Sonic Boom Prediction and Measurement Analysis Methods for Certification of Quiet Supersonic Aircraft

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Introduction

- **Industry is pursuing civil supersonic products**

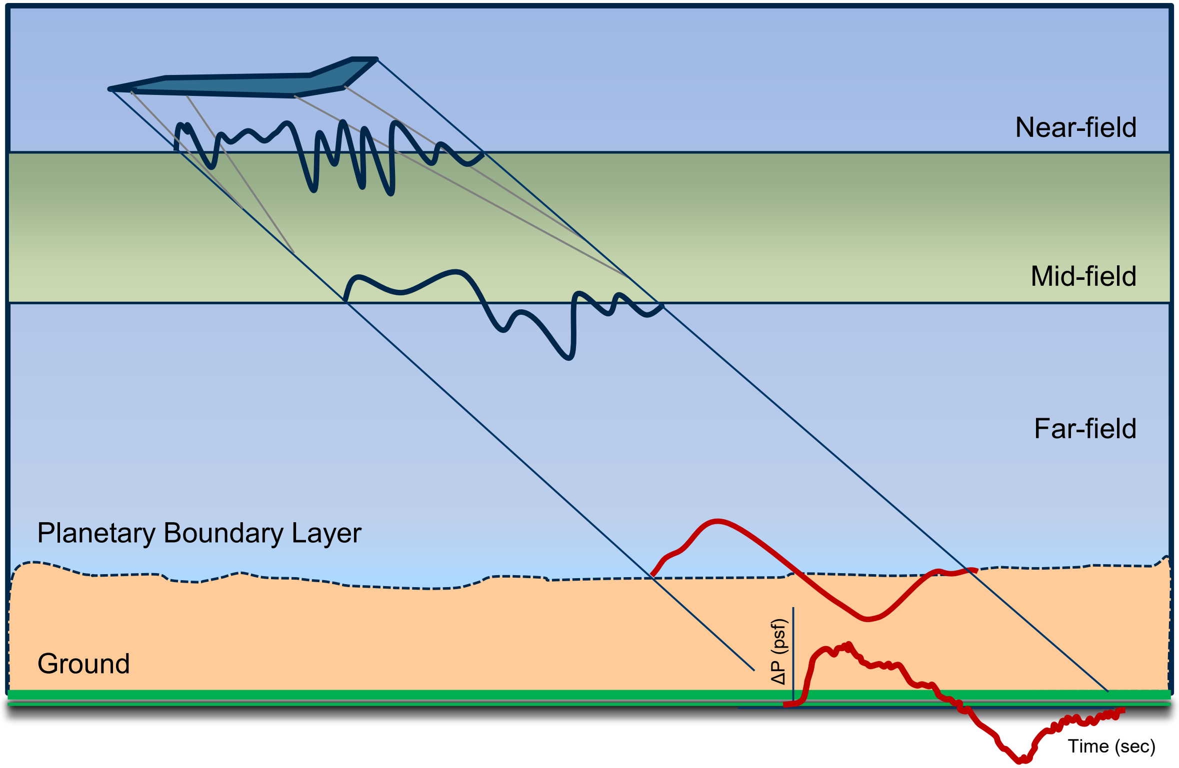
- **Two regulatory issues for civil supersonic flight: limiting terminal noise during subsonic flight and sonic boom during supersonic flight**
- **For sonic boom, formulating an international standard for low-boom capable, supersonic designs to potentially amend ban on civil supersonic overland flight worldwide**
  - Noise-based certification standard for supersonic en route (sonic boom) noise
  - Standard would include noise metric, test procedures, and noise limits
- **NASA is building the X-59 QueSST low-boom demonstrator to support standards development**
  - Prediction tool validation for shaped booms
  - Community response testing

Overview of International Standards Development

- **International Civil Aviation Organization (ICAO)**
  - Works through Committee on Aviation Environmental Protection to create global harmonized aviation environmental standards (e.g., aircraft noise and emissions)
  - Standards and Recommended Practices (SARP) are developed in working groups
  - Working group members include national aviation authorities, international non-governmental orgs, regional state orgs, subject matter experts
  - Structured process to review and propose SARPs for adoption by ICAO
- **Concept of fairness ("level playing field")**
  - Reference day atmosphere adjustments
  - Already implemented for subsonic aircraft noise standard
- **Other necessary criteria**
  - Robust and repeatable
  - Easily implemented and cost effective

Notional Certification Procedure

- **Reference Procedure Must Characterize Noise Performance at Reference Conditions**



Notional Certification Procedure Steps

Predictions to plan flight test → Test measurements → Test day predictions

Test measurements and Test day predictions → Validation or comparison of measurements and predictions

