



Comparison of Sonic Boom Noise Metrics from Predictions and Measurements Under Low Atmospheric Turbulence Conditions



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- **NASA goal to enable development of noise-based standard for commercial supersonic aircraft**
- **Need a noise metric that predicts human perception of sonic booms experienced both outdoors and indoors**
 - No internationally agreed-upon metric exists
 - Previous meta-analyses identified 5-6 metrics
 - Further downselection of metrics is desired
 - Need a robust metric that can be used with real-world measurements
- **Objective of current study**
 - Use existing measured sonic boom data from supersonic overflight to study metric performance

Sonic Booms in Atmospheric Turbulence (SonicBAT) Flight Test



➤ Flight test procedure:

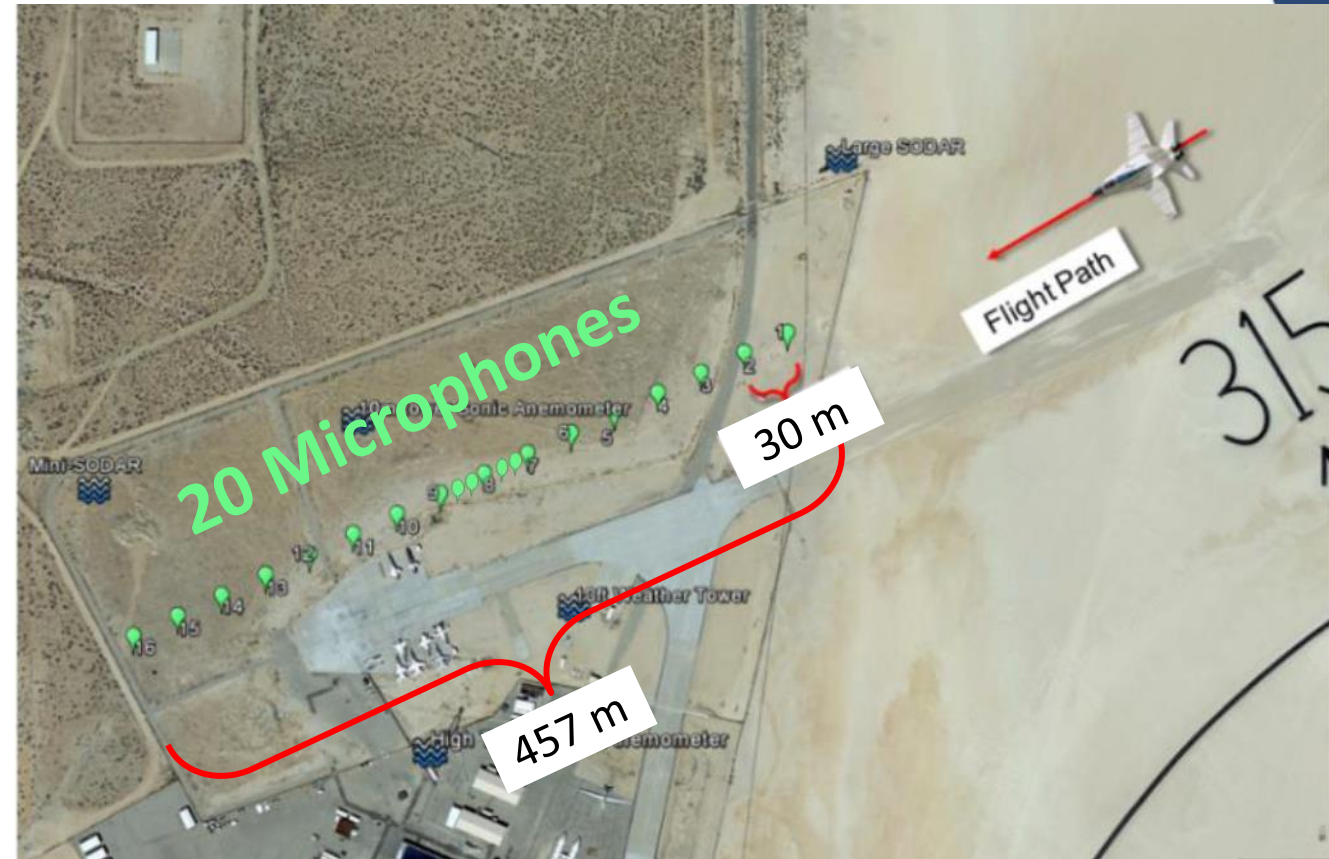
- Fly F-18 at Mach 1.4 at 34,000 ft. over microphone array through various levels of atmospheric turbulence (July 11-22, 2016)
- 20 flights (69 passes) at Edwards AFB

➤ Flight test goal:

- Understand turbulence effects on ground measurements of sonic booms
- Turbulence effects model validation

➤ Use low turbulence data from this test for a different purpose:

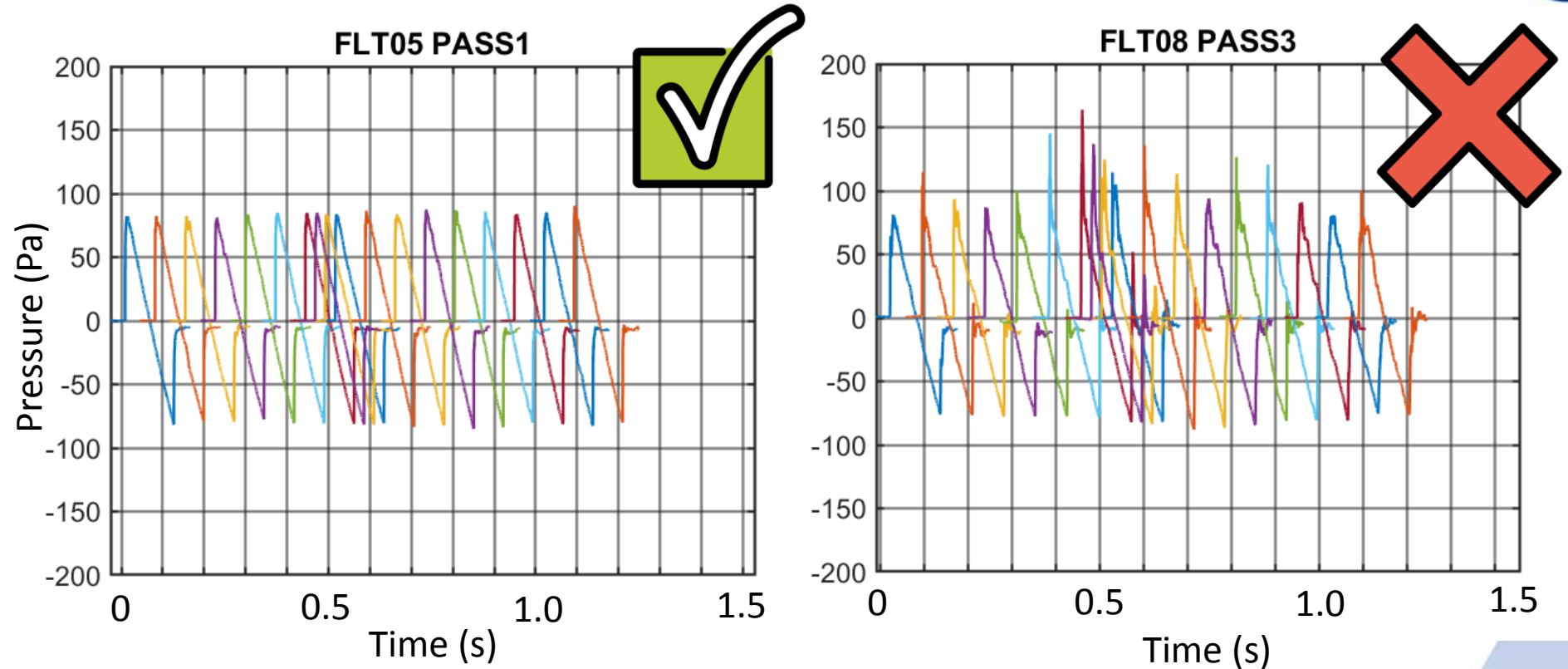
- Test our prediction capabilities
- Evaluate noise metrics
 - Future noise certification standard may utilize ground measurements of booms in low-turbulence conditions



SonicBAT Low-Turbulence Passes Offer Analysis Opportunities



Example ground recordings from 2 passes



- **Identified 6 supersonic passes with low turbulence**
 - Analysis of ground boom variability and atmospheric turbulence measurements
- **Next step: predict ground waveforms using NASA's PCBoom propagation code**



