



Developing Certification Procedures for Quiet Supersonic Aircraft using Shaped Sonic Boom Predictions Through Atmospheric Turbulence

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Introduction



- Industry is pursuing civil supersonic products



- Two regulatory issues for civil supersonic flight: limiting airport noise during subsonic flight and sonic boom during en route supersonic flight
- For sonic boom, formulating an international standard for low-boom capable, supersonic designs to potentially amend ban on civil supersonic overland flight worldwide
 - Noise-based certification standard for supersonic en route (sonic boom) noise
 - Certification standard would include noise metric, [test procedures](#), and noise limits
- Data from the NASA X-59 QueSST low-boom demonstrator will be used to support standards development with scientific data
 - Prediction tool validation for shaped booms
 - Community response testing

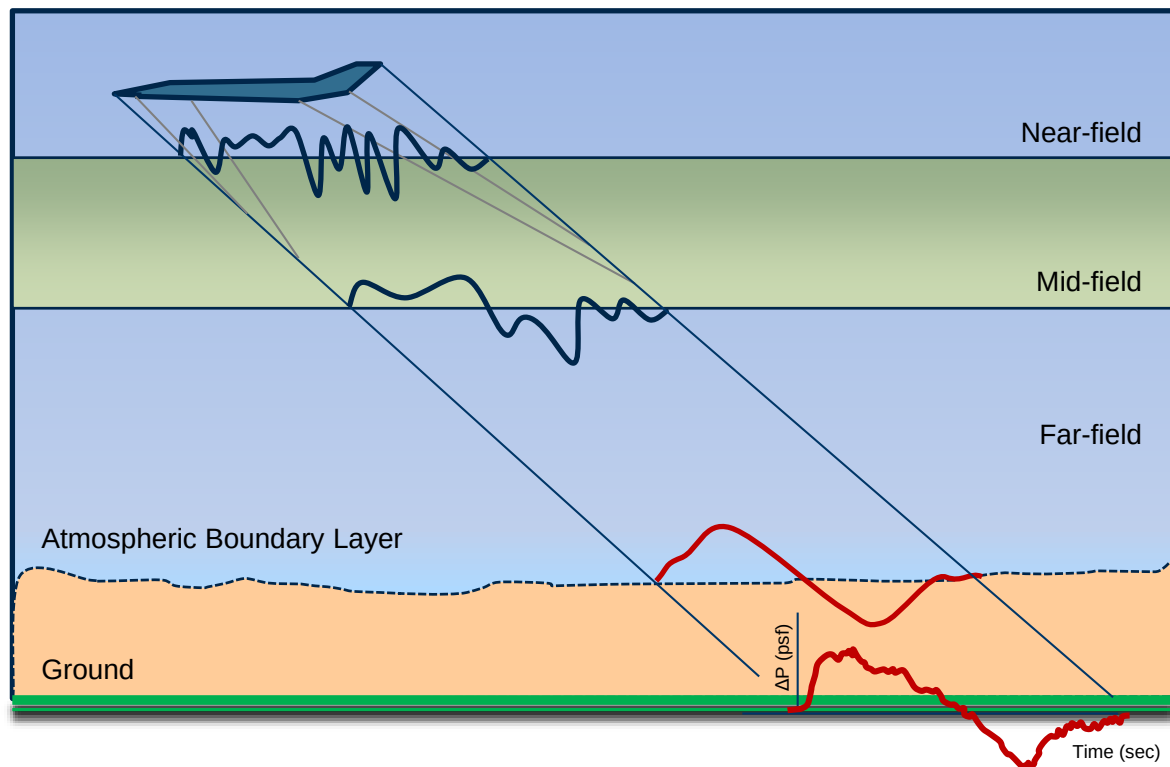


Notional Certification Procedure

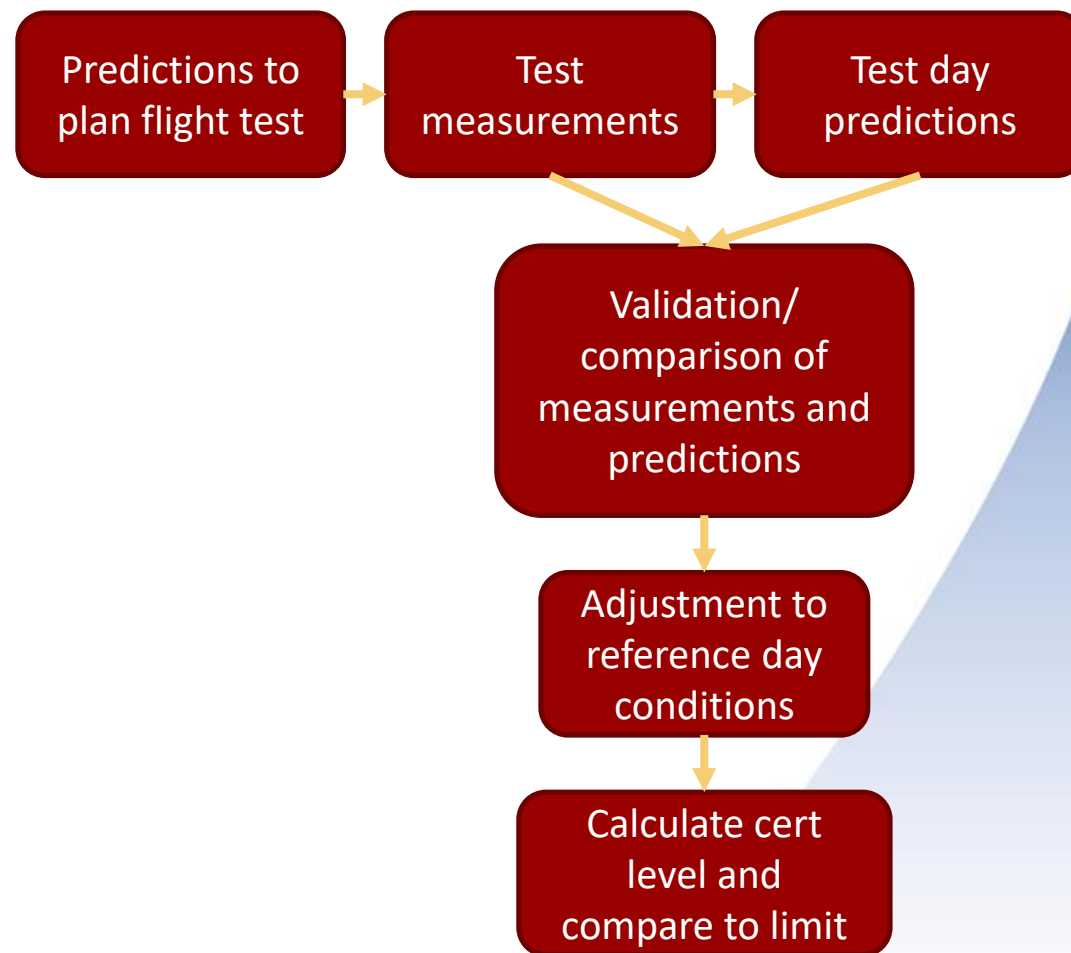


