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companion

Source localisation measurements with microphone arrays on turbofan and open rotor engines

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Outline

- The EU project Companion
- Source localisation with microphone arrays
- localisation of directive sound sources with SODIX
- Preparation for source localisation measurements in Companion
  - USF open rotor engine
  - UHBR turbofan engine
- Wind tunnel measurements using models
- In-flight measurements at full scale

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The COMPANION Project

COMPANION - COMmon **P**latform and **A**dva**N**ced **I**nstrumentation readiness for ultra efficient propulsion demonstrati**ON**

Consortium:

AIRBUS, DLR, ONERA – The French Aerospace Lab, NLR, Centrale Lyon, EASN technology innovation services, DNW German-Dutch Wind Tunnels, INSA Institut National des Sciences Appliquées Lyon

Coordinator: Airbus

Duration: 30 months - from January 1st, 2024 to June 30th, 2026

EU contribution: 19.947 M€

Part of the Clean Aviation Joint Undertaking initiative

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The European research project COMPANION

Main objectives:

- **Define, design and prepare** a **common Flight Test Demonstrator (FTD) platform** to enable the validation of the following **ultra-efficient propulsion systems**:
  - an **Open Fan** demonstrator
  - **an hybrid electric Ultra High Bypass Ratio Turbofan** demonstrator
- **Deliver the hardware of the flight test platform** ready for engine installation, hosting **standard and special flight test instrumentation** to assess the **demonstrator engines** and measure **related emissions**.
- **Flight clearance process will be initiated** and will benefit from EASA experts

Objectives in acoustics:

- sound source analysis for open fan and UHBR engines in wind tunnel and flight tests
- localising the sound sources and their directivity in order to extrapolate to far field positions

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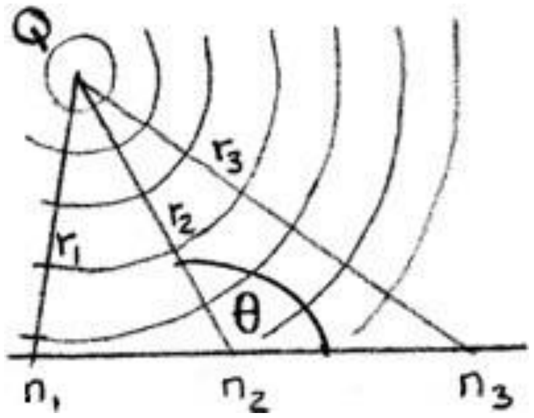
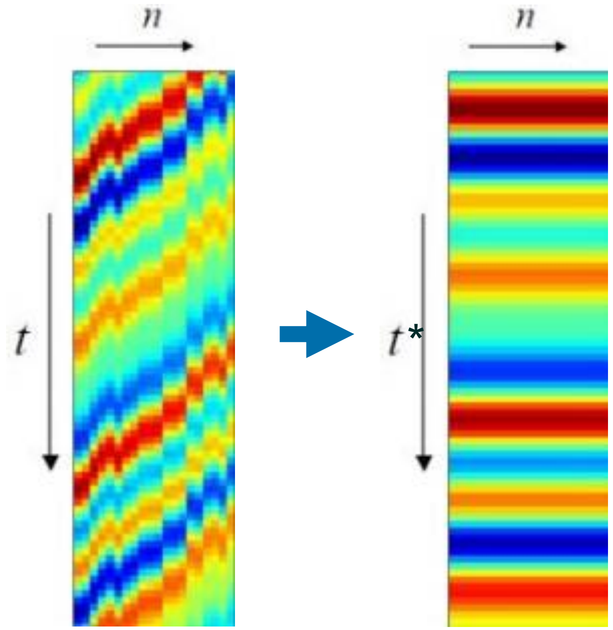
Source localisation with microphone arrays

- Beamforming for stationary sound sources:
  - Sound source *Q*,
  - microphone channels n,
  - constant speed of sound (*c* ≈ 340 m/s),
  - propagation time from source to microphone: $\tau_i = r_i / c$
  - signal at source reconstructed by delay and sum:

$$p_Q(t) = \sum_{i=0}^{N-1} p_i(t - \tau_i).$$

    - signals from the source *Q* add constructively,
    - signals from other source positions are “out of phase” - they add destructively
- can be transformed into the frequency domain, using operations on *cross-spectral matrices*





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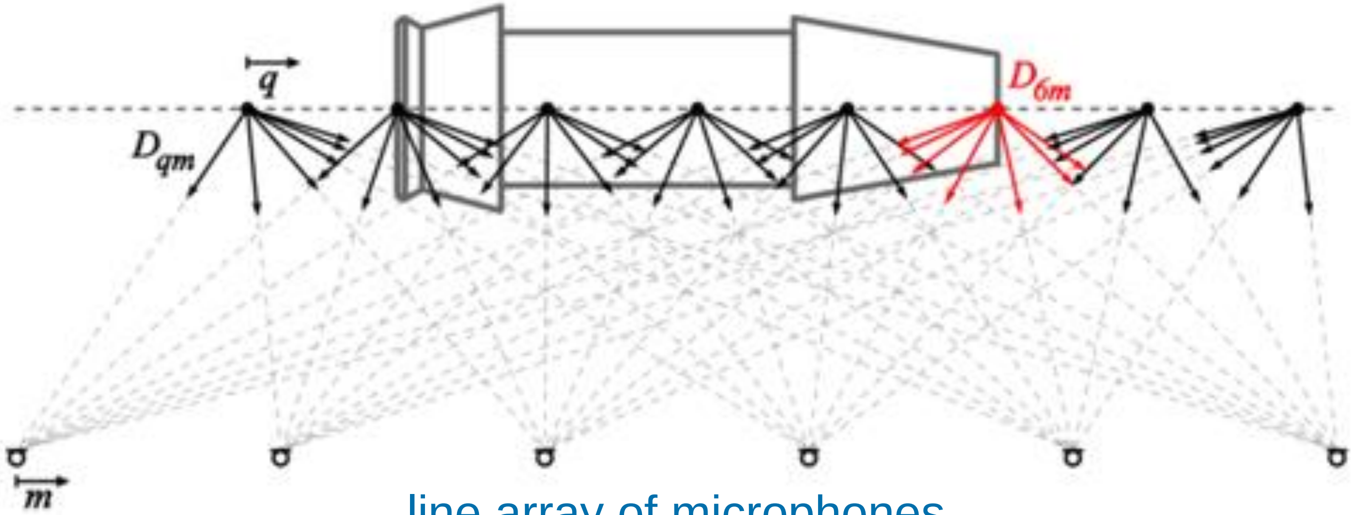
Localisation of directive sources

