



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 a 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 ICAO 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 harmonized global aviation standards for 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 “level playing field”

- Reference day atmosphere adjustments
- Already implemented for subsonic aircraft noise standard

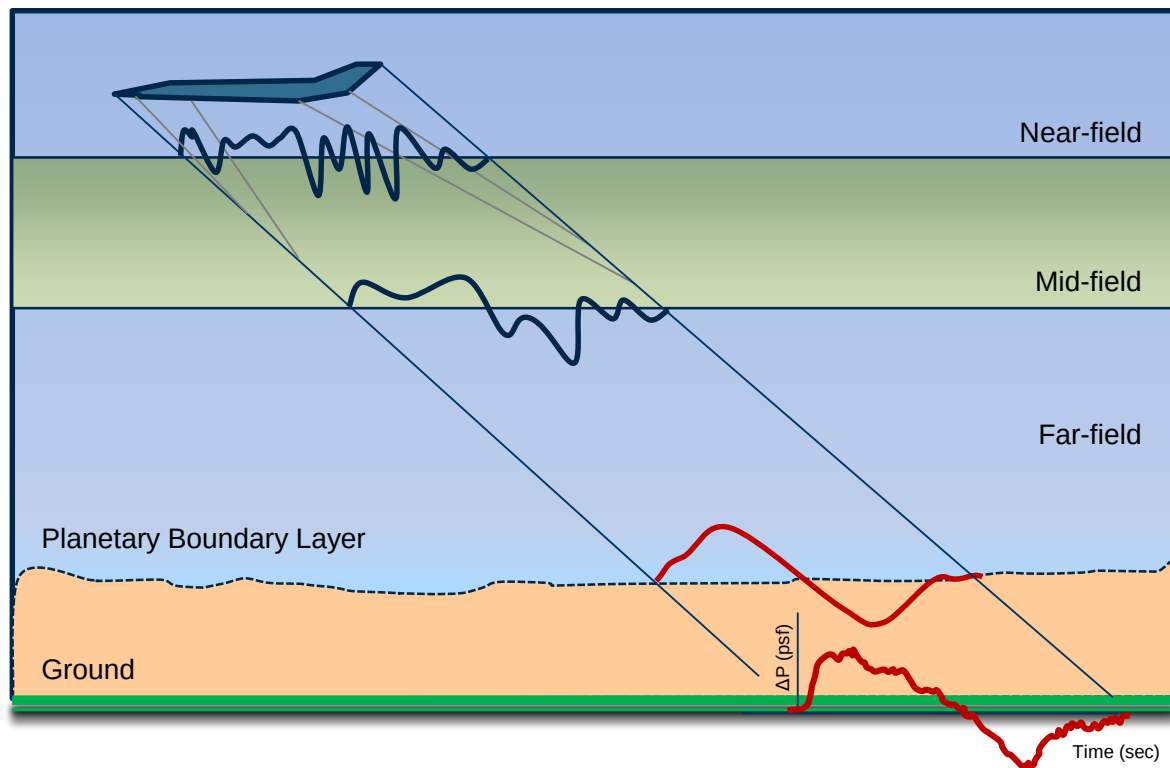
➤ Other necessary criteria

- Robust and repeatable
- Easily implemented and cost effective

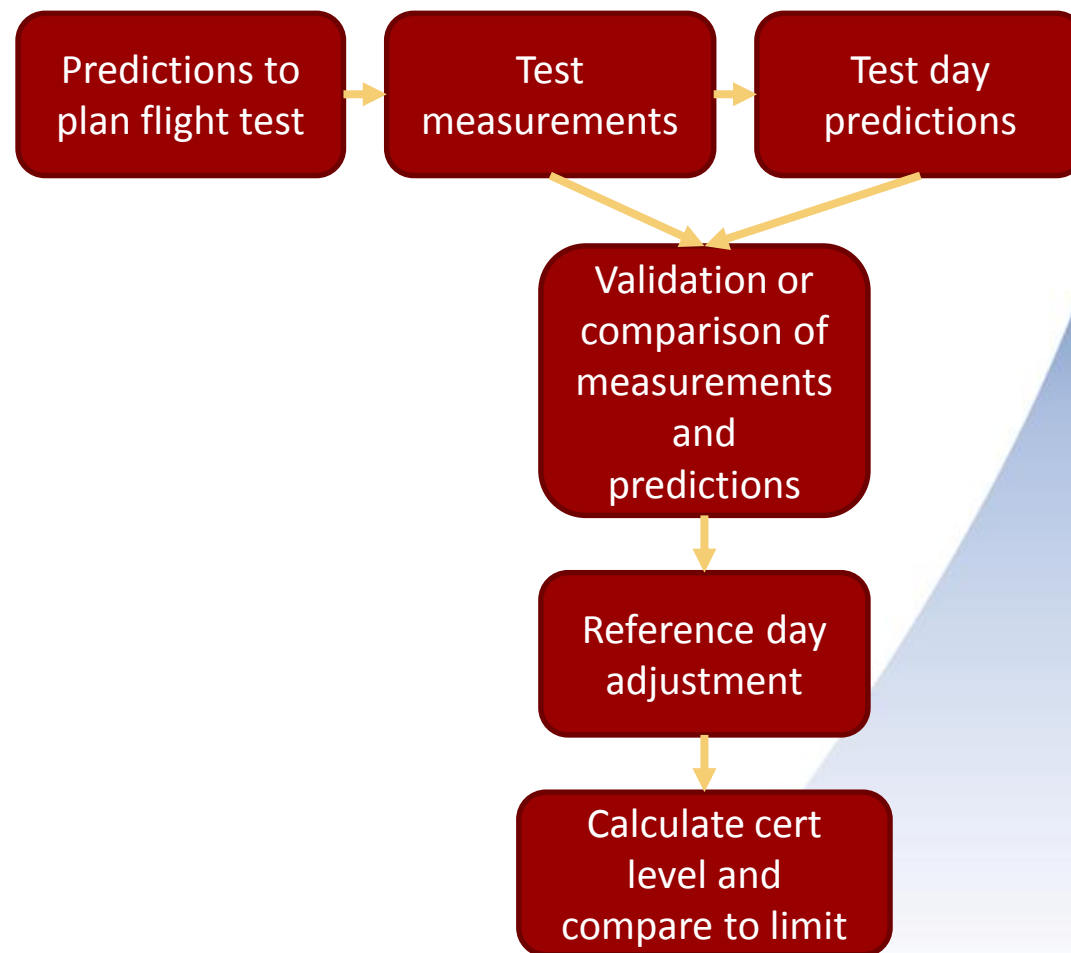
Notional Certification Procedure



➤ Reference Procedure Must Characterize Noise Performance at Reference Conditions