➤ Boom propagation prediction tool overview

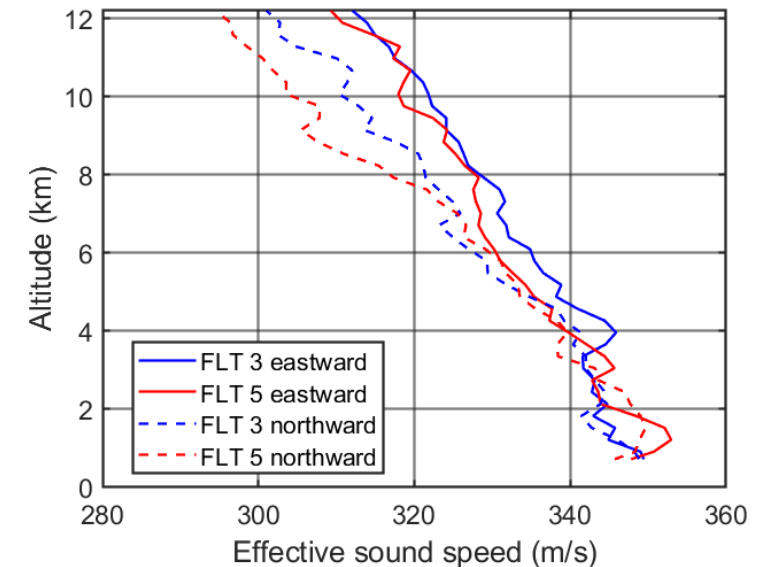
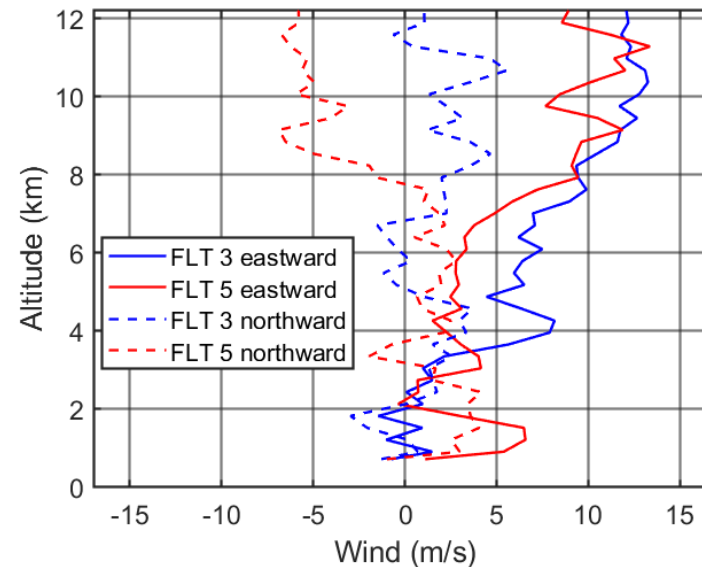
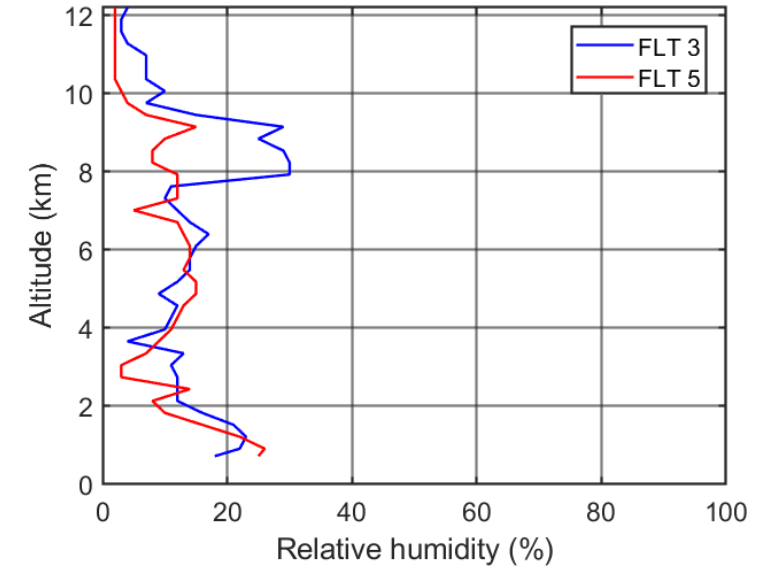
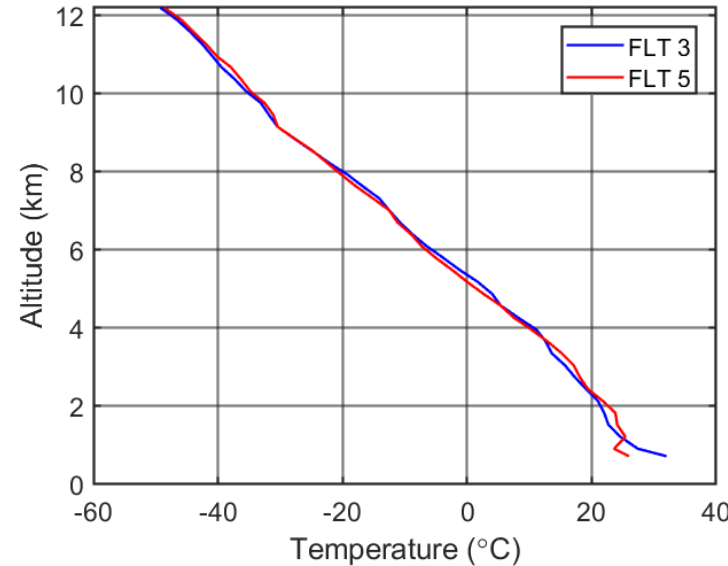
- Inputs:
 - Aircraft nearfield pressure
 - Aircraft trajectory
 - Altitude, heading, lat/lon, Mach, derivatives...
 - Atmospheric profile
 - Temperature, relative humidity, winds
- Output:
 - Ray landing position
 - Ground waveform
- Propagation methods:
 - Ray tracing
 - Implements the extended generalized Burgers equation
 - Nonlinearity, absorption/dispersion, geometrical spreading

➤ No turbulence effects included here

Predictions for Low-Turbulence Passes of SonicBAT



- **Prediction inputs:**
- F-18 nearfield CFD from Boeing
 - Measured F-18 trajectories
 - Measured weather balloon data
 - One profile per flight
 - Hot-dry climate

