CABIN ACOUSTICS IN AIRCRAFT RESEARCH

Joint Research Activities of HAW Hamburg and Airbus in Aircraft Cabin Acoustics

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Hamburg Aerospace Lecture Series
April 4th, 2019

https://doi.org/10.5281/zenodo.5588928

HAW HAMBURG

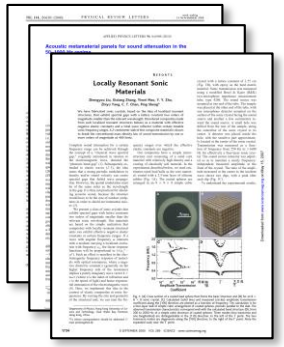
TECHNOLOGY DEVELOPMENT

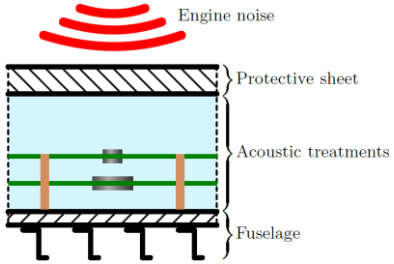
Industrialization

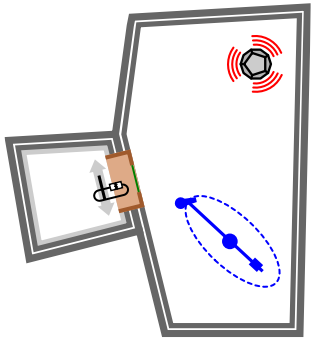
Applied research

Fundamental research

TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Physical principles identified	*Technology concept formulated*	*Proof-of-concept*	*Validation in laboratory*	*Validation in realistic einvironment*	*Technical feasibility demonstrated*	*Flight tests*	*First integration in production*	*Technology is flight-proven*







Source: airbus.com

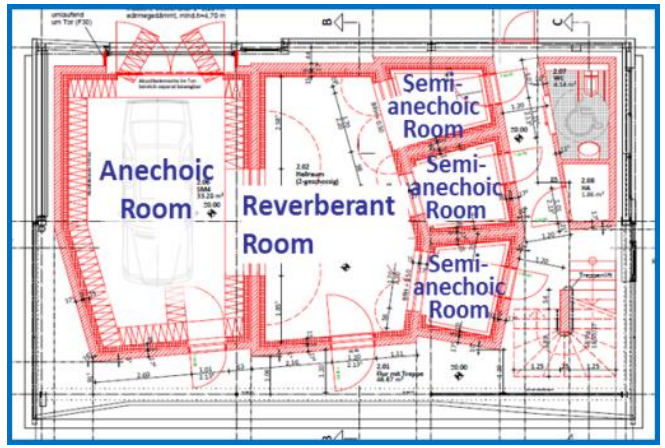
Source: airbus.com

Scope of HAW Hamburg aircraft cabin acoustics research activities

AIRCRAFT CABIN ACOUSTICS RESEARCH FACILITIES AT HAW HAMBURG

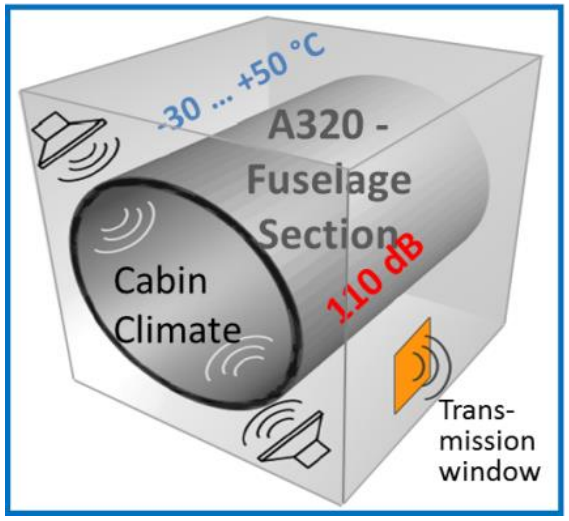
Acoustic laboratory (TRL* 1-4)

*"**TRL – Technology Readiness Level"** (NASA Definition)



Climate & Acoustics Chamber (TRL 3-4)

(in cabin & cabin systems laboratory)



FlightLab-Demonstrator (TRL 4-6)

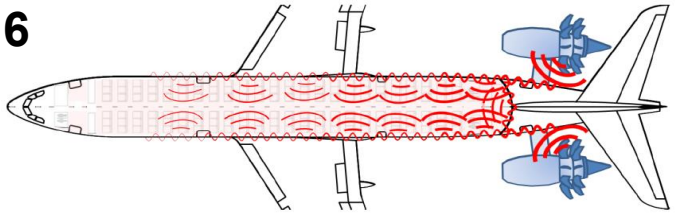
(w/ Airbus in ZAL – Center of Applied Aeronautical Research)