➤ Procedure Must Characterize Noise Performance at Reference Conditions

- Concept of fairness (“level playing field”)



Notional Certification Procedure Steps



“Simulated Measurement” Datasets



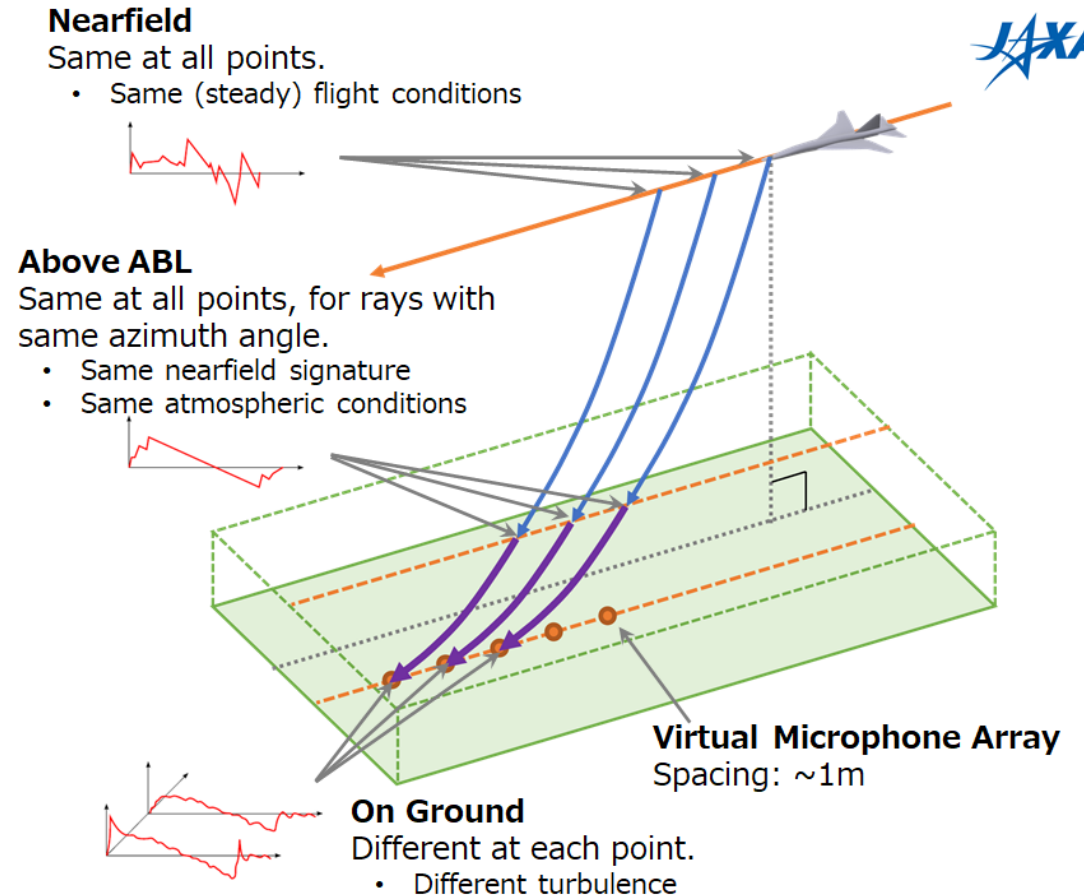
- **No existing measured shaped low-boom aircraft data**
 - Need for a dataset to aid in developing procedures
 - Procedures will be tested with X-59 data in the future
- **Create simulation datasets**
 - Run simulations with sonic boom propagation software packages that include effects of atmospheric turbulence to approximate expected real-world variability in ground signatures
 - Based on previous analyses of N-wave test data, need to include turbulence in predictions
 - Set turbulence parameters based on measurements for greater realism
 - NASA SonicBAT flight test campaign (July 2016 at Edwards AFB, CA, USA) [Bradley et al.*]
 - Turbulence measurements with sonic anemometer and SODAR
 - Use one low-turbulence measurement as first step
 - Include trajectory variability for greater realism
 - Also based on SonicBAT with aircraft trajectory data variability