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Reference day adjustment

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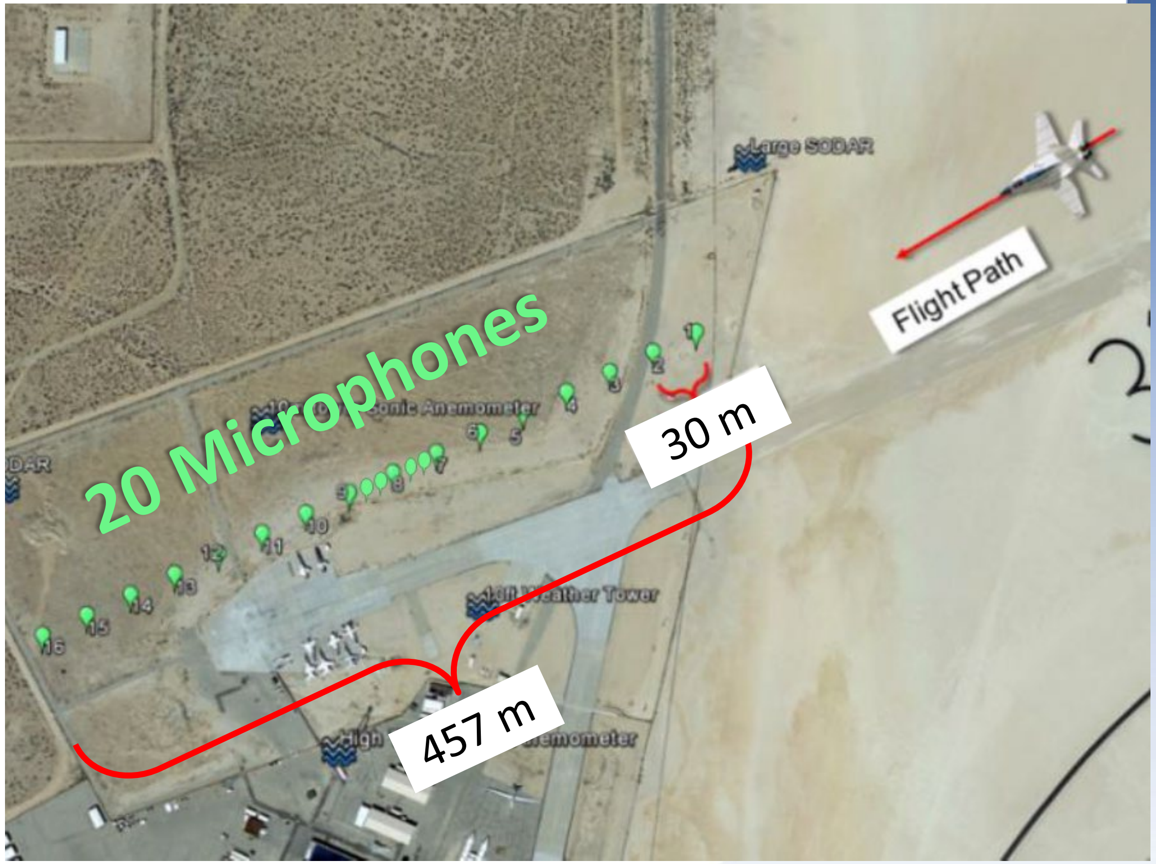
Calculate cert level and compare to limit

Test Dataset

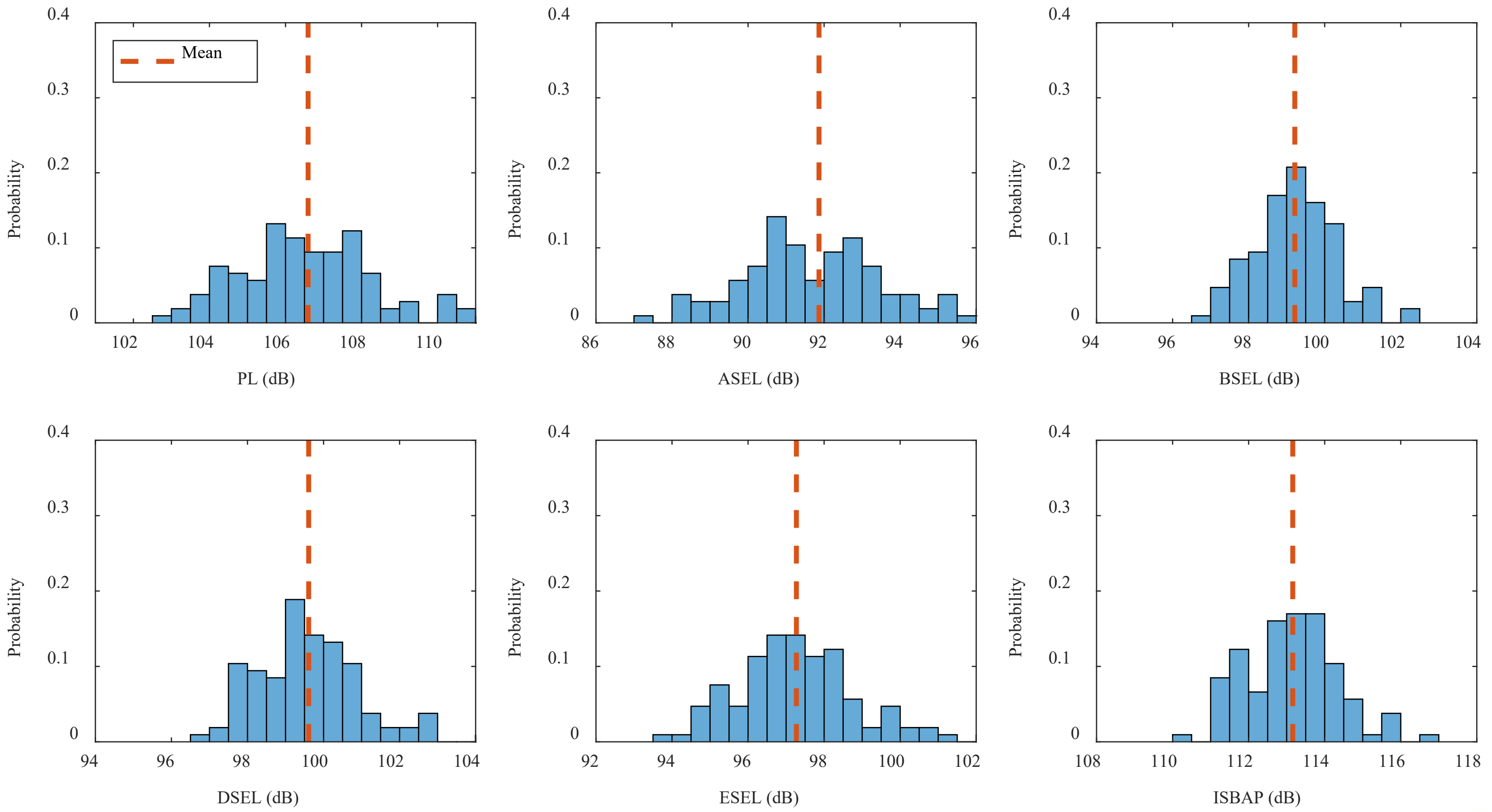
- **Develop procedures using existing measured (N-wave) sonic boom data**
  - Procedures will be tested with X-59 data when available
- **NASA SonicBAT summary**
  - Flight test procedure:
    - Fly F-18 at Mach 1.4 at 10.4 km over microphone array through various levels of atmospheric turbulence (July 11-22, 2016)
    - 20 flights (69 passes) at Edwards AFB, CA
  - Flight test goal:
    - Understand turbulence effects on ground measurements of sonic booms
    - Turbulence effects model validation
  - Use <u>low-turbulence</u> data from this test