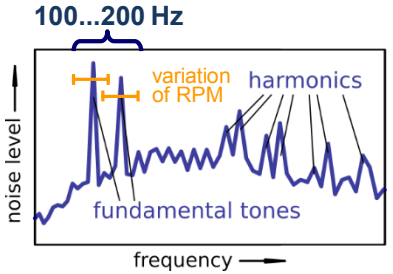
RECENT HAW RESEARCH PROJECTS

COCLEA
comfortable cabin for low emission aircraft

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Project COCLEA: 2012-2016



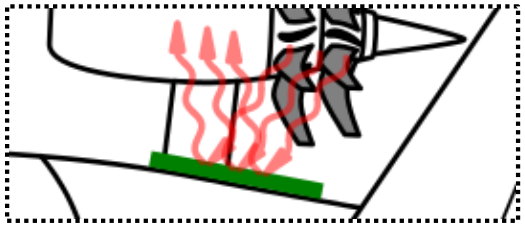


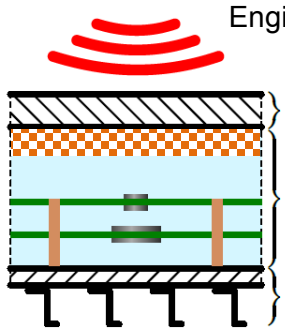
Project partners:

AIRBUS
AIRBUS GROUP INNOVATIONS
Fraunhofer IAP
HAW HAMBURG
TUHH
Hamburg University of Technology

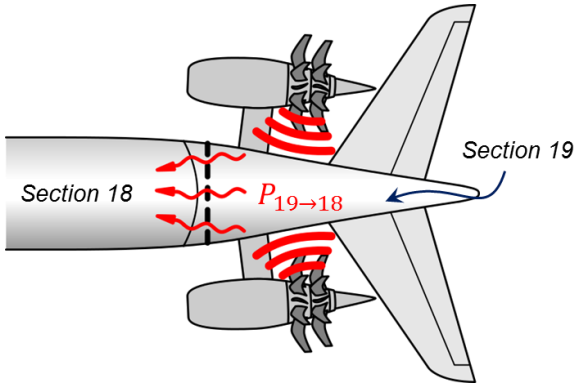
Activities:

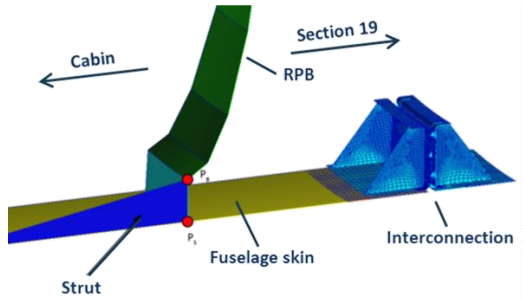
- Concept studies for a reduction of noise transmission into passenger cabins of aircraft types powered with **open rotor engines**





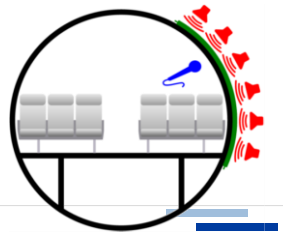
Fuselage noise shield with integrated metamaterials





Dynamically decoupled section interconnection

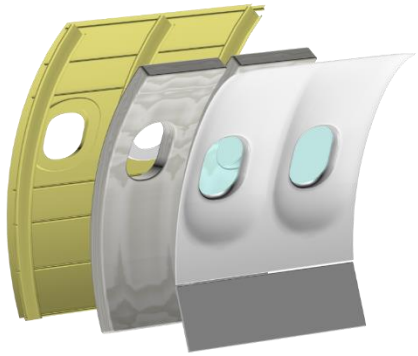
- Design, build, and operate a **vibro-acoustic fuselage test bench** (with Airbus)



RECENT HAW RESEARCH PROJECTS

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Project Flight-LAB: 2016-2019



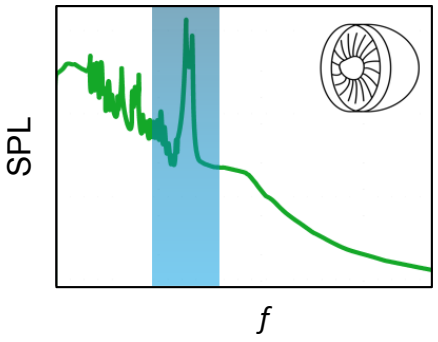
Flight-LAB

Project partners:

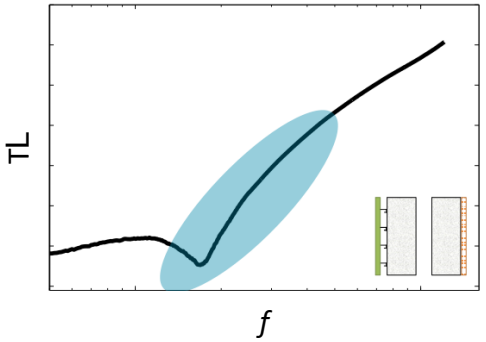
AIRBUS, DLR, HAW HAMBURG, Novicos, TUHH Hamburg University of Technology, ZAL

Activities:

- Concepts studies for new noise reduction means
- Design of improved light weight sound insulation for low frequency broadband and tonal sound excitation.

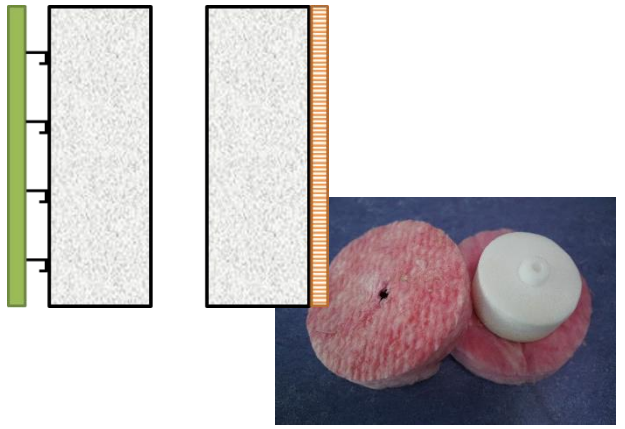


Sound pressure level of future aircraft engines

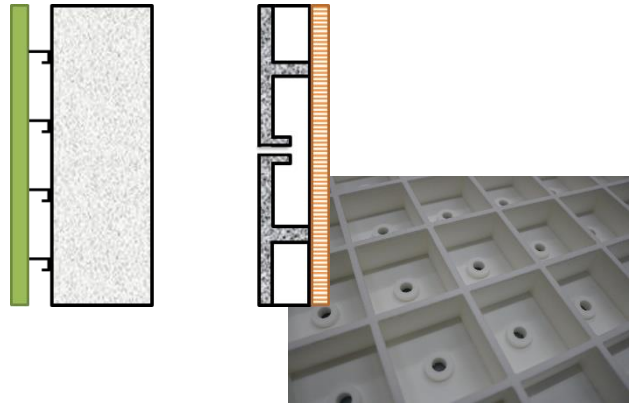


Sound transmission loss of aircraft cabin wall

Approach for new noise reduction means:



Resonators: embedded in to the insulation



Resonators: connected to cabin lining

RECENT HAW RESEARCH PROJECTS

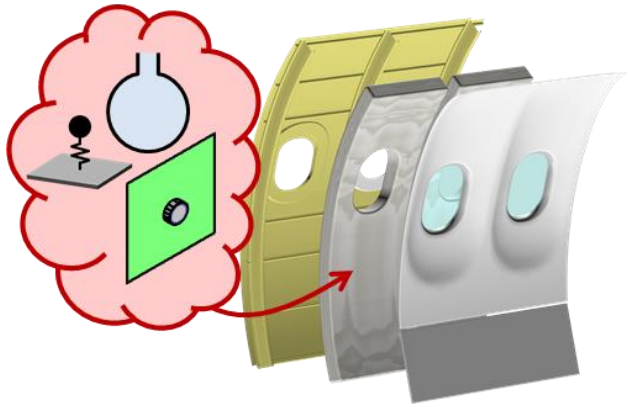
New Acoustic Insulation Meta-Material Technology for Aerospace

SPONSORED BY THE
Federal Ministry of Education and Research

Project NAIMMTA: 2017-2020

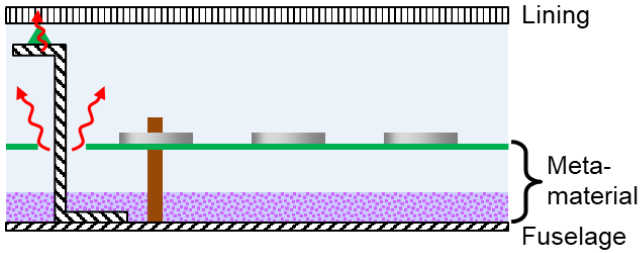
Activities:

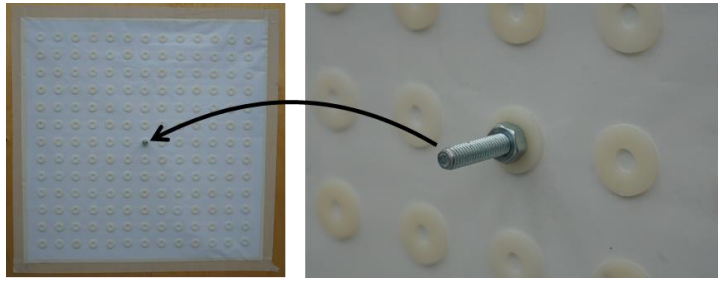
- Integration of thermo-acoustic insulation packages with **integrated acoustic metamaterials** for improved low-frequency sound insulation in the aircraft side wall
- Technology development with industrial partners to **at least TRL 5**



Project partners:

3M, AIRBUS, ÉTS Le génie pour l'industrie, HAW HAMBURG, HUTCHINSON, Mecanum, Canada NRC·CNRC, Université de Sherbrooke, ZAL





Integration of metamaterial blankets in aircraft side wall

Source: hutchinson-aero-cabin.com

Thermal properties of metamaterial blankets

RECENT HAW RESEARCH PROJECTS

Project KOKAGEL: 2018-2020

Activities:

- Concepts studies for a new cabin wall insulation with aerogel materials for commercial aircraft

Requirements:

- Reduction of (especially low frequency) engine noise transmission
- Increasing of atmospheric humidity in the cabin, without having the risk of condensation or icing in the cabin wall
- Low weight, high fire retardancy, hydrophobic, recyclability, easy to install …

Concepts:

- Use of Aerogel materials (99,9 % porosity, light, non-inflammable)
- Removal of humidity via an air channel in the wall
- Combination of fiberglass & Aerogel
- etc

Konzeptstudien für eine neue Kabinenwandisolation mit Komponenten aus Aerogelmaterialien für Verkehrsflugzeuge

Supported by:

Federal Ministry for Economic Affairs and Energy

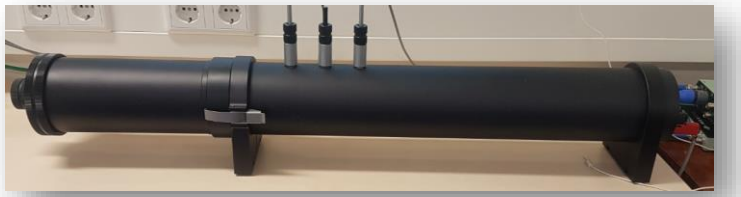
on the basis of a decision by the German Bundestag

Project partners:

DLR Deutsches Zentrum für Luft- und Raumfahrt

HAW HAMBURG

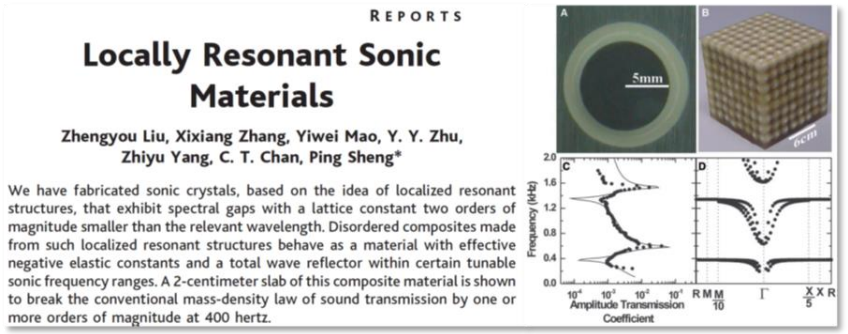
Novicos



RESEARCH EXAMPLE: NOISE SHIELD WITH ACOUSTIC METAMATERIALS

HAW HAMBURG

BRIEF INTRODUCTION TO ACOUSTIC METAMATERIALS



REPORTS

Locally Resonant Sonic Materials

Zhengyou Liu, Xixiang Zhang, Yiwei Mao, Y. Y. Zhu, Zhiyu Yang, C. T. Chan, Ping Sheng*

We have fabricated sonic crystals, based on the idea of localized resonant structures, that exhibit spectral gaps with a lattice constant two orders of magnitude smaller than the relevant wavelength. Disordered composites made from such localized resonant structures behave as a material with effective negative elastic constants and a total wave reflector within certain tunable sonic frequency ranges. A 2-centimeter slab of this composite material is shown to break the conventional mass-density law of sound transmission by one or more orders of magnitude at 400 hertz.