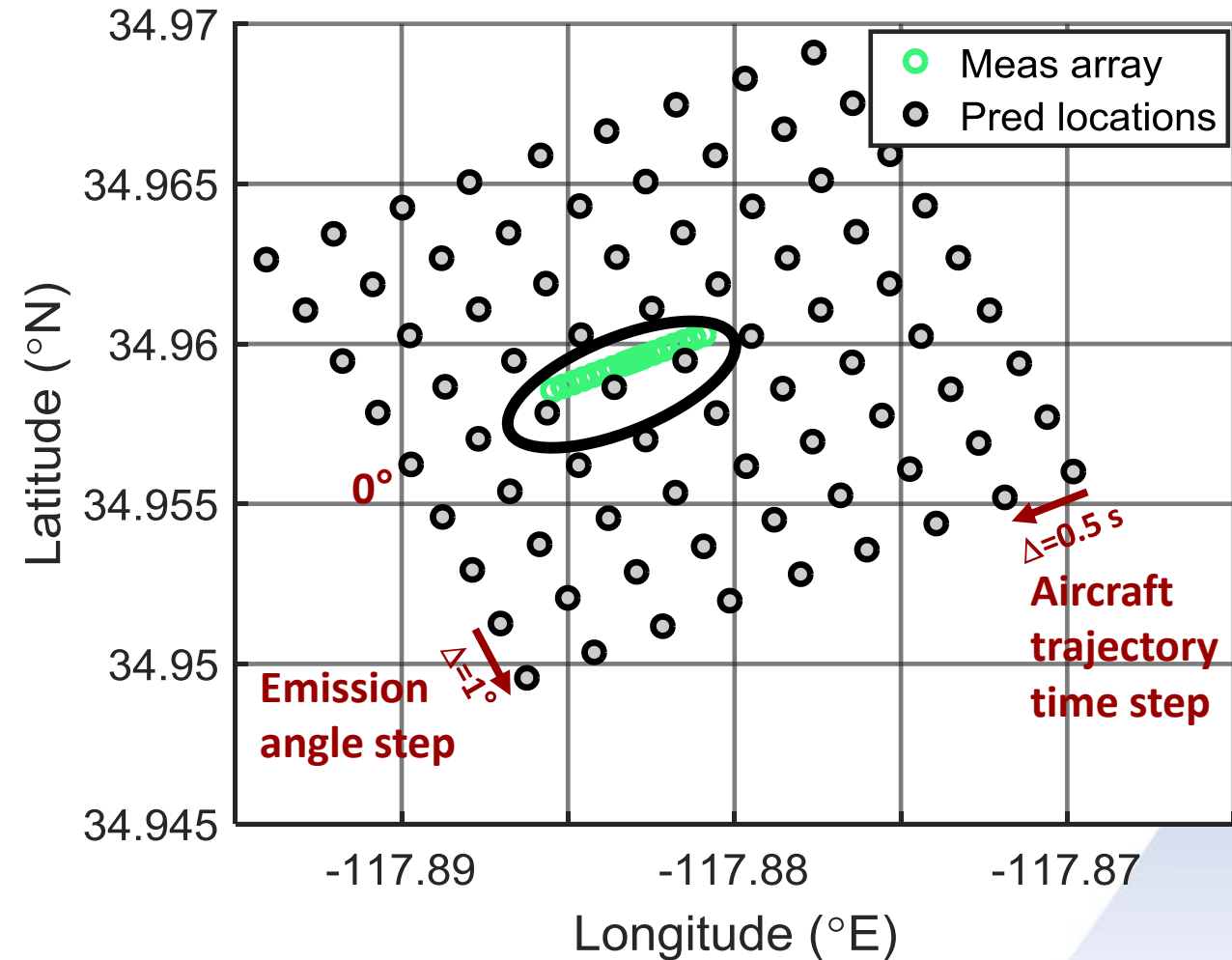


Predictions for Low-Turbulence Passes of SonicBAT



➤ Prediction outputs:

- Closest ray landings to each microphone captured
- Resolution:
 - Nearest 1 degree emission angle
 - Nearest 0.5 second trajectory time step
- Only 3-4 predictions used for each pass

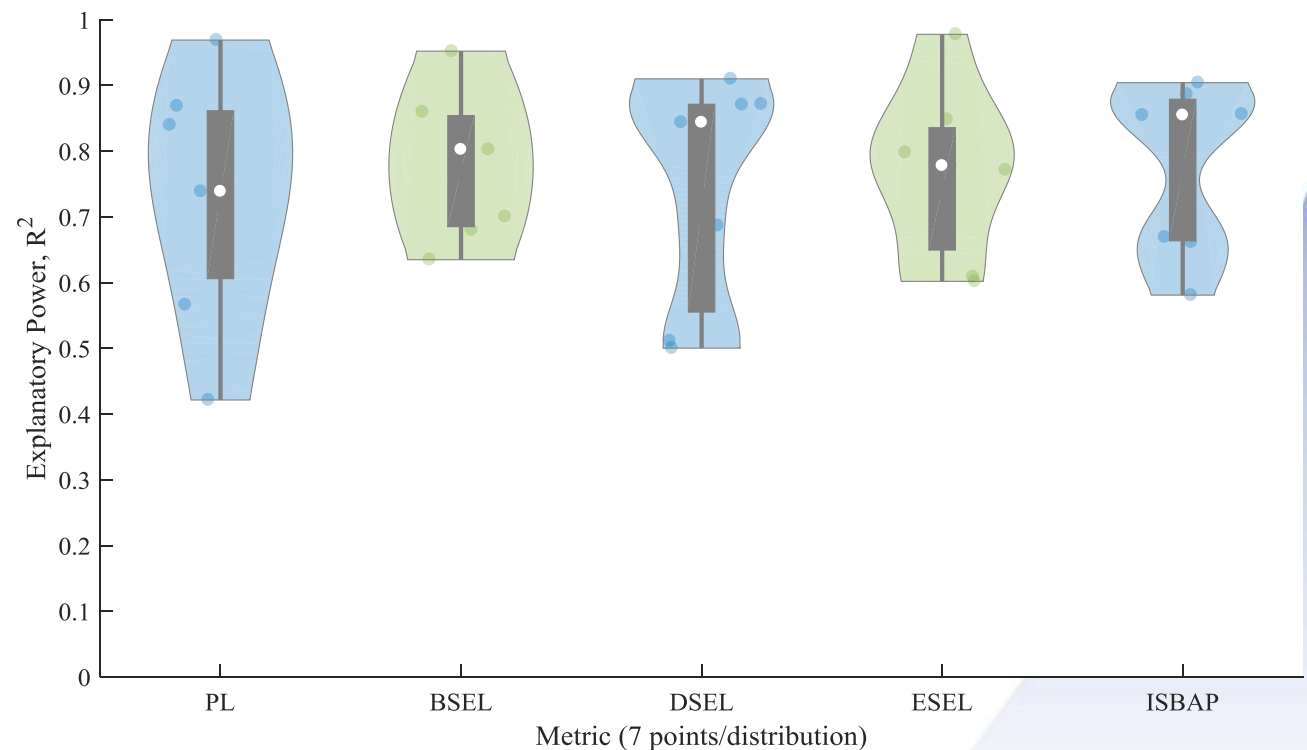
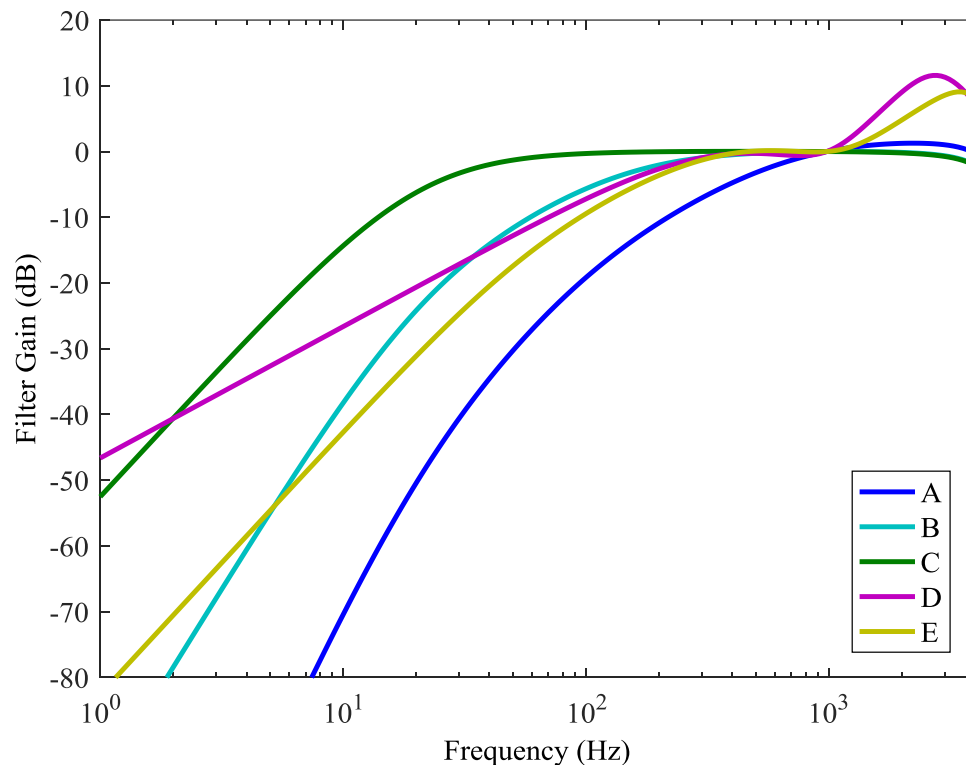


