Evaluating the Utility of Pressure Scanners for Unsteady Pressure Measurements in Wind Tunnel Characterization of the Space Launch System

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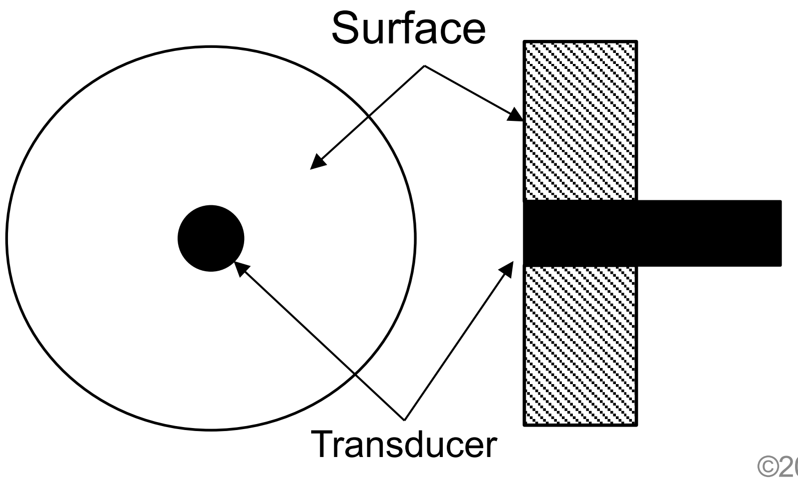
Introduction

- Capturing the unsteady attributes of the surface pressure is important for the characterization, modeling, prediction, and control of agile and modern aerospace systems.
- For wind tunnel applications:
  - Increase the number of measurement locations
  - Reduce the test article preparation and instrumentation cost
  - <u>Make use of the same **tap/tubing setup** for both steady and unsteady measurements</u>

Motivation

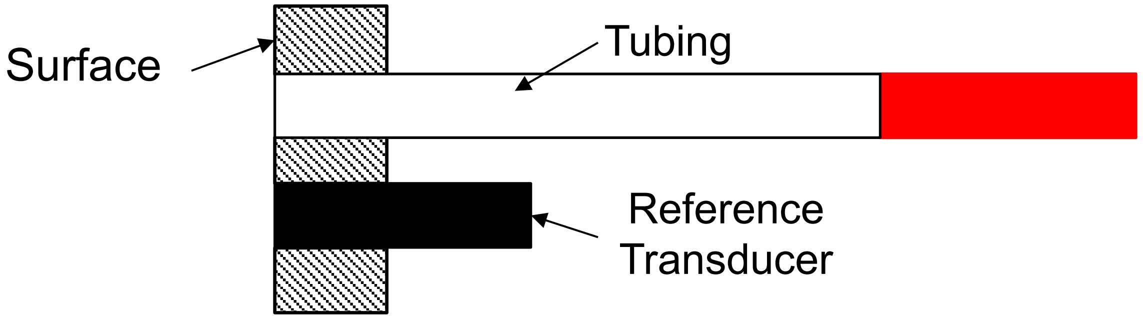
- Flush mounting the transducer is not always practical
  - Space
  - High Temperature
  - Electric discharge
  - Protect against physical contact (contaminations, etc.)
- Remote installation of the transducer can provide some advantages
- How far we can get from the surface and still capture the unsteady attributes of the fluctuating pressure field?
- Can we use pressure scanners (ESP) for unsteady pressure measurements?

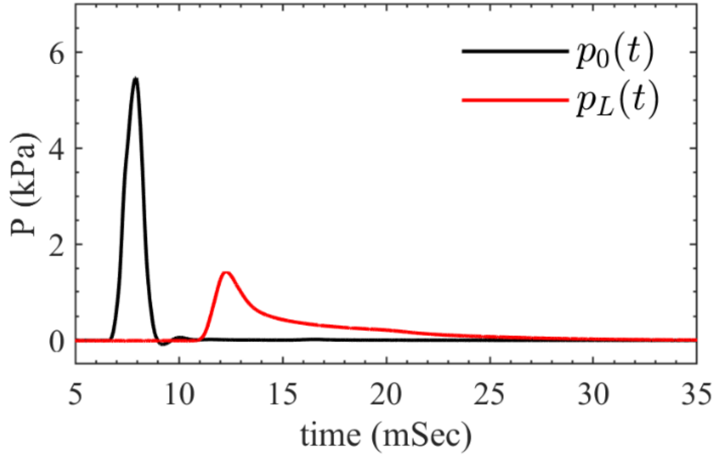


Objectives

- Evaluate the feasibility of using pressure scanning systems for time-resolved pressure measurements in the NASA Langley 14- by 22-Foot Subsonic Tunnel (14x22)

- Typical tubing system response (time-domain)





- System Response Model (SRM):
  - Analytical solution exists for a tubing system
  - Bergh and Tijdeman (1965)
  - Based on <u>ambient conditions</u> and <u>geometrical information</u>