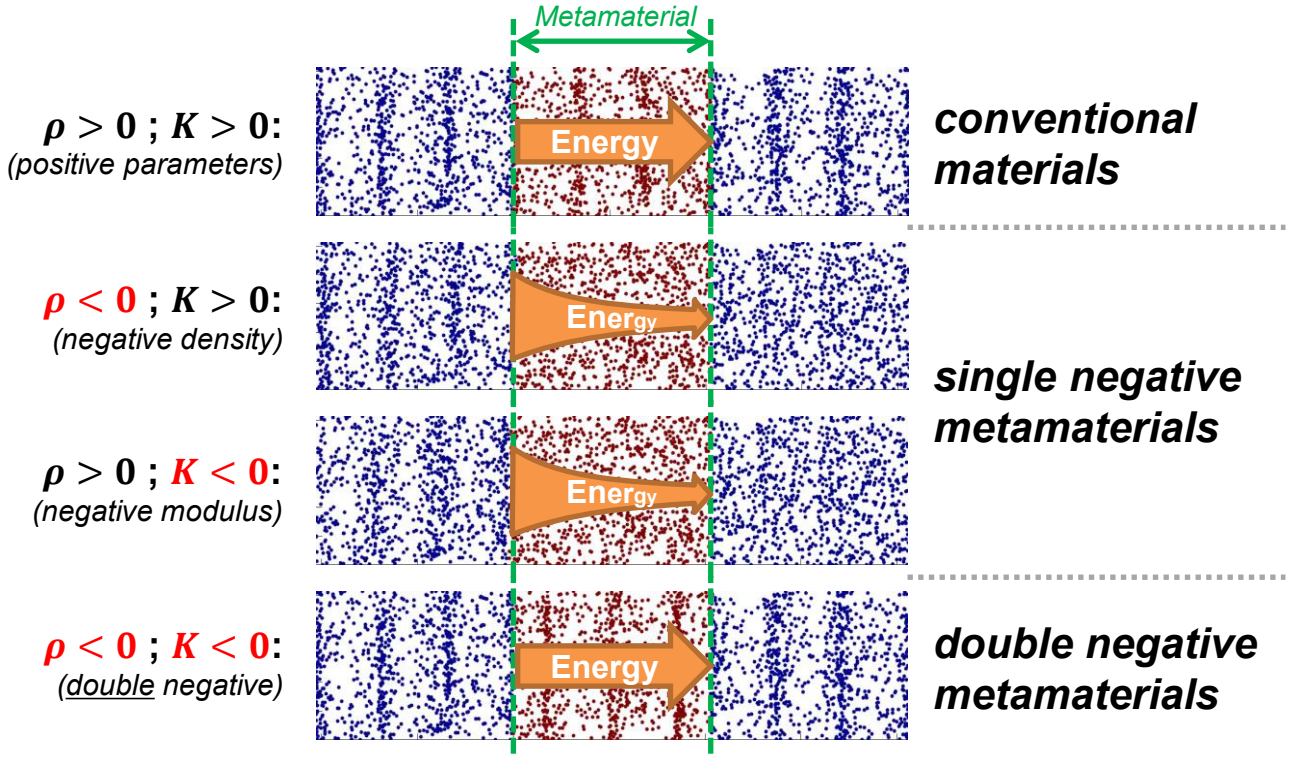
8 SEPTEMBER 2000 VOL 289 SCIENCE www.sciencemag.org

Possible definition of an acoustic metamaterial:

Composite structure composed of periodically arranged unit cells for the systematic manipulation of the effective material parameters for sound waves

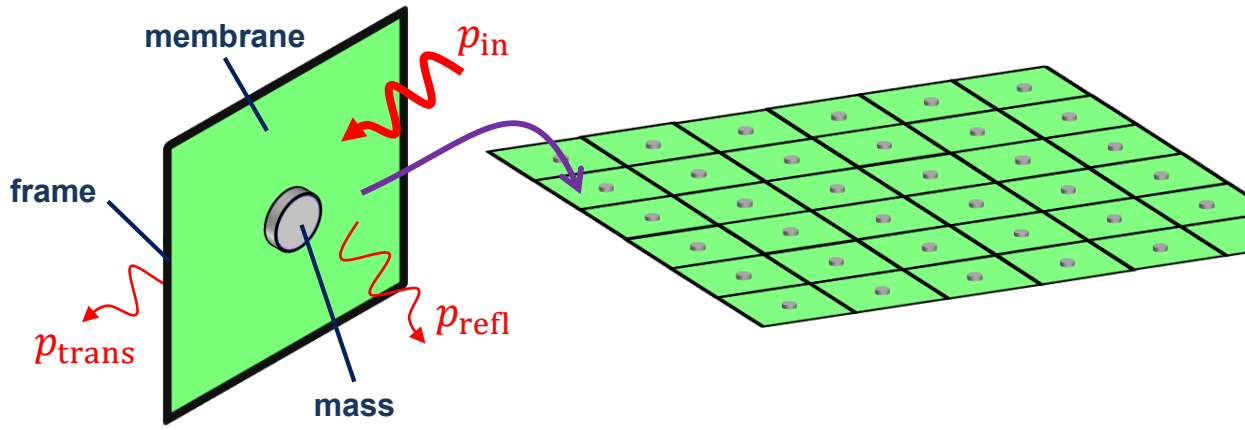
Acoustic material parameters:

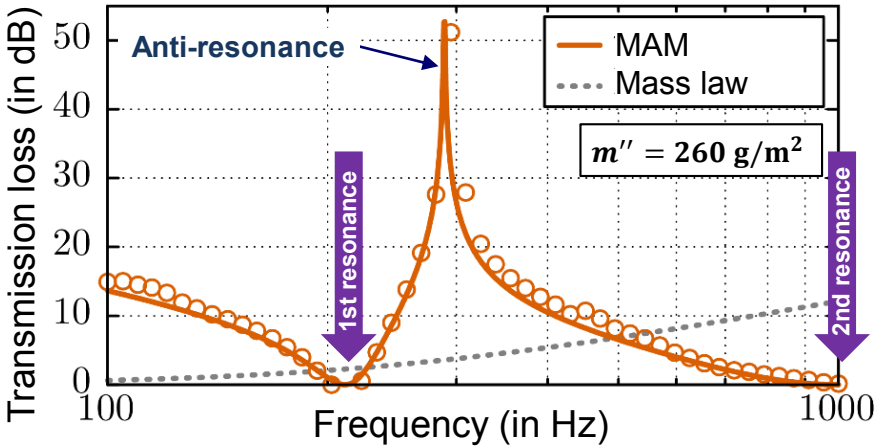
	Air	Water	
Density ρ *Inertia of fluid*	1.2	1000	kg/m³
Bulk modulus K *Stiffness of fluid*	142	2.2×10^6	kPa
$c = \sqrt{K/\rho}$ *Speed of sound*	342	1480	m/s
$Z = \sqrt{K\rho}$ *Impedance*	410	1.5×10^6	Pa s/m

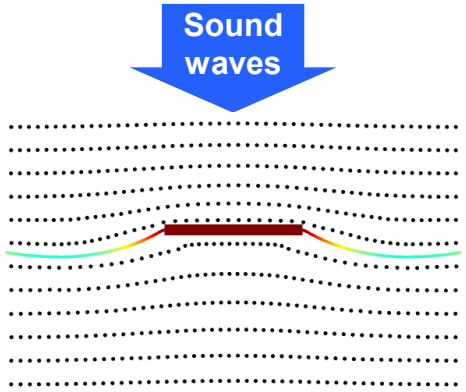


MEMBRANE-TYPE ACOUSTIC METAMATERIALS (MAM)

- *Z. Yang et al., Phys Rev. Lett. 101, 204301, 2008*
- Negative-density acoustic metamaterial
- **Lightweight** (≲ 1 kg/m²) and **thin** (≲ 2 mm)
- Still **high low-frequency sound reduction** (≲1 kHz)







TRL 1: basic principles observed

Anti-resonance:
- Membrane and mass out-of-phase
- Surface averaged displacement approx. 0

→ **High sound reduction!**

Can MAMs be used in aircraft to reduce low-frequency engine noise in the cabin?

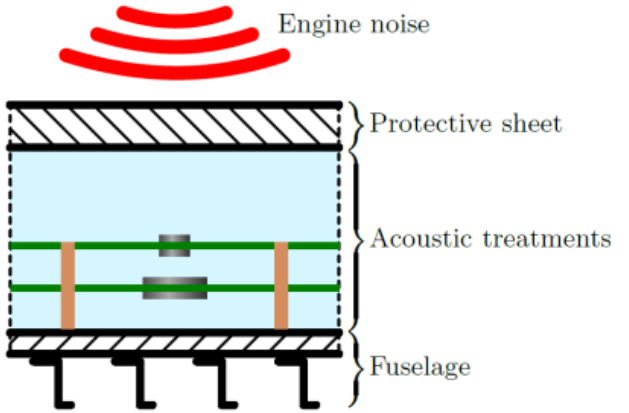
NOISE SHIELD WITH INTEGRATED MAMS

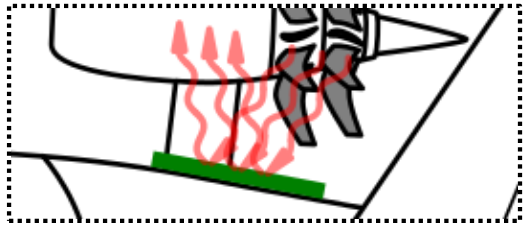
COCLEA comfortable cabin for low emission aircraft
Gefördert durch: Bundesministerium für Wirtschaft und Technologie aufgrund eines Beschlusses des Deutschen Bundestages