*K. Bradley, C. Hobbs, C. Wilmer, V. Sparrow, T. Stout, J. Morgenstern, K. Underwood, D. Maglieri, R. Cowart, T. Collmar, H. Shen, P. Blanc-Benon, “Sonic booms in atmospheric turbulence (SonicBAT): The influence of turbulence on shaped sonic booms,” NASA/CR-2020-220509, 2020.

“Simulated Measurement” Dataset Conditions



- **Input sonic boom signature from X-59 C609 design**
 - Mach 1.4
 - Cruise altitude 16,459.2 m
- **One set of turbulence parameters corresponding to low turbulence**
 - Include multiple random realizations to be treated as multiple flight passes in analyses
 - Include 3 different atmospheric boundary layer (ABL) heights (268.2 m, 411.4 m, and 1026.7 m)
- **Predictions at 4,000+ simulated microphone locations for each turbulence realization**
 - 6 sonic boom metrics
- **Also predict ground waveform under Reference Day conditions (no turbulence)**

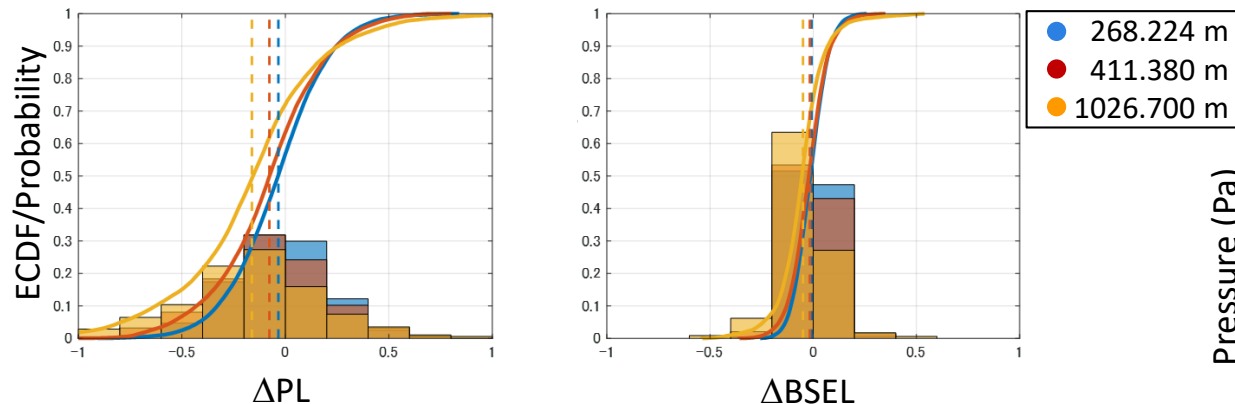


Description of Turbulized Boom Datasets



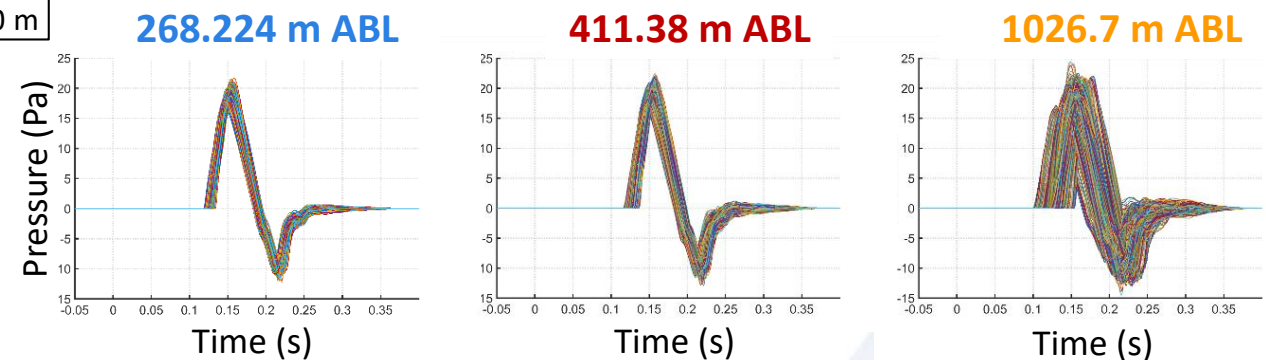
➤ JAXA method

