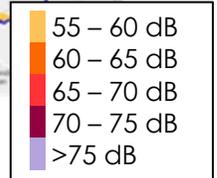
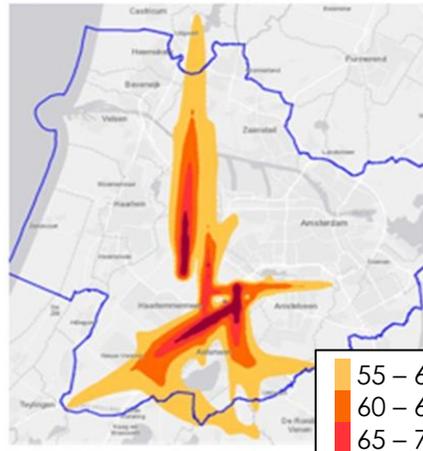


Aircraft Jet-Noise Diagnosis Using Massive Acoustic Camera

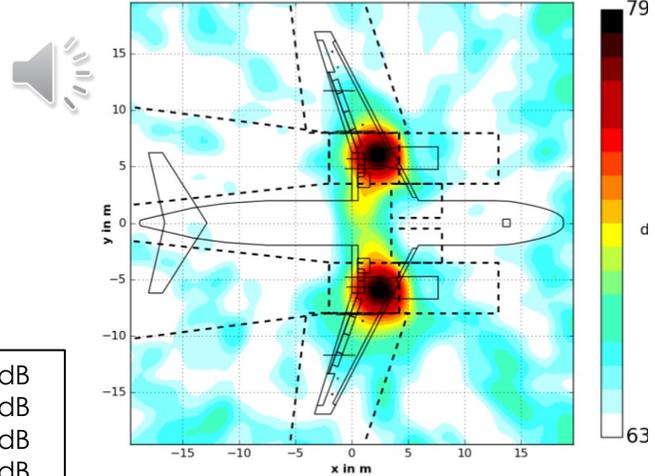
Ricardo Moreno

Supervisors: Marco Raiola and Luis A. Azpicueta Ruiz

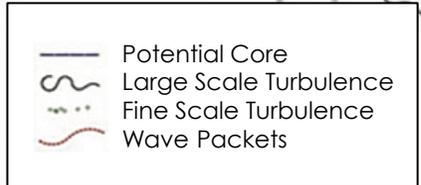
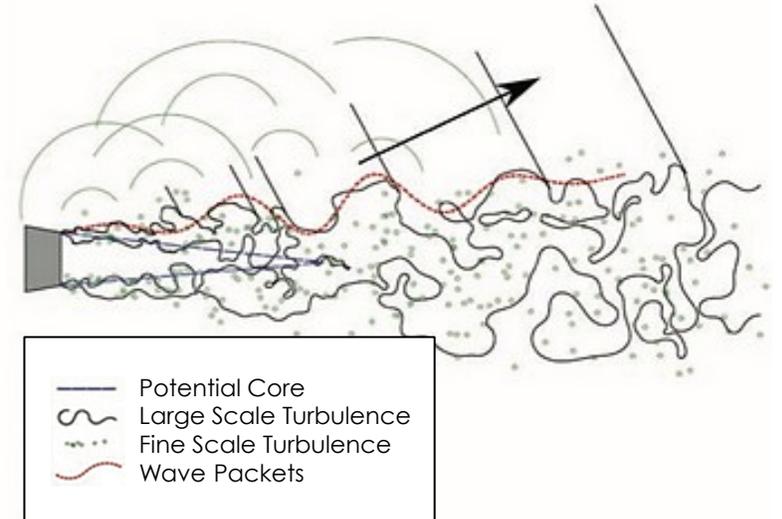
Aircraft Jet-Noise



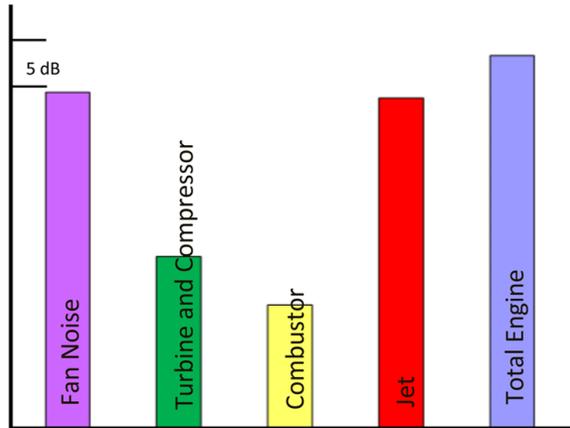
The Phenomena Project (2021)



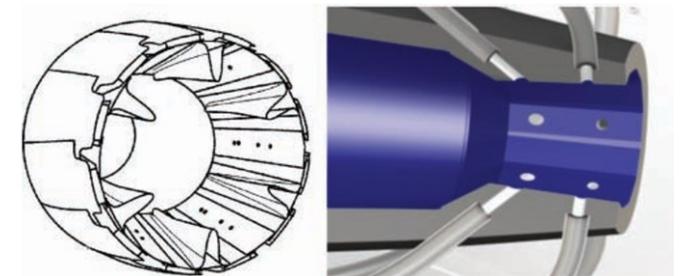
Siller, H., Schumacher, T., & Hage, W. (2020).