- Method: **SODIX** - **SO**urce **DI**rectivity modelling in the cross-spectral matrix
- takes the directivity of (aircraft engine) sound sources into account using a
- model of *(broadband uncorrelated)* point sources with directivity,
  - different amplitudes D_{qm} from every source point q to every microphone m
  - solve for q times m unknowns in every frequency band!



line array of microphones

The SODIX algorithm

SODIX determines $\boldsymbol{D_{qm}}$ for $\boldsymbol{q}$ times $\boldsymbol{m}$ unknowns from microphone array data

- operates in the frequency domain
- fits a model cross spectral matrix to the measured cross-spectral matrix

$$C_{mn}^{\text{mod}} = \sum_{q=1}^{Q} g_{qm} D_{qm} D_{qn} g_{qn}^{*}$$

propagation of sound

source amplitudes

- by minimising the cost function

$$F(D) = \sum_{m,n=1}^{M} ||Cmn - C_{mn}^{\text{mod}}||^2$$

measured cross-spectral matrix

- using an optimisation scheme

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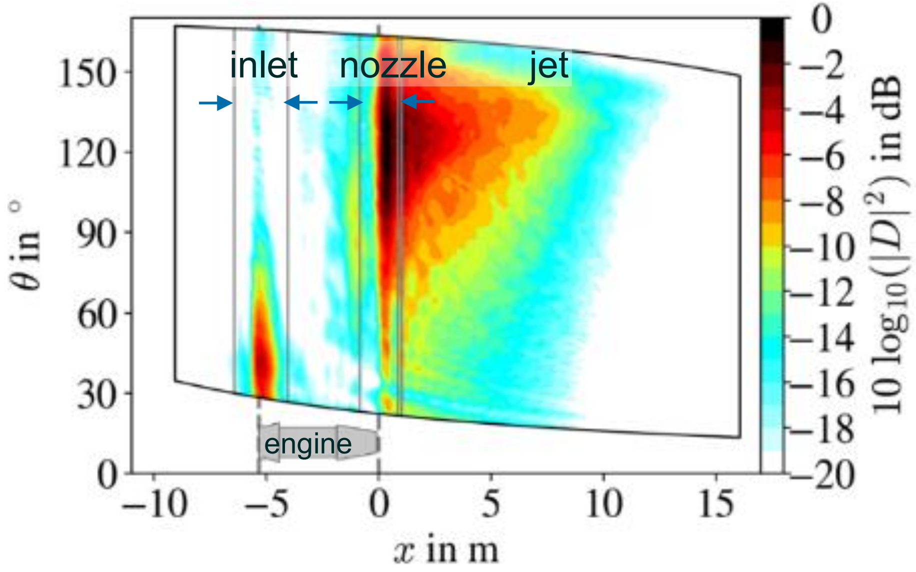
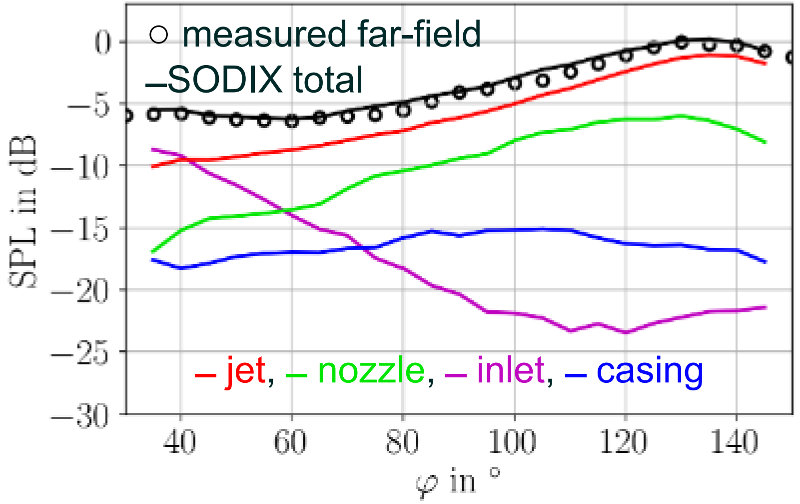
SODIX applied to engines

- SODIX source directivity map:
  - *source* **amplitudes** on a contour map,
  - axial source **position *x*** and
  - **directivity:** emission angle ***θ***
- Source breakdown:
  - directivity of the sound field of the engine and its components
  - integration over source areas:
    - engine inlet
    - nozzle
    - jet
  - extrapolation of integrated power to far-field positions

400 Hz, low engine speed:





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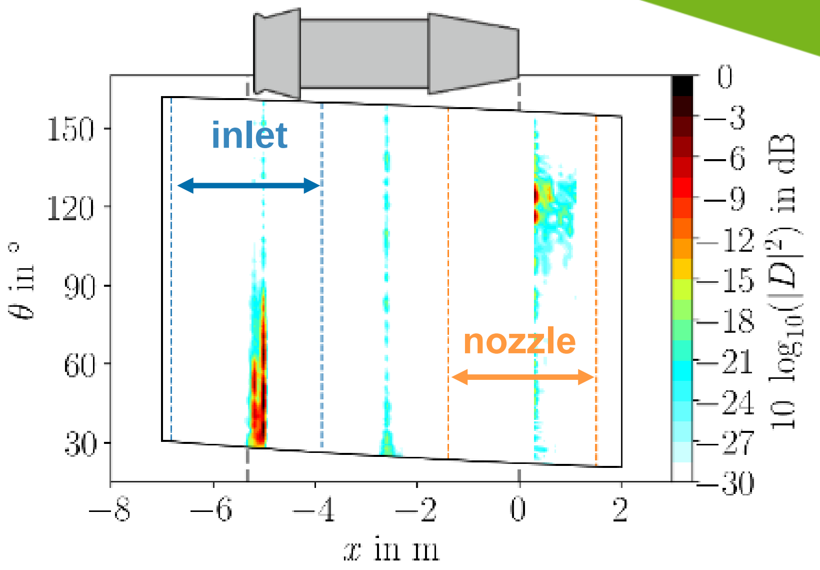
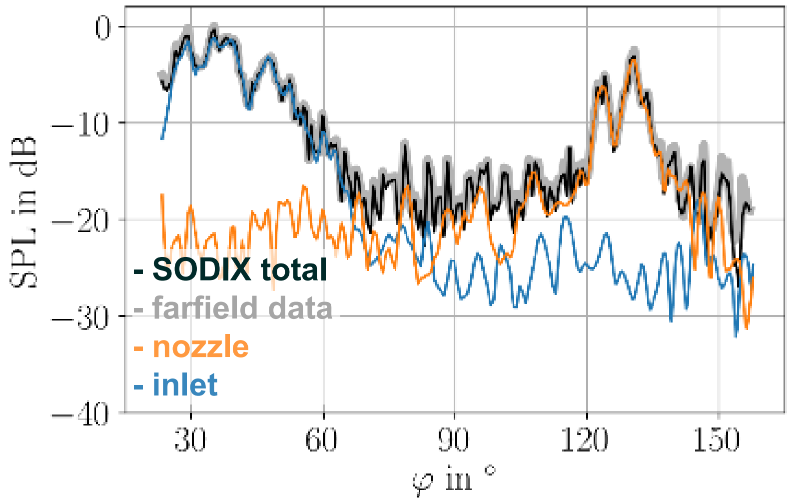
Extensions of SODIX

