Performance Evaluation of a Shaped Sonic Boom Detector and Classifier

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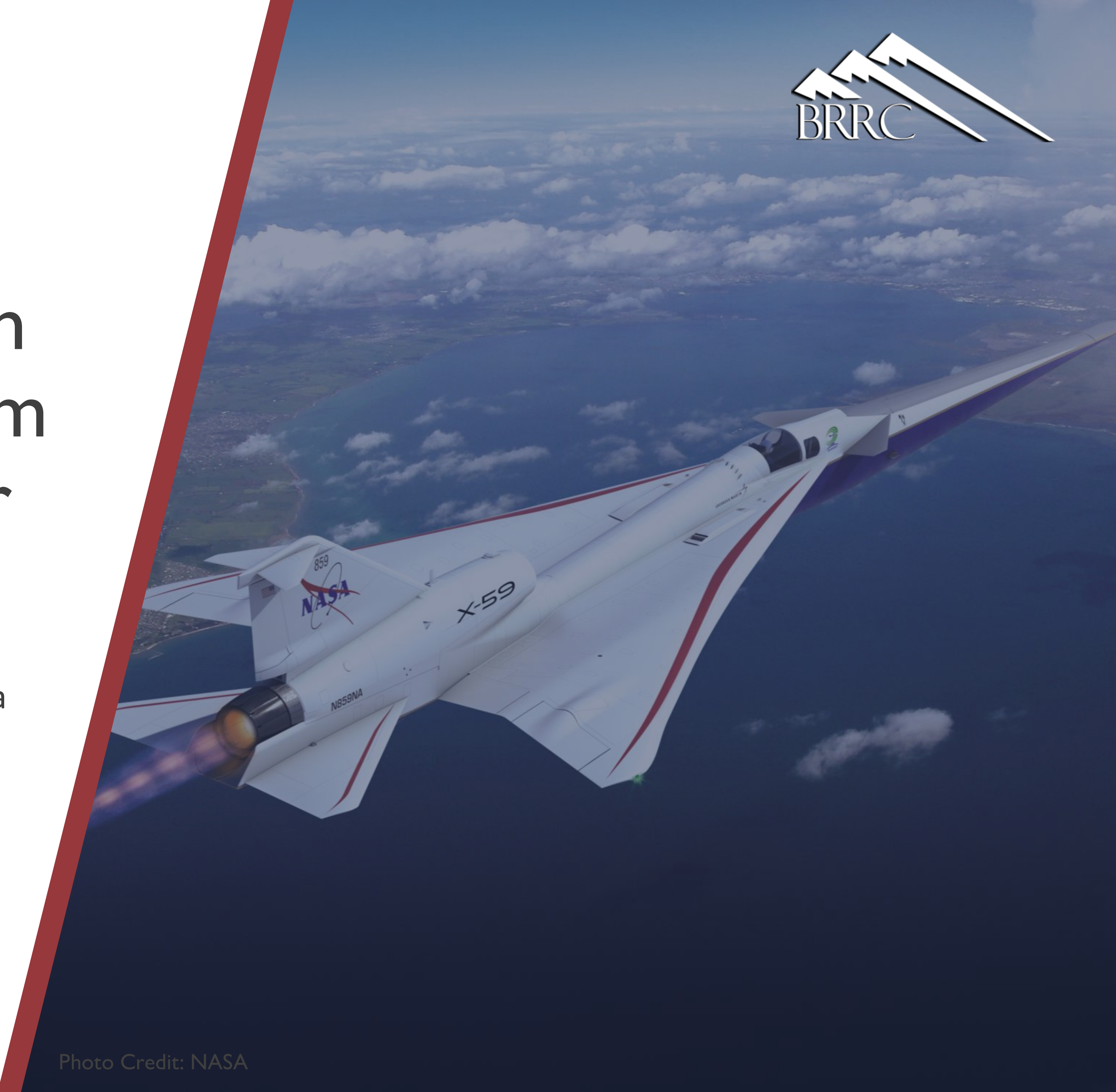
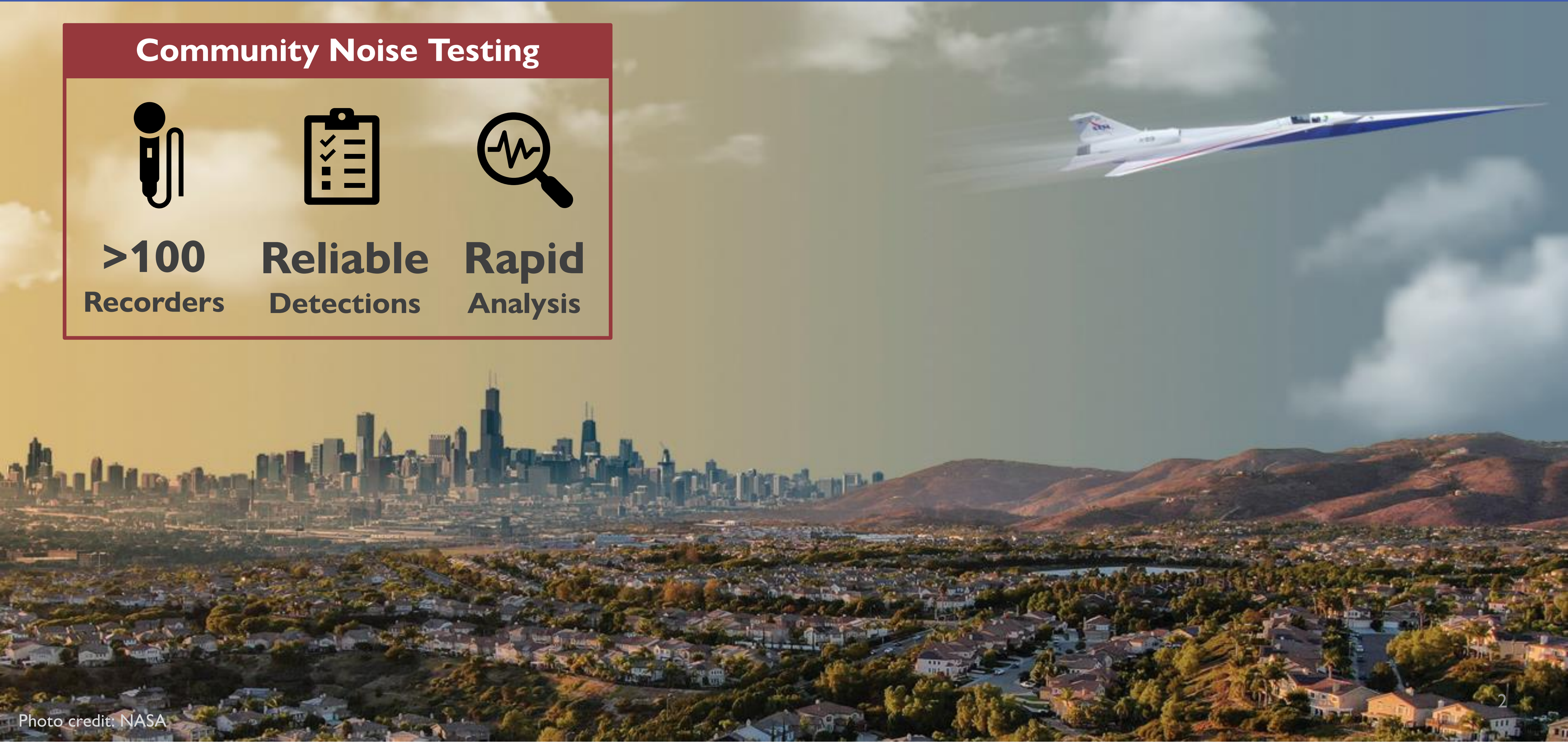


Photo Credit: NASA

Scope



Community Noise Testing

>100 Recorders

Reliable Detections

Rapid Analysis

Photo credit: NASA

Outline

1. Review Community Noise Testing Workflow
2. Shaped Sonic Boom Detector
3. Shaped Sonic Boom Classifier
4. Preliminary Performance Results
5. Summary