Notional Certification Procedure Steps



➤ Develop procedures using existing measured (N-wave) sonic boom data

- Procedures will be tested with X-59 data when available

➤ NASA SonicBAT summary

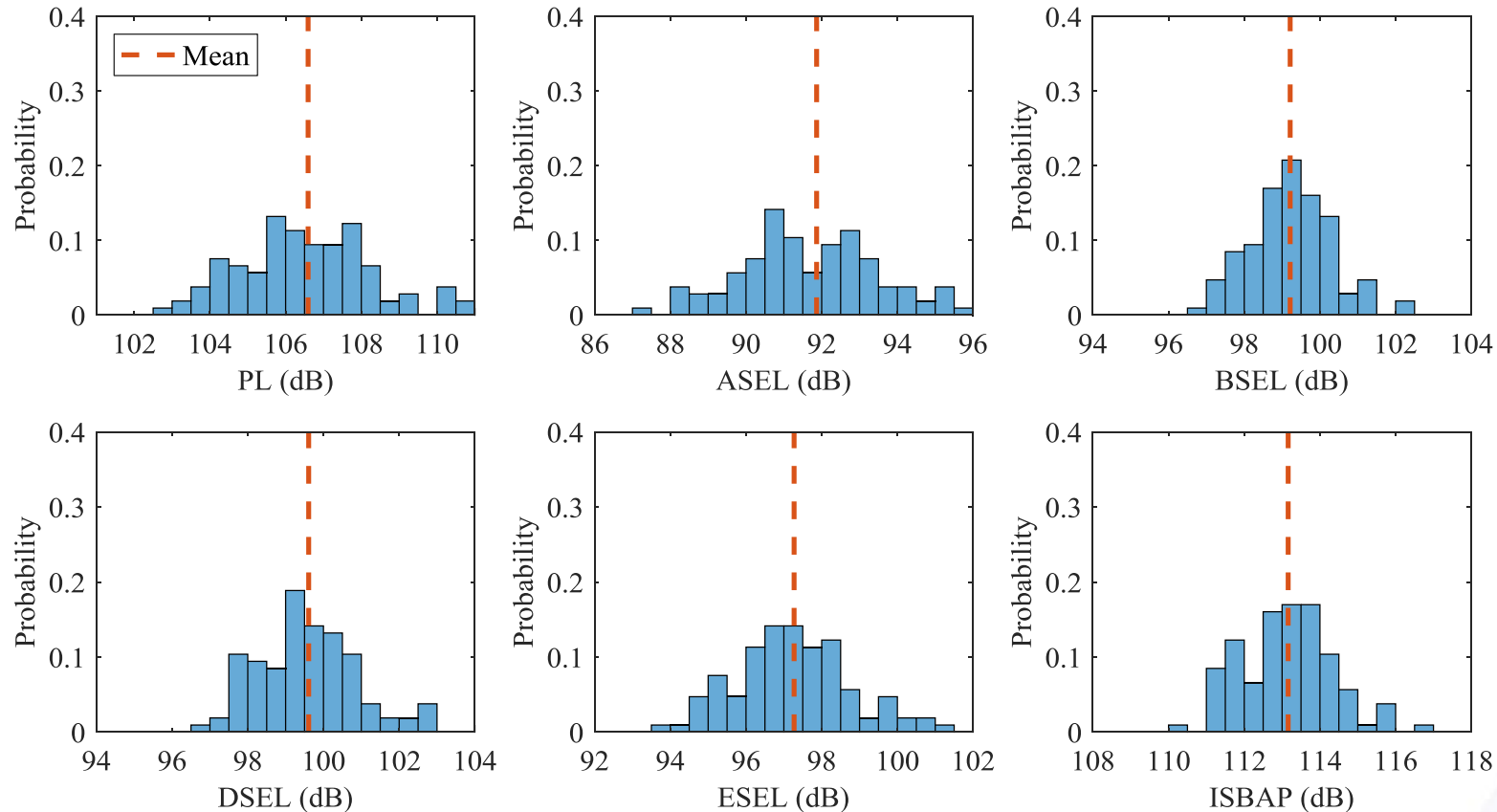
- Flight test procedure:
 - Fly F-18 at Mach 1.4 at 10.4 km over microphone array through various levels of atmospheric turbulence (July 11-22, 2016)
 - 20 flights (69 passes) at Edwards AFB, CA
- Flight test goal:
 - Understand turbulence effects on ground measurements of sonic booms
 - Turbulence effects model validation
- Use low-turbulence data from this test