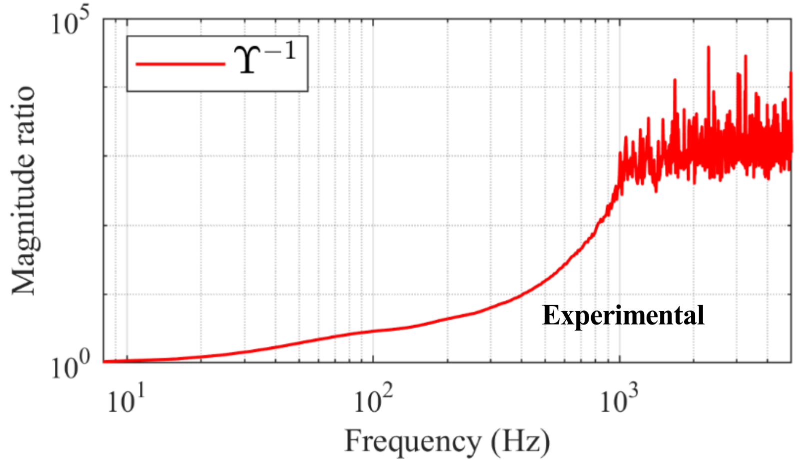
Output

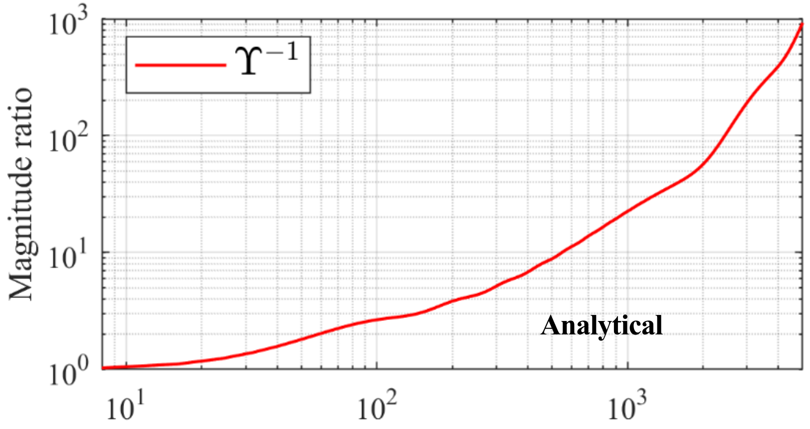
Input

$$\frac{P_L(\omega)}{P_0(\omega)} = \frac{1}{\cosh\left[\omega\Gamma_p \frac{L}{c}\right] + V\frac{\omega\Gamma_p}{A_c c}\sinh\left[\omega\Gamma_p \frac{L}{c}\right]} = \Upsilon(\omega)$$

PRESSURE SYSTEMS

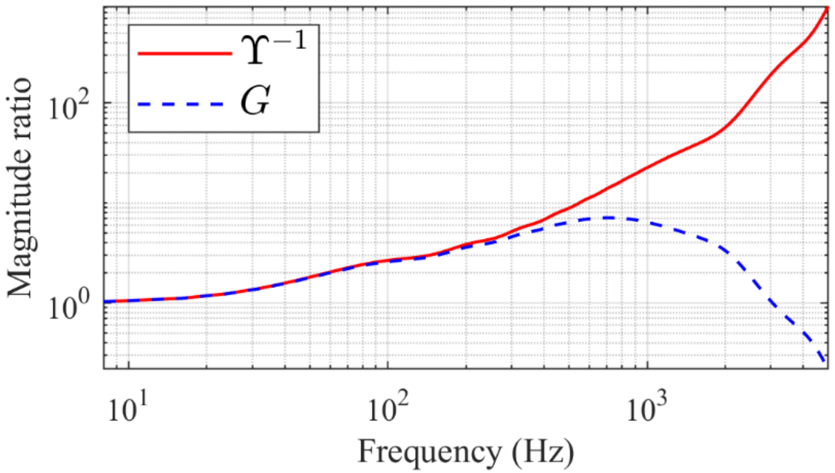
- Due to noise amplification, Bergh and Tijdeman model (or the equivalent experimental transfer function) can not be used for reconstructing the measurements.





- A filtered inverse transfer function is needed:
  - Whitmore (1990)
  - $\hat{P}_0(\omega) = G(\omega)P_L(\omega)$

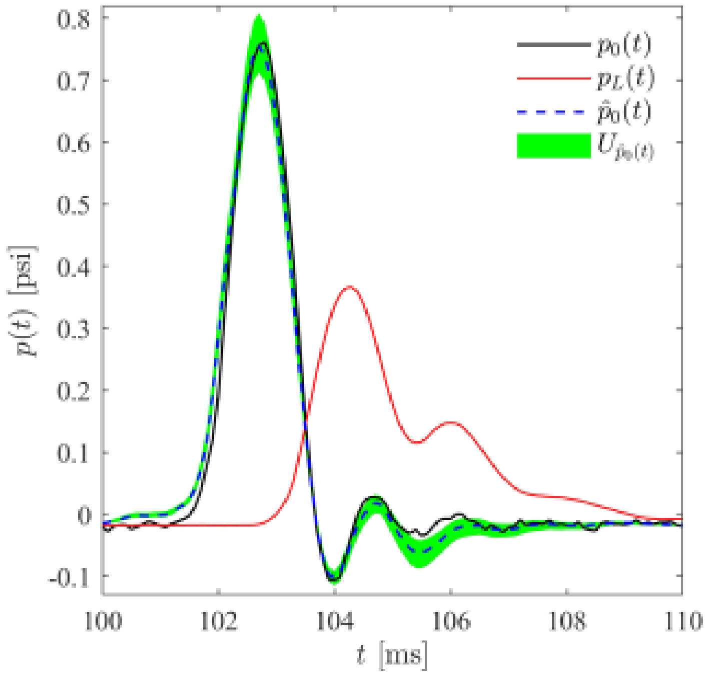
$$G(\omega) = \left\{ \frac{\Upsilon(\omega)^* \left(\frac{||P_{00}||^2}{||N||^2}\right)}{||\Upsilon(\omega)||^2 \left(\frac{||P_{00}||^2}{||N||^2}\right) + 1} \right\}$$

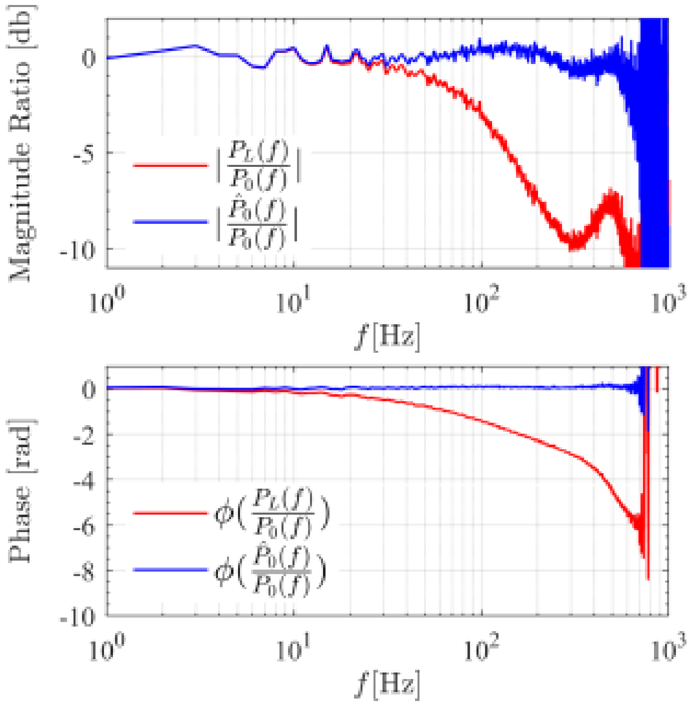


Approach
In-situ Tubing Response Characterization

- Dynamic response of each pressure tap is characterized individually prior to gathering wind tunnel measurements