Analyses of Measured Data

- **Develop procedures using existing measured (N-wave) sonic boom data**
- **Distribution of measured data (N=106)**
  - Distributions vary by metric and by pass

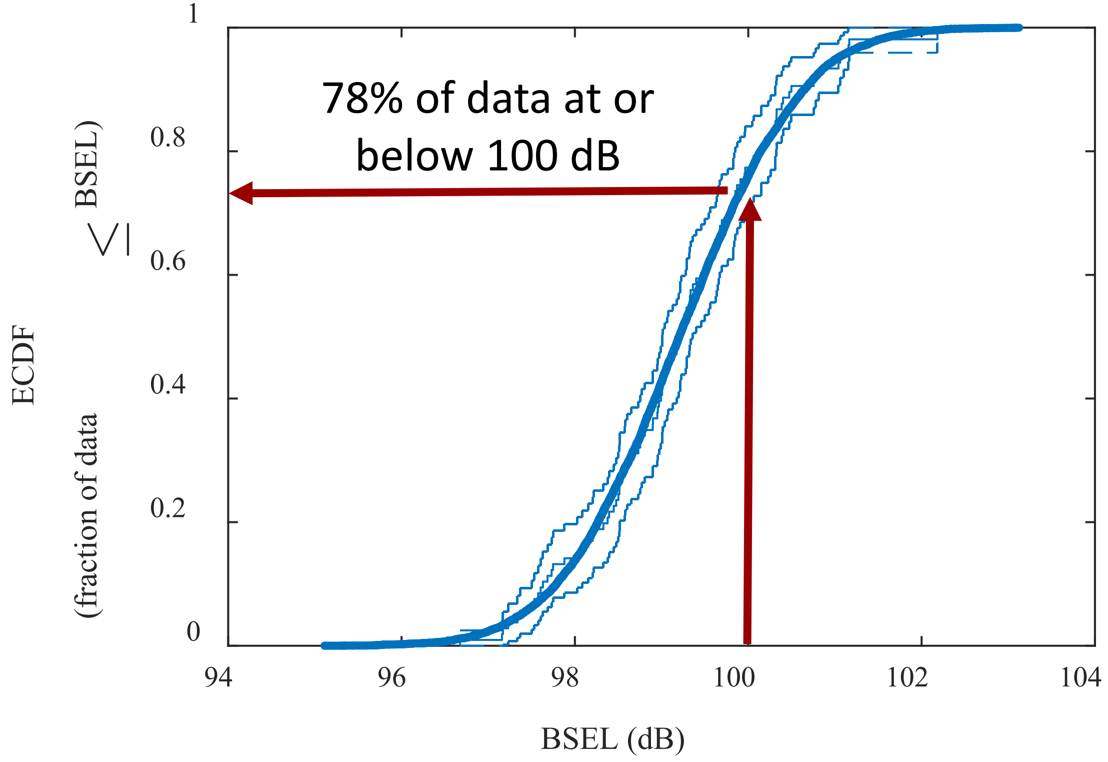
Six metrics under consideration