Analyses of Measured Data



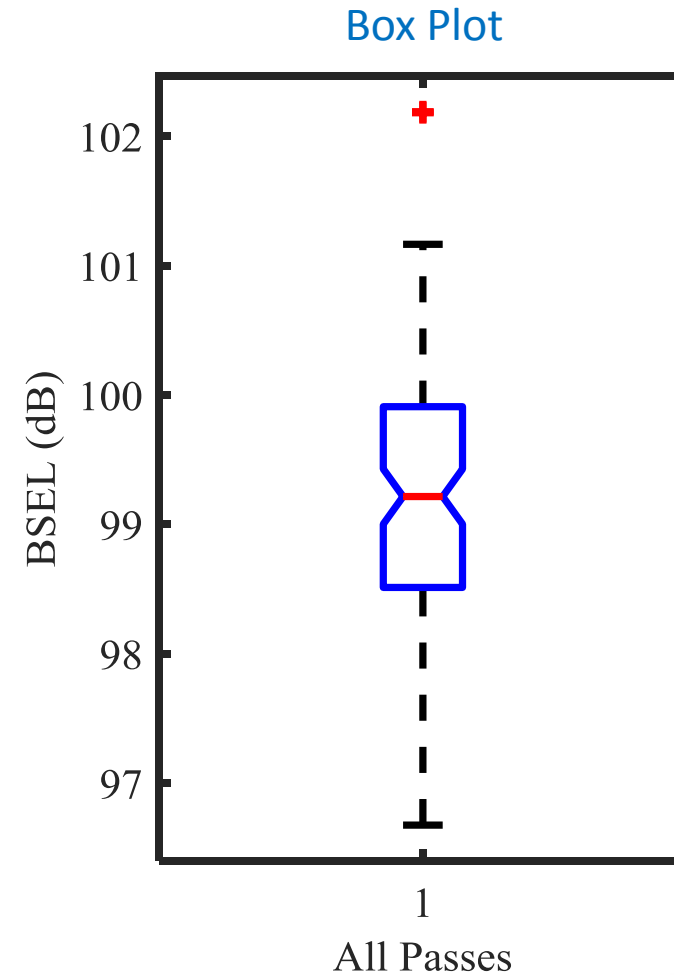
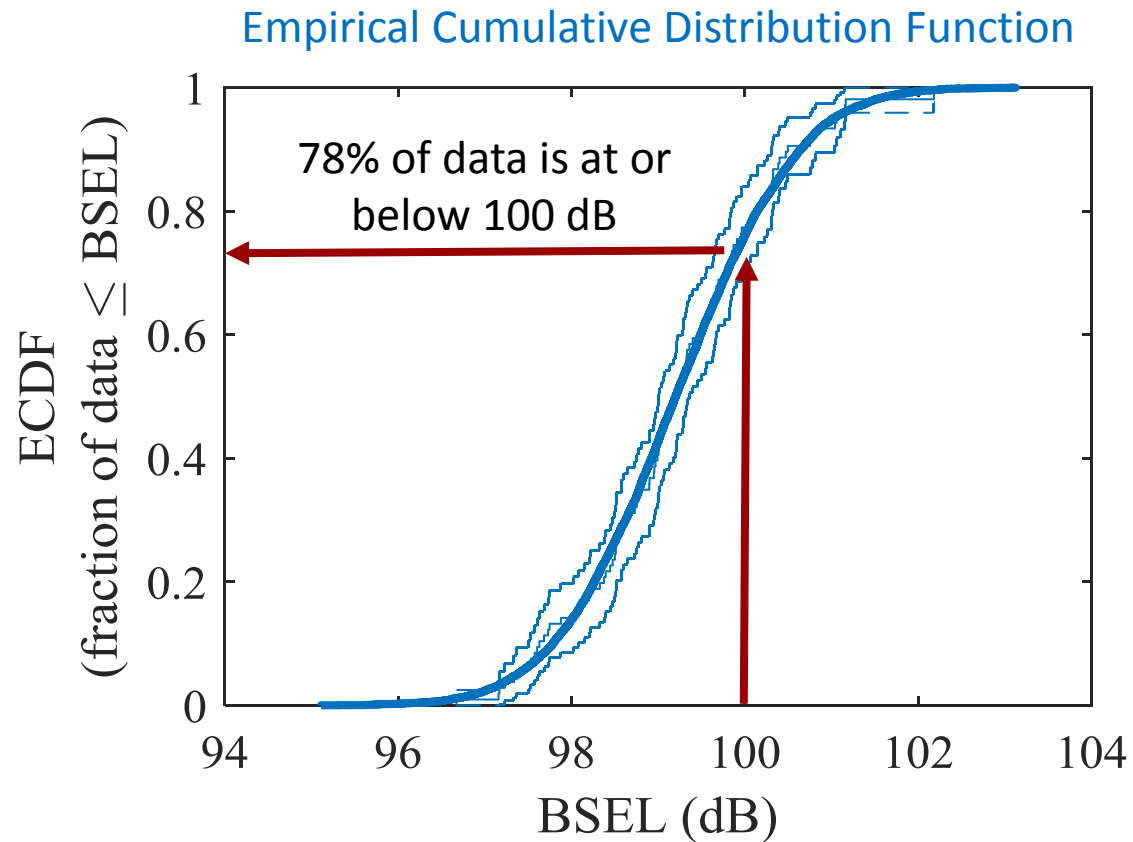
- Develop procedures using existing measured (N-wave) sonic boom data
- Distribution of measured data (N=106)
 - Distributions vary by metric and by pass