Hand-held characterization device



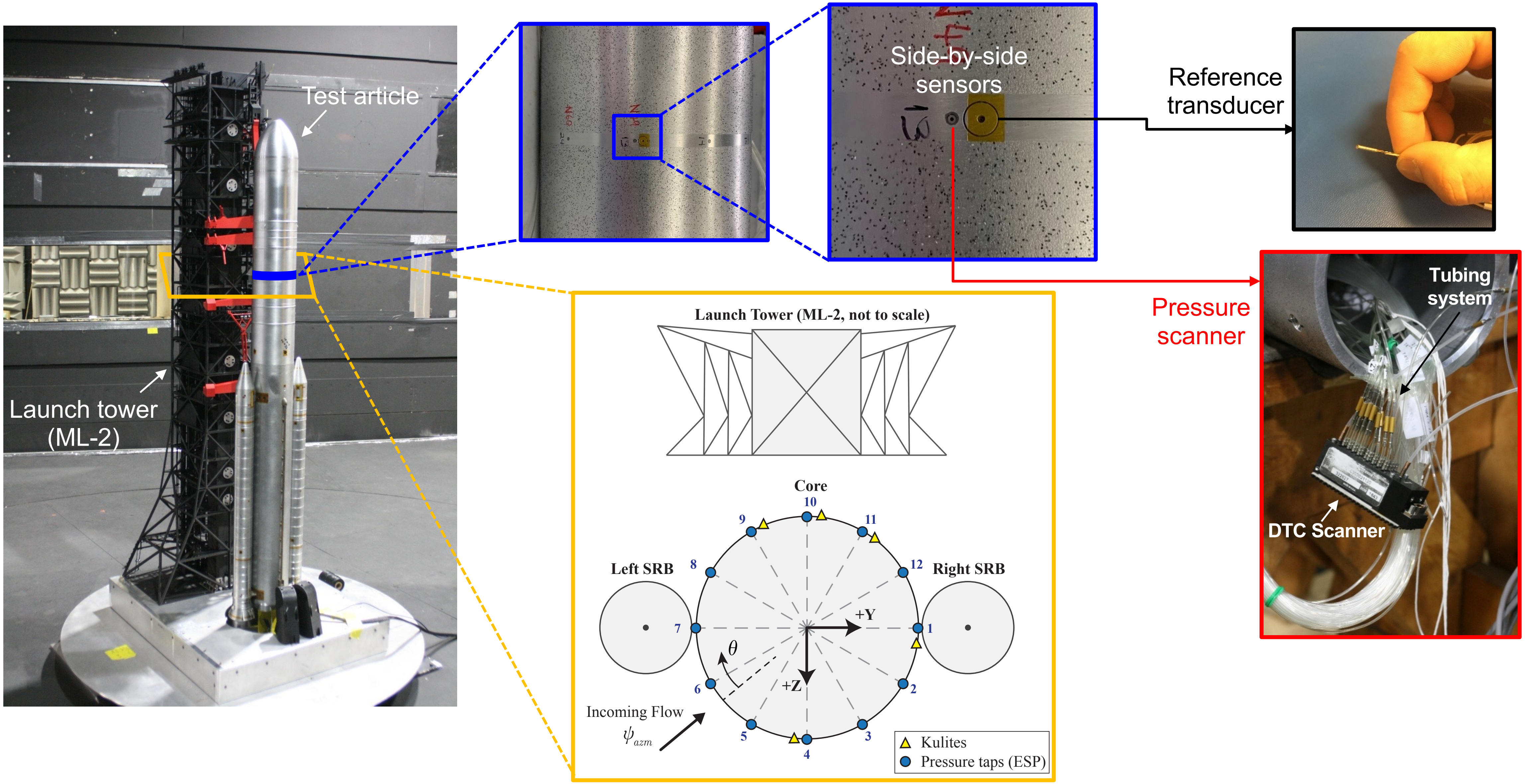


$$G(\omega) = \left\{ \frac{\boxed{\Upsilon(\omega)}^{*} \left(\frac{||P_{00}||^2}{||N||^2}\right)}{||\Upsilon(\omega)||^2 \left(\frac{||P_{00}||^2}{||N||^2}\right) + 1} \right\}$$

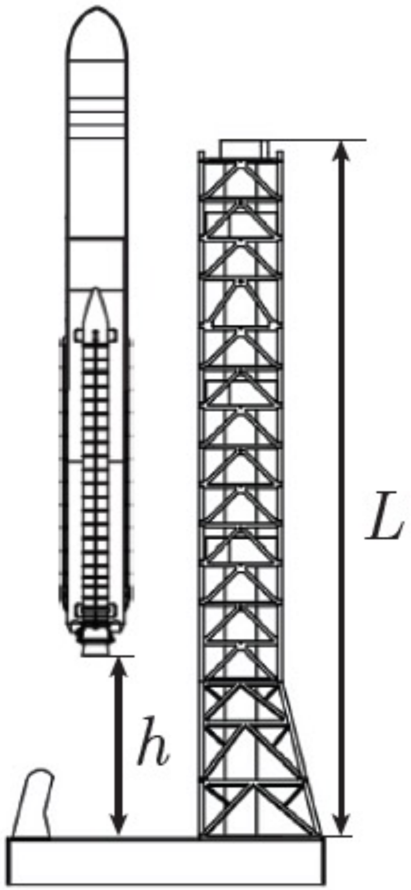
$$\frac{1}{\cosh\left[\omega \Gamma_p \frac{L}{c}\right] + V \frac{\omega \Gamma_p}{A_c c} \sinh\left[\omega \Gamma_p \frac{L}{c}\right]} = \Upsilon(\omega)$$

