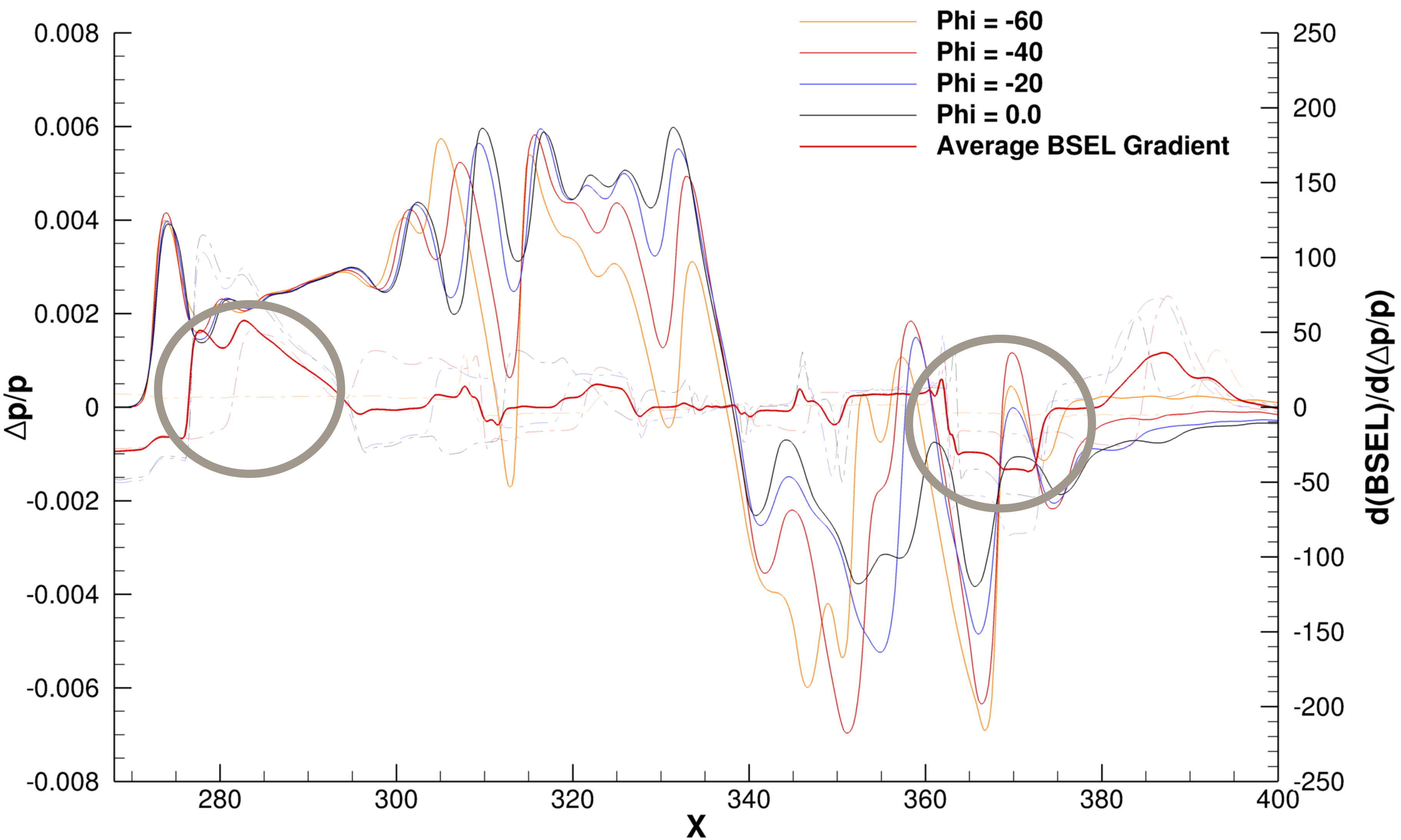
Highlights: Loudness Gradients



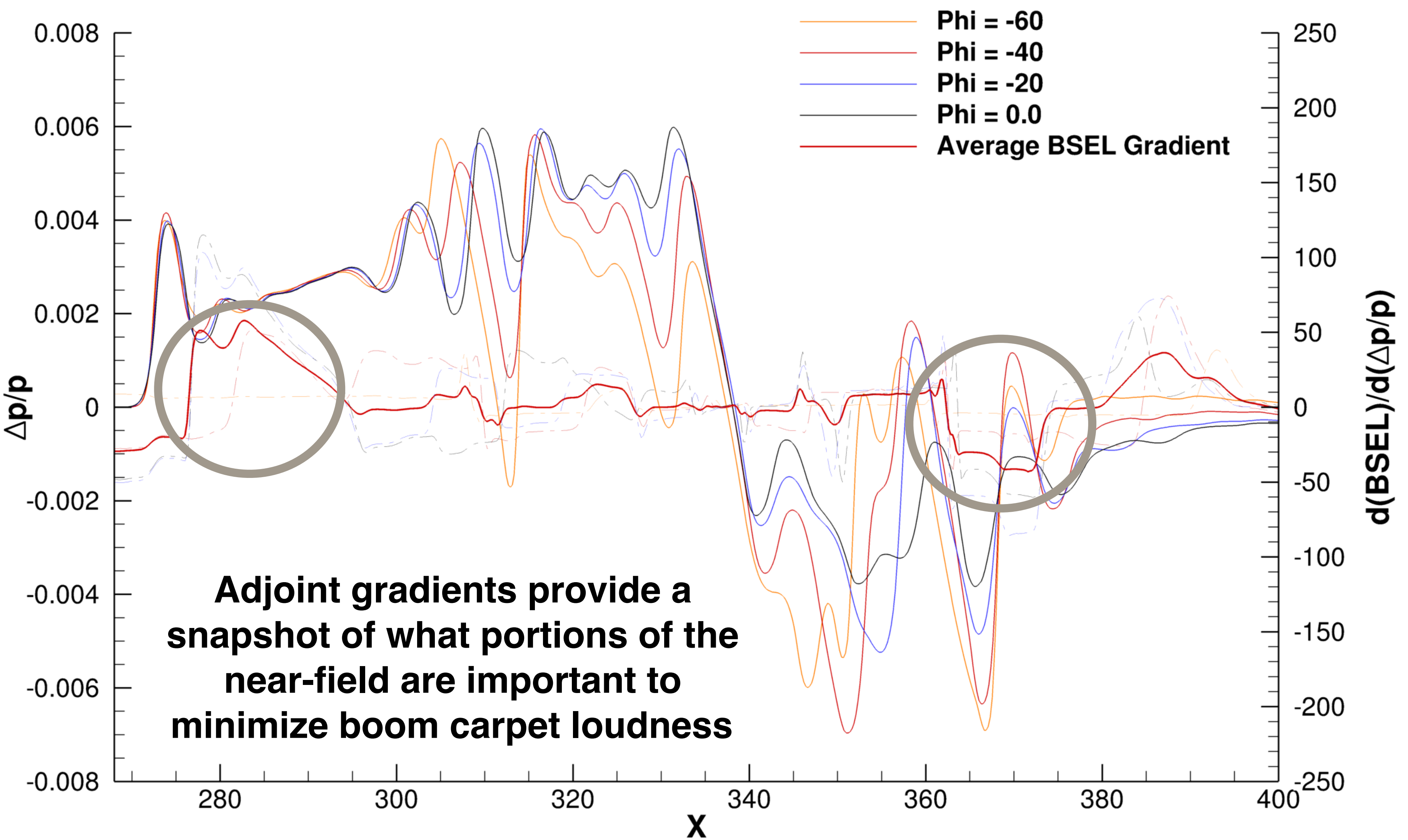
Highlights: Loudness Gradients



Highlights: Loudness Gradients



Highlights: Loudness Gradients



Summary

- Near-field waveforms propagated using sBOOM
- Lateral cut-off azimuths using standard atmospheres are usually quite different from measured/realistic atmospheres
  - Lateral cut-off rays in realistic atmospheres can travel far
  - Could have low grazing angles
- Focus predictions show much higher loudness values than cruise booms (as expected)
- Different implementation of the underlying mechanisms seem to change the underlying characteristics of the ground signatures
  - Poisson vs. Acoustic Potential solutions
  - Wind considerations
  - As loudness levels get lower, there is potential for numerical noise to increase
- Loudness build-up plots can localize the loudness dominating portions of the signatures
- Loudness gradients provide a snapshot to allow optimization of the OML

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Acknowledgments

- NASA Commercial Supersonic Technology (CST) Project
- Boom prediction workshop organizing committee

Thank You! – Any Questions?