




# AeroAcoustics.jl: A julia package for aeroacoustics

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## Summary

Aeroacoustics is an interdisciplinary research field situated between aerodynamics and acoustics. It focuses on understanding the sound generated by the motion of air around solid bodies and plays an important role in research areas such as automotive, aerospace, and wind energy sciences ([Allen et al., 2002](#)). However, the airflow responsible for sound generation typically generates unwanted background noise, which masks the true acoustic emission of the test item from measurement equipment. Therefore, isolating the sound emitted by the test item becomes essential to obtain reliable evaluations, which is pivotal in the development of noise-reducing technologies for cars, airplanes, and wind turbines. One common solution strategy involves the use of *acoustic images* computed using microphone arrays. The acoustic images help visualize and quantify the spatial distribution of sound across the test item, and enables precise assessment of acoustic emissions without contamination from background noise ([Glegg & Devenport, 2017](#)).

[AeroAcoustics.jl](#) is a julia ([Bezanson et al., 2017](#)) package for working with microphone arrays and acoustic imaging techniques. Methods for computing acoustic images often share the same codebase and utility functions, making them suitable candidates for a modular software package. It is the intention, that [AeroAcoustics.jl](#) can serve as a foundation for benchmarking existing methods and developing new ones within the aeroacoustics community. In addition to that, [AeroAcoustics.jl](#) is also a good candidate for teaching and entry-level programmers due to its simple API.

## Statement of need

The [AeroAcoustics.jl](#) package provides a collection of commonly used acoustic imaging techniques, developed by the aeroacoustic community, such as conventional beamforming ([Johnson & Dudgeon, 1993](#)), DAMAS ([Brooks & Humphreys, 2006](#)), and CleanSC ([Sijtsma, 2007](#)). The [AeroAcoustics.jl](#) package also include newer techniques found in the literature, e.g., fista ([O. Lylloff et al., 2015](#)) and mean mutual-coherence weights ([Amaral et al., 2018](#)).

Only one other open-source software package exists with similar features; [acoular](#) ([Saradj & Herold, 2017](#)), which is written in Python. [Acoular](#) has a broader scope than [AeroAcoustics.jl](#), including generation of simulated data, and analysis in both the time-domain and frequency-domain. A few repositories can be found online with code written in Matlab, but with limiting packaging functionality and few features; these do not constitute proper open-source software packages <sup>1</sup>.

A benchmark case study was conducted in 2017, where different research groups with different software used the same datasets and the same algorithms to compare results ([Bahr et al., 2017](#); [Saradj et al., 2017](#)). One conclusion was that, although using seemingly the same algorithm written in different software codes, the results differed. The study did not compare the codes

<sup>1</sup>An overview can be found here: [beamforming-tools](#)

because most of the participants did not use publicly shared code. This is a testament to the need for open-source software, and AeroAcoustics.jl provides yet another option for the community to adopt open-source practises.

AeroAcoustics.jl is the fast, entry-level open source software package, that fills the gap between the existing codebases available online. It has already been used in publications (Fischer et al., 2022, 2023; Plaza et al., 2022), a PhD thesis (O. A. Lylloff, 2020), for research and commercial activities at the Poul la Cour Wind Tunnel, and also in teaching 46600 Aeroacoustics.

## Example

To use the methods included in AeroAcoustics.jl, an Environment struct must be defined. This holds essential information about the computational domain, microphone array geometry and measurement data. The Environment struct is used by most functions in the AeroAcoustics.jl package, which makes it easy to add new methods and algorithms, because the required input is typically stored in Environment. Below is an example of this:

```
E = Environment(
    z0=z0,
    micgeom=micgeom,
    CSM=CSM,
    flim=(3000,4000),
    Nx = 21,
    Ny = 21,
    xlim=(-0.5,0.5),
    ylim=(-0.5,0.5),
    multi_thread = true
)
steeringvectors!(E)
b = beamforming(E)
```

where

- z0 is the distance from the microphone array to the acoustic imaging plane,
- micgeom is the coordinates to each microphone in the microphone array,
- CSM is the cross-spectral matrix (measurement data),
- flim are the frequency limits of interest,
- Nx and Ny is the desired number of grid points in the x- and y-direction of the acoustic image
- xlim and ylim is the desired extent of the acoustic image
- multi\_thread can enable or disable multi-threading in appropriate functions across the AeroAcoustics.jl package.

In this example, steeringvectors!(E) mutates the argument and add steeringvectors to the Environment, which is required to compute acoustic images. The function is aware of the defined options in Environment and will only calculate for the appropriate domains, e.g., frequency limits, grid points, etc., reducing the computational load. Finally, the acoustic image is computed using b = beamforming(E).

An example from a wind tunnel measurement is shown in Figure 1. Between the green walls, which is made of Kevlar and transparent to sound, an airflow encloses a section of an airfoil (shown in black), and acoustic measurements are conducted with a microphone array (blue dots) just on the other side of the green wall. The resulting acoustic image is overlayed the airfoil for visualization, using Makie.jl (Danisch & Krumbiegel, 2021), and shows, that the dominant part of the acoustic energy arise from the trailing edge of the airfoil (as expected from theory).

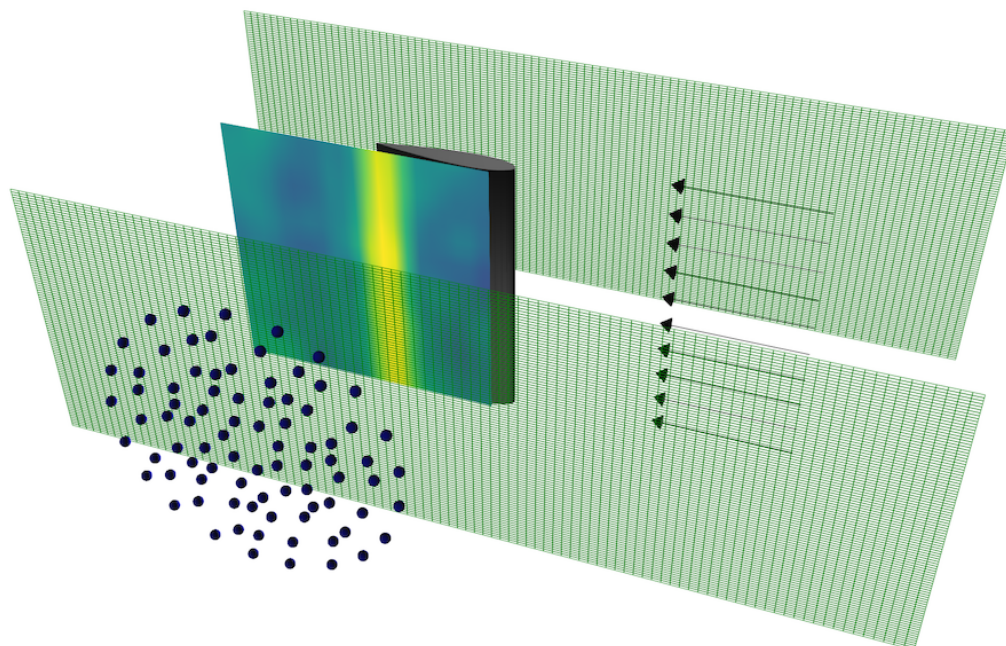


Figure 1: Example of beamforming in a wind tunnel

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