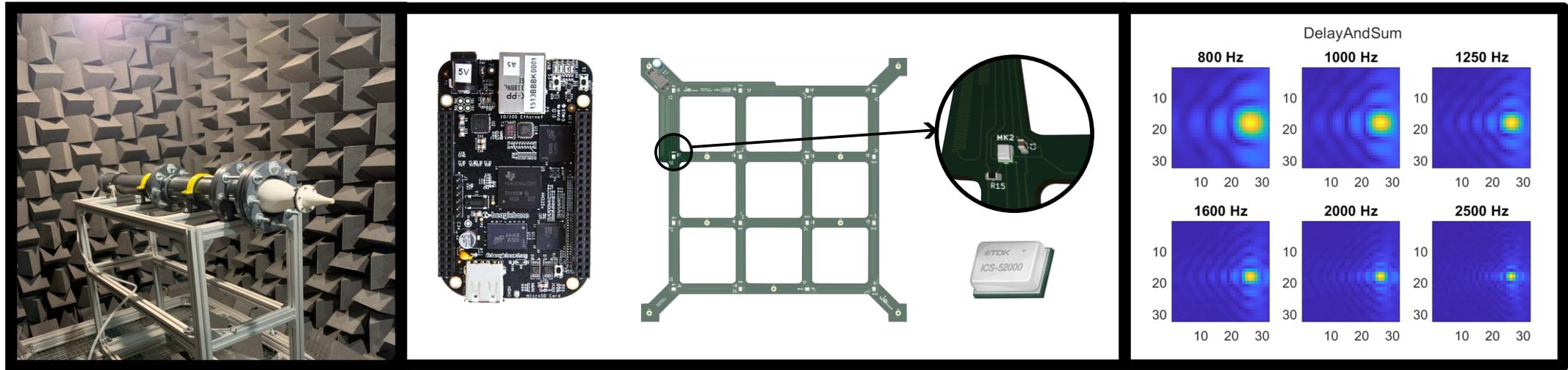
Acoustics Today Journal (2013)



“Typical” Departure Noise Distribution Nesbitt, E. (CEAS - 2019).



