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

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Introduction

- 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
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
- 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
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

Predictions for Low-Turbulence Passes of SonicBAT

![Graph showing prediction locations and aircraft trajectory](image)
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

All 6 passes combined (N=106)

- Distributions vary by metric
- Standard deviations of 1.1 to 2 dB
Calculated Data (Individual Pass)

- Calculations conducted for each separate pass
  - One example pass shown (N=17)
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 \( \leq 0.2 \) dB along array
  - Minor differences in trajectory and ray path
  - Same atmospheric parameters applied with no turbulence
- Variation in predictions between passes \( \leq 0.2 \) dB
- Variation in predictions between flights \( \leq 0.3 \) 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