Analyses of Measured Data



➤ Alternate statistical representations of data

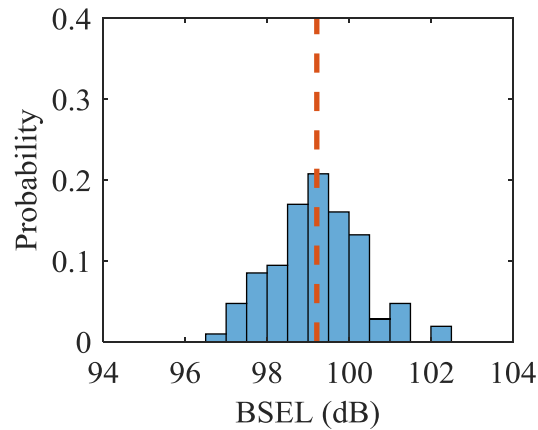


Analysis of Aggregate or Individual Measurements

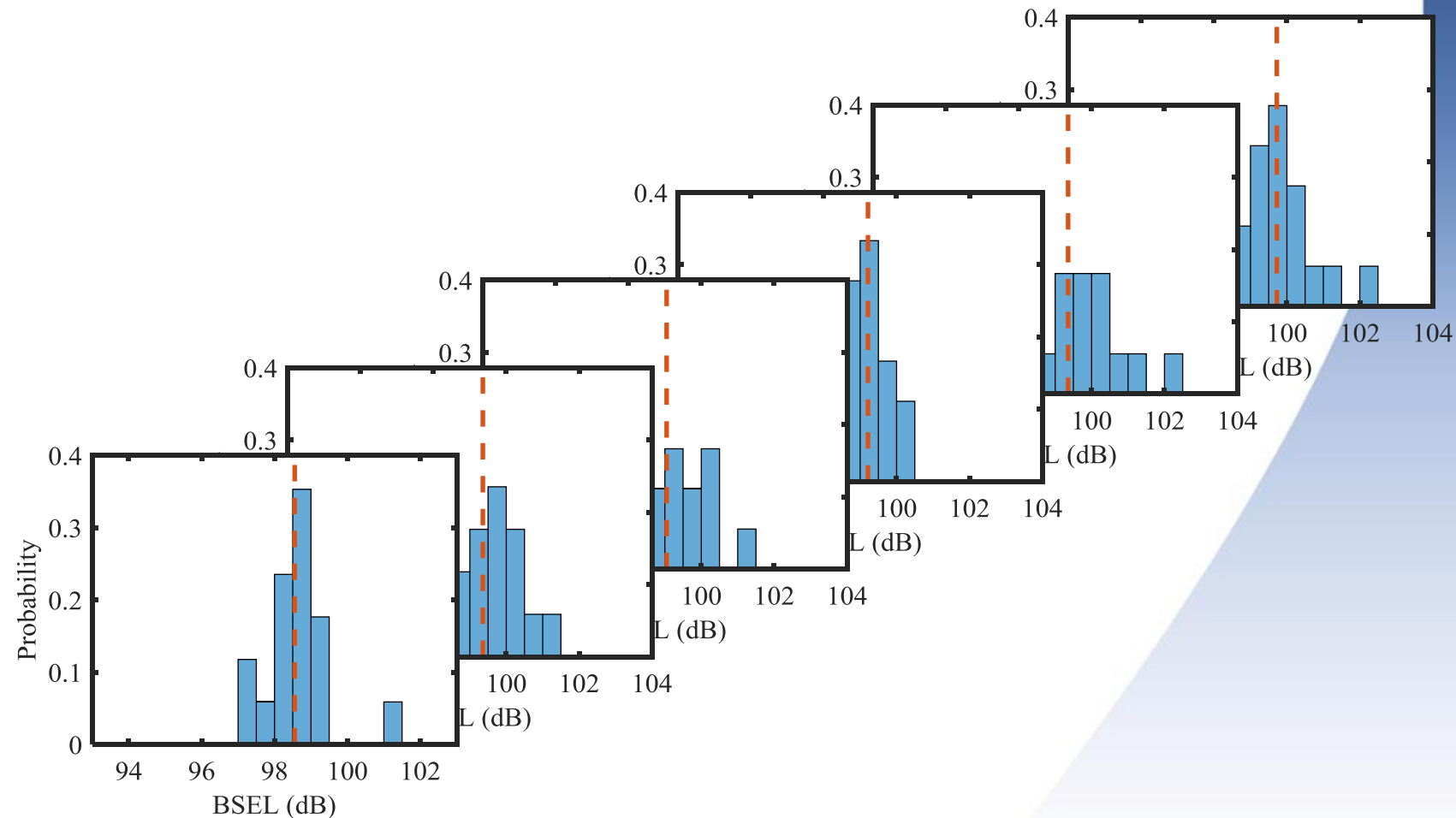