Jet-Noise Diagnostic

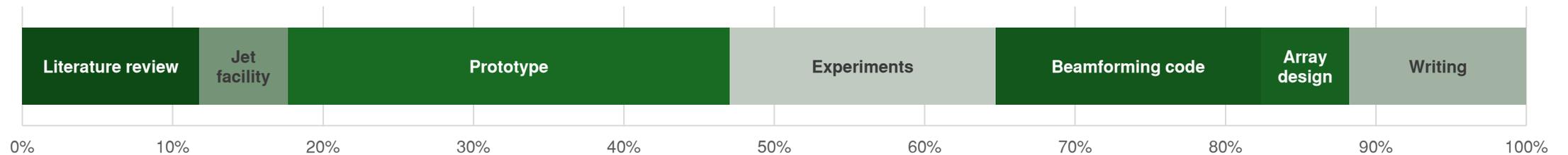


Test site and sound source

Low-cost **Massive** Acoustic Camera

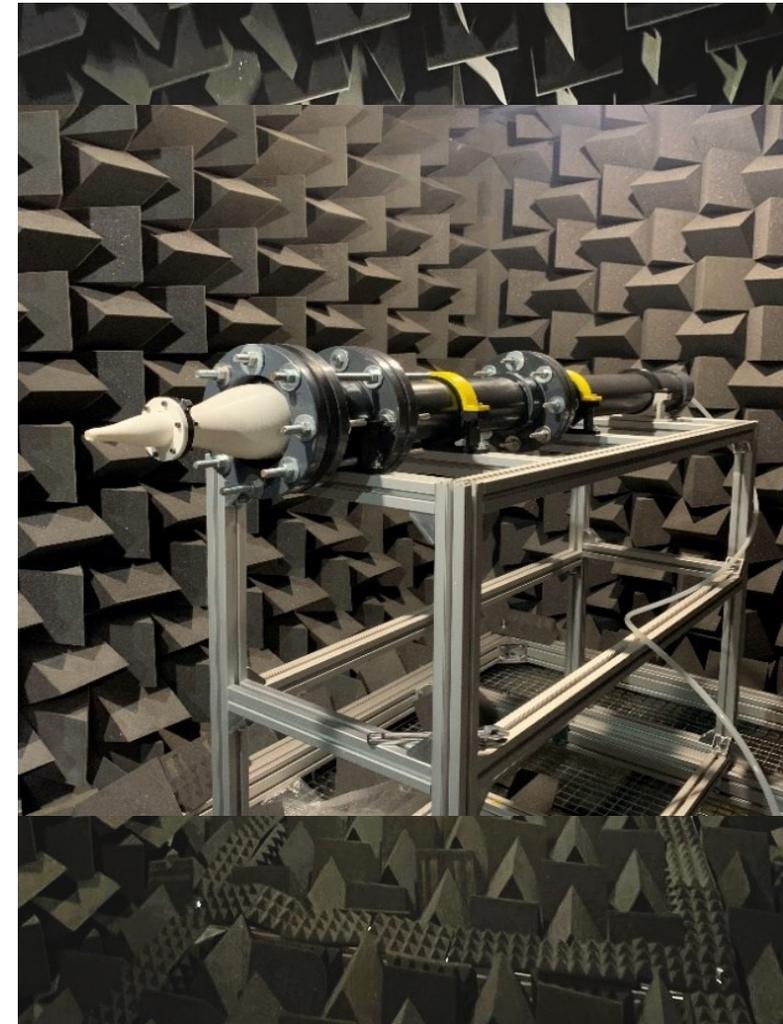
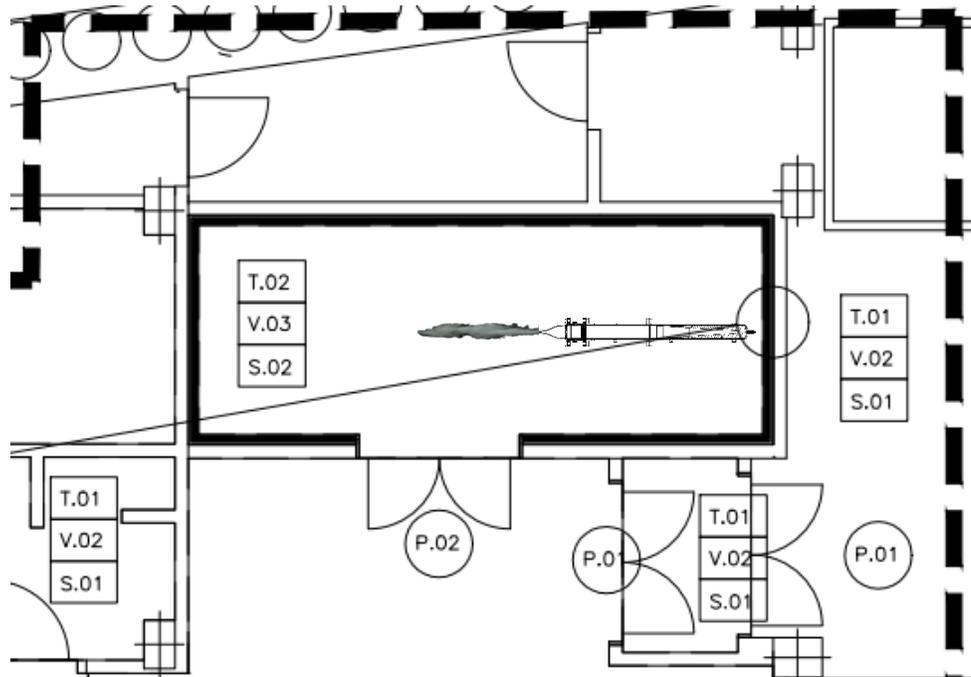
Beamforming

TIME & EFFORT DISTRIBUTION – 18 MONTHS IN REVIEW



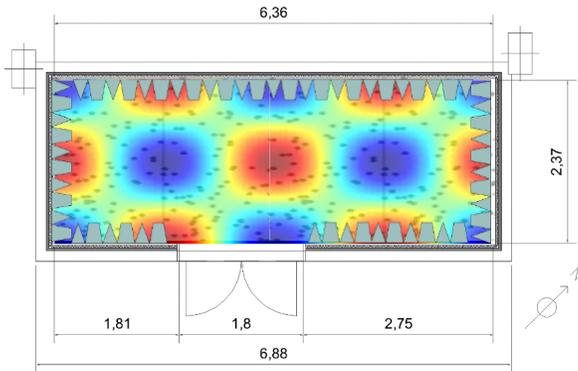
Jet-Noise Facility

- Anechoic chamber with internal dimensions: 6.36 m x 2.37 m, height 2.7 m
- Usable volume: 28m³