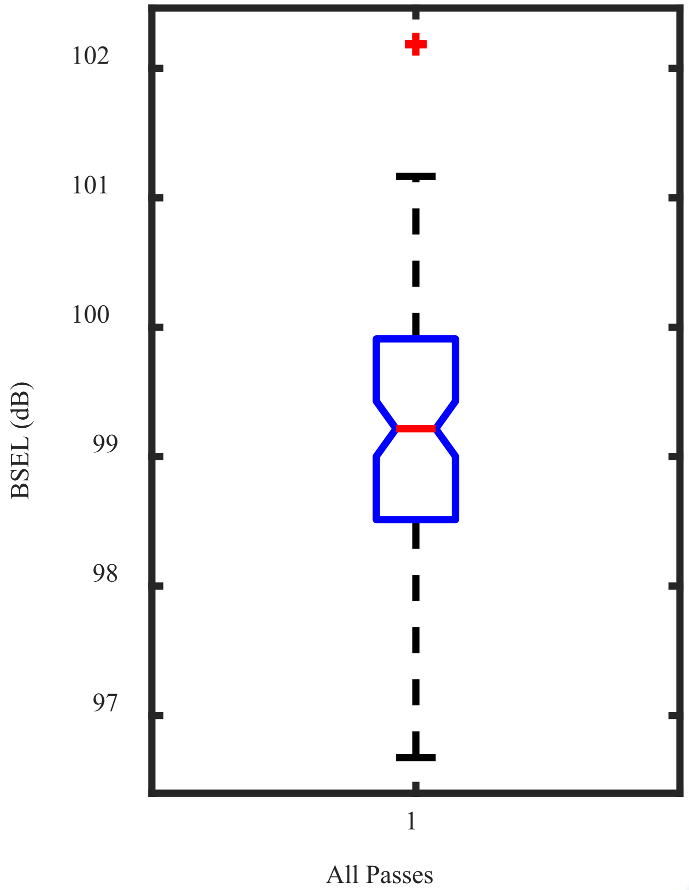
Analyses of Measured Data

- **Alternate statistical representations of data**

Empirical Cumulative Distribution Function

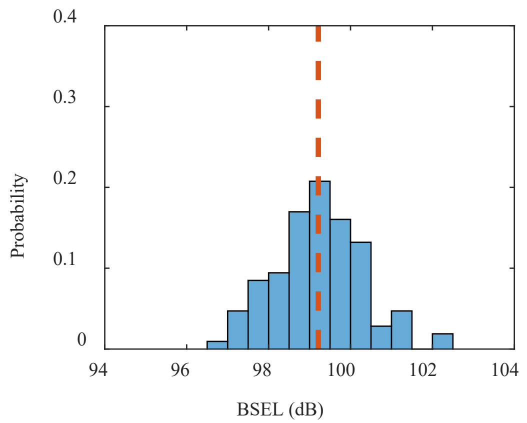


Box Plot

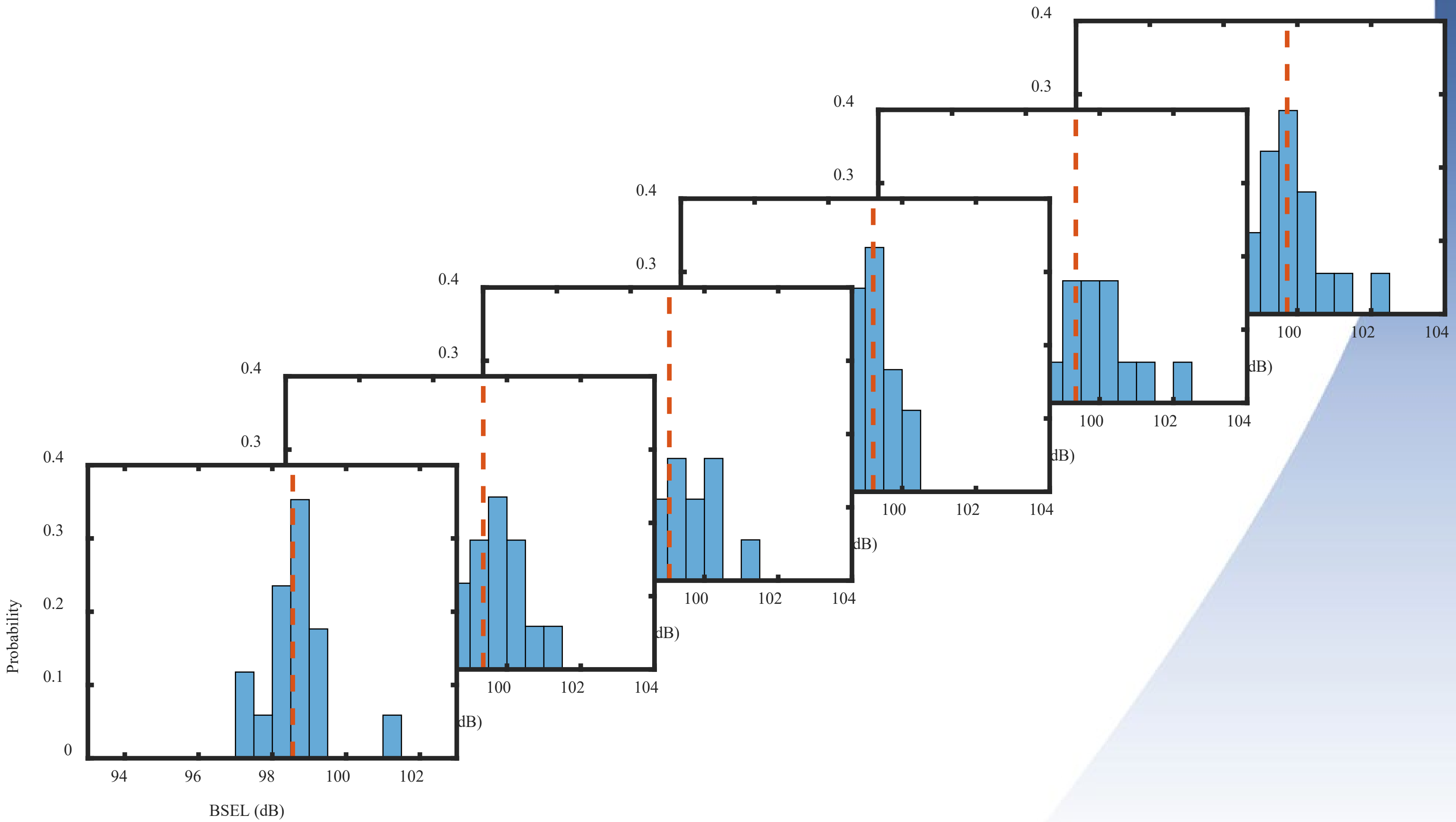