➤ All 6 passes combined (N=106)

- Standard deviation of 1.1 dB



➤ Calculations conducted for each separate pass (N=17)

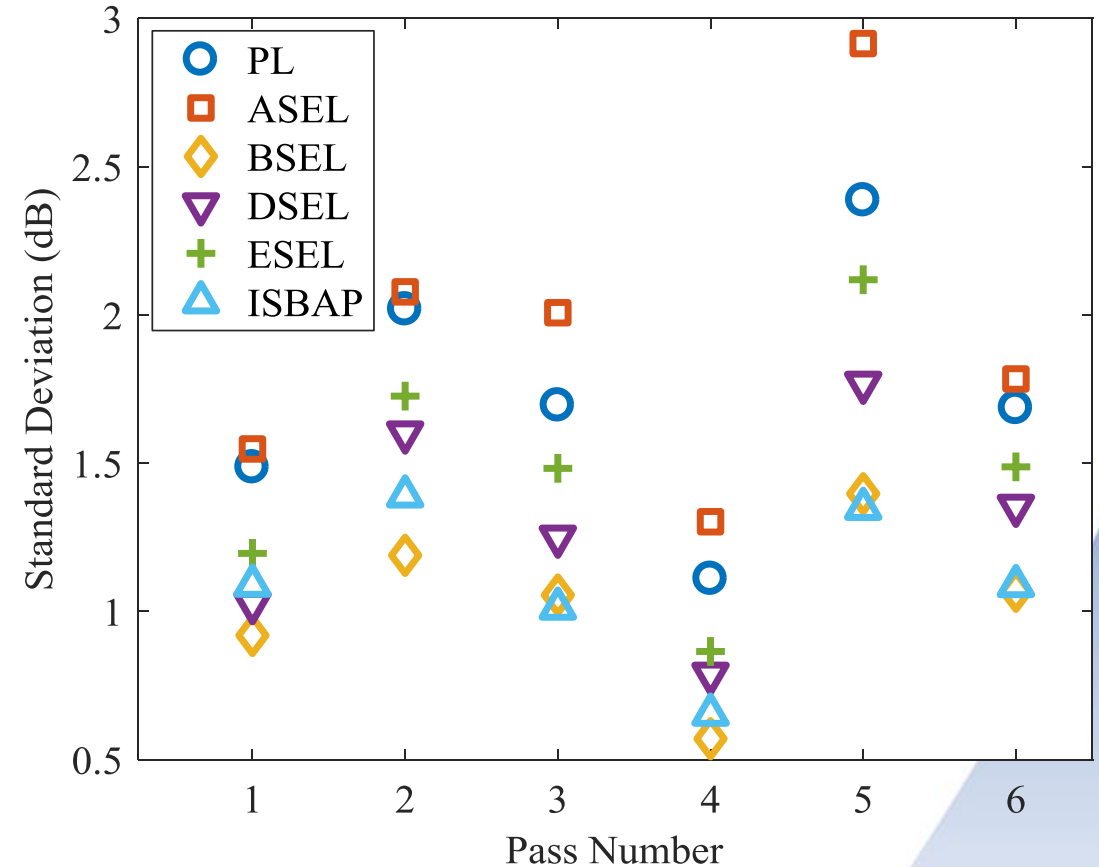
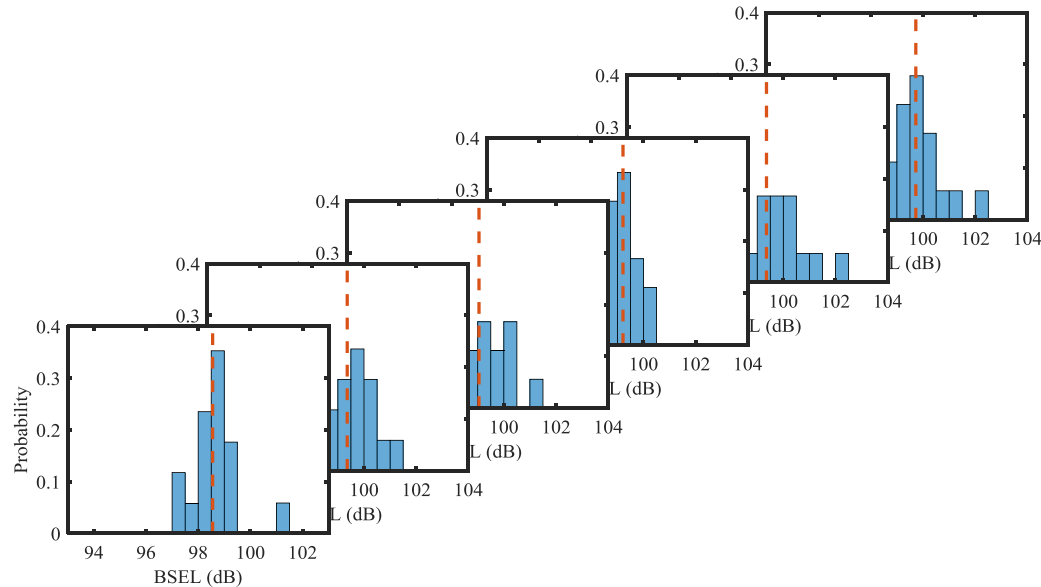