From Anechoic Chamber to Jet facility

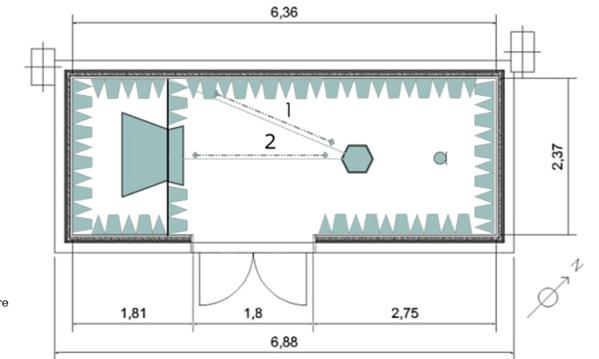
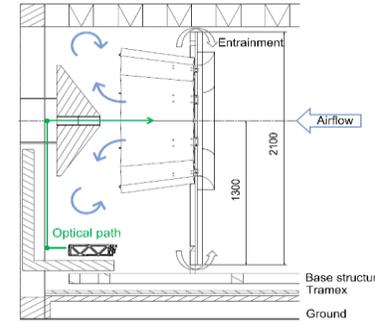
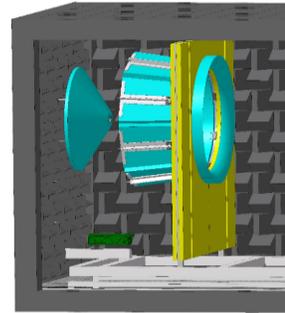
STANDING WAVES



CUT-OFF FREQUENCY

$$0.2 = \frac{c}{4f_c}$$

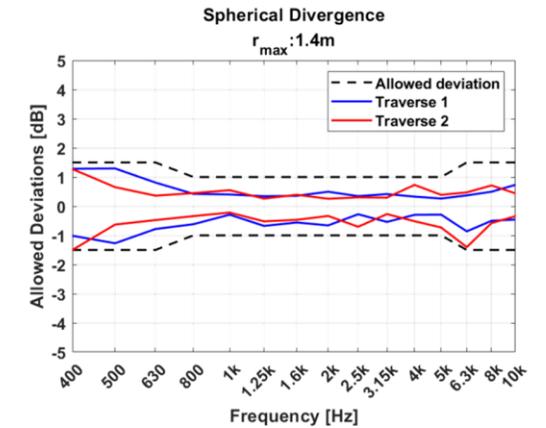
$$f_c = 428\text{Hz}$$



REVERBERATION TIME



FREE-FIELD QUALIFICATION



Accuracy and repeatability of experimental results

AIDAA CEAS AIAA 30th AIAA/CEAS Aeroacoustics Conference - 2024

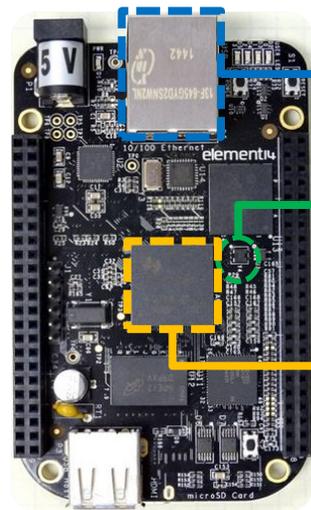
Paper: Implementation of a Jet Collector and Dissipation Cavity into a Closed Anechoic Chamber for jet noise studies

Customized Sound Acquisition System

REQUIREMENTS

- **Low-cost**
- **High performance for audio recording**
- **Multichannel recordings**
- **Modular array**
- **Signal Multiplexing**