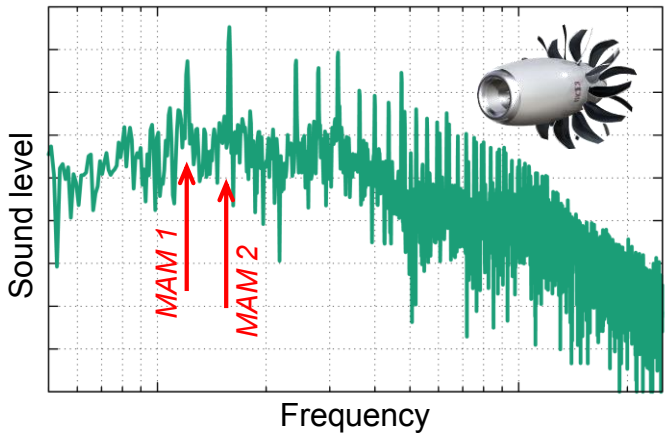
TRL 2: technology concept formulated

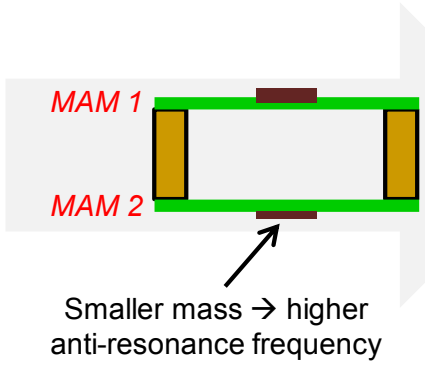
Multi-layered structure on aircraft:

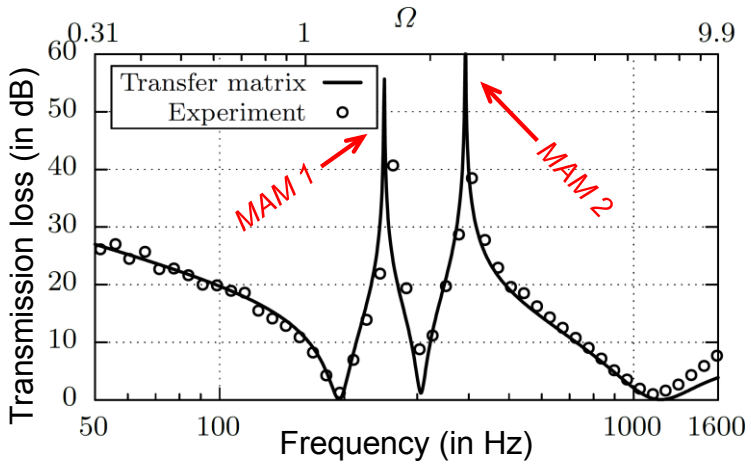
1) **Fuselage** ensures structural integrity
2) **Acoustic treatments** efficiently reduce low-frequency tonal noise
3) **Protective sheet** against ice fragments from engines, athmospheric conditions, and aerodynamic flow