Analysis of Aggregate or Individual Measurements



➤ 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

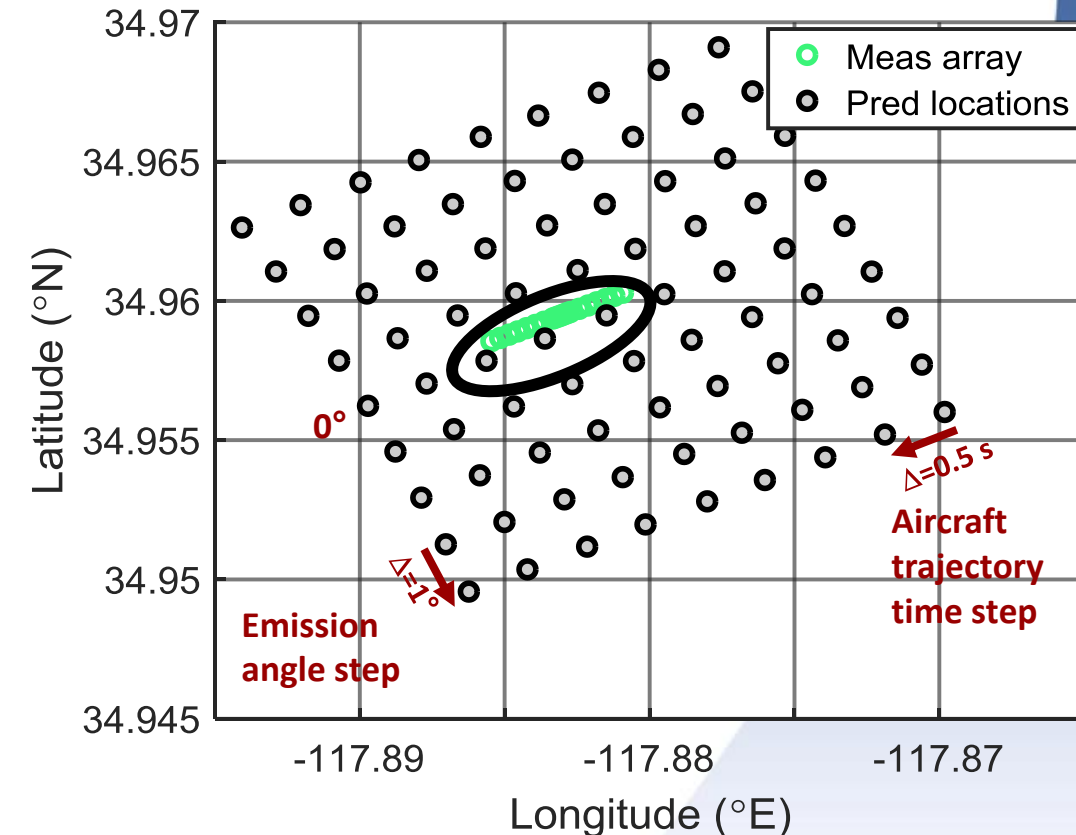
- Ray tracing
- Implement the nonlinear wave equation
 - Nonlinearity, absorption/dispersion, geometrical spreading