BEAGLEBONE BLACK

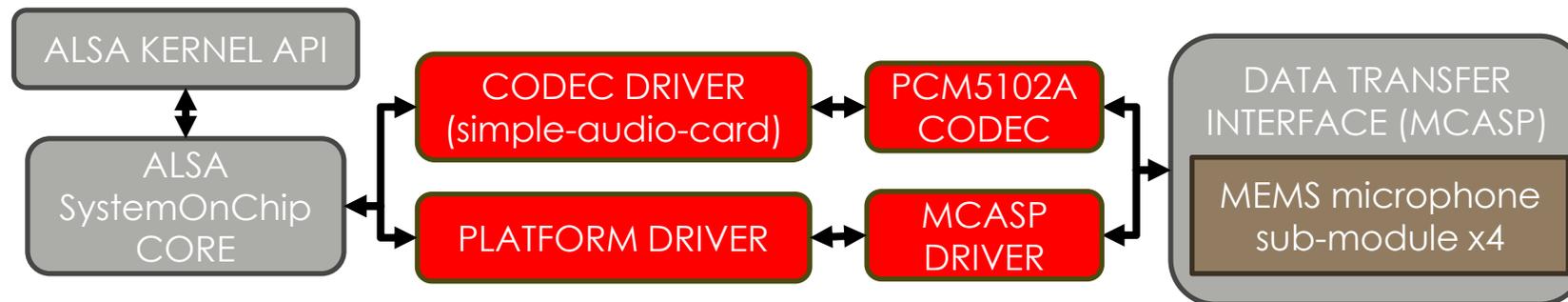
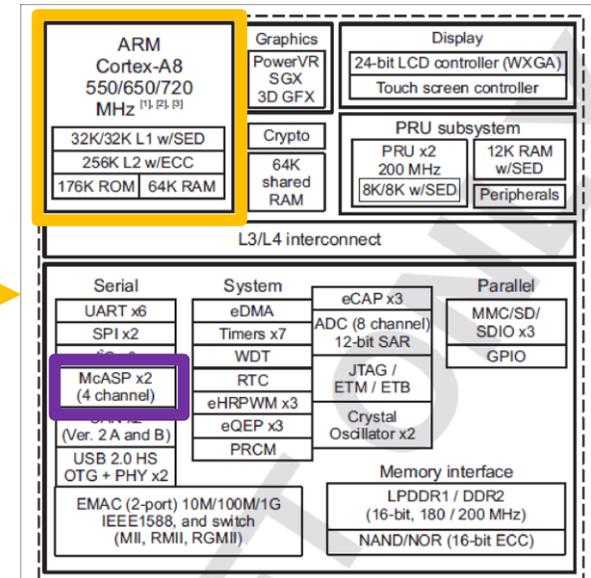


Ethernet port

24.576 MHz oscillator

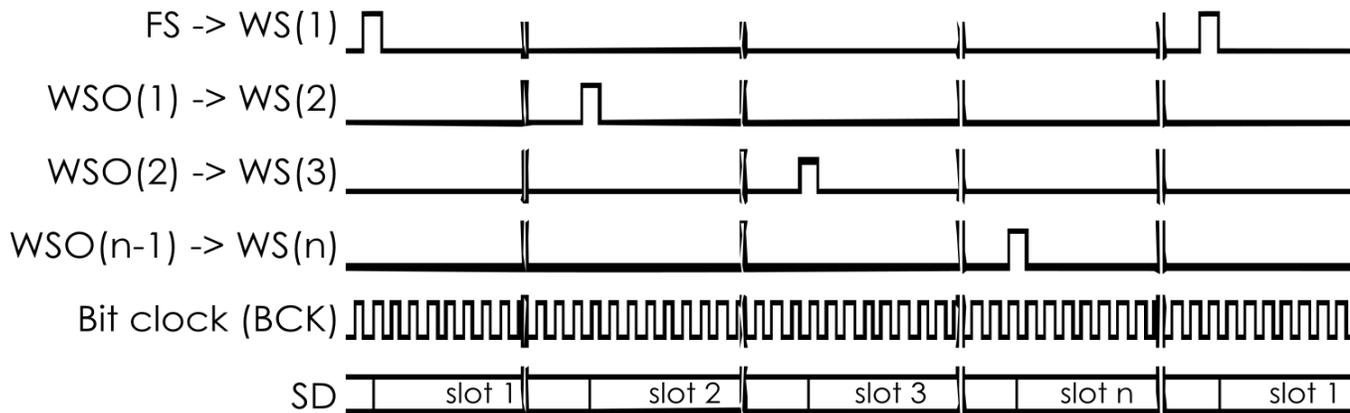
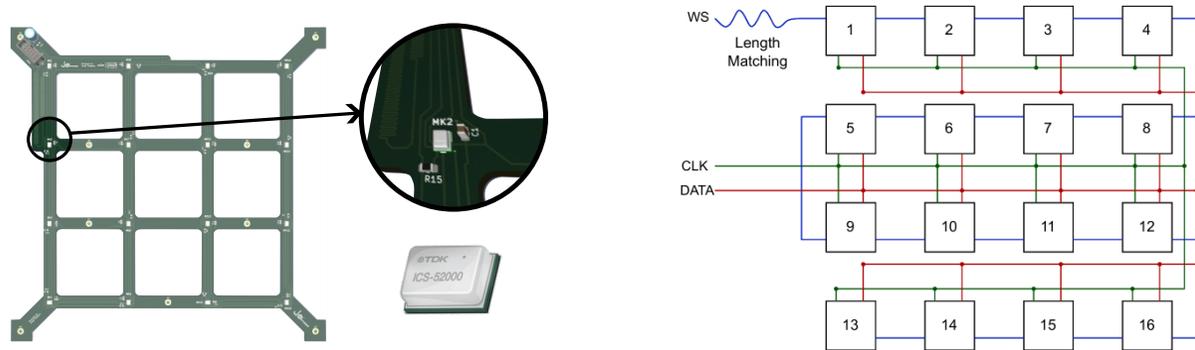
AM3358 microprocessor