Analysis of Aggregate or Individual Measurements

- **All 6 passes combined (N=106)**
  - Standard deviation of 1.1 dB

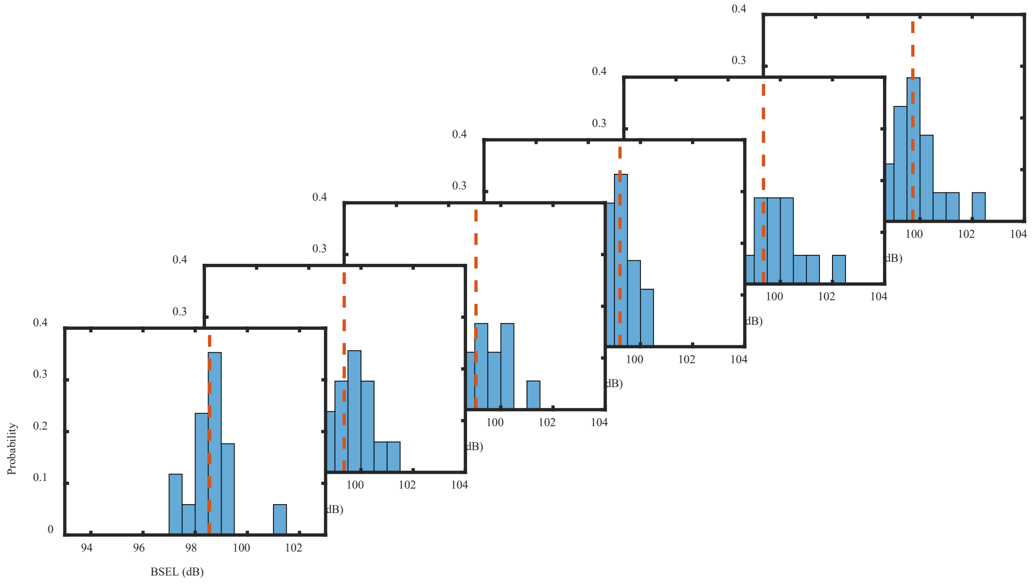


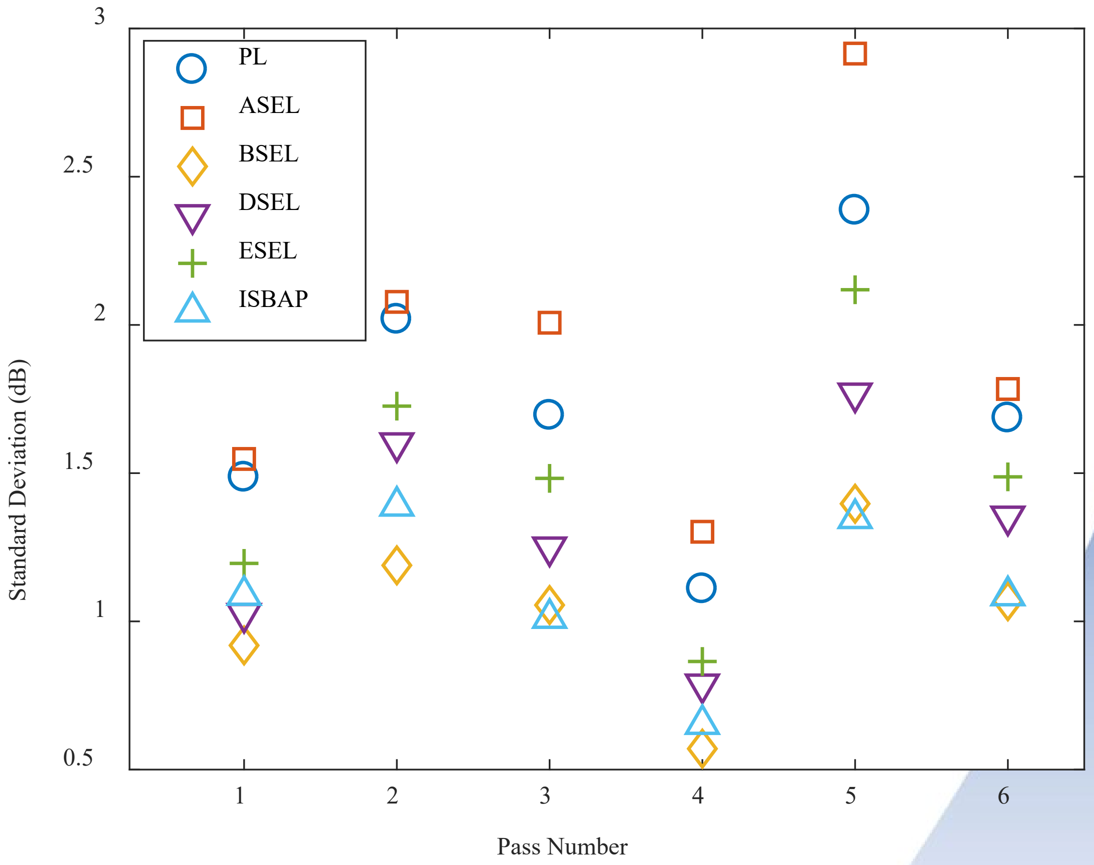
- **Calculations conducted for each separate pass (N=17)**