Sonic Boom Noise Metrics



➤ Six noise metrics identified in previous work

- PL, ASEL, BSEL, DSEL, ESEL, ISBAP
 - Indoor Sonic Boom Annoyance Predictor = ISBAP = PL + 0.4201 (CSEL – ASEL)
- Meta-analyses showed that all correlate well with human response outdoors and indoors

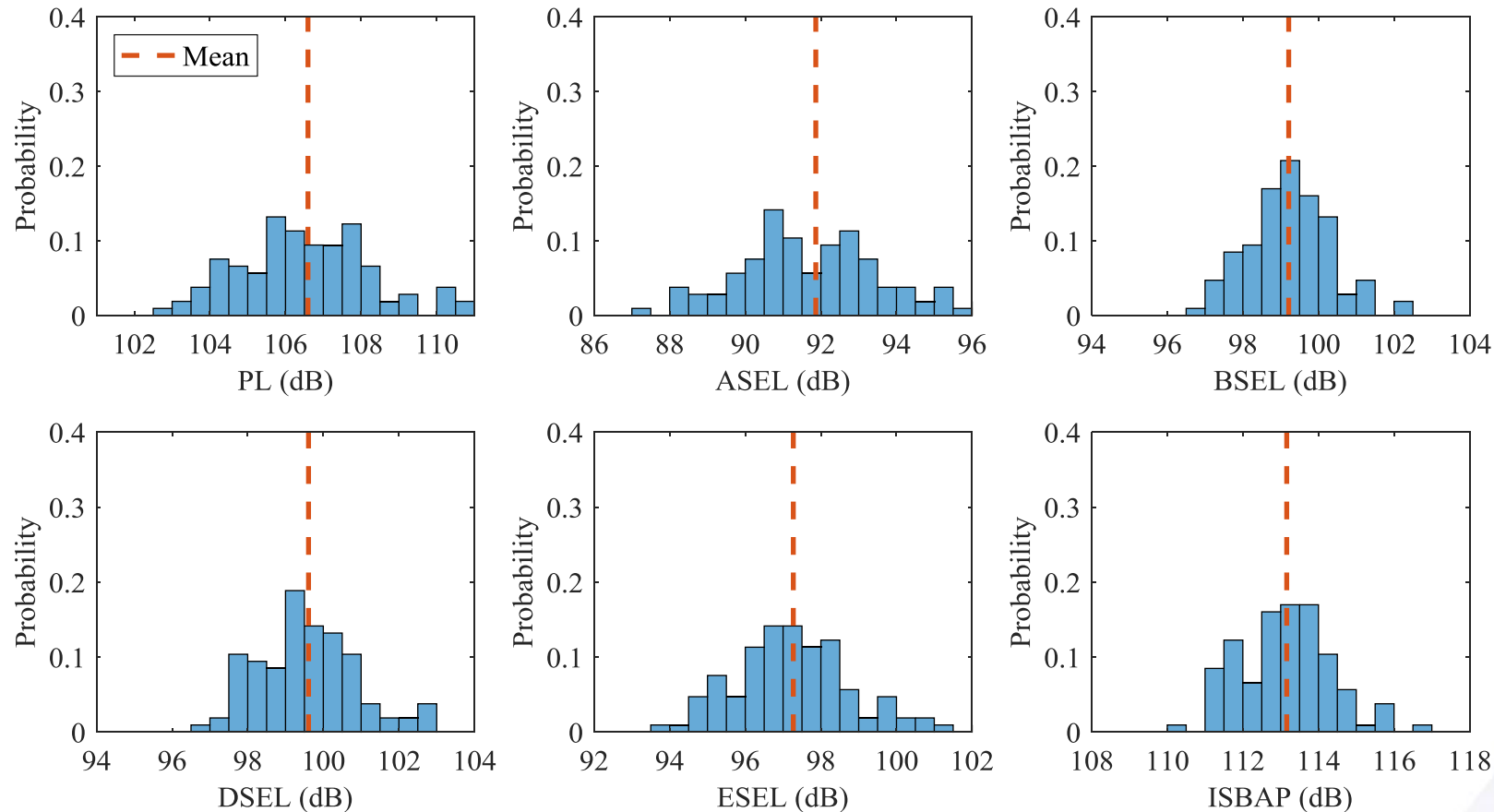


Measured Data (Grouped)