Embedded Linux system
Advanced Linux Sound Architecture
Audio recording codecs and drivers



MEMS microphones

16-MICROPHONE SUB-MODULE PROTOTYPE



$$\text{BCK} = \text{slots} \times 32\text{bits} \times \text{fs} \rightarrow 4.096 \text{ MHz}$$

Limitations:

- Sample Frequency
- Maximum trace length
- Up to 16 daisy-chain microphones per data line

16 mics x 4 McASP serializers
 $\times 16 \text{ BBB} = 1024 \text{ mics}$



TECNIACUSTICA 2024 Conference

Paper: **64-MICROPHONE MODULE FOR A MASSIVE ACOUSTIC CAMERA**

Jorge Ortigoso Narro¹, Ricardo Moreno²
 Daniel de la Prida³, Marco Raiola² and Luis A. Azpicueta-Ruiz¹



FORUM ACUSTICUM
 EURONOISE 2025

CHARACTERIZATION OF PLANAR CIRCULAR AND SQUARE MEMS MICROPHONE ARRAYS FOR LOW-POWER ACOUSTIC APPLICATIONS

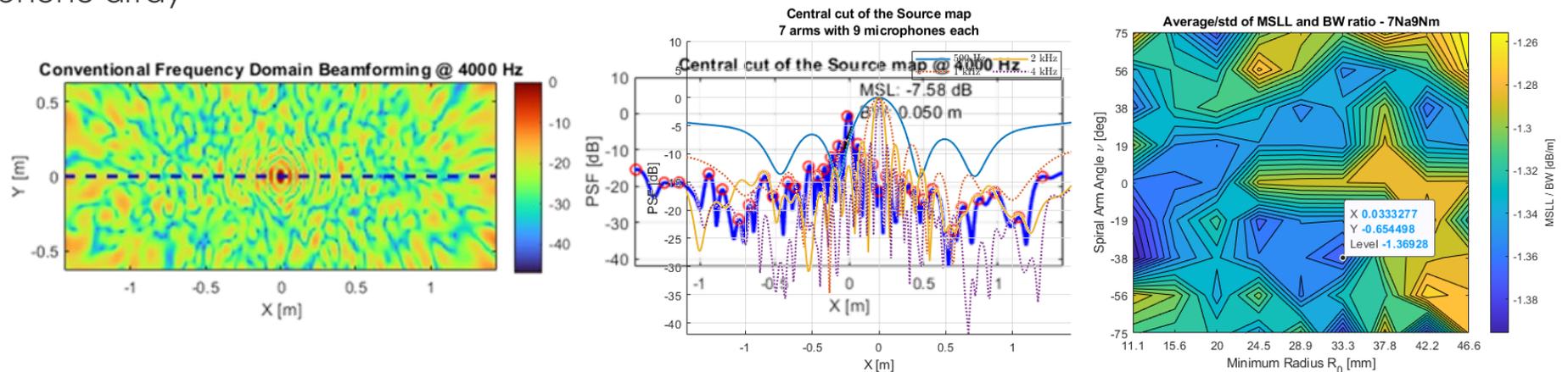
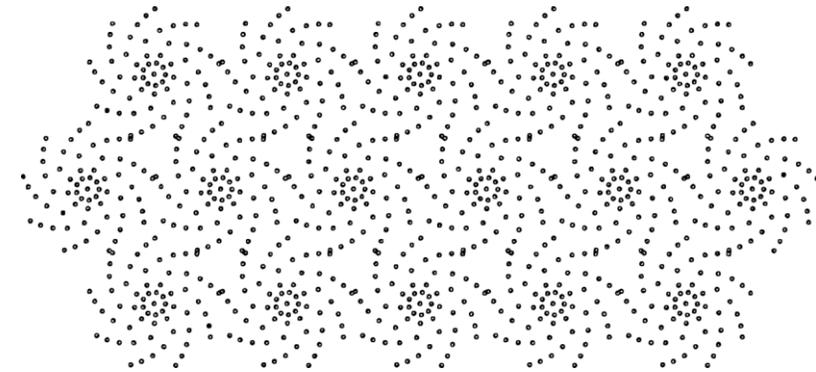
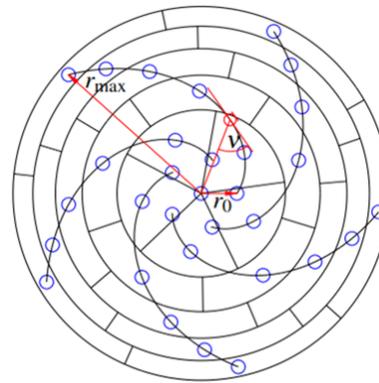
Ricardo Moreno^{1*} Jorge Ortigoso-Narro² Marco Raiola¹
 Luis A. Azpicueta-Ruiz² Daniel de la Prida³