Photo Credit: NASA

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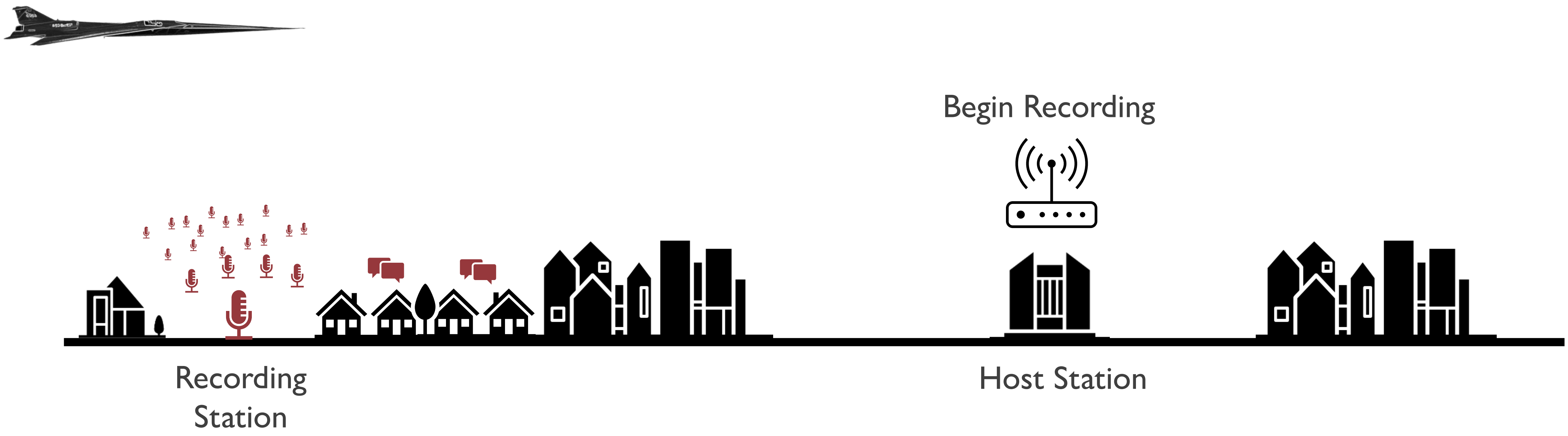
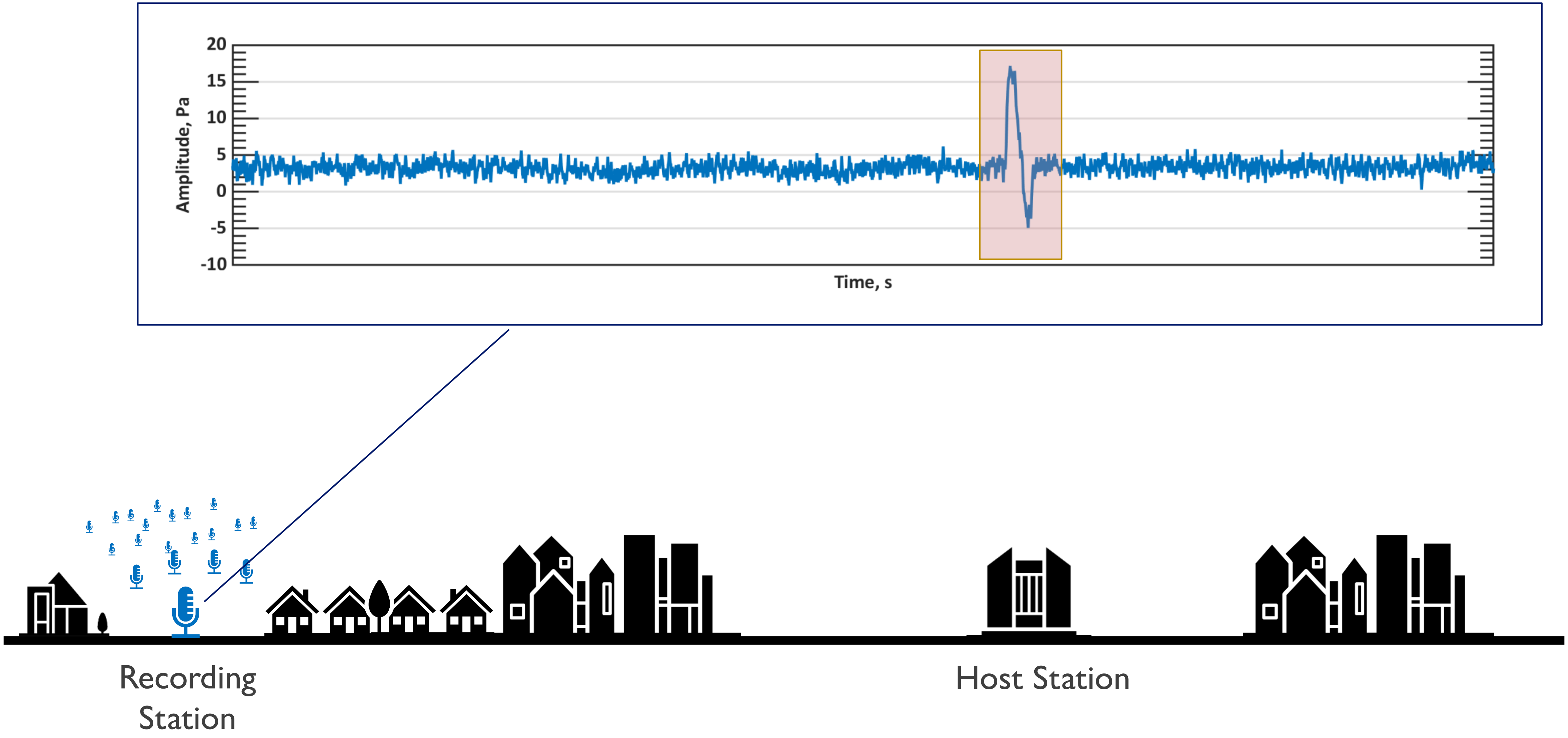
Community Noise Measurements



Neighborhood icons created by Creatype - Flaticon

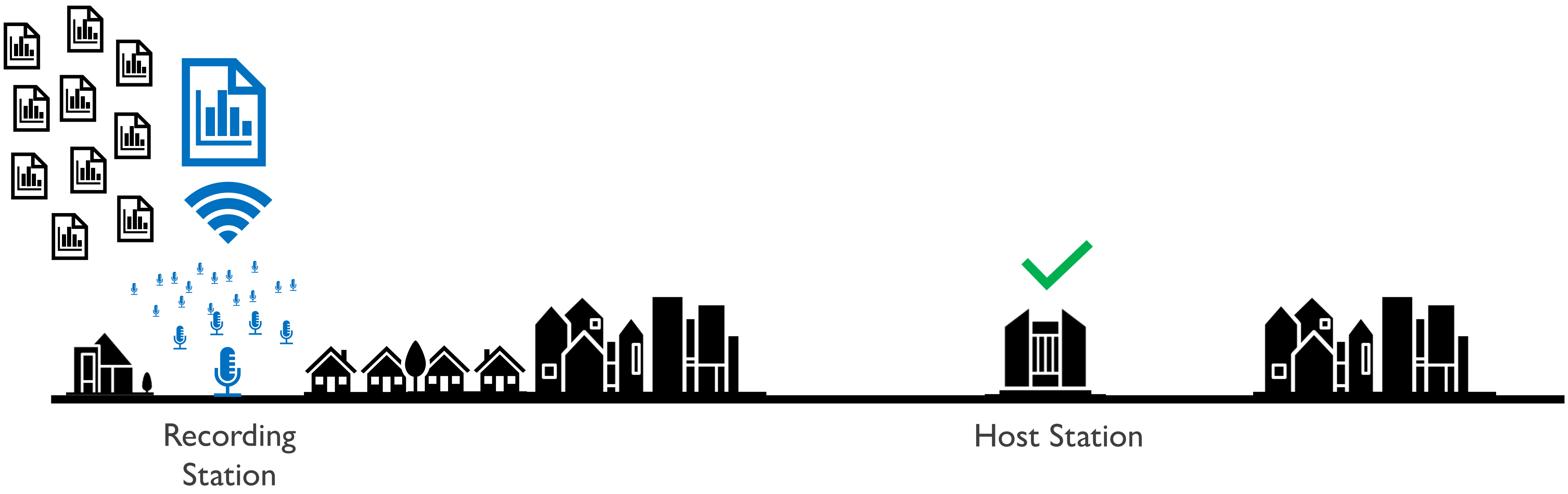
Community Noise Measurements



Neighborhood icons created by Creatype - Flaticon

Community Noise Measurements

- Recording Station Processing Software
  - Sonic Boom Detector
  - Sonic Boom Classifier
  - Sonic Boom Metrics Calculations