Analysis of Aggregate or Individual Measurements

- **Distributions vary by pass**
  - Meteorological conditions
  - Flight conditions
    - Mach number, altitude, trajectory, weight
  - Amount of variation also depends on metric





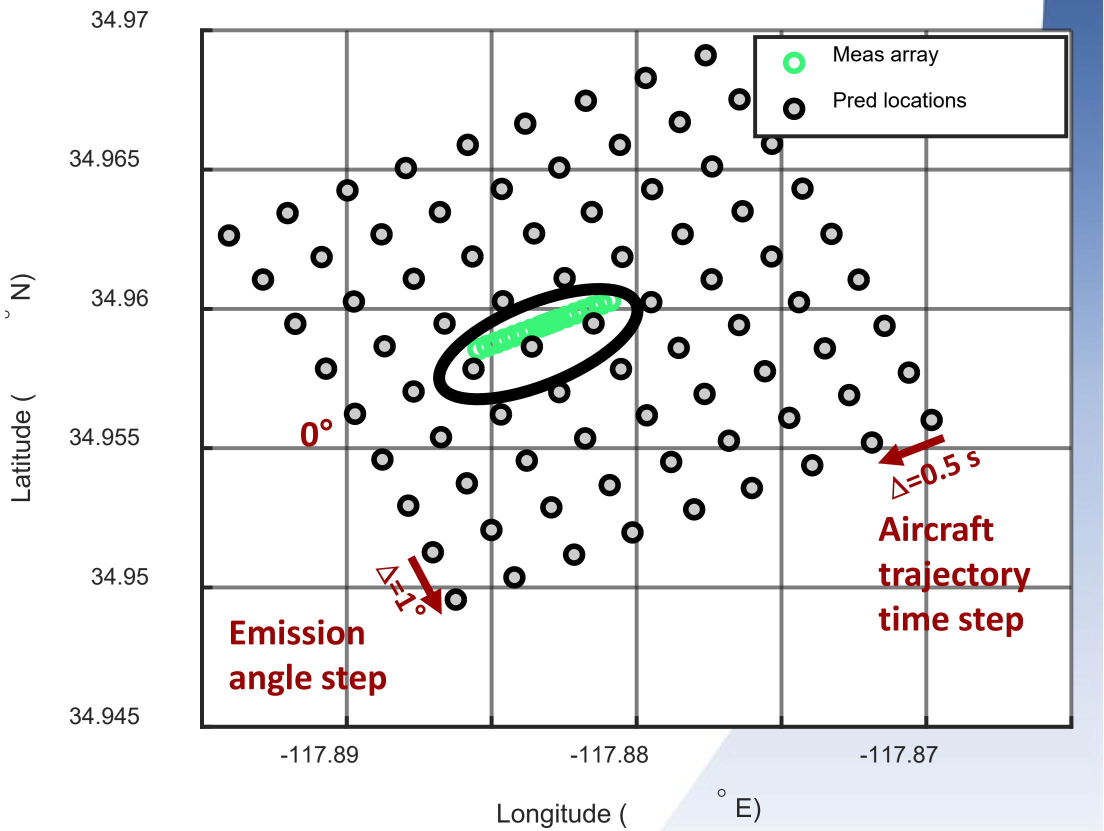
Boom Propagation Predictions

Propagation methods

- Ray tracing
- Implement the nonlinear wave equation
  - Nonlinearity, absorption/dispersion, geometrical spreading

Inputs

- F-18 nearfield pressure from CFD
- Measured F-18 trajectory
  - Altitude, heading, lat/lon, Mach, derivatives
- Measured atmospheric profile from weather balloon
  - Temperature, relative humidity, and winds as a function of altitude
  - One profile per flight