- SODIX has originally been developed for the analyis of incoherent broadband sources
- recent extensions
  - fully and partially coherent sources (e.g. fan noise emitted from turbofan inlet and exhaust)
  - tonal sources (ducted fans, open fans and interaction tones)
  - shear layer correction for open wind tunnel experiments





SODIX with partially coherent source model
3 kHz fan tone

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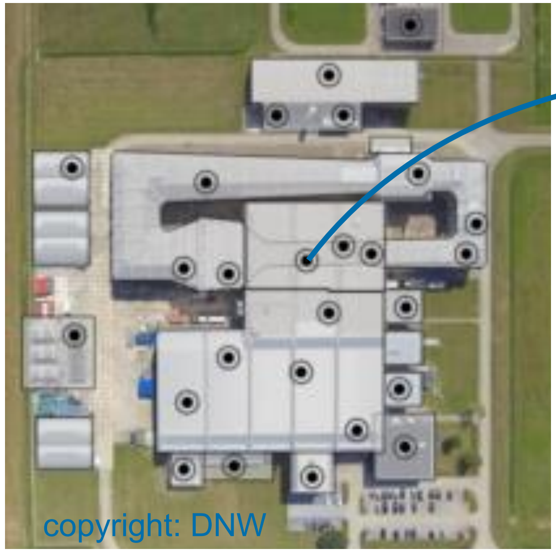
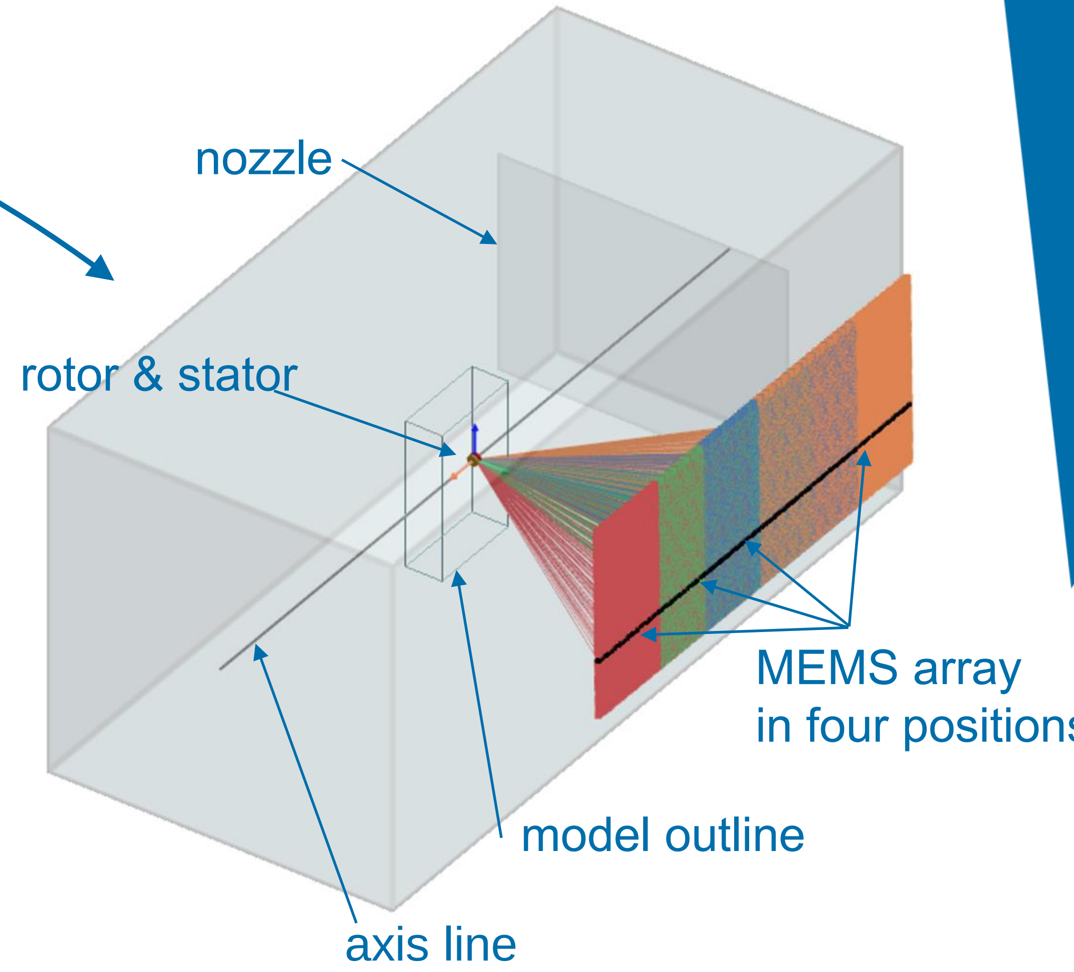
Wind Tunnel Experiments