➤ All 6 passes combined (N=106)

- Distributions vary by metric
- Standard deviations of 1.1 to 2 dB

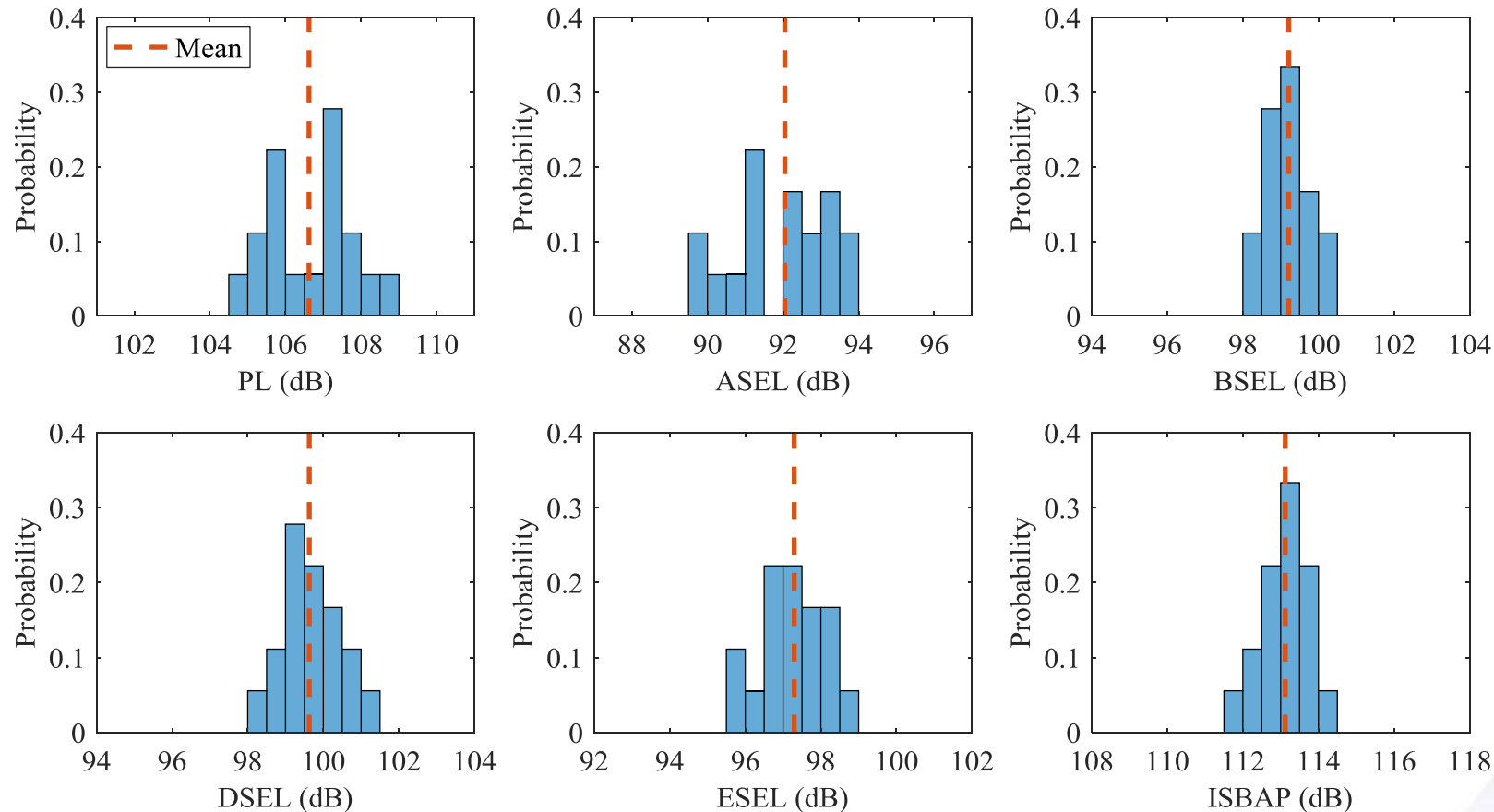


Measured Data (Individual Pass)



➤ Calculations conducted for each separate pass

- One example pass shown (N=17)