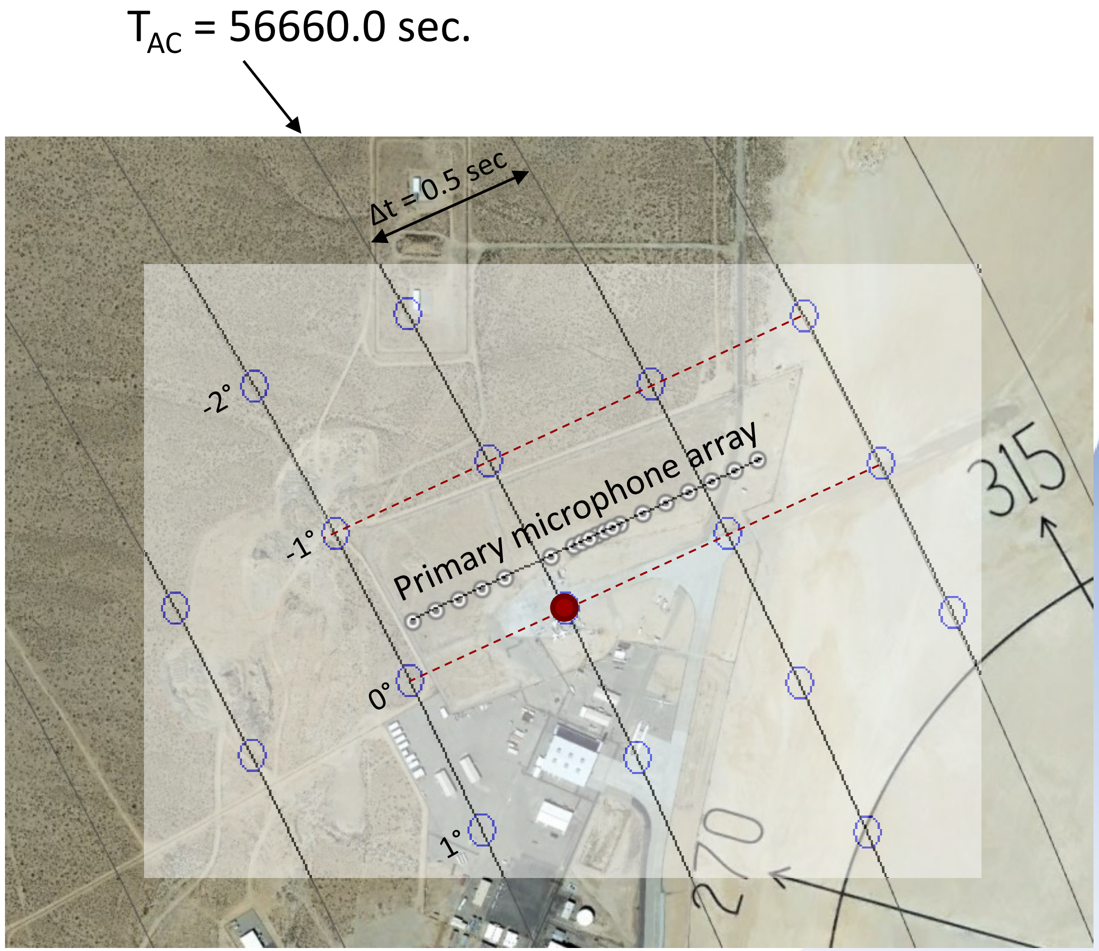
Output

- Ray landing positions closest to microphone array
- Ground waveforms at these positions

Boom Propagation Predictions

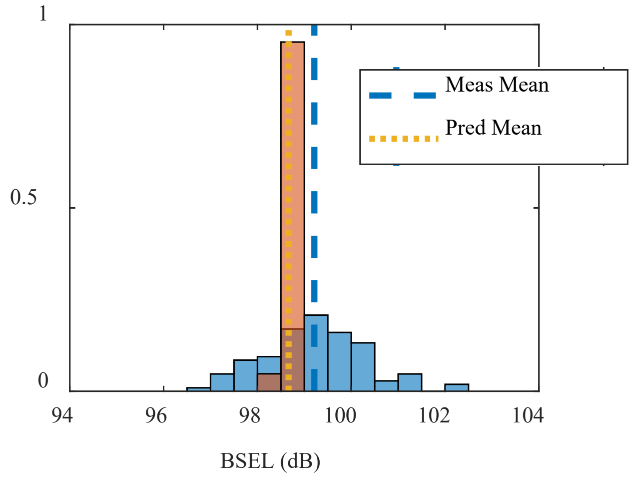
- **Can a single ray represent the microphone array?**
  - Propagation predictions completed for a set of ground intersection points bounding the microphone array
  - For a single stratified atmosphere without turbulence, differences in modeled PL at these points are ≤0.04 dB

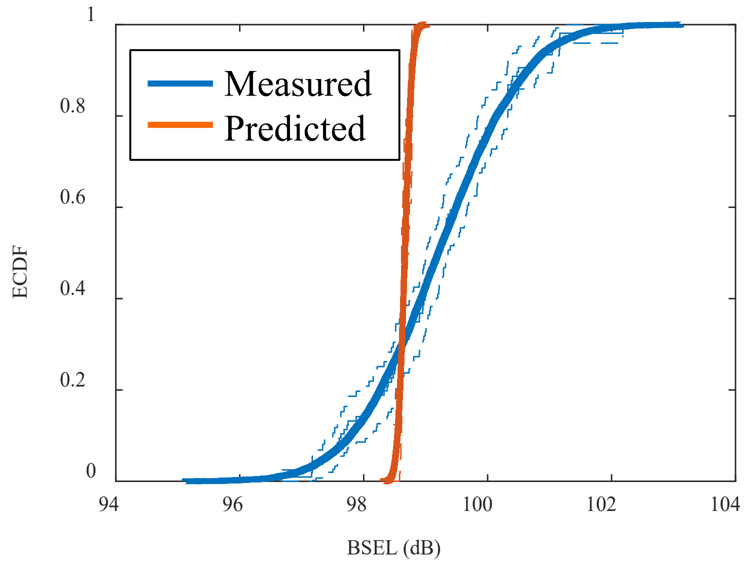
Δt	ΔPL across predictions	
	$\phi = 0°$	$\phi = -1°$
−1.0 sec.	+0.00 dB	+0.00 dB
−0.5 sec.	−0.01 dB	−0.02 dB
T_{AC} = 56660.0 sec.	**106.32 dB**	−0.04 dB
+0.5 sec.	−0.01 dB	−0.03 dB