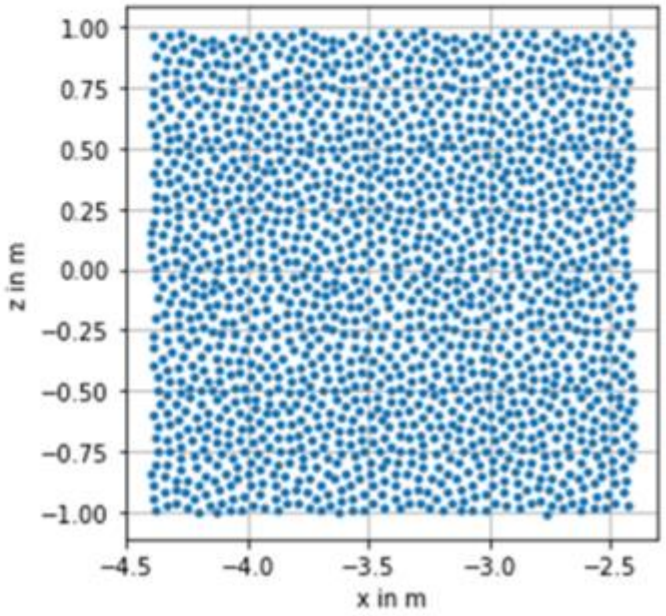




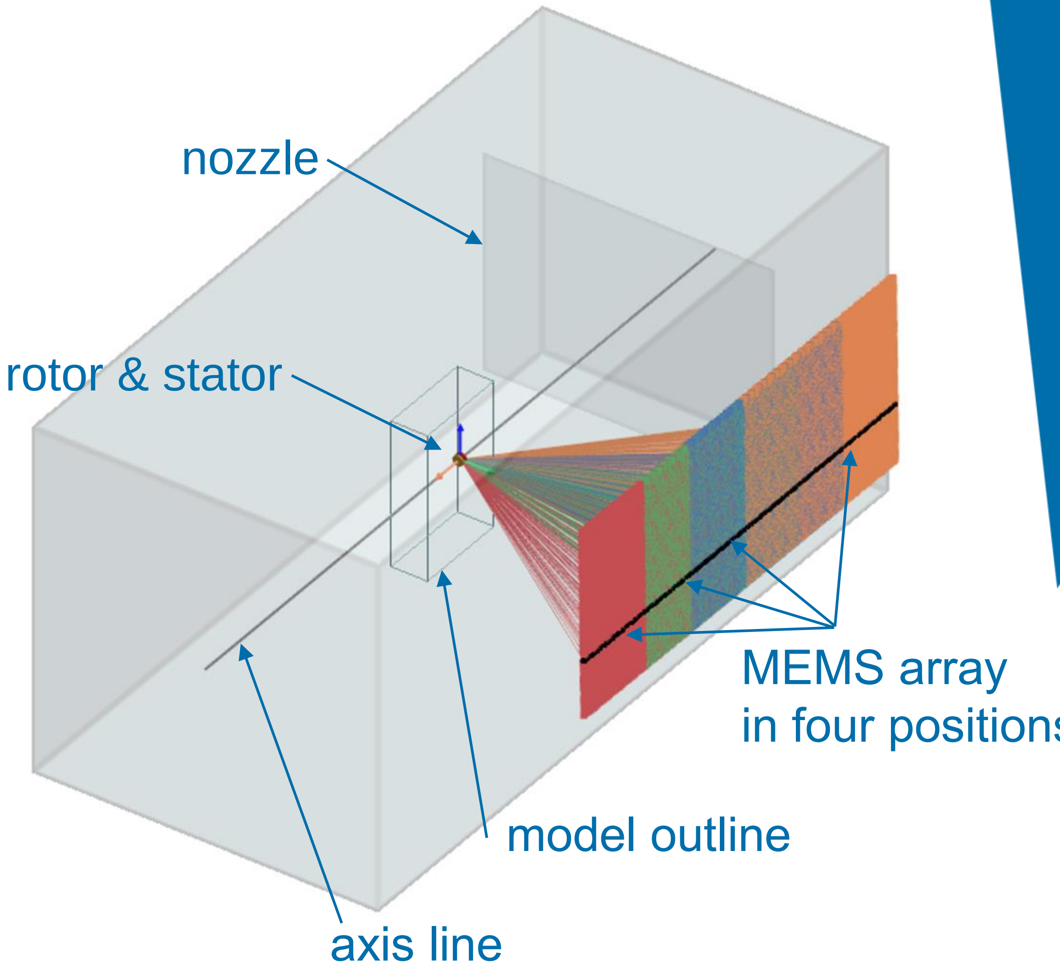
Wind tunnel model test in the DNW-LLF

- open fan with stator
- 9.5 m x 9.5 m test section
- open jet, 8 m x 6 m cross section
- up to 68 m/s (Mach 0.2)

MEMS array



- 2 m x 2 m centre region of the MEMS array
- full size: 6.8 m x 5 m
- 12.000 MEMS sensors
- provided by DLR AS-EXV Göttingen