Neighborhood icons created by Creatype - Flaticon

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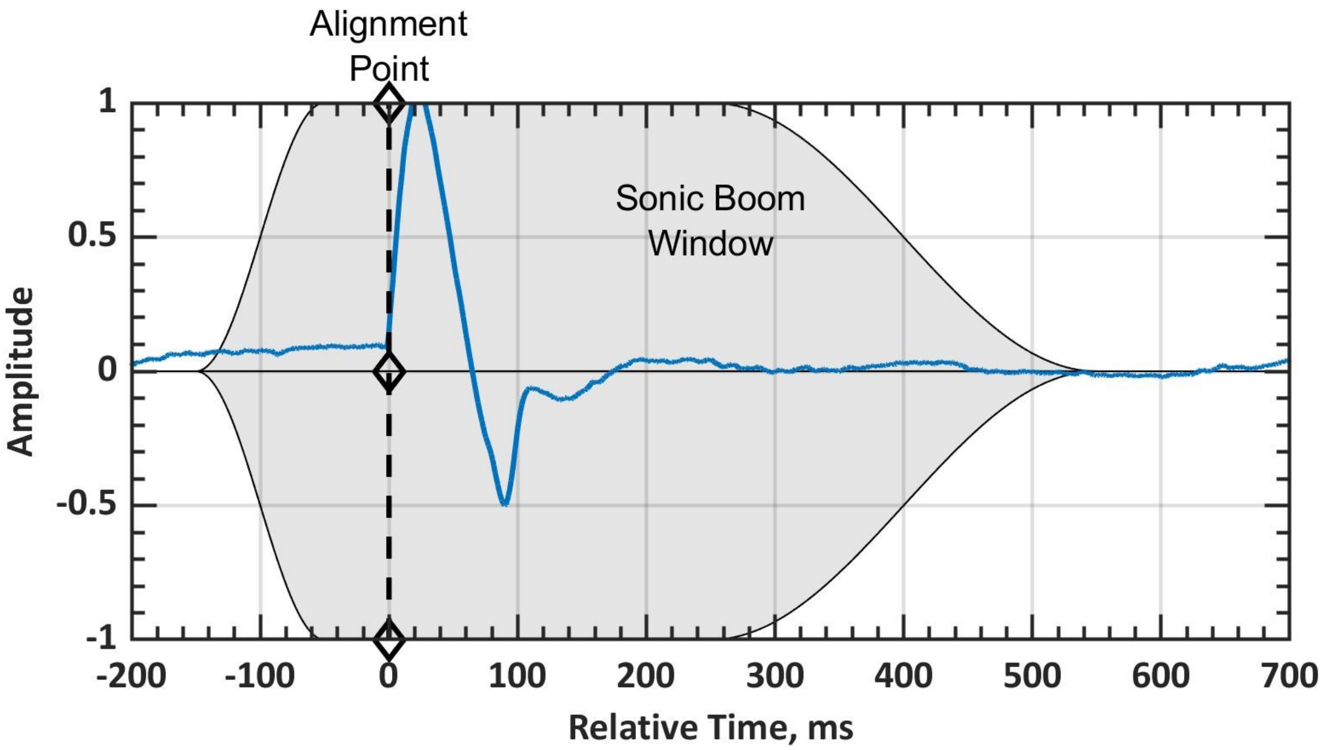
Shaped Sonic Boom Detector

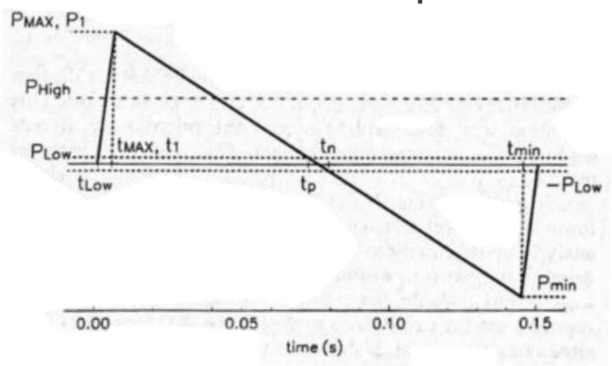
- Goal: Detect sonic boom with temporal accuracy of <100 ms
- Local detection time used to window and calculate sonic boom metrics



Select Prior Work

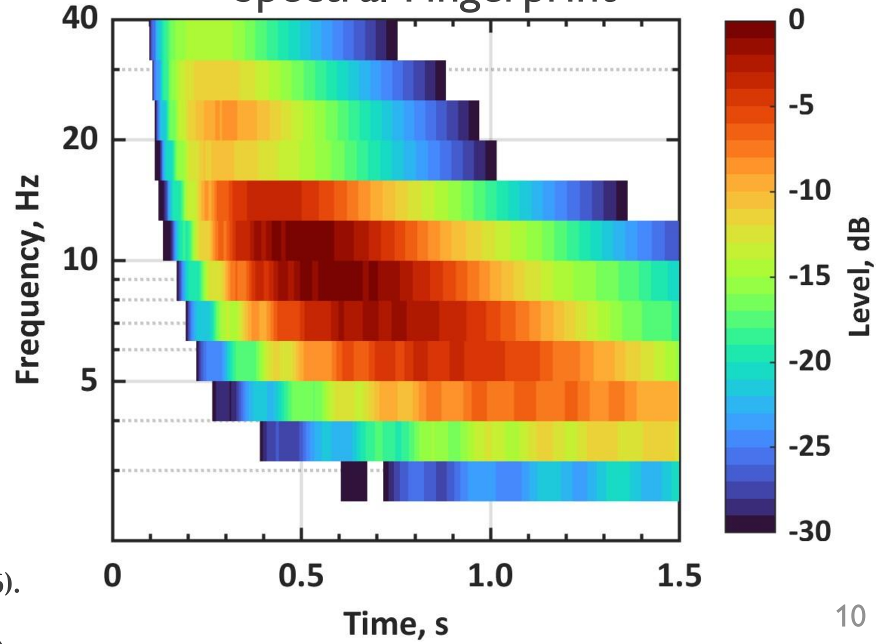
- BEARS Algorithm (Lee and Downing, 1996)
  - Rise-time-based method for N-waves
- Auto Boom Finder (Hobbs, 2012)
  - Bandpass amplitude detector for N-waves
  - Utilized in WSPR 2011 and QSF18
- Spectral Fingerprint Method (Klos, 2022)
  - Compares the spectrogram of a simulated shaped sonic boom to the waveform spectrogram
  - Highly effective for nontraditional booms