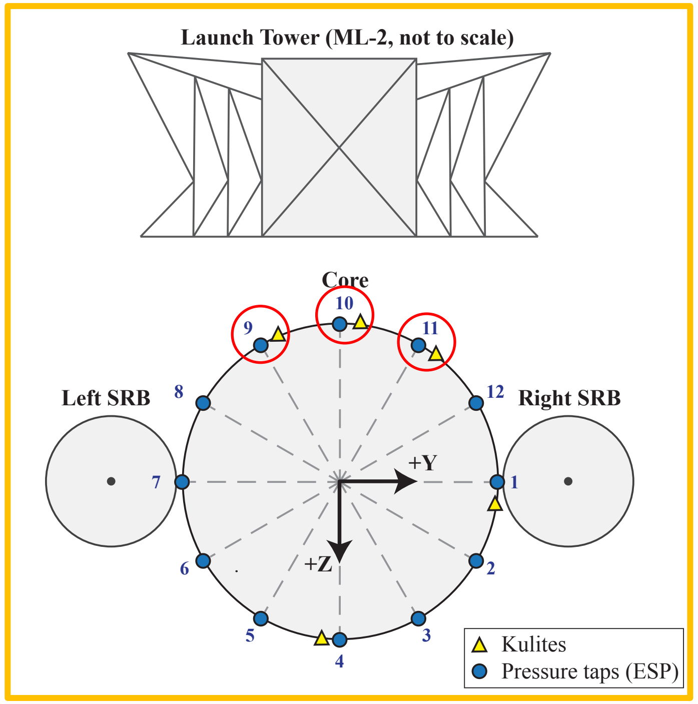
All port parameters are saved

Experimental Setup



Test Cases

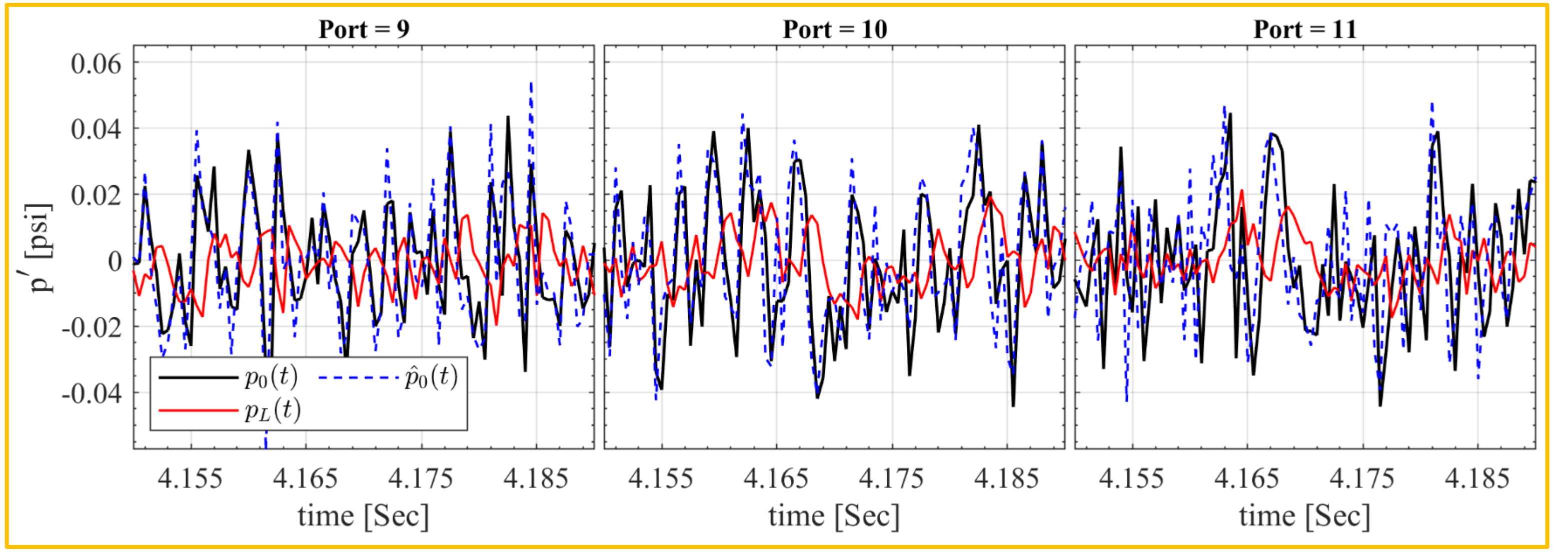


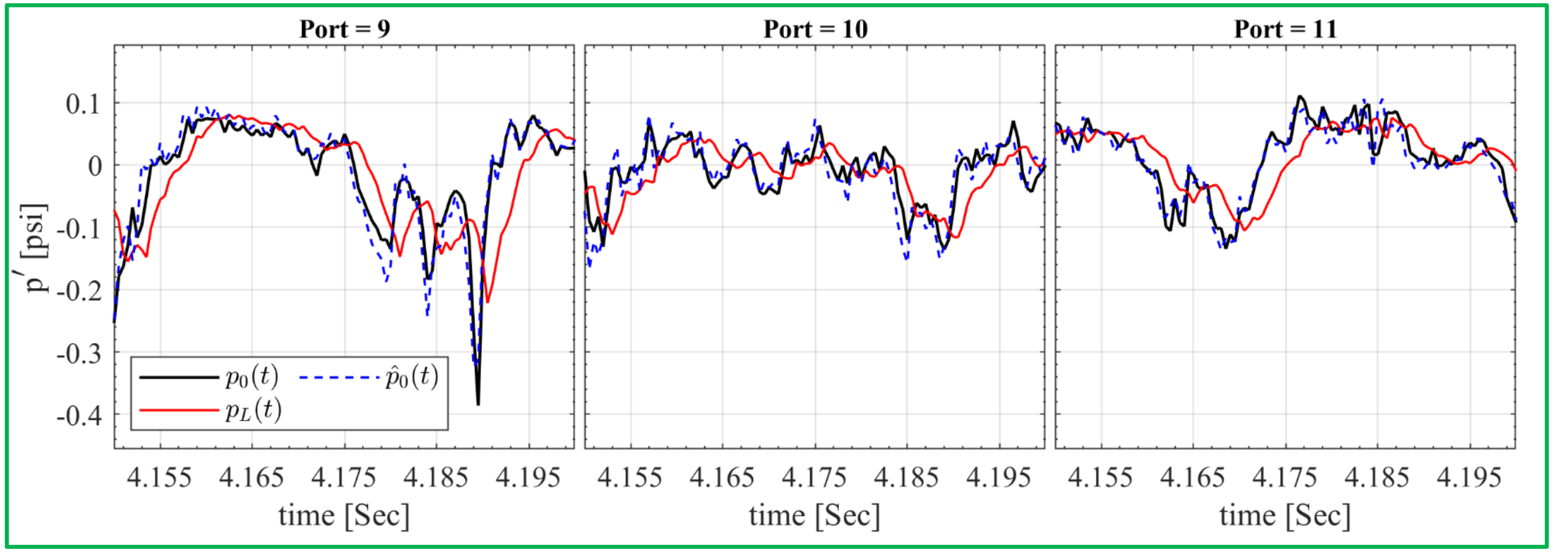


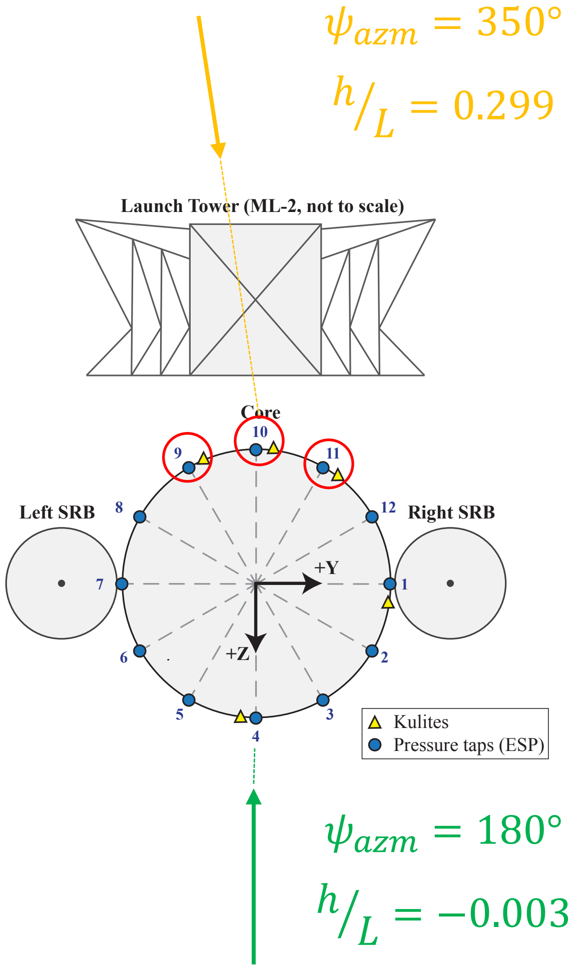
	h/L	ψ_{azm} [°]	q_∞ [psf]	Ma
Case 1:	-0.003	180	50	0.186
Case 2:	0.299	350	50	0.186
Case 3:	0.876	240	50	0.187