- Lighthill-Westervelt-equation-based model solved by one-way HOWARD approach.
- Effects of nonlinearity, thermo-viscous and molecular relaxation, Blokhintsev energy conservation, diffraction, and inertial scattering included.
- Atmospheric turbulence modeled as velocity fluctuation by random Fourier mode and modified von-Karman spectrum.



➤ Penn State method

- PCBoom 6.7.1.1 NASA tool used for no turbulence portion from cruise altitude to top of ABL, and KZKFourier 2D2.4 tool used for turbulent propagation from top of ABL to ground
- KZKFourier uses a nonlinear KZK propagation equation including nonlinearity, diffraction, absorption, and a random Fourier modes implementation of turbulence.
- Ostashev & Wilson turbulence model includes both buoyancy and wind shear and is altitude dependent.



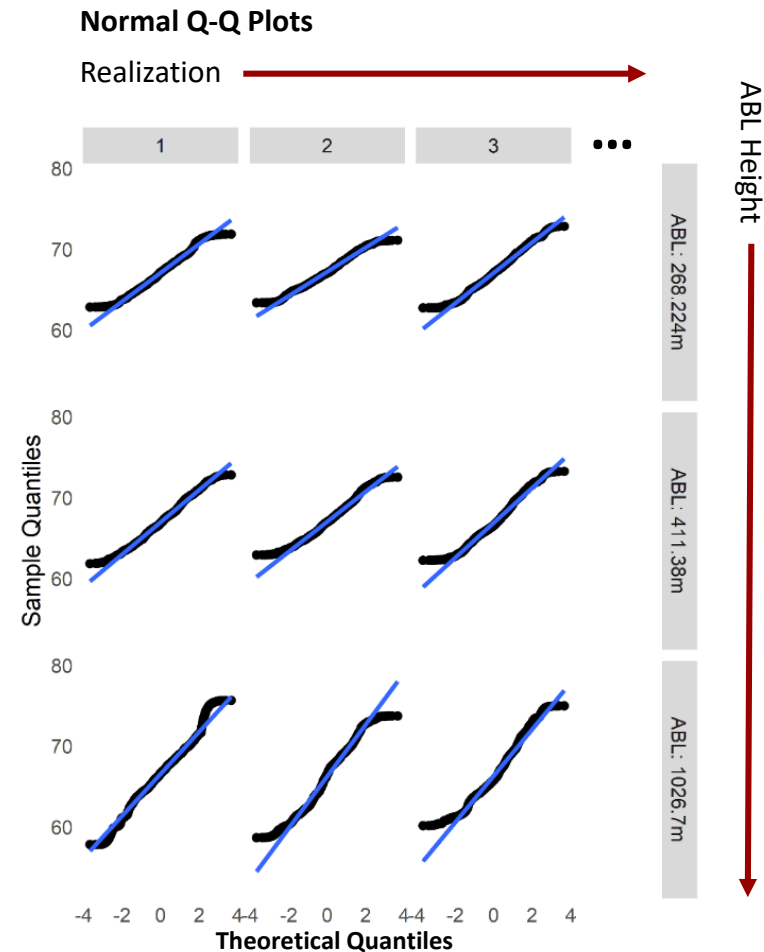
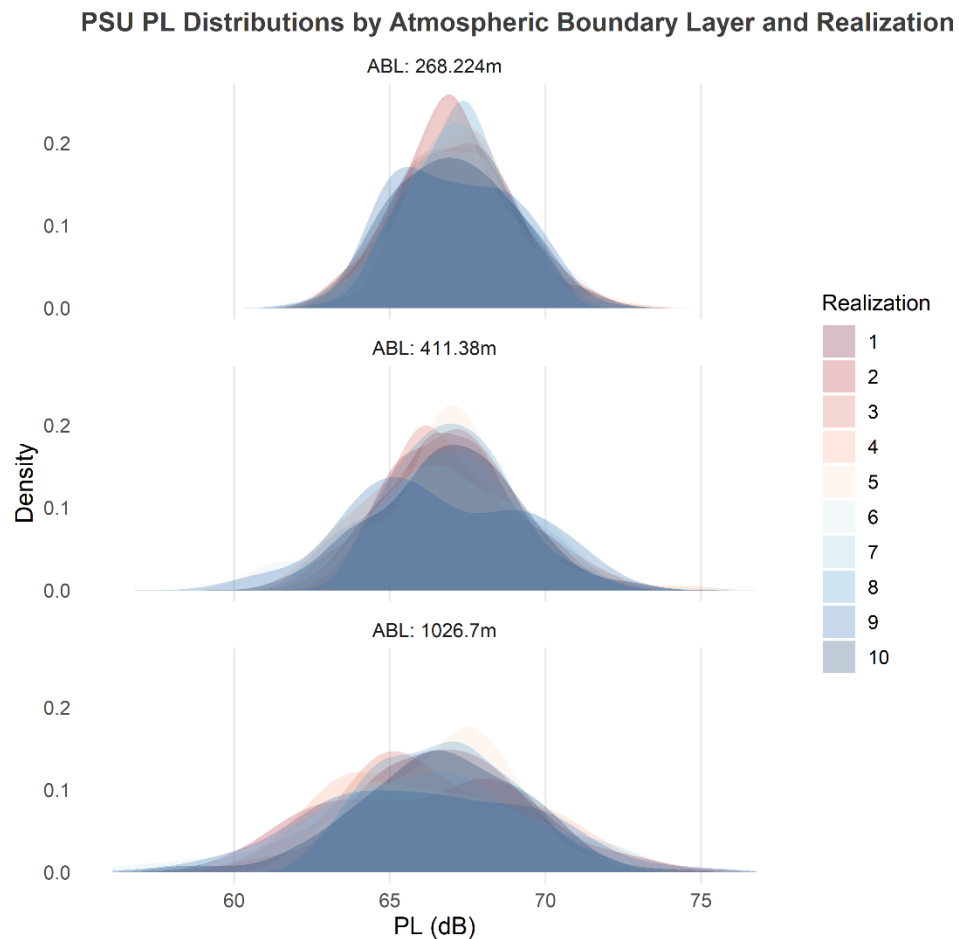
M. Kanamori et al., "Numerical Evaluation of Sonic Boom Deformation due to Atmospheric Turbulence," AIAA Journal, Vol. 9, No. 3, pp. 972–986, 2021.