N-Wave Example



Lee and Downing, 1996

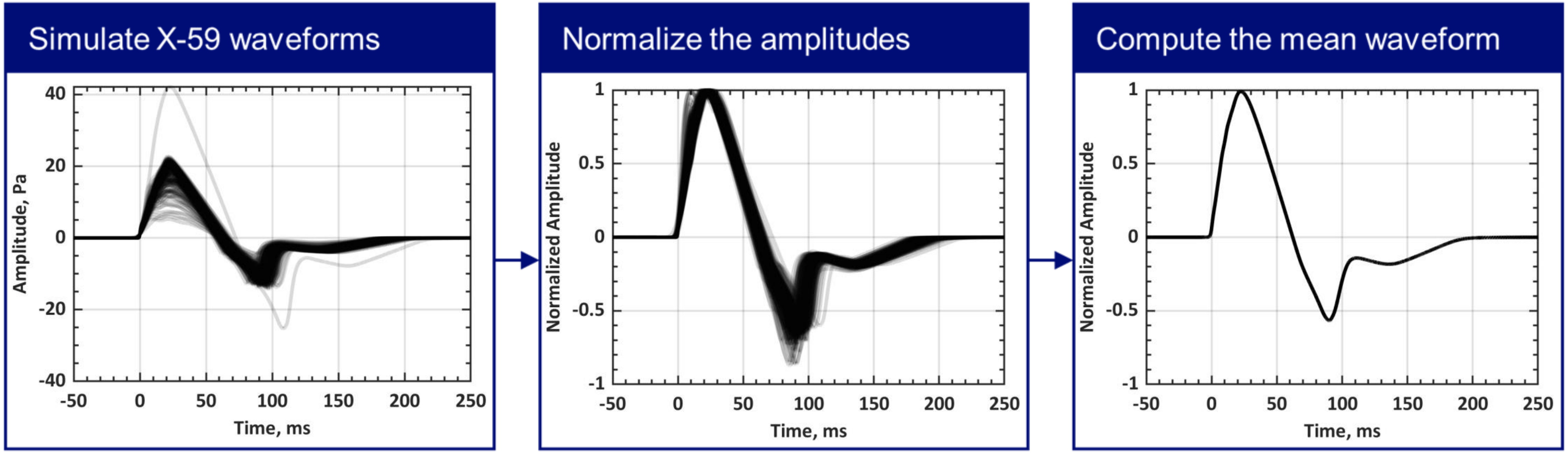
Spectral Fingerprint



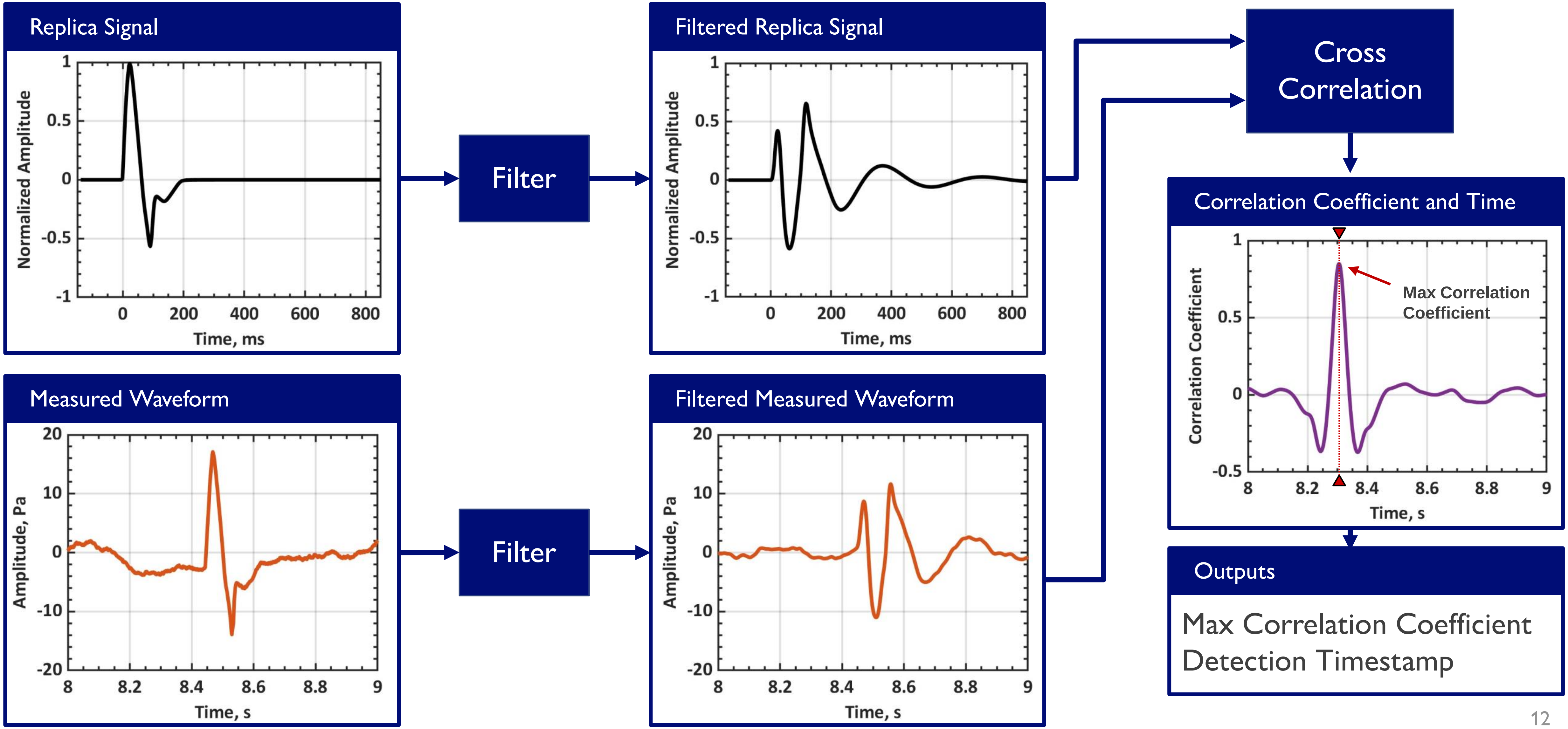
Lee and Downing, "Boom Event Analyzer Recorder: Unmanned Sonic Boom Monitor", J Aircraft 33 (1), pp. 171-175 (1996).
Hobbs, "Auto Boom Finder Program (ABF)," Wyle Technical Note TN 12-30, Arlington, Va (2012).
Klos, "Finding X-59: A Spectral Fingerprint Based Sonic Boom Finder Algorithm" NASA TM (Unpublished Draft) (2022).

Replica Signal Generation

- Replica signal is chosen to most resemble the expected sonic boom waveform
- 200 X-59 Sonic Boom Waveforms (W. Doebler) from C612A (On Design) and propagated using PCBoom



Replica Correlator



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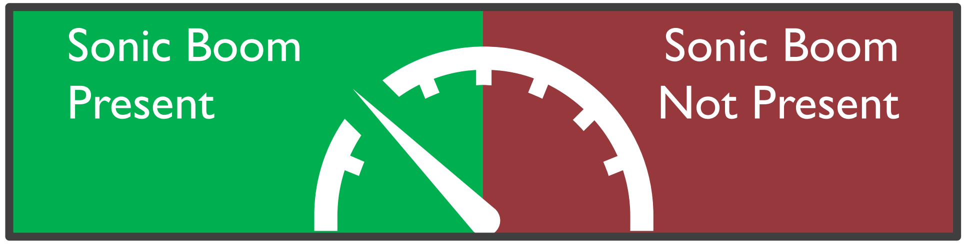
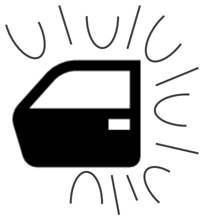
Sonic Boom Classifier





Why do we need a classifier?

- No guarantee that a GRS will record a sonic boom, but the detector will output the most likely sonic boom detection time
- Need a method to classify a sonic boom in the presence of ambient noise

Key Parameters

- Detector correlation coefficient
- Corresponding sonic boom level (select OTO band levels)

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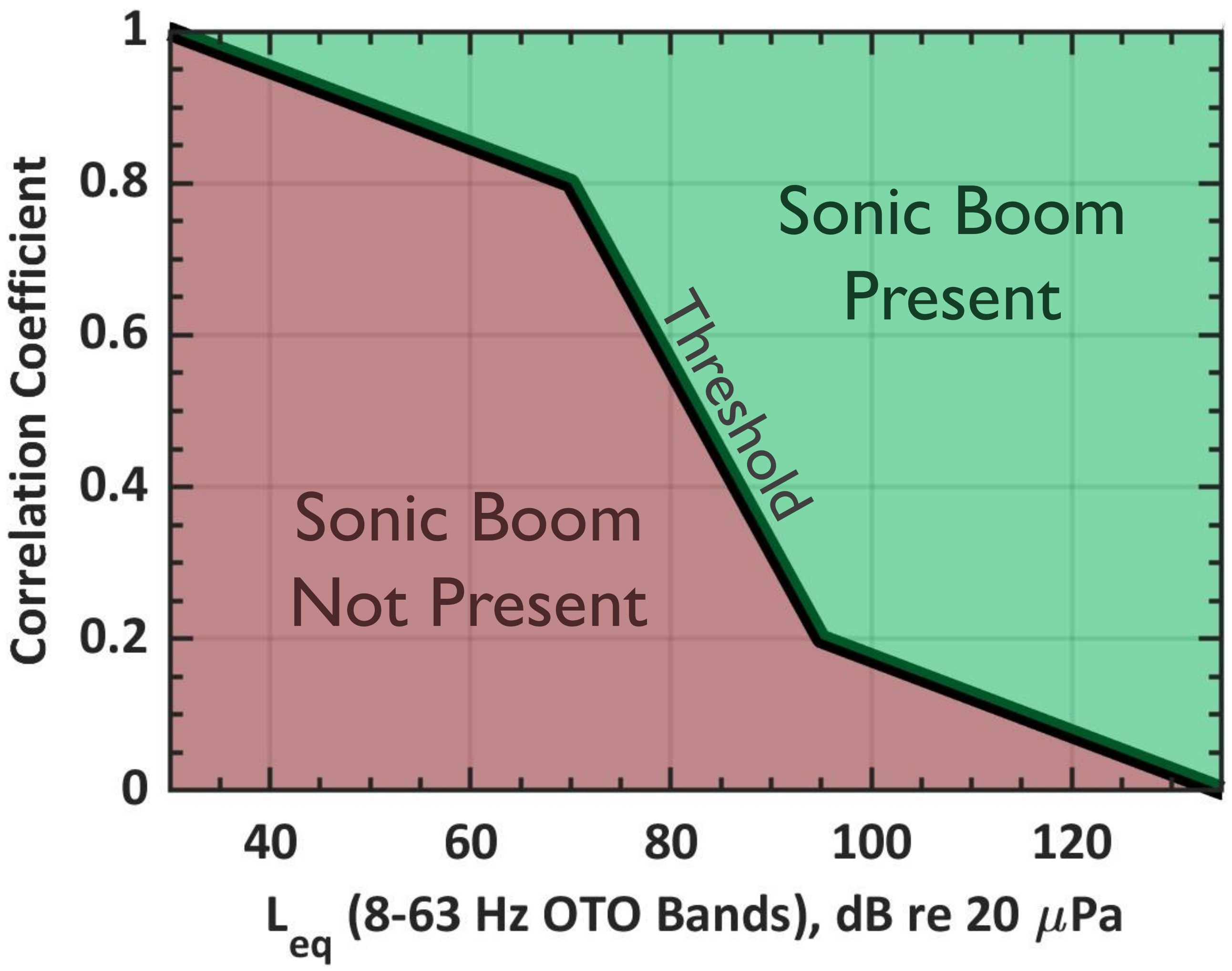
Wind icons created by Those Icons - Flaticon