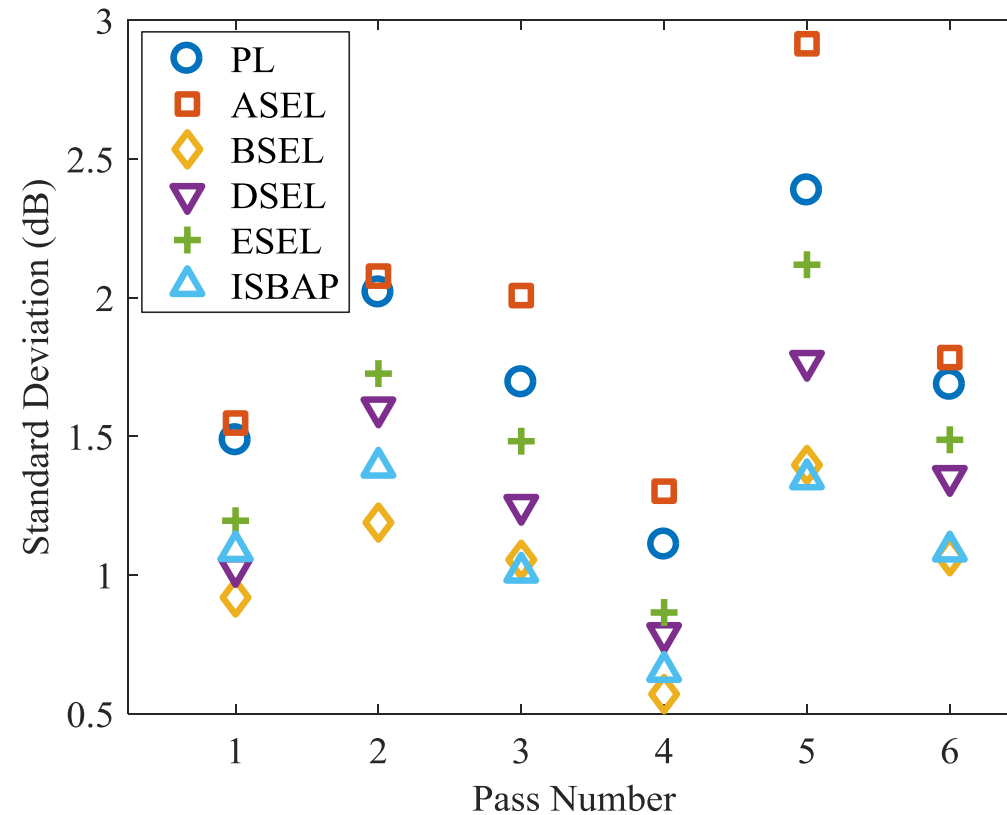


Measured Data (Per Pass)



➤ Comparison of standard deviations

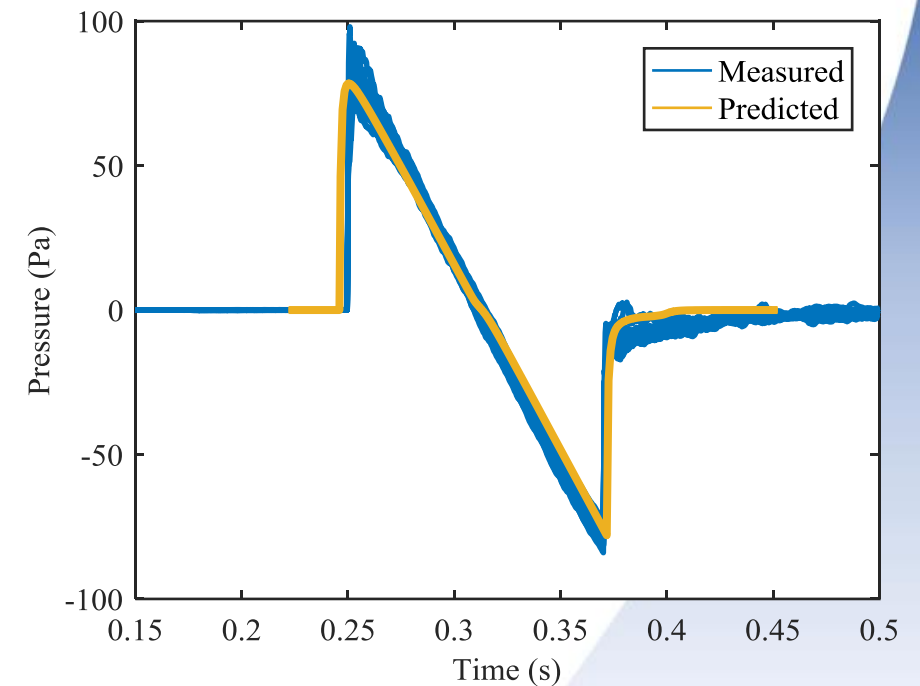
- Varies between passes
- Ranges from 0.6 to 2.9 dB
- BSEL and ISBAP have lowest values



Comparison of Measured and Predicted Data



- **Example waveform comparison between measured and predicted for one pass**
- **Note that predicted waveforms for a given pass have very low variability along array**
 - Variation in predictions is ≤ 0.2 dB along array
 - Minor differences in trajectory and ray path
 - Same atmospheric parameters applied with no turbulence
- **Variation in predictions between passes ≤ 0.2 dB**
- **Variation in predictions between flights ≤ 0.3 dB**
- **Assume that variations in measured data are due to atmospheric turbulence**