➤ 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



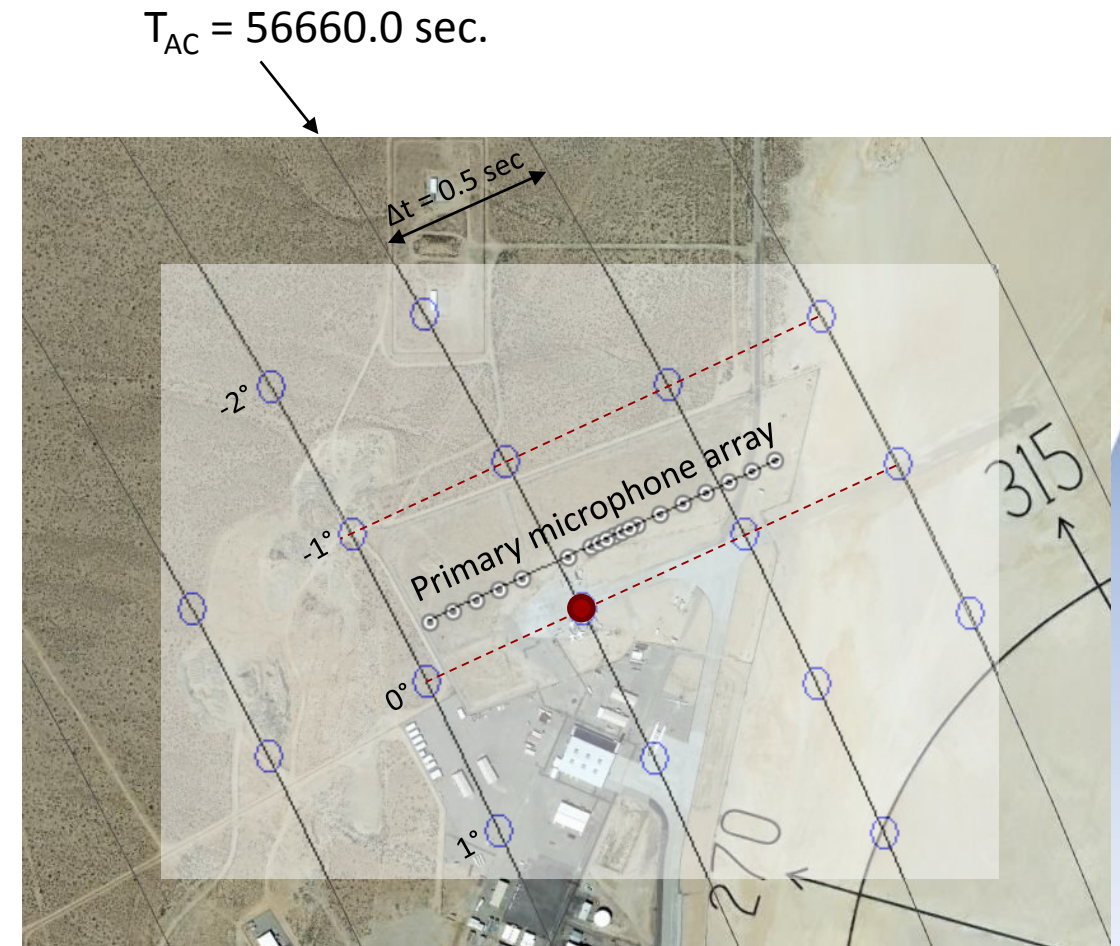
Boom Propagation Predictions



➤ Can a single ray represent the microphone array?

- Propagation calculations completed for a set 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