Classifier Description



Outline

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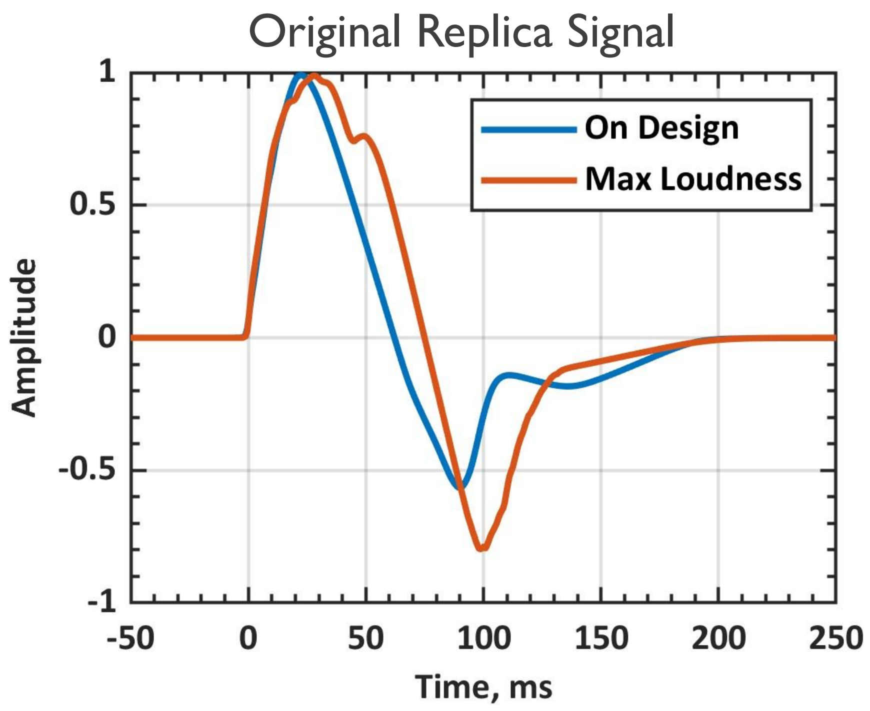
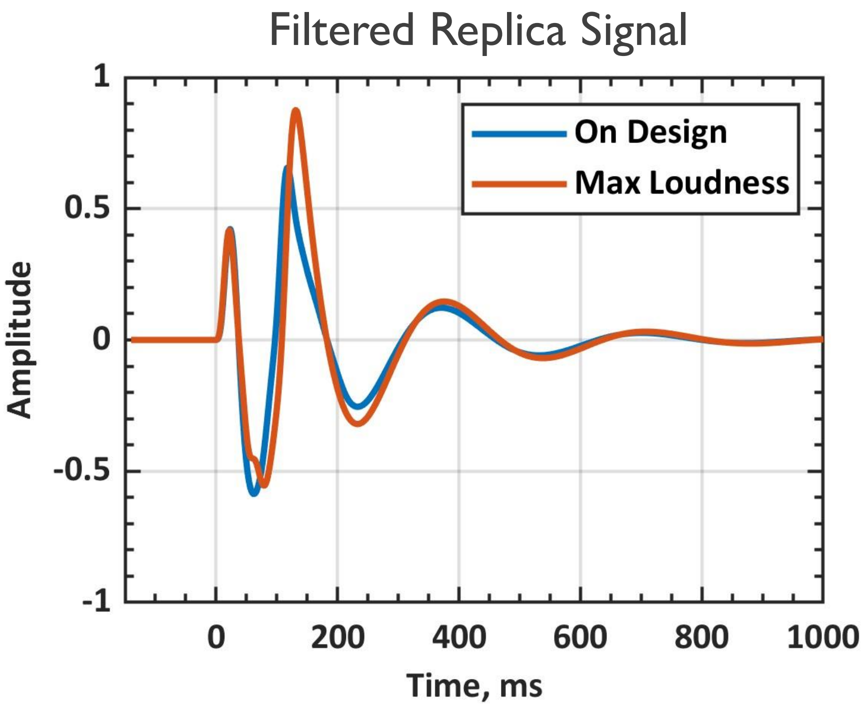
Datasets





- **Sonic Boom Simulations**
  - NASA C612A Cylinder comprises two designs: On Design (Min Loudness) and Max Loudness (Off Design)
  - Propagated in various undertrack scenarios via PCBoom for ~10k samples each
  - Replica signal will use On-Design case

NASA-Provided Datasets

- **Dataset:**
  - 25,000 samples per set
  - 30-second waveforms
  - X-59 Sonic boom propagated via PCBoom
  - Ambient noise from previous measurement (Galveston, TX)

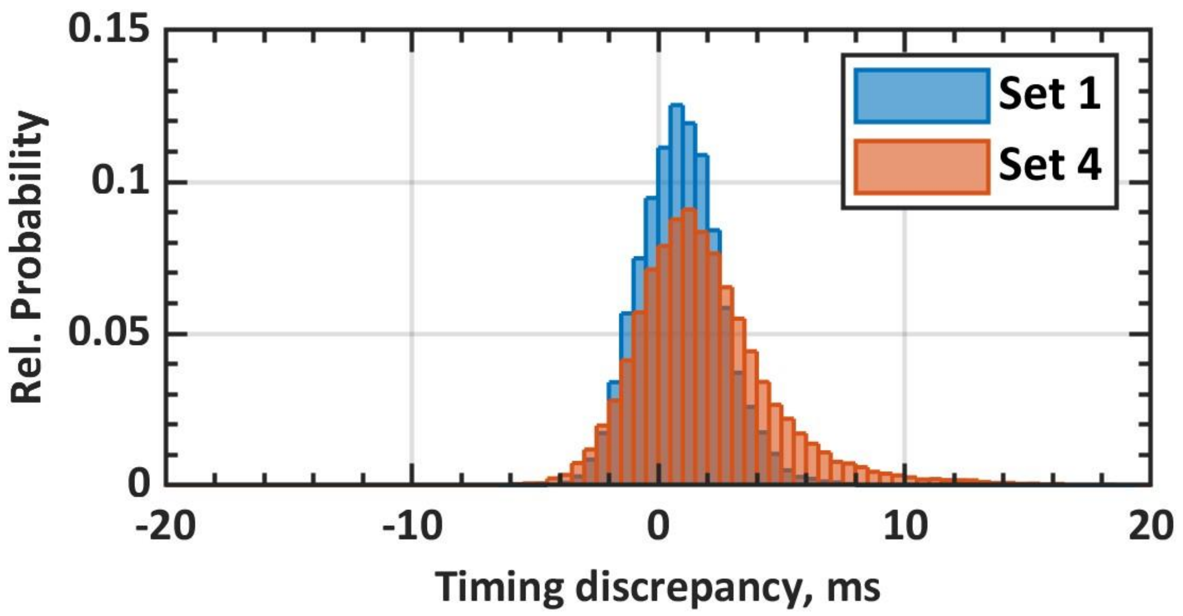
Dataset	Turbulence	Post boom noise	Impulsive noises
Set 1	No	No	No
Set 2	Yes	No	No
Set 3	Yes	Yes (+0 dB)	No
Set 4	Yes	Yes (–10 dB)	No
Set 5	Yes	Yes (–10 dB)	Yes