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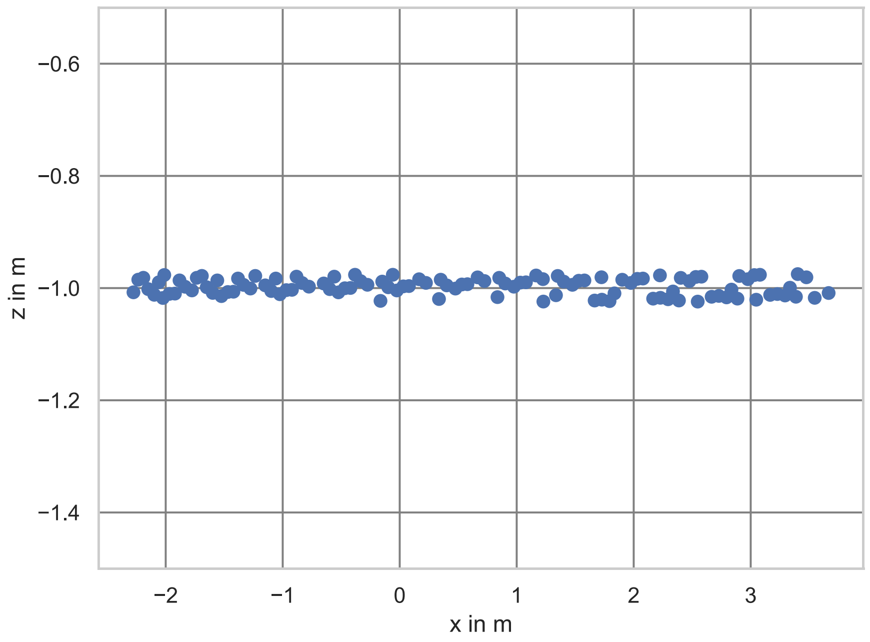
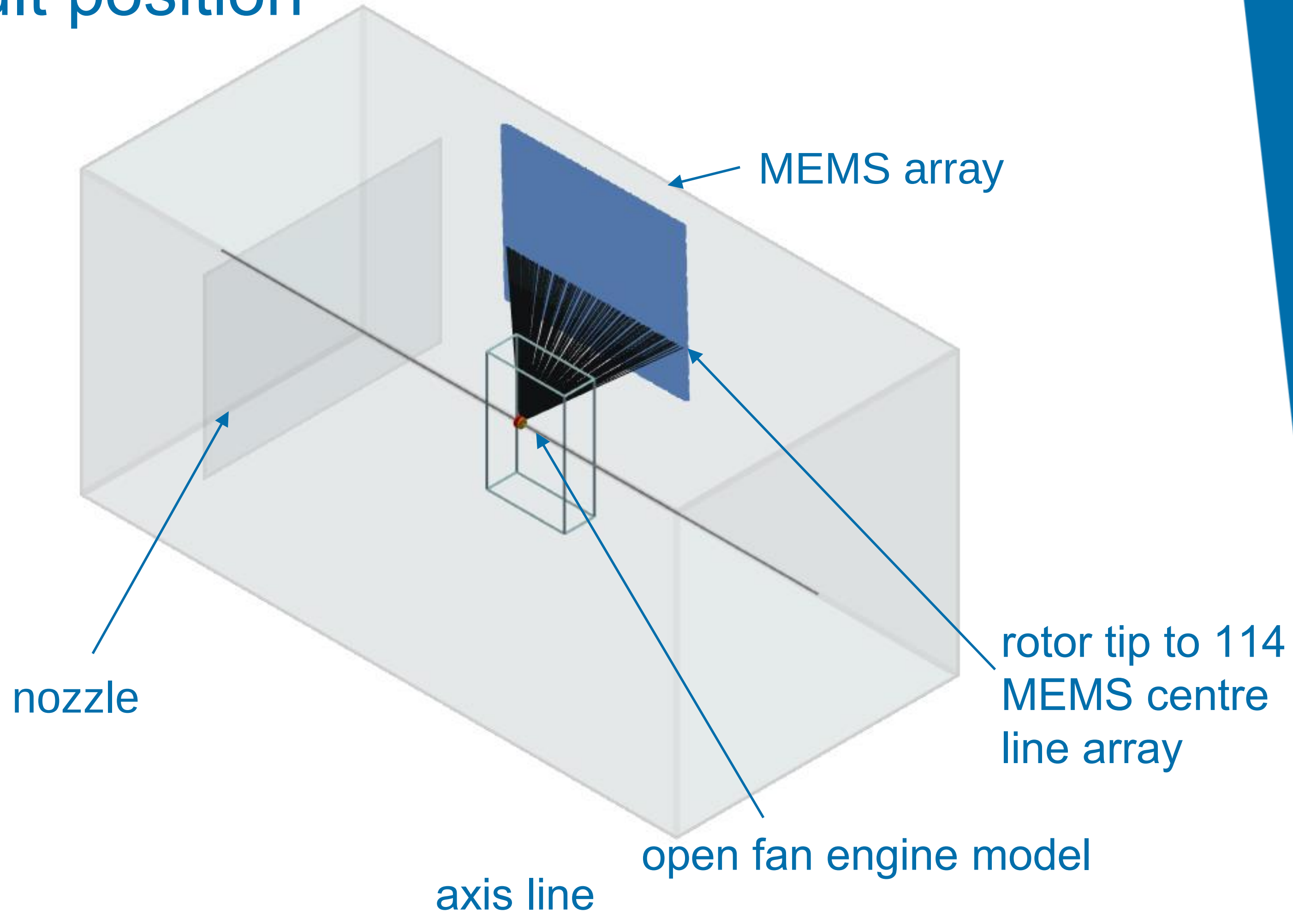
DNW LLF test section