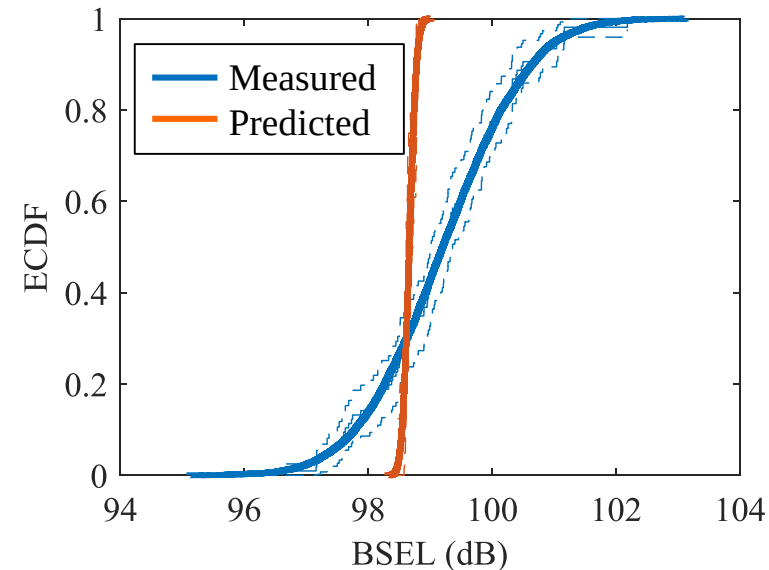
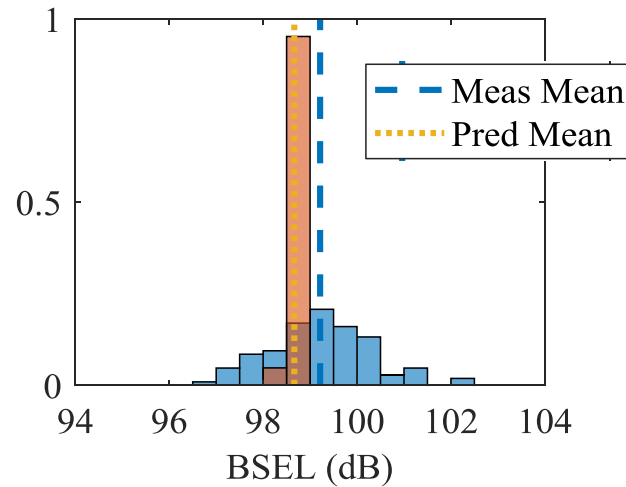
Δt	ΔPL	
	$\phi = 0^\circ$	$\phi = -1^\circ$
-1.0 sec.	+0.00 dB	+0.00 dB
-0.5 sec.	-0.01 dB	-0.02 dB
$T_{AC} = 56660.0$ sec.	106.32 dB	-0.04 dB
+0.5 sec.	-0.01 dB	-0.03 dB



Comparing Predictions and Measurements



- Certification procedure will include both measurements and predictions
- Test day predictions 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

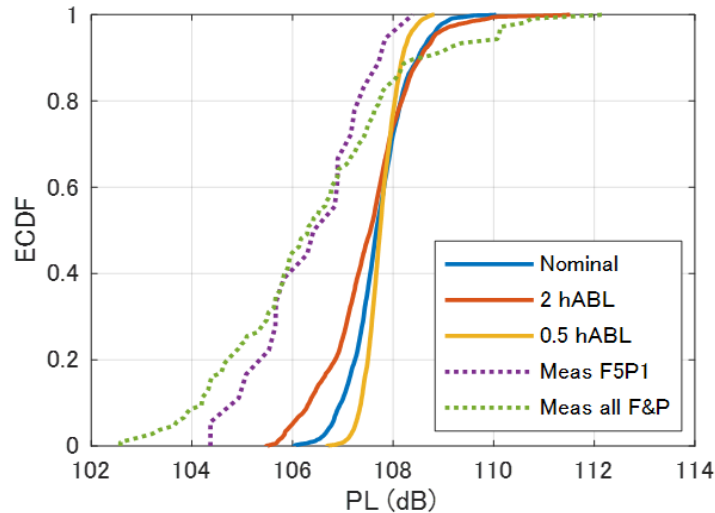


Comparing Predictions and Measurements

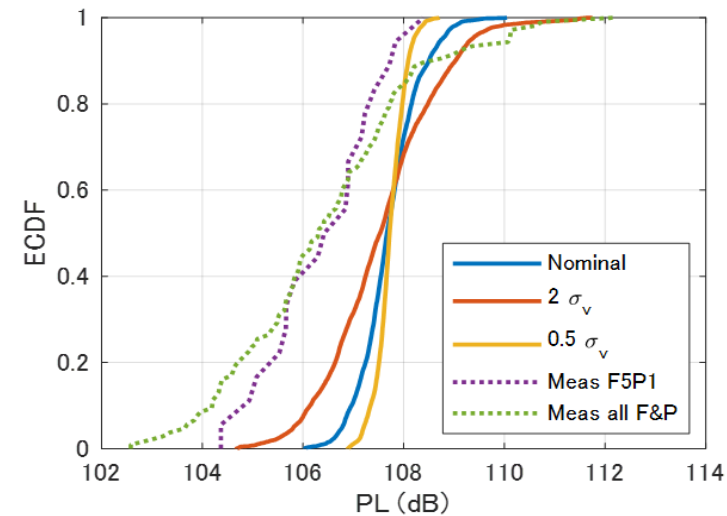


➤ Potential need to include turbulence in predictions

- 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)



- **Recognize that there is a large variability in test data for N-wave noise**
 - Shaped booms predicted to have smaller variation¹, but there will still be some variation (how much?)
- **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

¹Trevor 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

- **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