Ref: Table 3 of Klos (2022)

Sonic Boom Detector Performance – On Design

- Detection errors in each dataset were relatively similar
- Detection Failure:
  $|\text{Timing discrepancy}| > 100$ ms
- Failure rate was ~0.01% (1:10000)
- Detection times were within ± 20 ms of actual time in 99.8% of tests

Sonic Boom in Ambient Noise
Sonic Boom in Ambient Noise + Post-boom noise



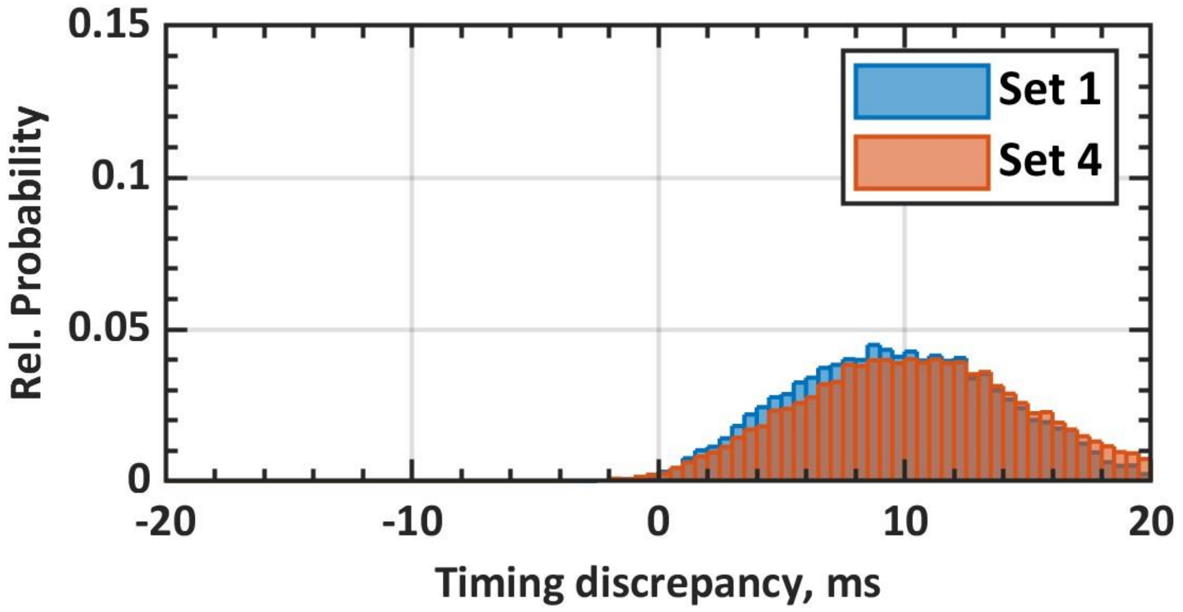
Failure Rates	Set 1	Set 2	Set 3	Set 4	Set 5
Detection > $\pm$20 ms	0.01%	0.16%	0.18%	0.18%	0.16%
Detection > $\pm$100 ms	0.01%	0%	0.01%	0.01%	0.01%

Sonic Boom Detector Performance – Max Loudness

- Detection errors in each dataset were relatively similar
- Detection Failure:
  $|\text{Timing discrepancy}| > 100$ ms
- Failure rate was ~0.01% (1:10000)
- Detection times were within ± 20 ms of actual time in 95-99% of tests

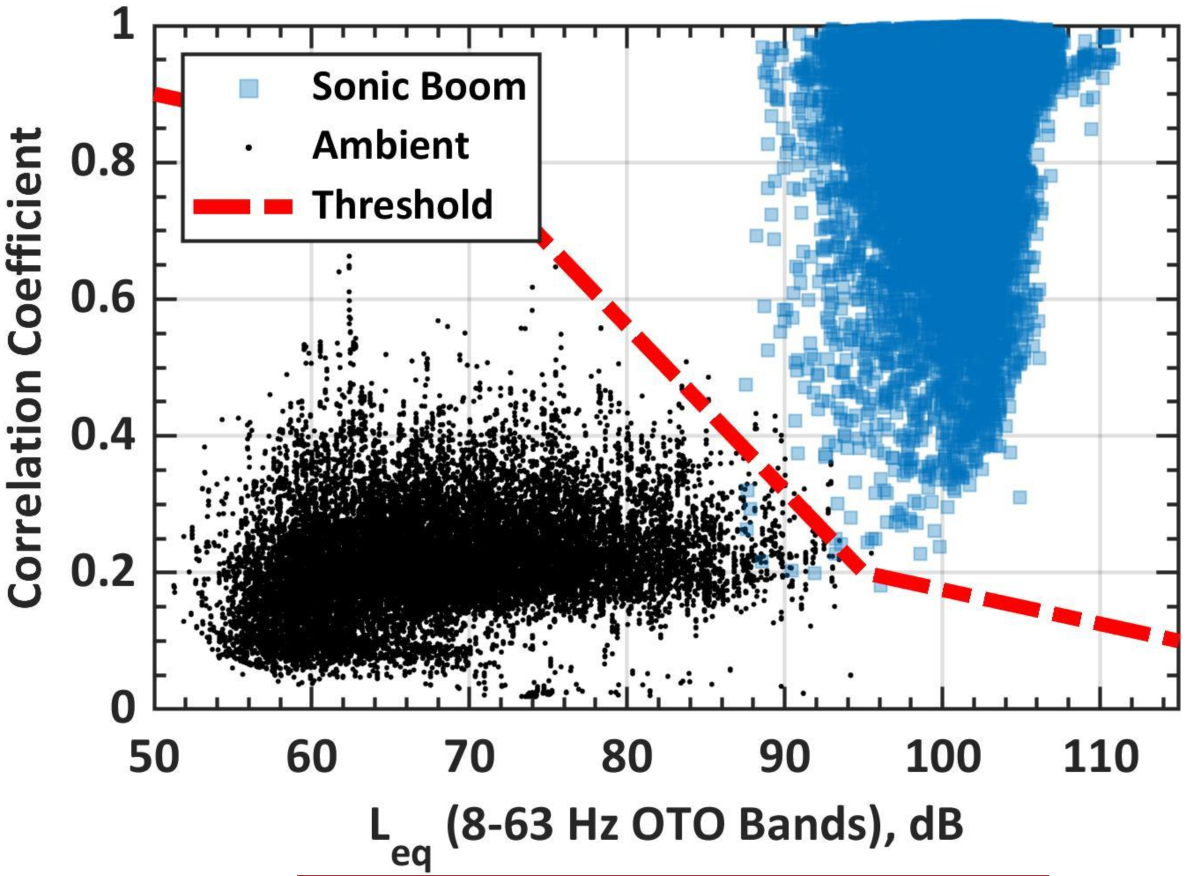
Failure Rates	Set 1	Set 2	Set 3	Set 4	Set 5
Detection > $\pm$20 ms	0.48%	4.17%	4.25%	4.16%	4.18%
Detection > $\pm$100 ms	0%	0.01%	0.01%	0%	0.01%