Results

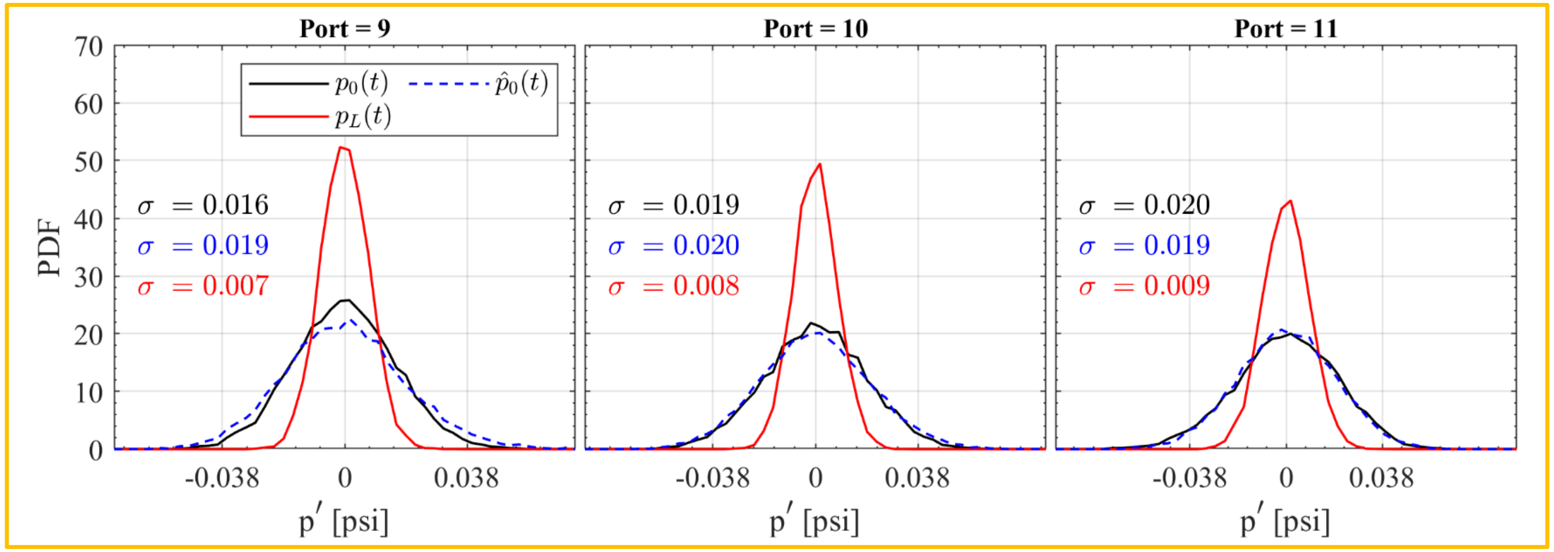
Time-domain Analysis

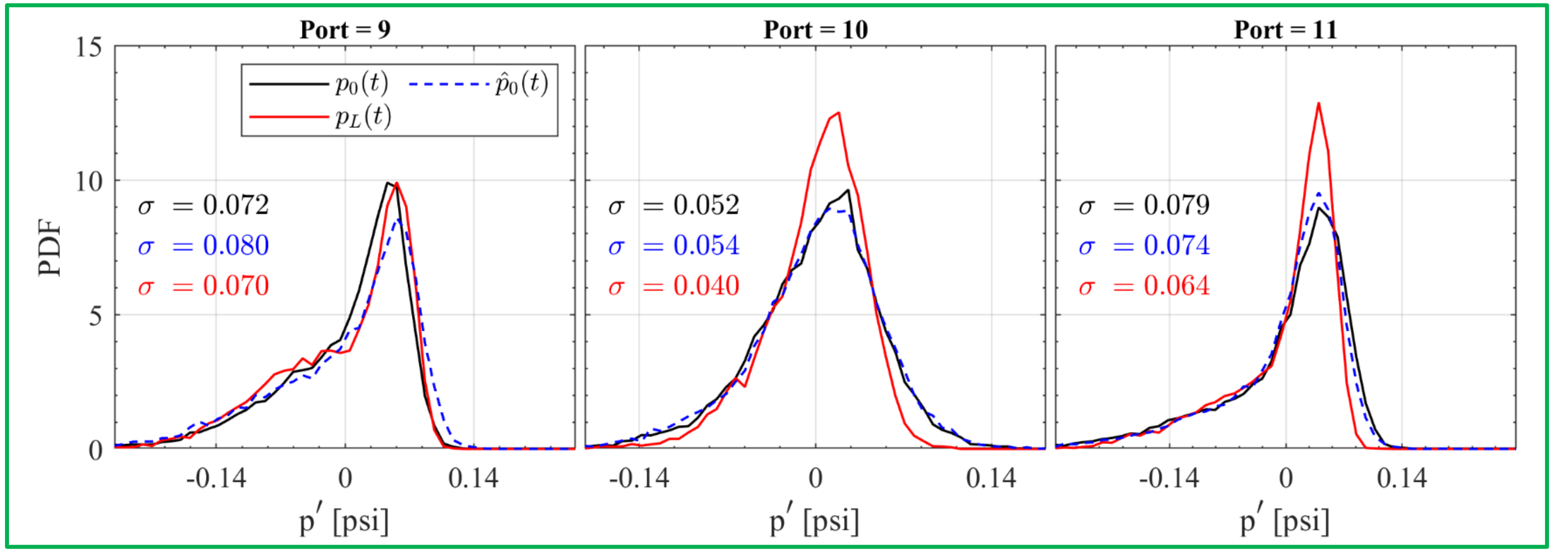


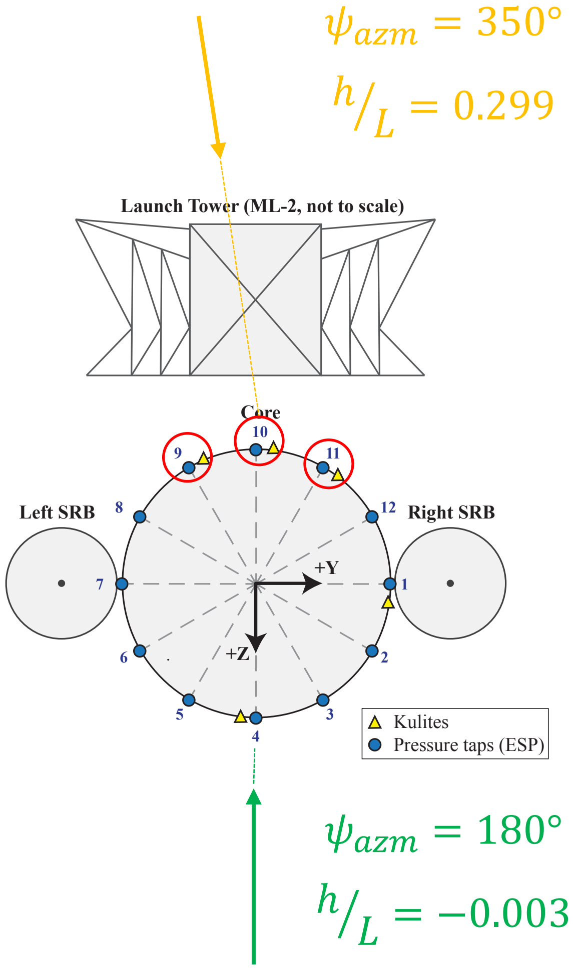




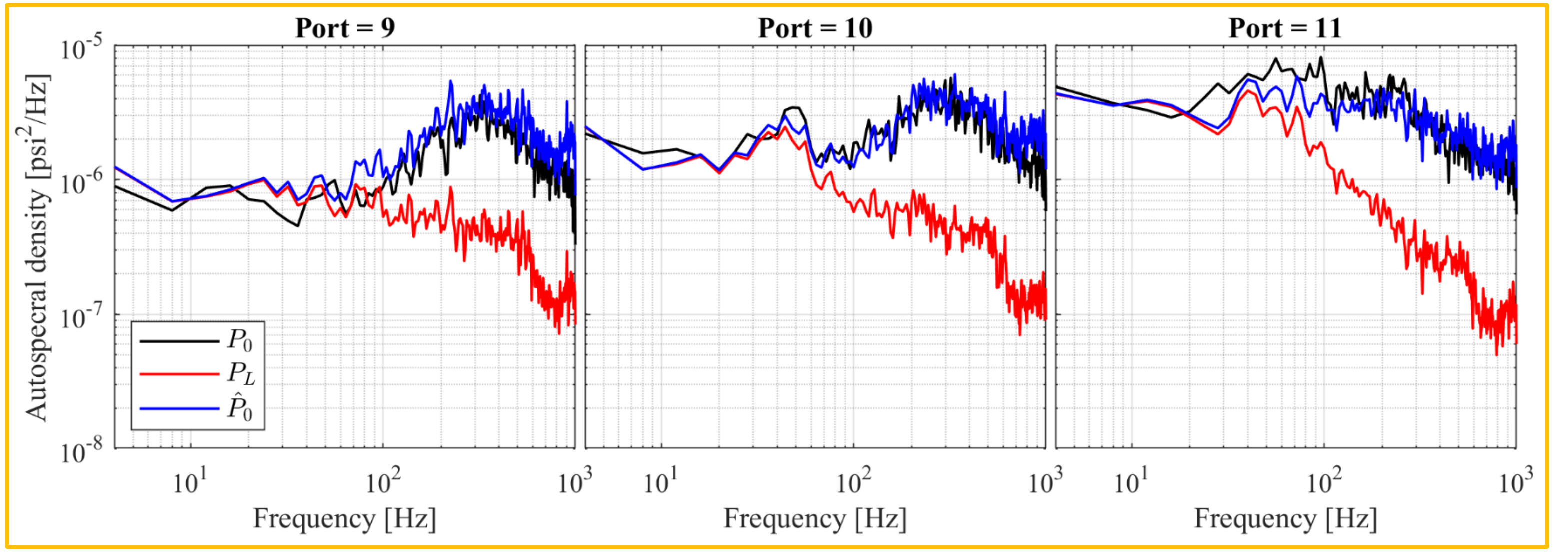
Results
Statistical Analysis

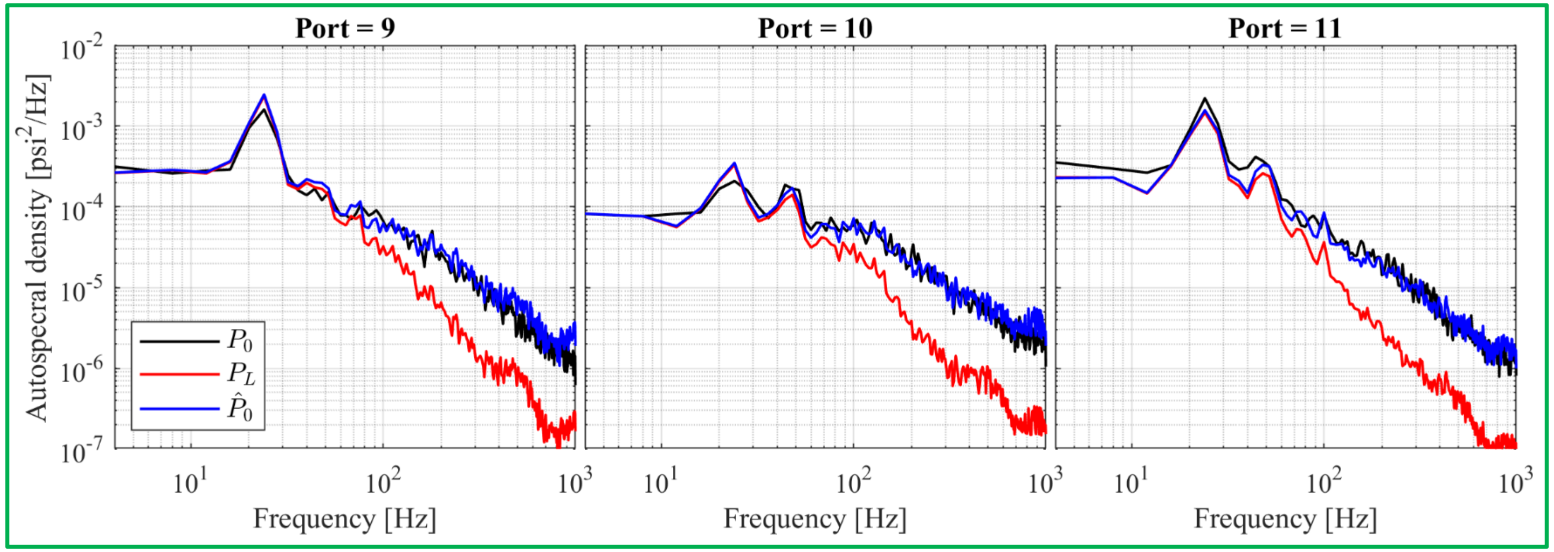






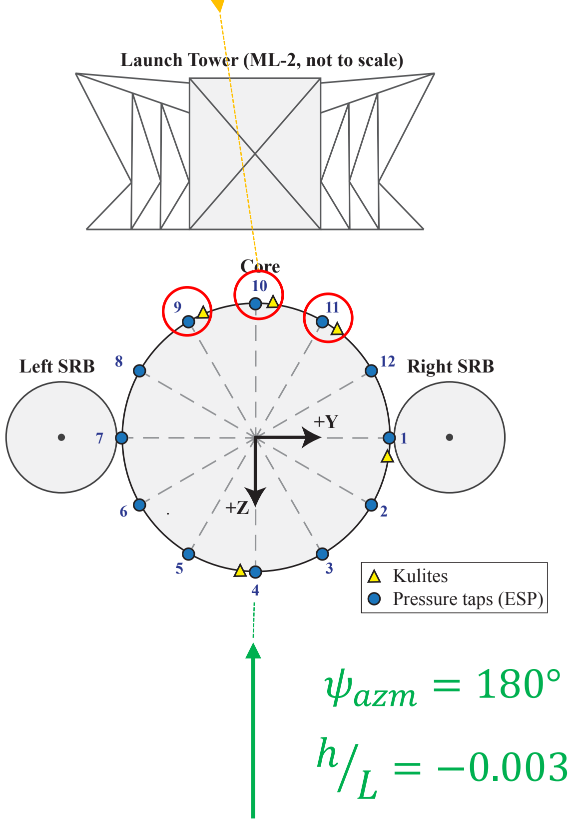
Results
Frequency-domain Analysis





$\psi_{azm} = 350°$

$h/_L = 0.299$

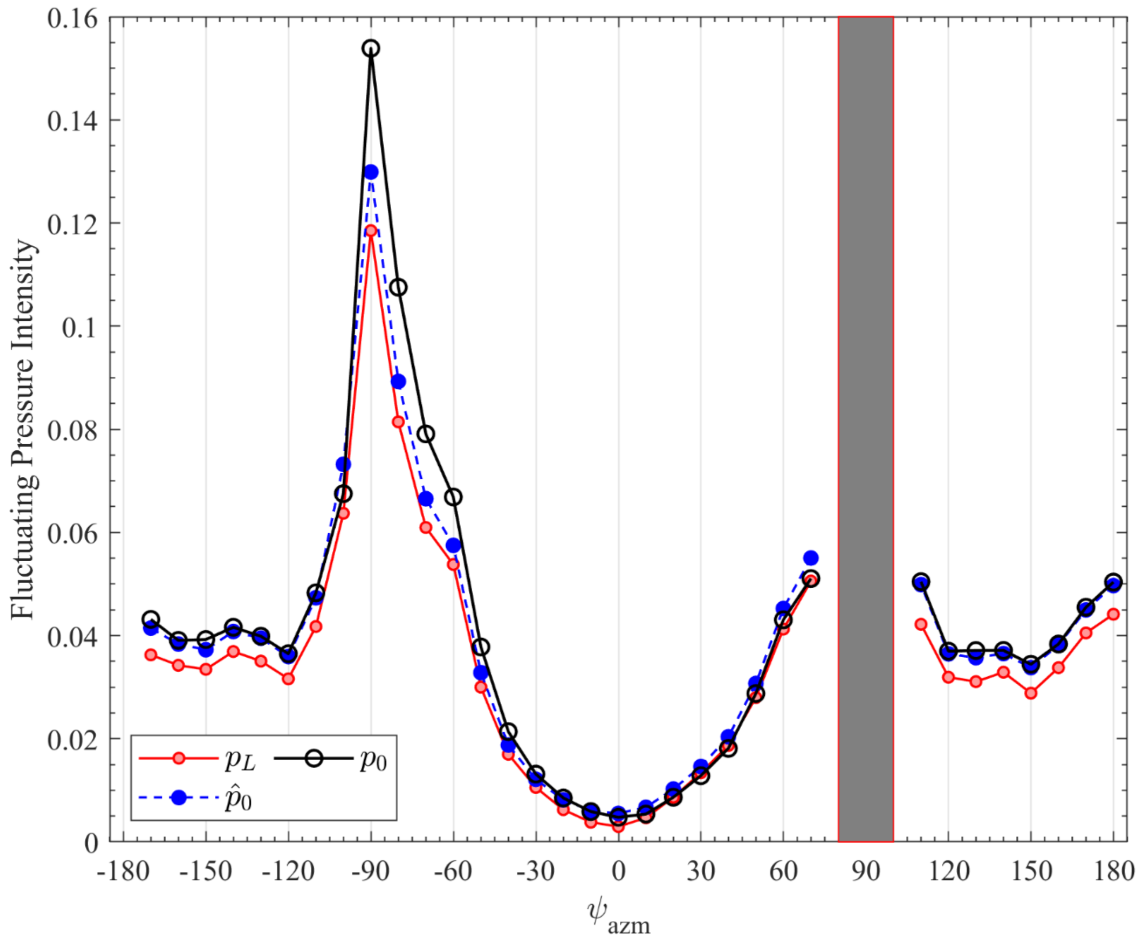


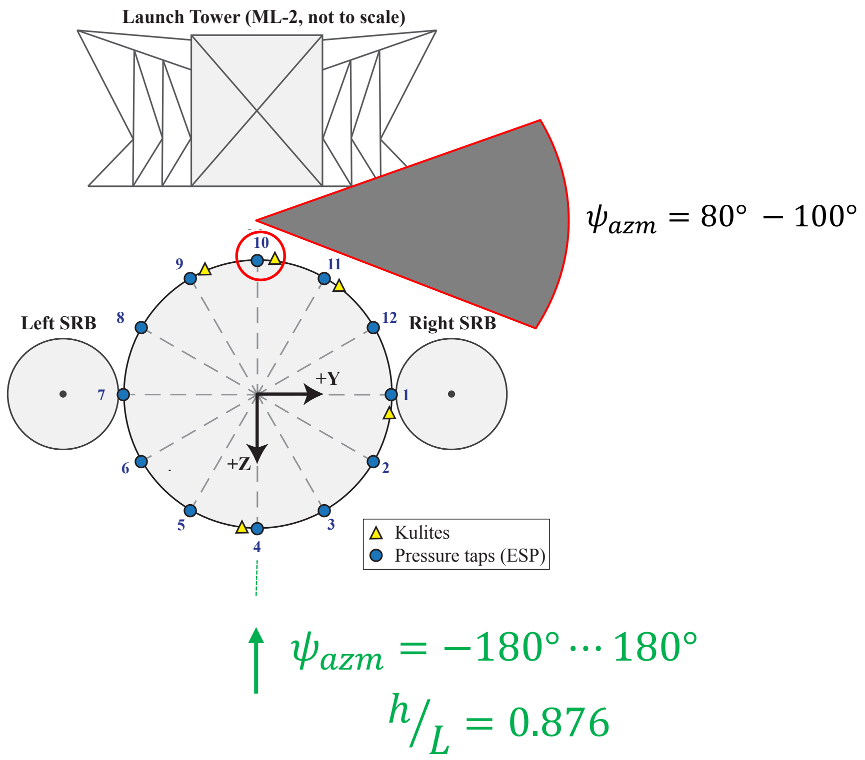
$\psi_{azm} = 180°$

$h/_L = -0.003$