Scalable Microphone Array

GENERAL DESIGN CRITERIA

- 64 microphones per **module**
- Module **synchronization**
- 16 daisy-chain microphones per **data line**
- Side-viewing array **placement**
- Acoustically and aerodynamically **transparent**
- Dominant **noise generation region**
- Spatial aliasing** -> Inter-mic spacing
- Microphone** dimensions
- Anechoic chamber **cut-off frequency**
- Aperture** of the microphone array

UNDERBRINK SPIRAL DESIGN OPTIMIZATION



Beamforming techniques

Delay-and-sum ✓ Completed

Time domain

Robust spatial resolution for broadband noise

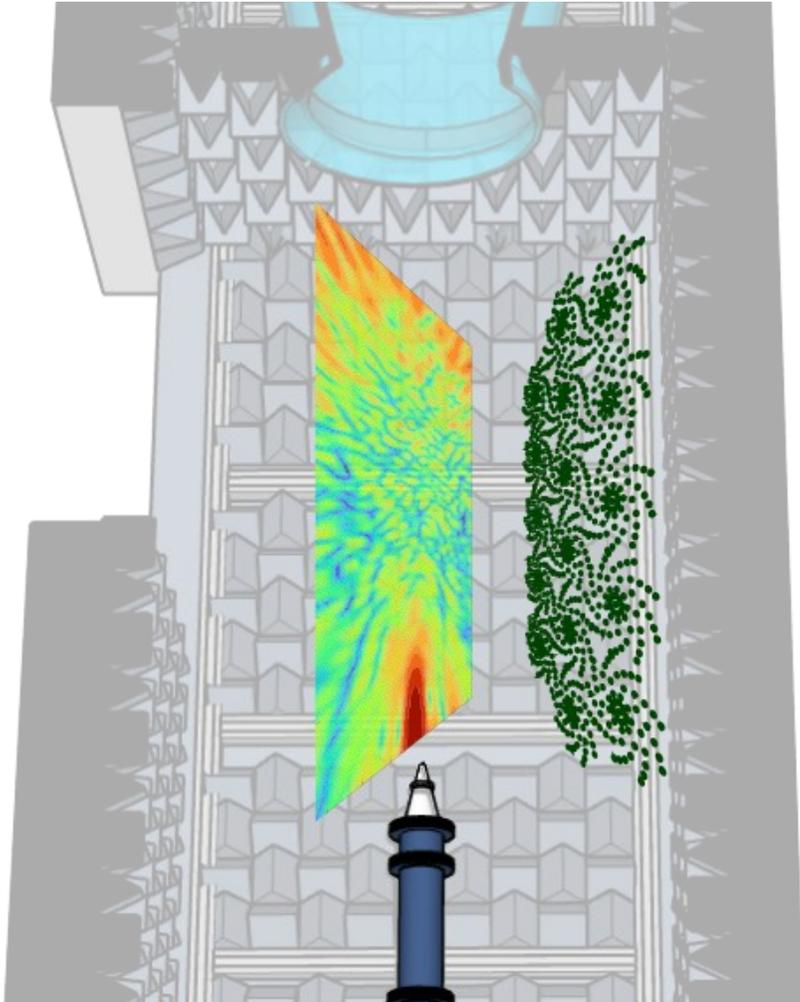
Simple, robust, and light to compute

Conventional Frequency Domain Beamforming ✓ Completed

Tonal and broadband sources

Uses FFT for efficient spectral decomposition

Detailed mapping across frequencies



Next Steps and Goals

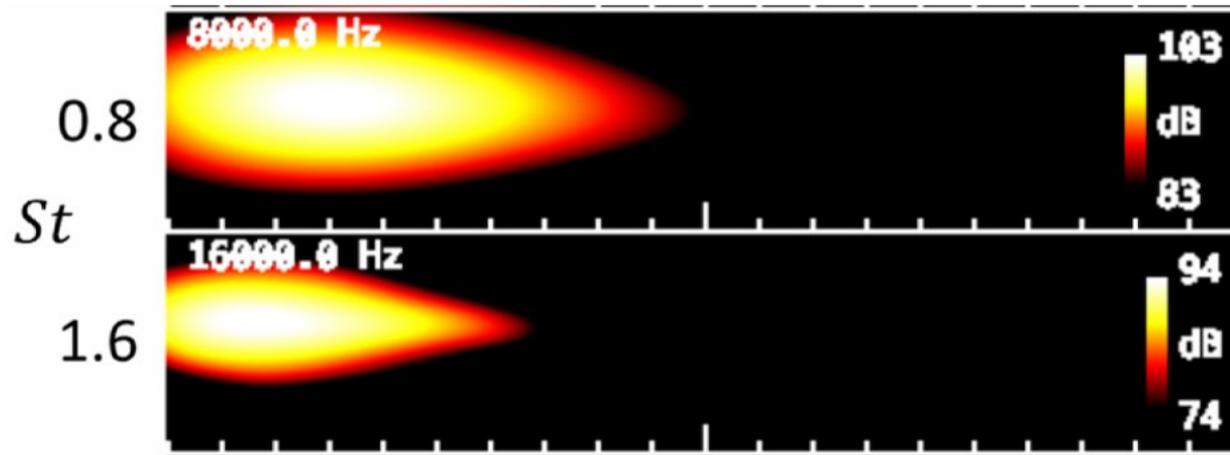
Large statistical data

Describe the acoustics that happen in the jet

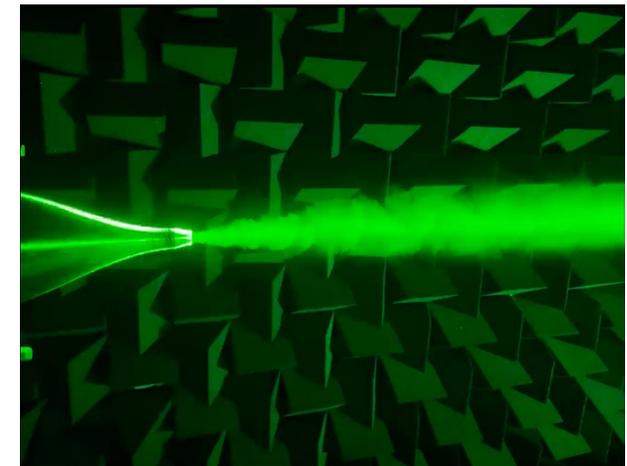
Study the interaction between flow dynamics and jet-noise sources in turbulent jets

Data-driven determination

- Sound patterns
- Flow states



Dougherty, 2023



Achievements

Conference proceedings