Sonic Boom in Ambient Noise
Sonic Boom in Ambient Noise + Post-boom noise



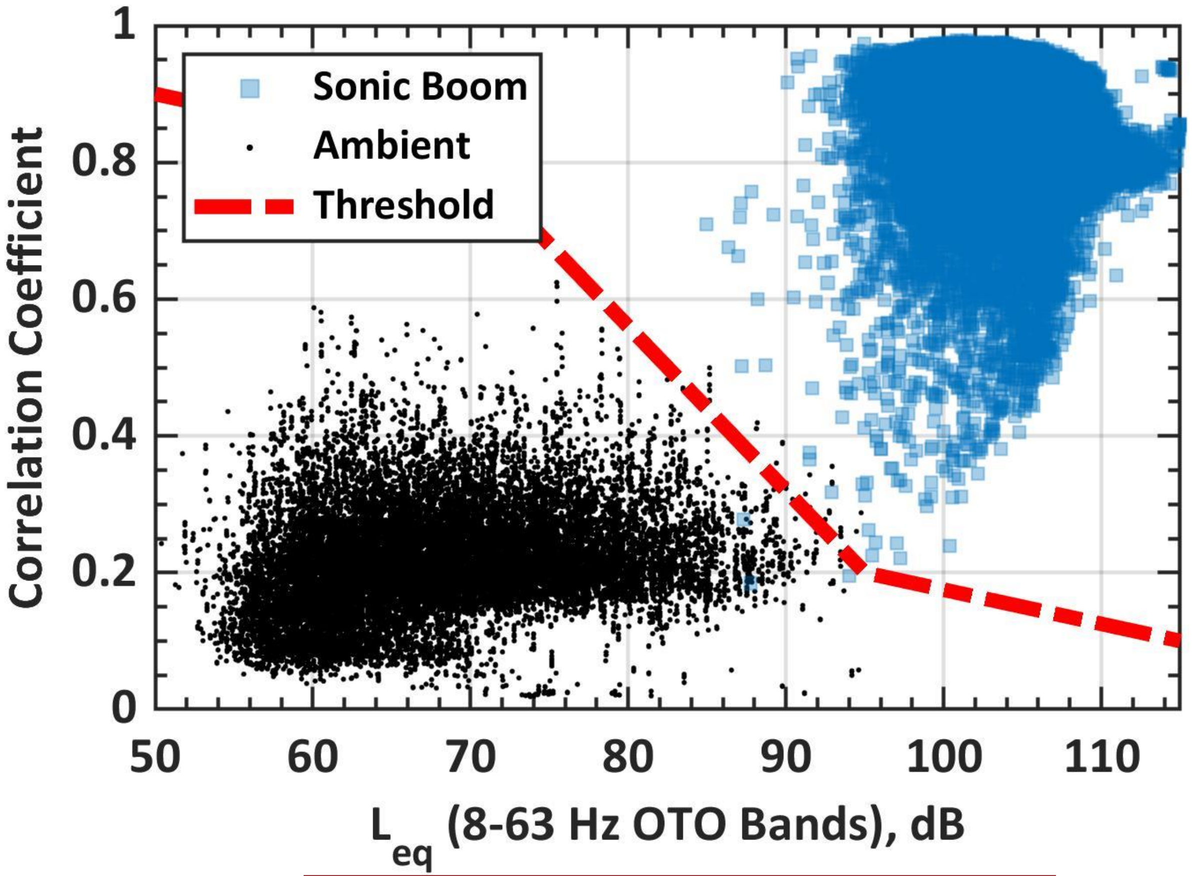
Classifier Performance

Classifier - On Design Cases



Classification Performance Results
True Positive Rate: .9999
False Positive Rate: .0024

Classifier Max Loudness Cases

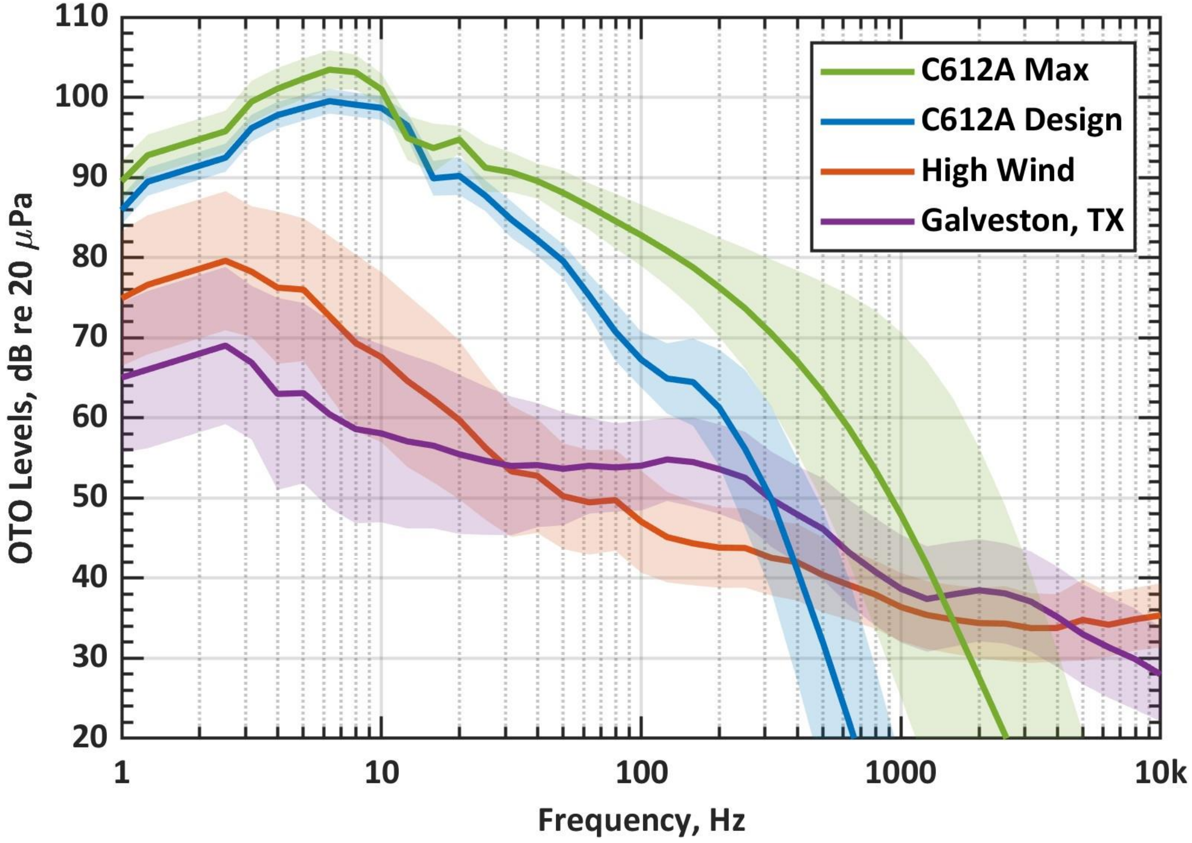


Classification Performance Results
True Positive Rate: >.9999
False Positive Rate: .0023

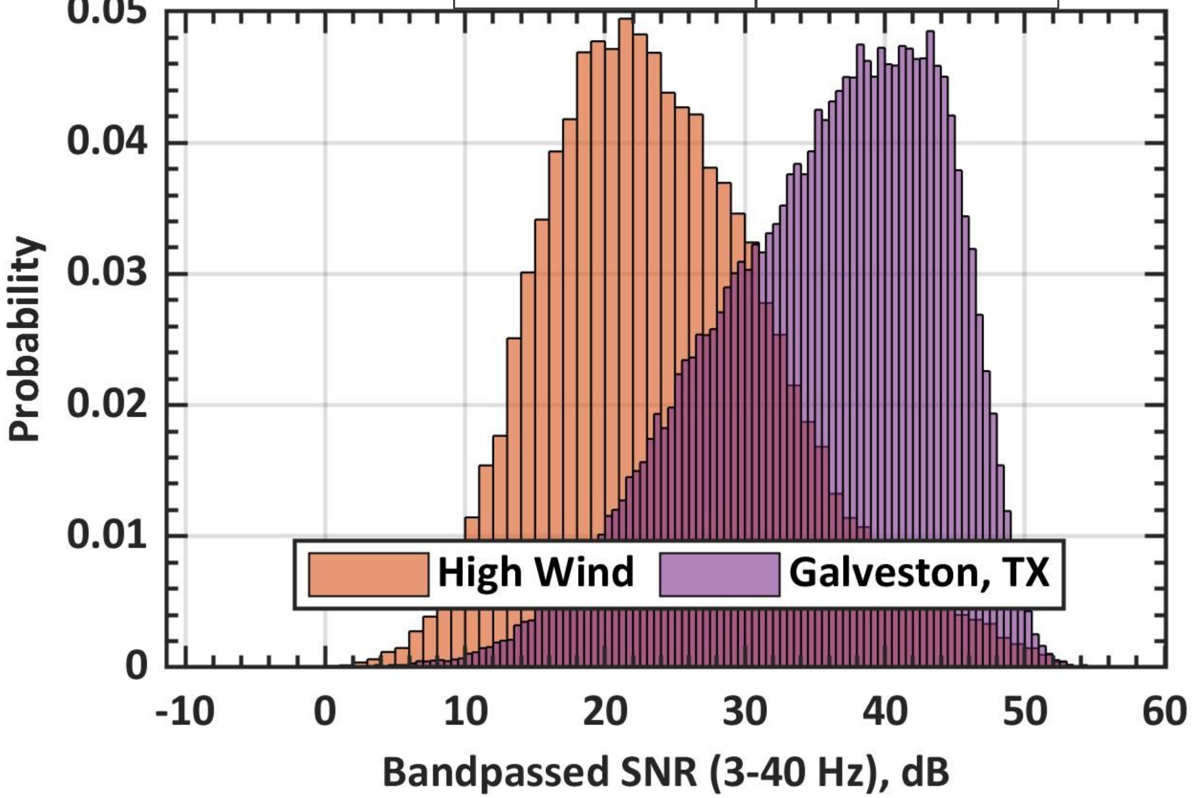
Detector performance in high-wind environments