Results

Fluctuating Pressure Intensity Distribution





Conclusions

PRESSURE SYSTEMS

- Pressure scanners can be effectively utilized for unsteady pressure measurements in low-speed wind tunnel applications.
- The Wiener deconvolution technique combined with the in-situ characterization methodology described in this paper reduce the uncertainty in the parameters needed for modeling the tubing geometry.
- The signal-to-noise ratio is critical for improving the quality and extending the range of frequencies that can be reconstructed. Design steps can be taken:
  - Pressure scanner range should be selected to allow maximum sensitivity.
  - Careful tubing design to minimize the attenuation and improve the signal-to-noise ratio.

Future Work

- Investigate aliasing effects in applications with signal content at higher frequencies close to the Nyquist frequency.
- Evaluate the behavior of the scanner's multiplexer under fast scanning conditions
- Application to compressible flows, different test species (such as R-134a refrigerant), and large temperature differences that can be experienced in flight testing or high-speed wind tunnel testing applications.
- Uncertainty estimation of the reconstructed pressure signals based on the WFSRM input parameters

Acknowledgments

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- We gratefully acknowledge the assistance of the 14- by 22-Foot Subsonic Tunnel facility staff in conducting these experiments.

BACKUP SLIDES

Attenuation and Amplification Behavior of the Tubing Sys. Response