- MEMS Array mounted in default position

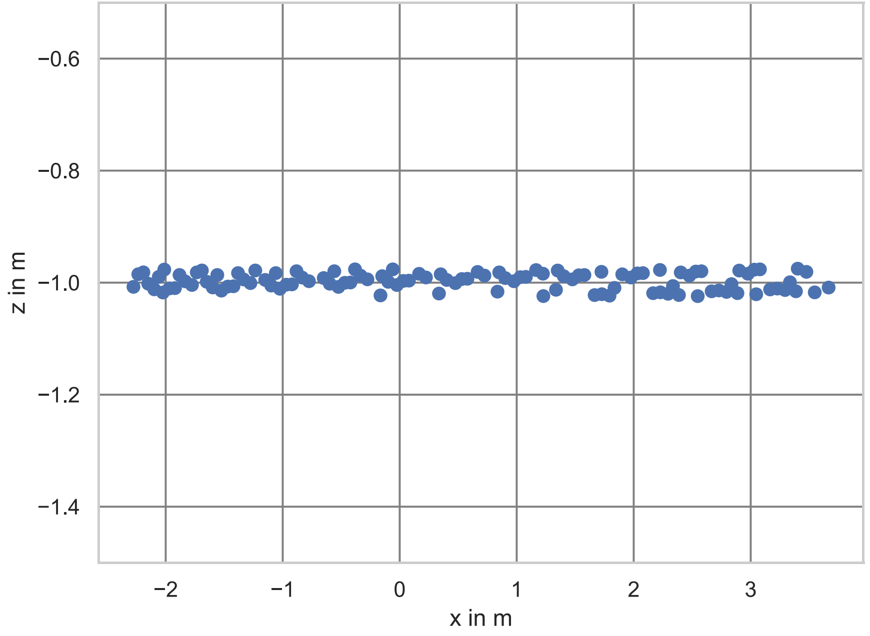


Sub-array for the SODIX analysis

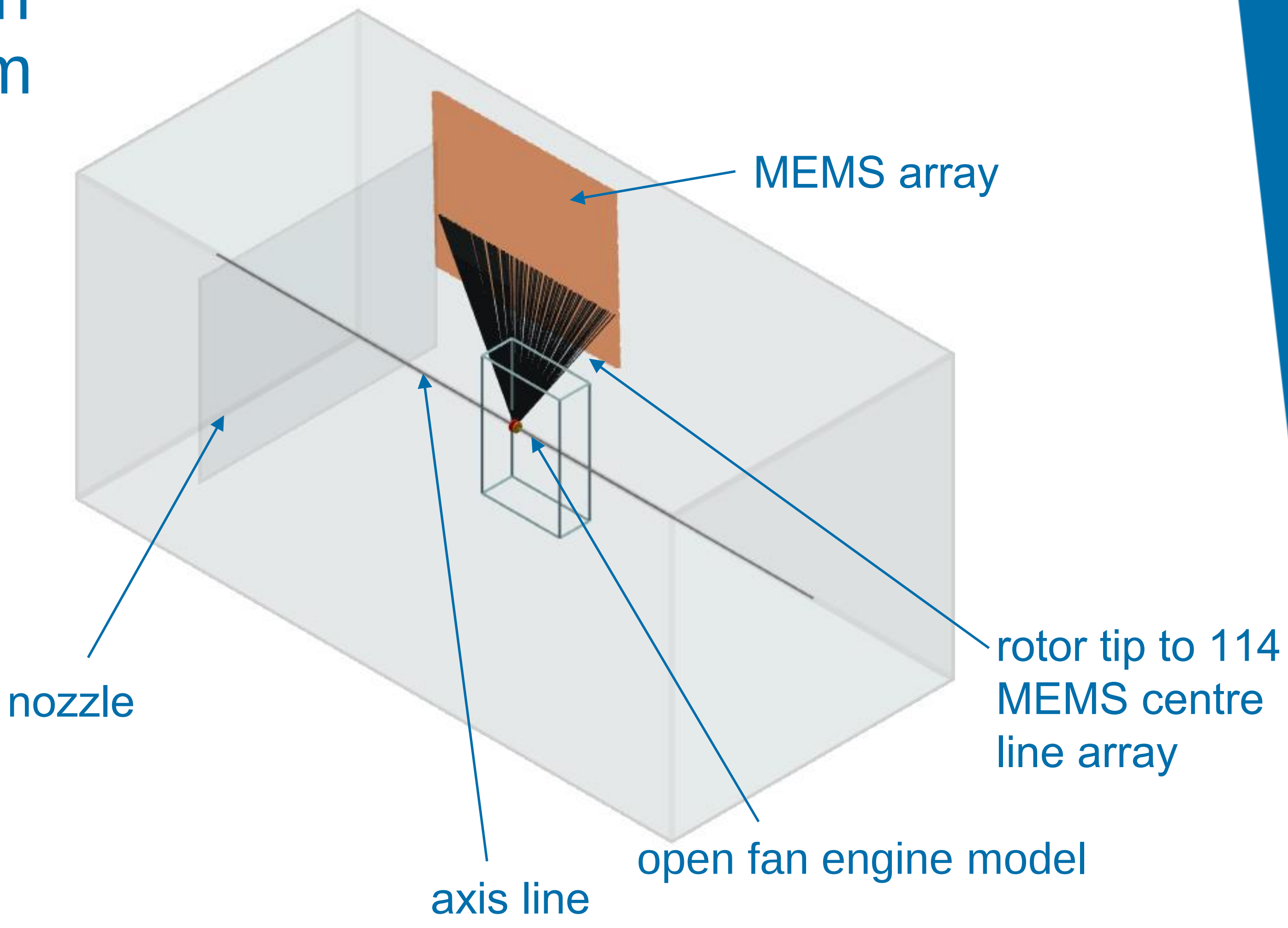


DNW LLF test section

- MEMS Array in forward position shifted upstream by x = -2.15 m



Sub-array for the SODIX analysis



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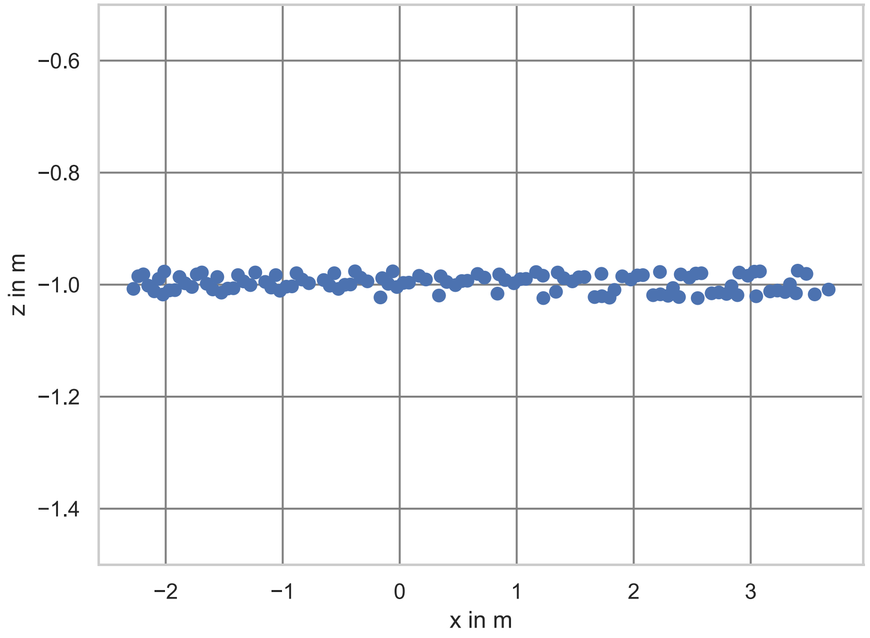
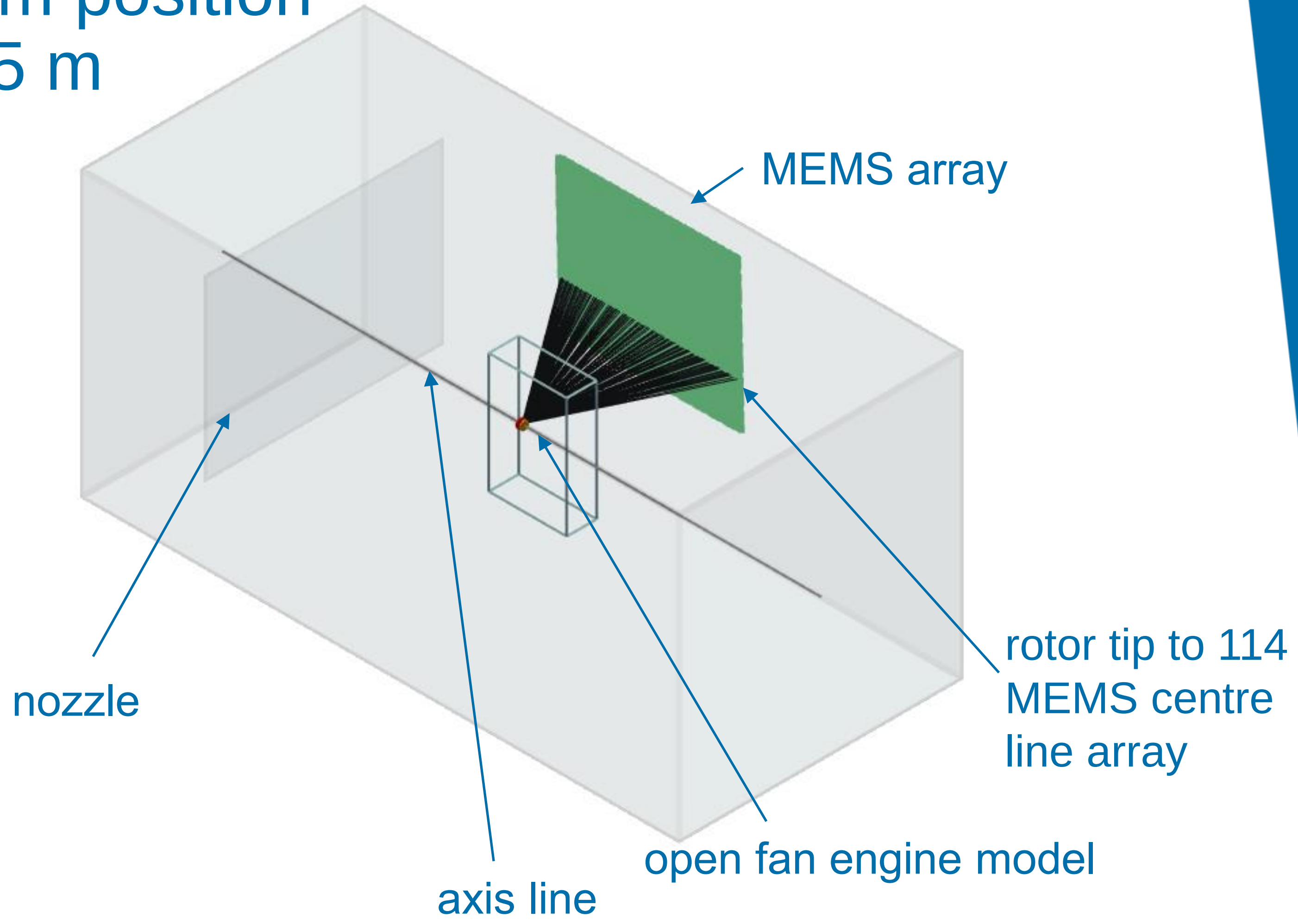
DNW LLF test section