Moreno, J. R., Ortigoso-Narro, J., Raiola, M., De la Prida, D. & Azpicueta-Ruiz, L. A. Characterization of Planar Circular and Square MEMS Microphone Arrays for Low-Power Acoustic Applications. Forum Acusticum Euronoise 2025, Malaga, Spain, June 22-27th, 2025.

Ortigoso-Narro, J., Moreno, J. R., De la Prida, D., Raiola, M. & Azpicueta-Ruiz, L. A. Microphone module for a massive acoustic camera. XIII Iberian Congress of Acoustics, XLV Spanish Congress of Acoustics, TECNIACUSTICA 2024, Faro, Portugal, September 11-13rd, 2024

Moreno, J. R., Franceschelli, L., De la Prida, D., Azpicueta-Ruiz, L. A., & Raiola, M. (2024). Implementation of a Jet Collector and Dissipation Cavity into a Closed Anechoic Chamber for Jet Noise Studies. 30th AIAA/CEAS Aeroacoustics Conference, Rome, Italy, June 4-7th, 2024.

Conferences

Forum Acusticum / Euronoise 2025, Malaga, Spain, June 23-26th, 2025

30th AIAA/CEAS Aeroacoustics Conference, Rome, Italy, June 4-7th, 2024.

Learning activities

EAA Summer School, Malaga, Spain, June 21-22nd, 2025

EAA Summer School, Turin, Italy, September 8-10th, 2023.

Outreach Activities

R. Moreno, Lucas Schneeberger “¿Fiat o Ferrari? Un experimento aerodinámico en vivo”, Semana de la Ciencia y la Innovación de Madrid 2024, 2024, November 15th

R. Moreno, Aeroacústica y análisis de chorros turbulentos en cámara anecoica”, European Researchers Night, 2024, Madrid, September 27th