K. Bradley et al., "Sonic booms in atmospheric turbulence (SonicBAT): The influence of turbulence on shaped sonic booms," NASA/CR-2020-220509, 2020.

Statistical Analyses



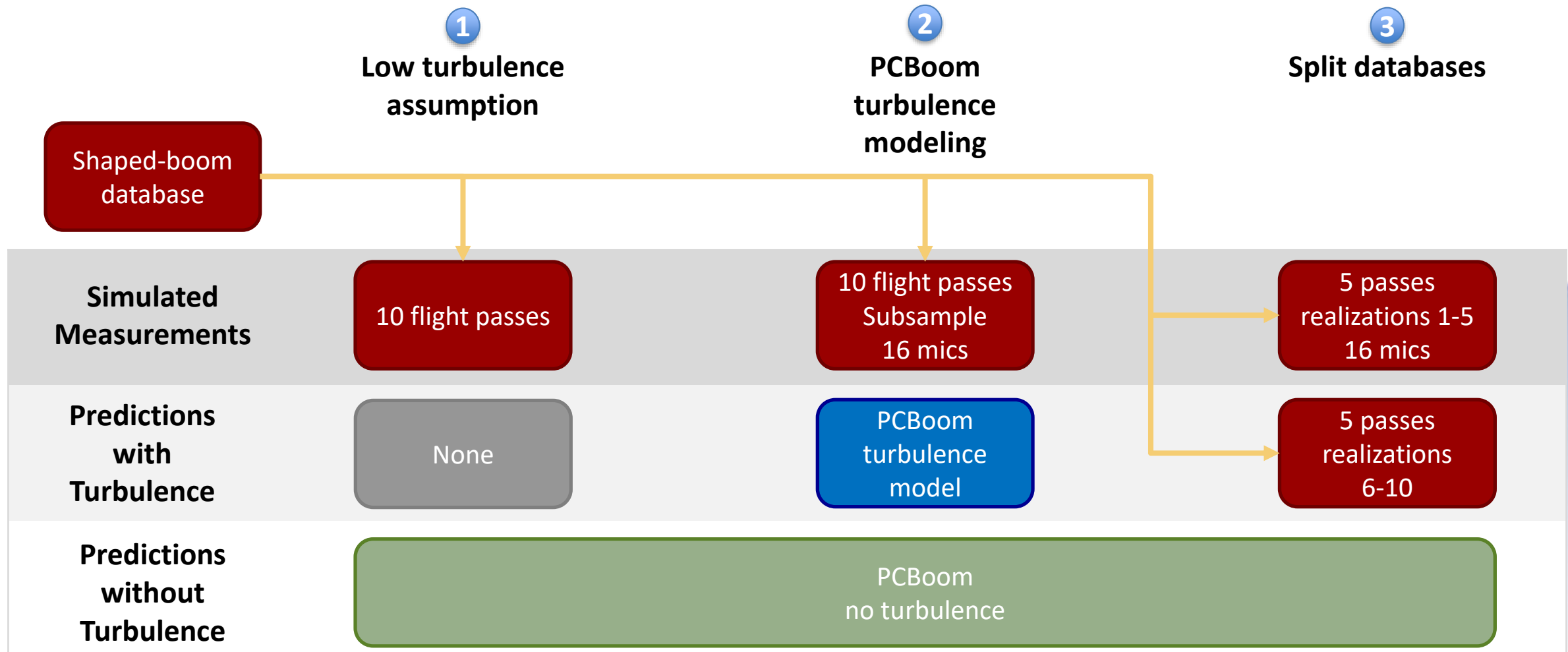
- Density plots and Quantile-Quantile plots indicate approximately normal distributions
- Spread in the noise metrics increases as the atmospheric boundary layer increases