- MEMS Array in first downstream position shifted downstream by x = 1.75 m



Sub-array for the SODIX analysis



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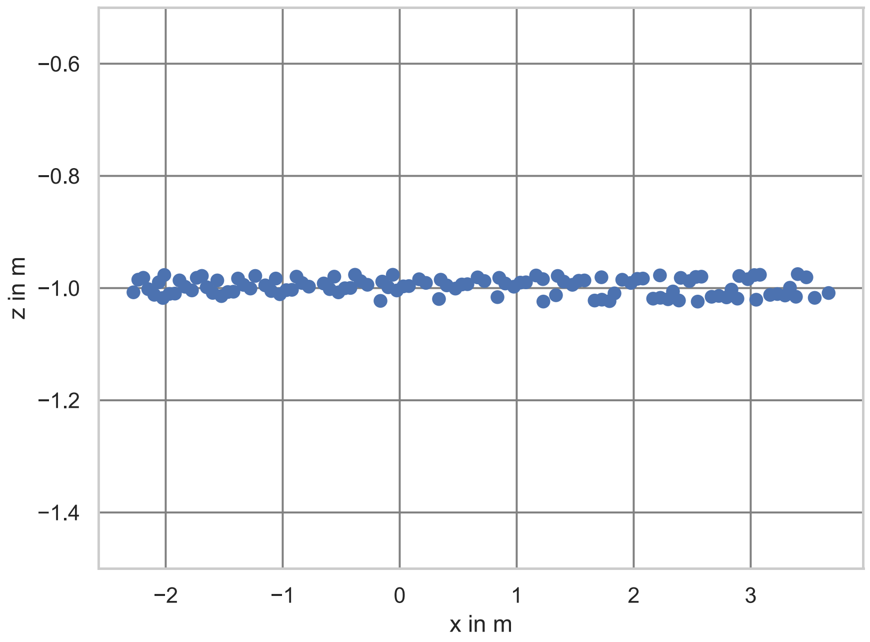
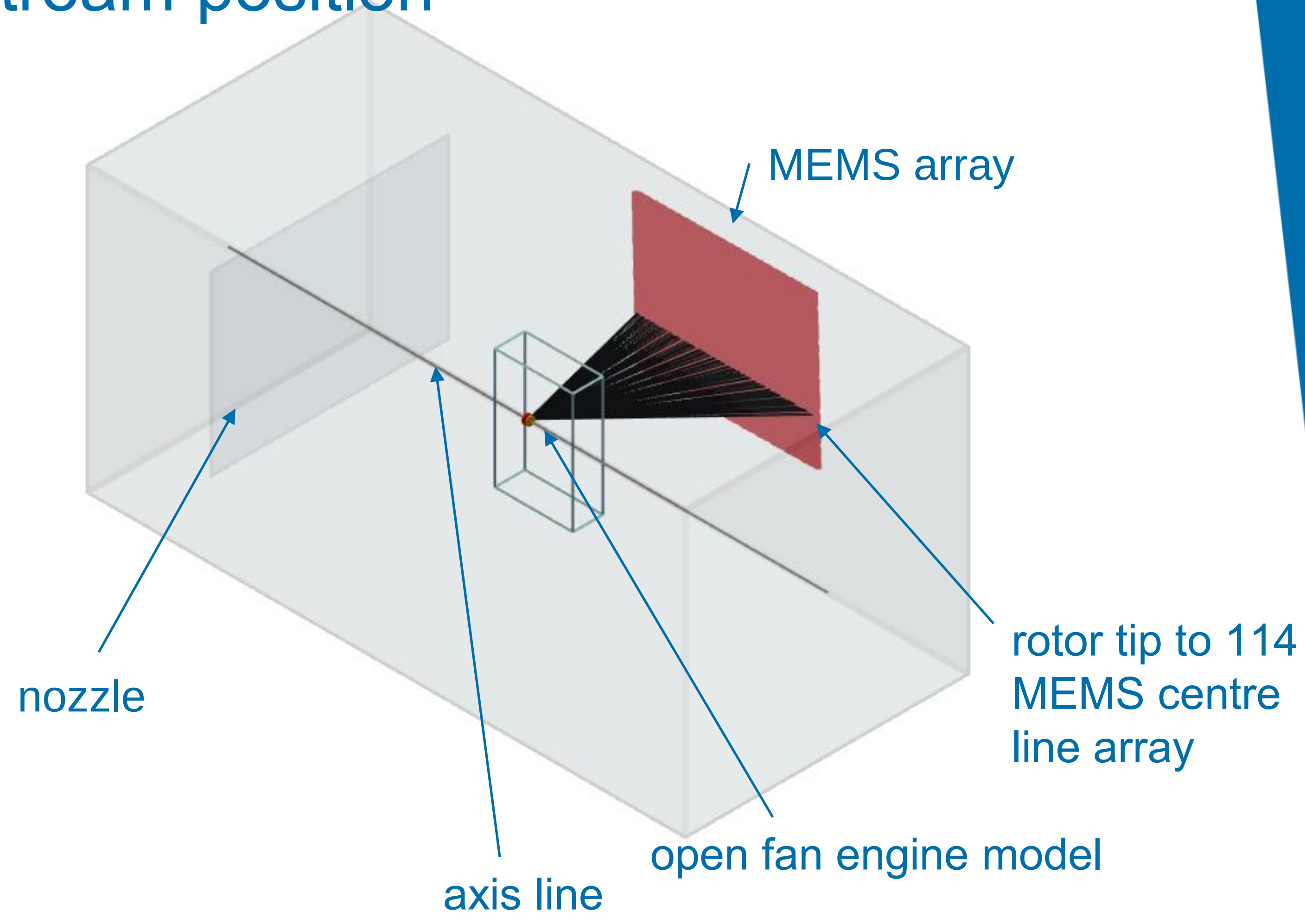
DNW LLF test section