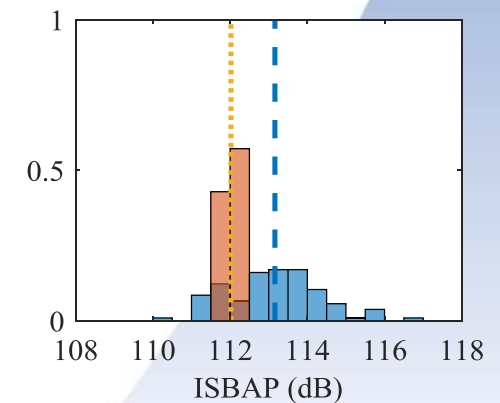
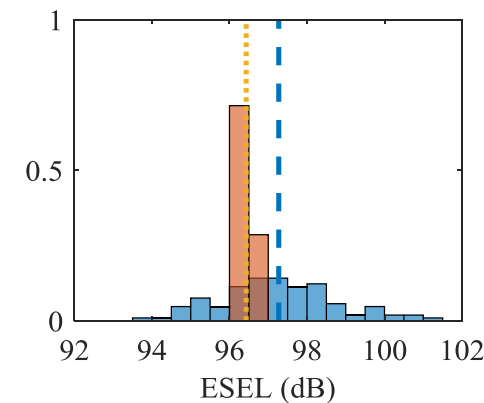
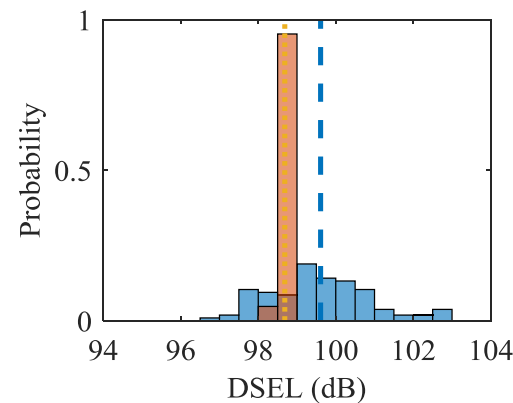
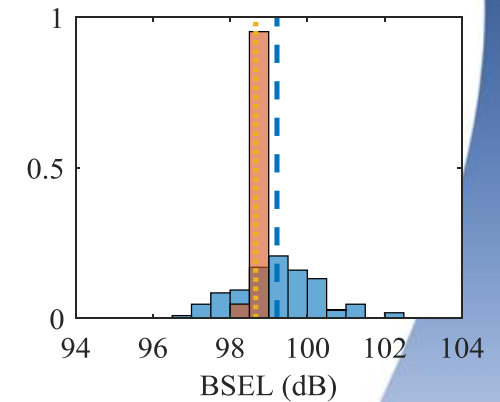
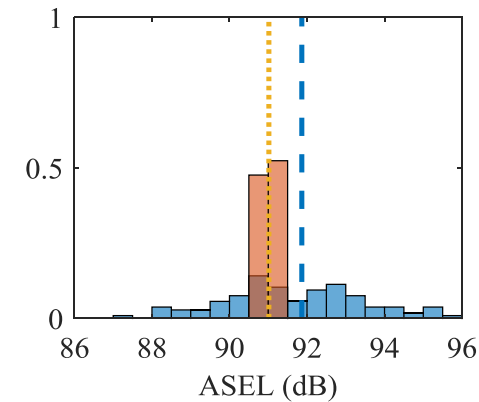
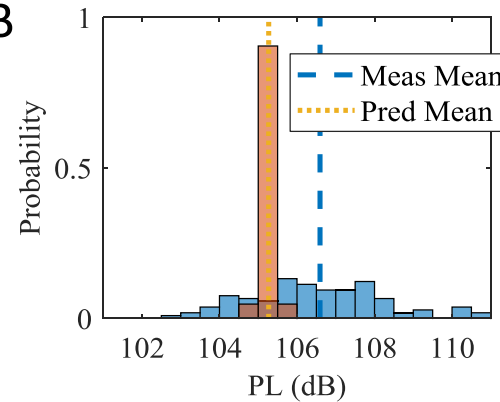
Comparison of Measured and Predicted Data (Grouped)



➤ Model underpredicts mean measured values

- Varies by metric
- Difference ranges from 0.6 to 1.3 dB

➤ Mean of predicted data (N=21) within standard deviation of the measured data mean



Comparison of Measured and Predicted Data (Per Pass)



➤ Model underpredicts mean measured values for all metrics

- Except for one case
- Model does not account for any atmospheric turbulence
- Note that predicted metrics have very low variability

➤ (Meas-Pred) difference varies between passes

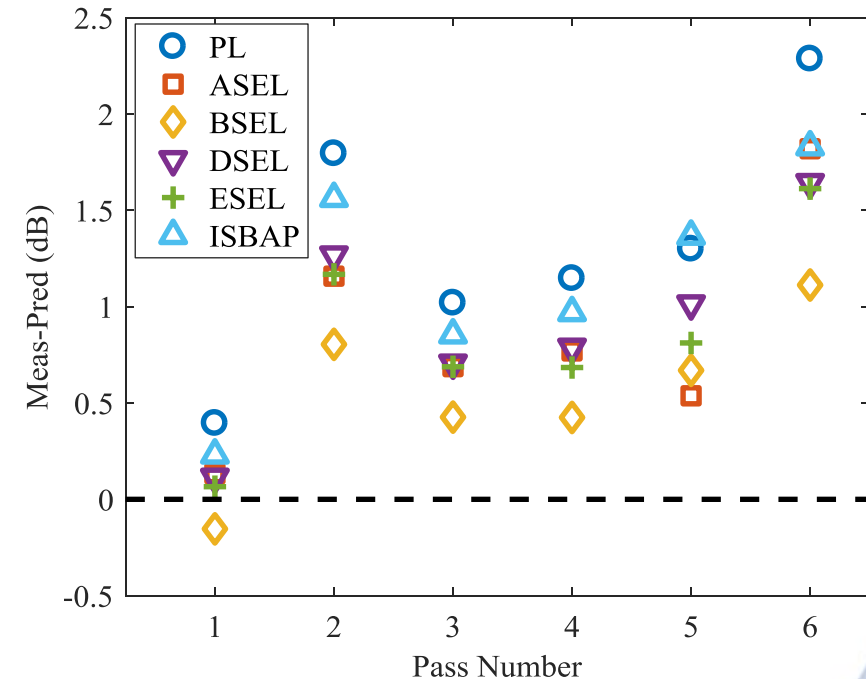
- Ranges from -0.2 to 2.3 dB

➤ BSEL differences are smallest

- Most robust to changes in waveforms due to turbulence

➤ PL differences are largest

- Most sensitive to (low) turbulence effects



Summary and Conclusions



- **Used sonic boom flight test data and predictions to explore metric variability**
- **BSEL consistently is least sensitive to low turbulence effects**
- **PL is one of the most sensitive metrics to small changes in waveforms**
- **Results valid for limited dataset**
 - F-18 N-wave sonic booms
 - Small subset of passes
 - Undertrack array
 - Low turbulence conditions
 - Hot-dry climate

Future Work



- Repeat for off-track microphone arrays
- Repeat for higher turbulence passes
- Analyze SonicBAT II data (hot-humid climate)
- Repeat analyses for quiet sonic thumps from NASA's X-59 QueSST aircraft