Comparing Predictions and Measurements

- **Certification procedure will include both measurements and predictions**
  - Helpful to investigate both with N-wave dataset
- **Test day predictions for N-wave signatures without atmospheric turbulence effects show much less variation than measurements**
- **Comparisons and adjustments to reference conditions are larger than preferred**
- **Hence this may require statistical approach**

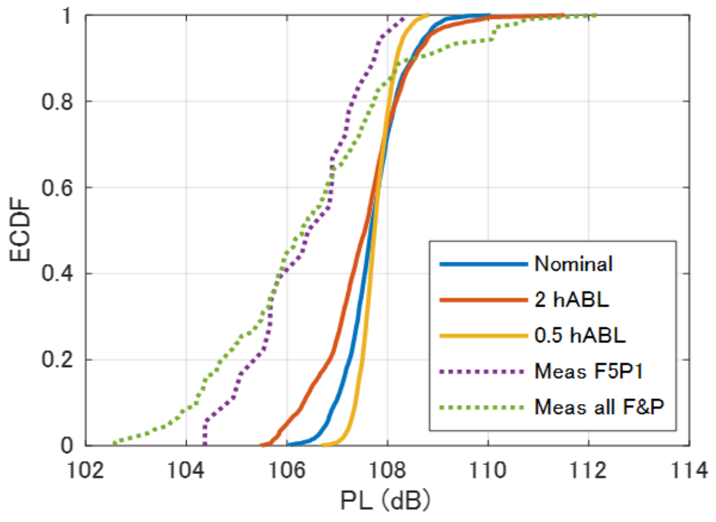




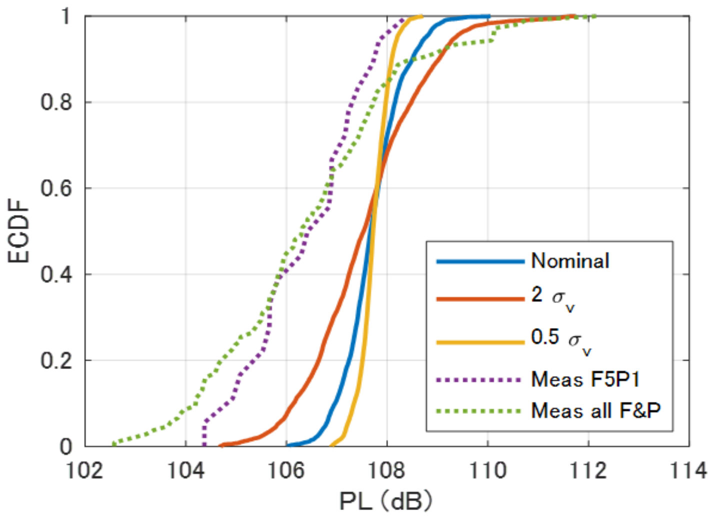
Comparing Predictions and Measurements

Potential need to include turbulence in predictions

- Propagation through many realizations of turbulence based on measured meteorological parameters
- Ground boom variability is increased and approaches that of measured data
- Increasing the turbulence level lowers the mean metric value



a) ABL thickness (h_{ABL})



b) Turbulence intensity (σ_V)

Items for Future Work

- **Recognize that there is a large variability in test data for N-wave noise**
  - Shaped booms predicted to have smaller variation[1], but there will still be some variation
- **Whether to compare individual measurement points, passes, or in aggregate**
- **What is an acceptable level of disagreement or adjustment to reference conditions?**
  - For subsonic aircraft, 14 CFR Part 36 sets minimum sample sizes and associated confidence intervals, establishes a window on temperature, relative humidity, wind/crosswind velocities, and requires "No anomalous meteorological or wind conditions that would significantly affect the measured noise levels…"
- **How many microphones and passes are needed?**
  - Do we need predictions at each microphone location?
  - Recognize that procedure needs to be simple and cost-effective
- **How might we consider refining our approach? How might scatter be reduced?**
  - Introduce test day meteorological limits
  - ANOVA and other statistical tests

[1]Trevor A. Stout and Victor W. Sparrow, "Three-dimensional simulation of shaped sonic boom signature loudness variations due to atmospheric turbulence," 25th AIAA/CEAS Aeroacoustics Conference, Delft, The Netherlands (20-23 May 2019), AIAA Paper 2019-2562

Summary

- **Existing dataset being used to exercise proposed certification procedure methods**
  - Real-world data presents challenges due to variability, even in “low-turbulence” conditions
  - Limited dataset with only two flights of an N-wave aircraft configuration
  - Will be able to exercise procedure methods with X-59 test data when available
- **It is not reasonable to expect very close agreement between predicted noise levels and measured ground data**
  - More work required to compare data statistically
  - May have to account for atmospheric turbulence effects in predictions