- MEMS Array in second downstream position shifted by x = 4.10 m



Sub-array for the SODIX analysis



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Flight test preparation

- Set up of a common flight test platform for flight tests of advanced propulsion systems:
- using an A380 aircraft for tests with
  - hybrid electric turbofan engines with an ultra-high bypass ratio (UHBR)
  - open fan engines
  - using
    - PIV,
    - microphone arrays

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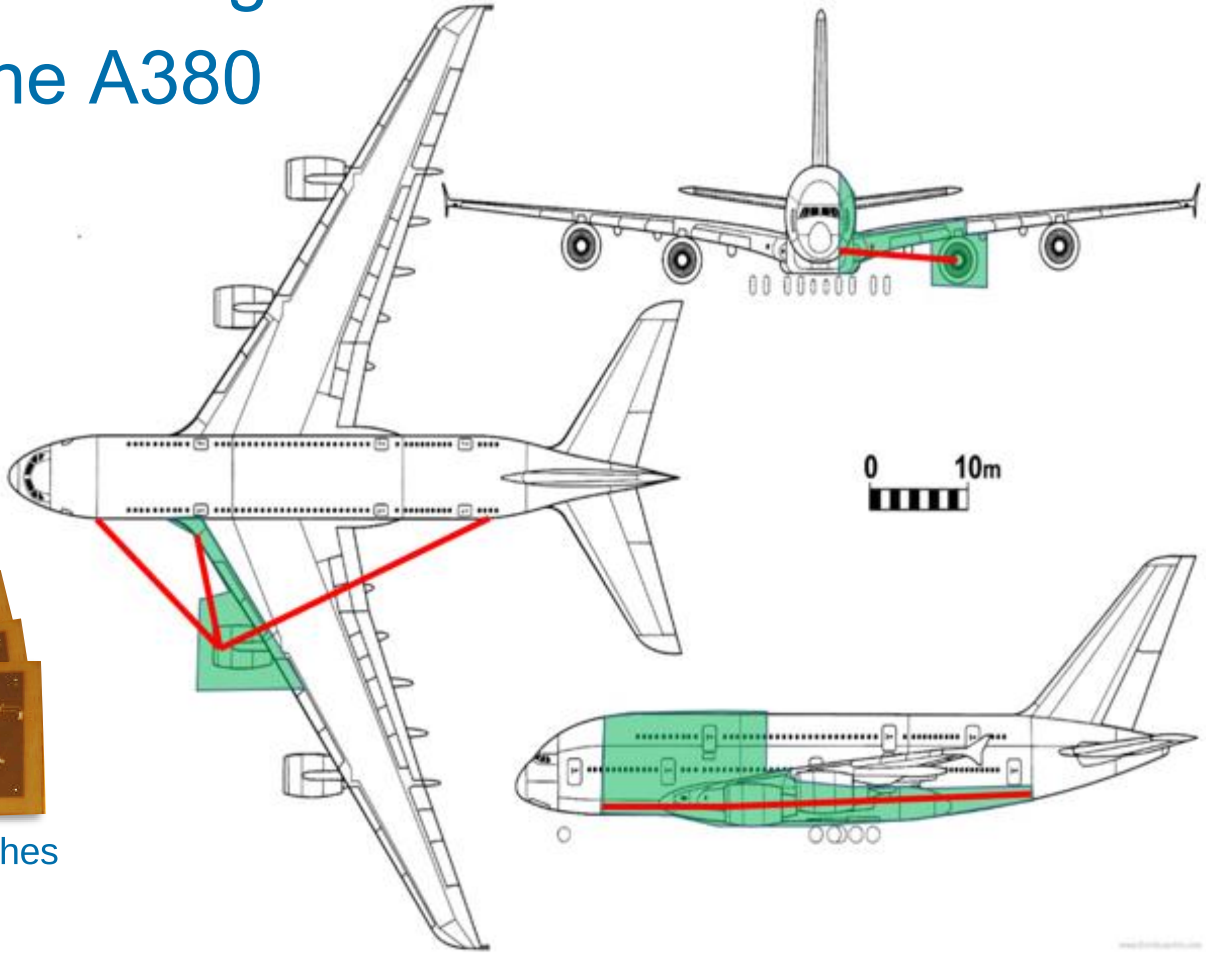
In-flight source localisation

- Localise and analyse sound sources in flight
- MEMS Arrays on the fuselage of the A380
- work share:
  - data acquisiton and preparation, including boundary layer noise removal by DLR AS-EXV
  - source localisation using SODIX by DLR AT-TRA

flexible MEMS patches
by DLR AS-EXV



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Conclusions

- Source localisation:
  - microphone arrays and beamforming techniques
  - SODIX method for the analysis of directive sources –
    source maps and far-field extrapolation of full sound field and components
- challenges for aircraft engines:
  - directive sound sources
  - broadband and tonal sources (incoherent, coherent, partially coherent)
- static measurements
  - open rotor model test in the DNW-LLF
- in-flight measurements
  - A380 test platform with MEMS array on the fuselage
  - preparation for open rotor and UHBR engine tests

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Acknowledgements

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Literature on beamforming and SODIX

Short selection:

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- Ulf Michel and Stefan Funke: *Inverse method for the acoustic source analysis of an aeroengine.* 2nd Berlin Beamforming Conference, 19-20 February 2008, Berlin, 2008.
- Stefan Funke: *Ein Mikrofonarray-Verfahren zur Untersuchung der Schallabstrahlung von Turbofantriebwerken.* Dissertation, TU Berlin, 2017.
- Siller, König, Funke, Oertwig and Hritsevskyy: *Acoustic source localization on a model engine jet with different nozzle configurations and wing installation.* International Journal of Aeroacoustics, 16 (4-5), 2017
- Sebastian Oertwig: *Erweiterung eines Quelllokalisierungsverfahrens zur Untersuchung der gerichteten Schallabstrahlung von Flugtriebwerken für breitbandige und tonale Schallquellen.* Dissertation, TU Berlin, 2024.