Data Subsets for Predictions and “Measurements”



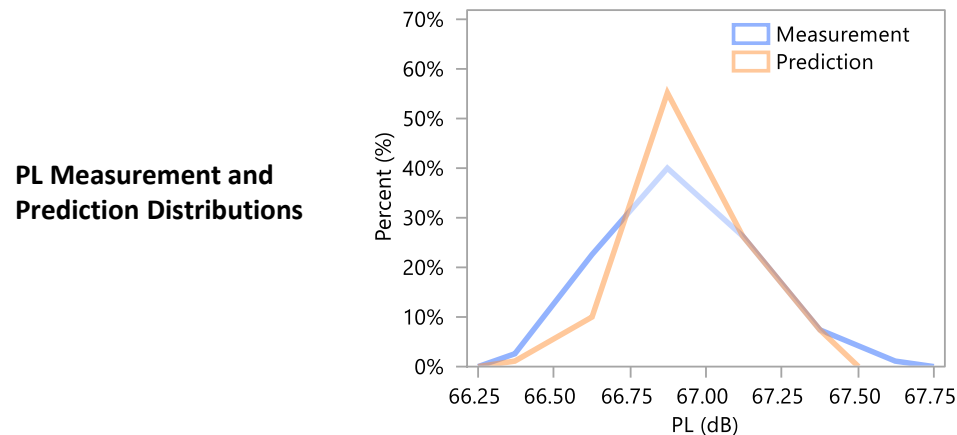
- Certification scheme requires **measured** levels and predicted levels at test-day conditions (**with** and **without** turbulence). Different approaches have been evaluated:



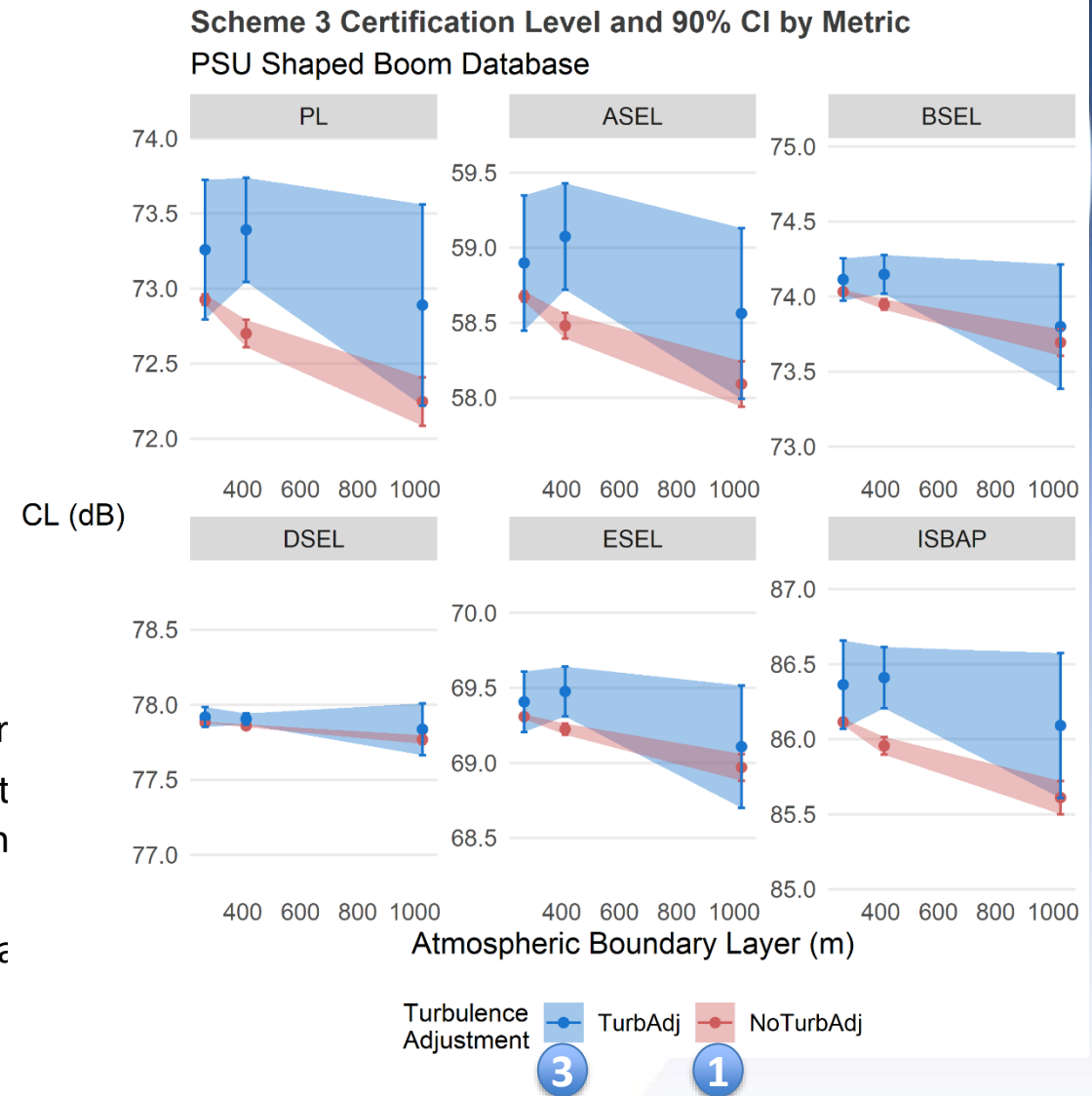
Certification Level Analysis



- Predictions can be validated with measurements by comparing the distributions and summary statistics



- Certification Levels are reported in terms of Reference Day to correct for atmosphere and turbulence effects
 - With 90% confidence intervals
 - Some metric certification levels have more variability than other
 - Split database method of incorporating a turbulence adjustment increases the certification level and its confidence interval width
 - As the atmospheric boundary layer increases in height, the certification level tends to decrease while the confidence interval widths increase, both with and without the turbulence adjustment