- Detector relies on high SNR in low-frequency bands
- High-wind ambient recordings
  - 15-22 mph sustained winds
  - 27-38 mph gusts
- ~20 min of ambient recordings
  - Ground microphones
  - Large windscreens (23 cm diameter)

X-59 Sonic Boom and Ambient Noise Spectra

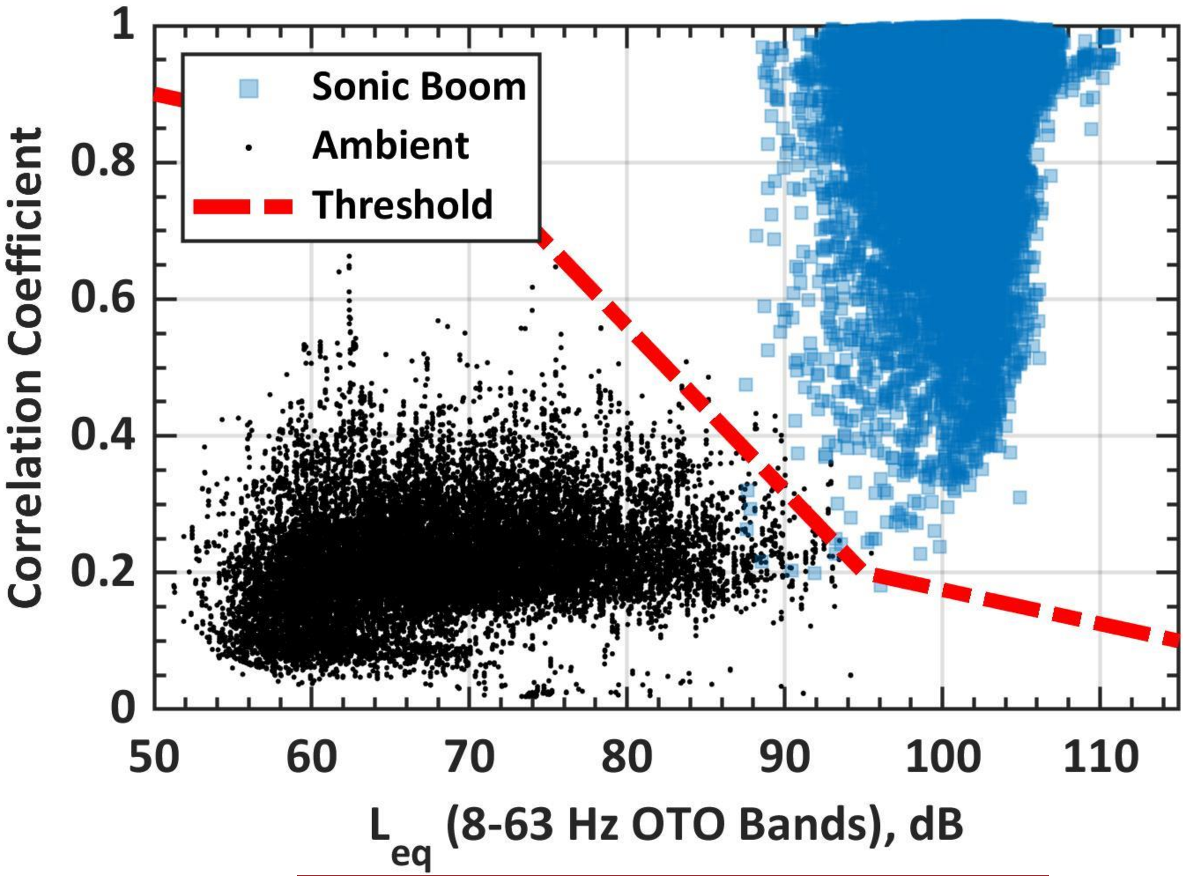


High Wind ~20 dB	Galveston ~35 dB



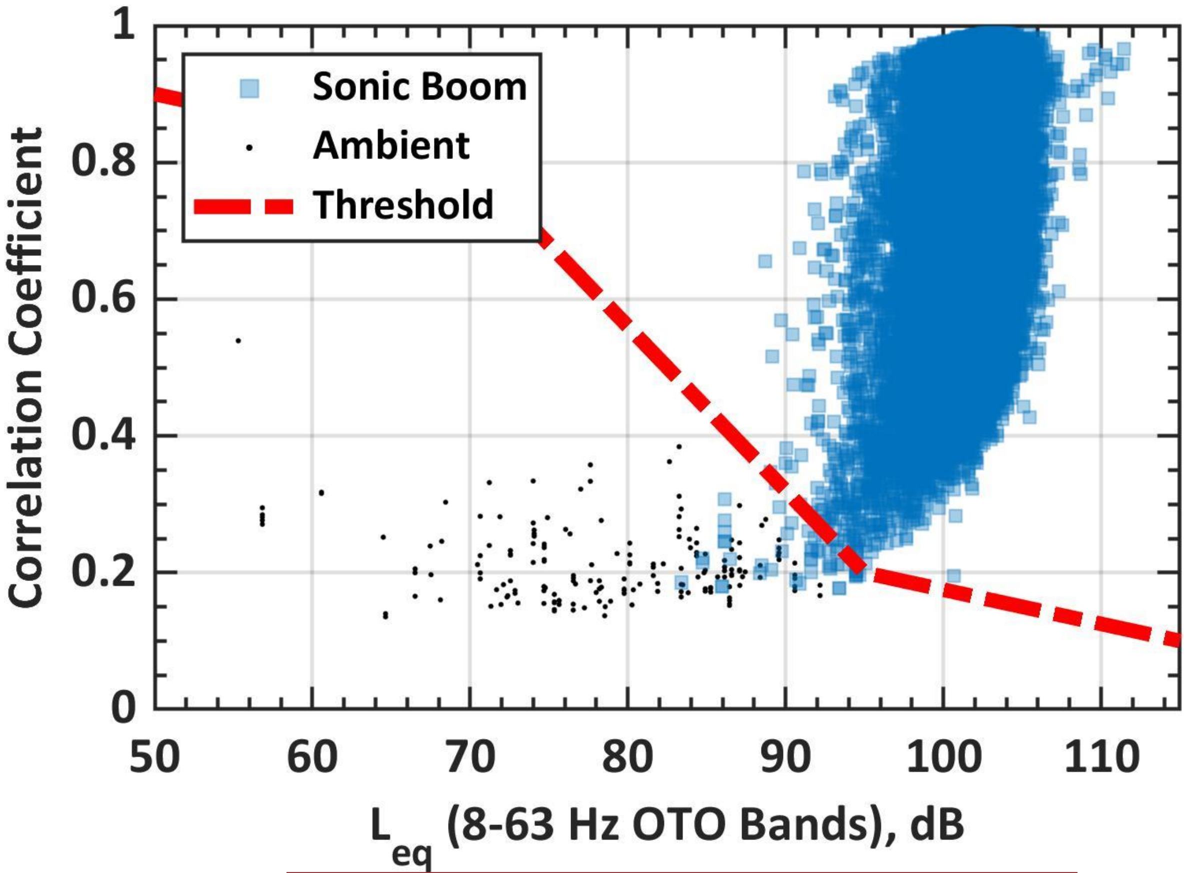
Signal to Noise Ratio for Different Noise Datasets

Classifier – On Design – Galveston



Classification Performance Results
True Positive Rate: .9999
False Positive Rate: .0024

Classifier – On Design – High Wind



Classification Performance Results
True Positive Rate: .9989
False Positive Rate: 0 (Data Limited)

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Summary

BRRC

Shaped Sonic Boom Detector

- Replica correlator design
- Replica signal based on simulation—generalizable to any signal
- Failure rate 1:10,000

Shaped Sonic Boom Classifier

- Input detection correlation coefficient *and* bandlimited levels at detection
- True positive rate ~0.9999 with False Positive Rate ~0.0024
- Expect >20 dB SNR in frequency band of interest, 35 dB SNR Typical

Backup Slides

Photo Credit: NASA

ROC Curves for Different Ambient Noise Datasets