Certification Level Analysis Example



➤ Scheme certification level evaluation, Method 2, ABL height = 1026.7 m

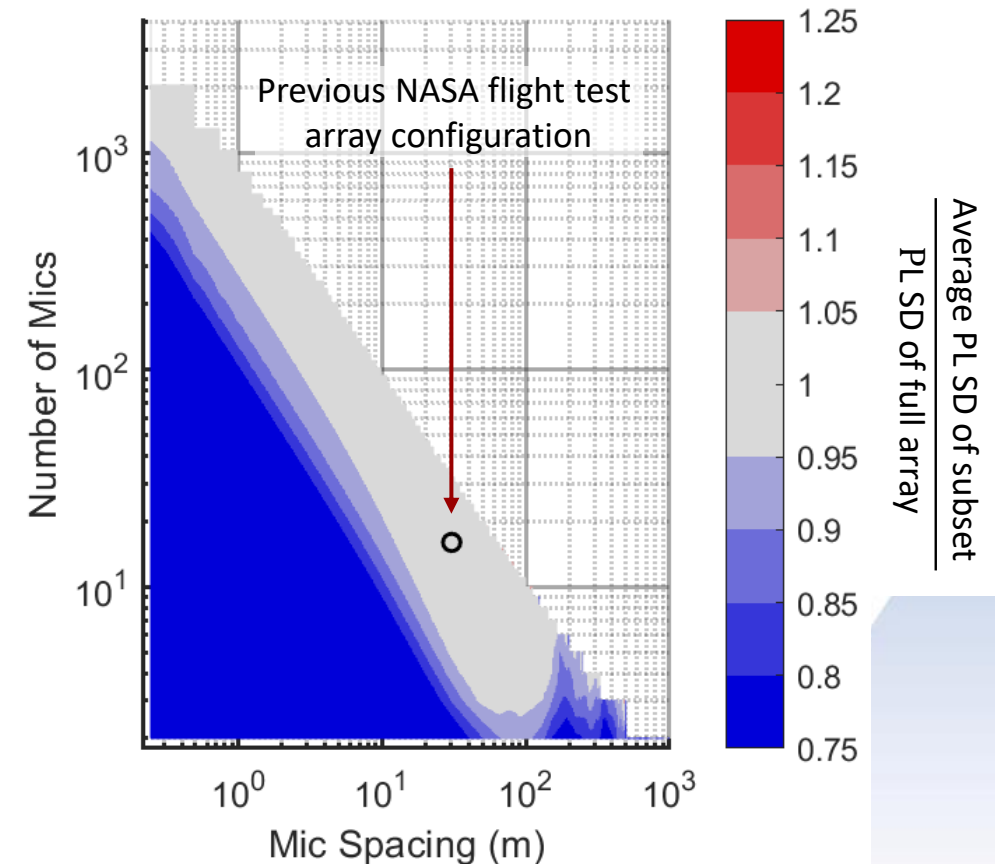
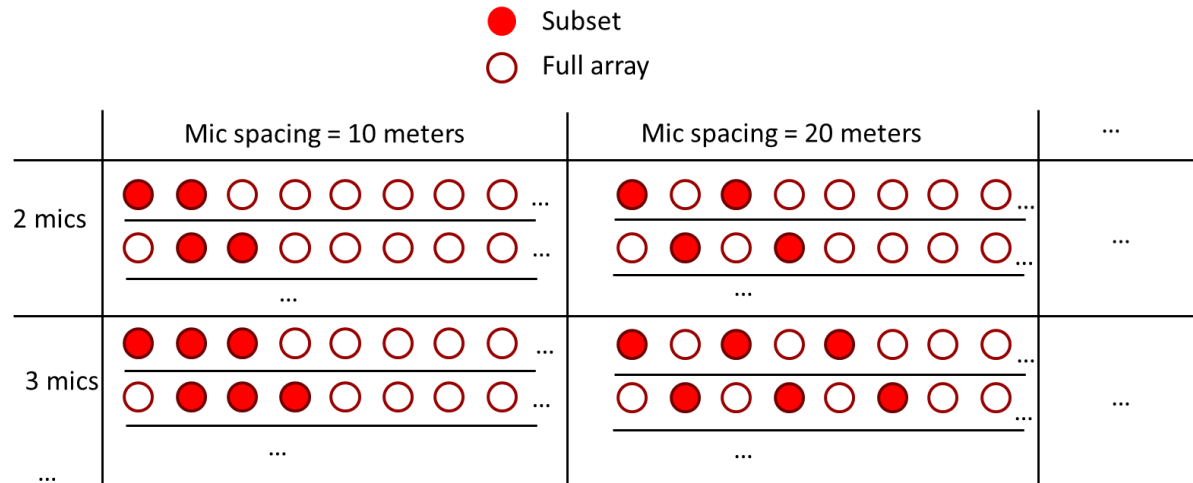
- $CL = \text{measurement} + \Delta_{\text{atm}} + \Delta_{\text{turb}}$
- Using subsampled shaped boom database levels as proxy measurements (16 measurements, 10 passes)
- Using PCBoom for all predictions:
 - Perturbations added to test-day trajectory points to synthesize multiple “as-flown” passes
 - PCBoom FiltView module used to estimate test-day predicted levels with turbulence; FiltView uses FIR filters to produce “turbulized” waveforms from a nominal PCBoom waveform without turbulence
 - Note: FIR filter set was developed from simulations using a measured waveform from an N-wave aircraft, and does not include filters for DSEL metric

		PL (dB)	ASEL (dB)	BSEL (dB)	DSEL (dB)	ESEL (dB)	ISBAP (dB)
Using PSU database	Mean	74.008	61.393	73.418		68.546	85.474
	90% CI	0.412	0.351	0.264		0.271	0.317
Using JAXA database	Mean	74.471	61.712	73.928		68.771	85.824
	90% CI	0.228	0.110	0.115		0.134	0.179

Microphone Number and Spacing Analysis



- Investigate options for realistic array size in certification measurements
- Tradeoff between number of microphones and spacing between them
 - Compare PL standard deviation of subset to standard deviation (SD) of full set



- **Simulation datasets being used to exercise proposed certification procedure methods**
 - There are challenges due to variability, even in “low-turbulence” conditions
 - Limited dataset with only one turbulence condition and one aircraft configuration
 - Will continue to exercise methods with predictions under higher turbulence conditions
 - Will be able to exercise procedure methods with X-59 test data when available
- **Certification level analyses demonstrate scheme viability**
 - Some metric certification levels have more variability and larger adjustments
 - Split database method of incorporating a turbulence adjustment increases the certification level and its confidence interval width
- **Results with limited dataset indicate that a modest number of microphones spaced ~30 m apart may be adequate**



- **What is an acceptable level of adjustment to reference conditions?**
 - For subsonic aircraft, 14 CFR Part 36 sets minimum sample sizes and associated confidence intervals, establishes a window on meteorological conditions over the short propagation path. Cannot adopt directly for supersonic en route noise.
- **How might we consider refining our approach? How might scatter be reduced?**
 - Introduce test day meteorological limits
- **Assume that data needs to be analyzed in aggregate across microphone locations and passes. How many flight passes are needed?**
 - Recognize that procedure needs to be simple and cost-effective
- **How should sensitivity to variations in aircraft trajectory/condition be handled?**