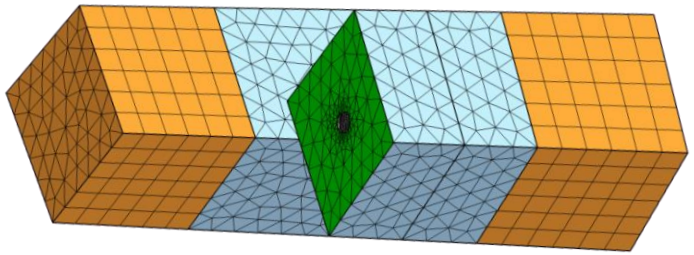


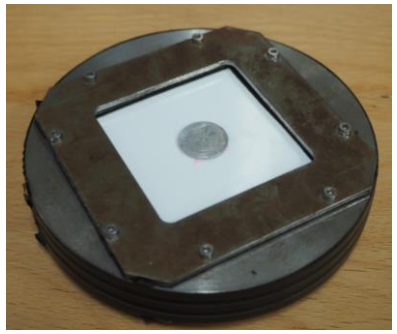




NOISE SHIELD WITH INTEGRATED MAMS

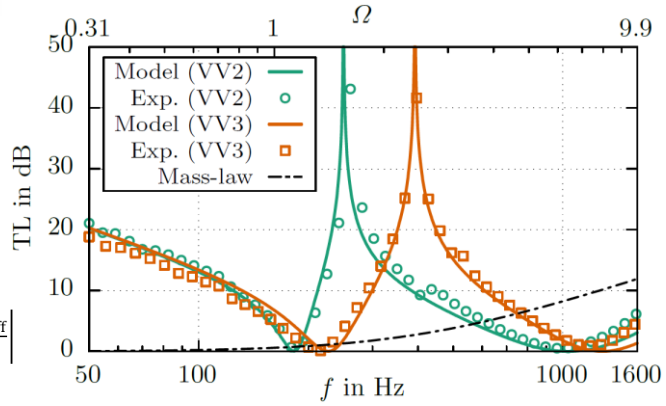
TRL 3: analytical and experimental proof-of-concept



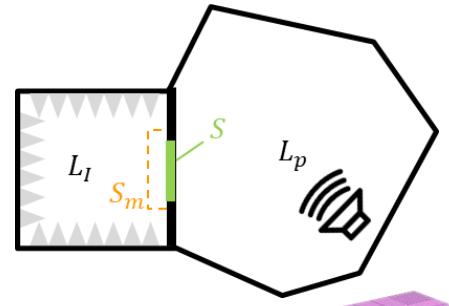


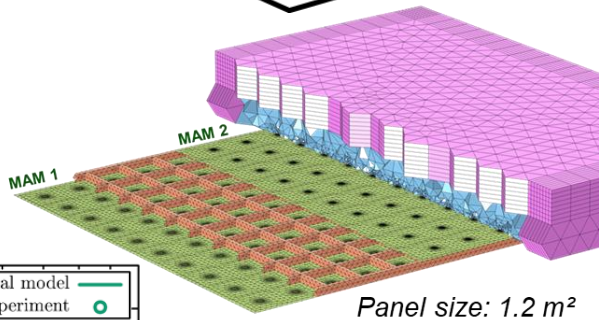
$$\begin{bmatrix} \mathbf{C}-\omega^2\mathbf{M} & \mathbf{0} & -\mathbf{L} \\ \mathbf{0} & -\omega^2\mathbf{M}_\mathrm{M} & \mathbf{Q} \\ -\mathbf{L}^\mathrm{T} & \mathbf{Q}^\mathrm{T} & \mathbf{0} \end{bmatrix} \begin{pmatrix} \mathbf{w} \\ \mathbf{w}_\mathrm{M} \\ \mathbf{f}_\mathrm{M} \end{pmatrix} = 2P_\mathrm{in} \begin{pmatrix} \mathbf{b} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}$$

$$\rightarrow\ m''_\mathrm{eff} = \frac{\langle P_\mathrm{in}\rangle}{-\omega^2\langle w\rangle} = \frac{P_\mathrm{in}}{\mathbf{b}^\mathrm{T}\mathbf{w}} \rightarrow\ \mathrm{TL} = 20\lg\left|1+\frac{\mathrm{i}\omega m''_\mathrm{eff}}{2Z_0}\right|$$

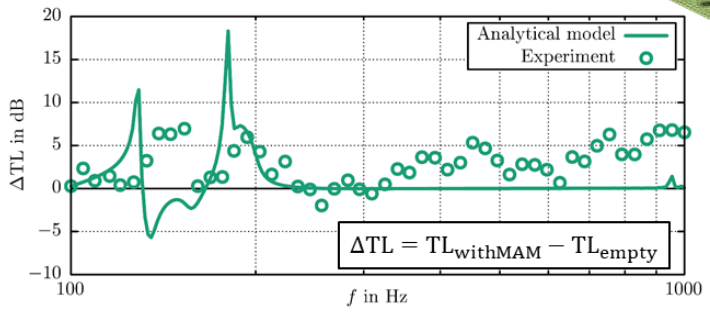


TRL 4: validation in laboratory environment





Panel size: 1.2 m²

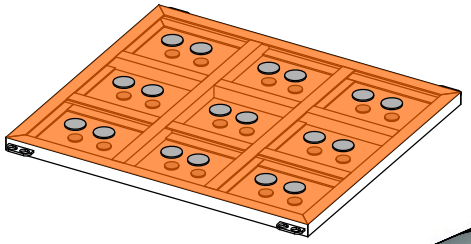


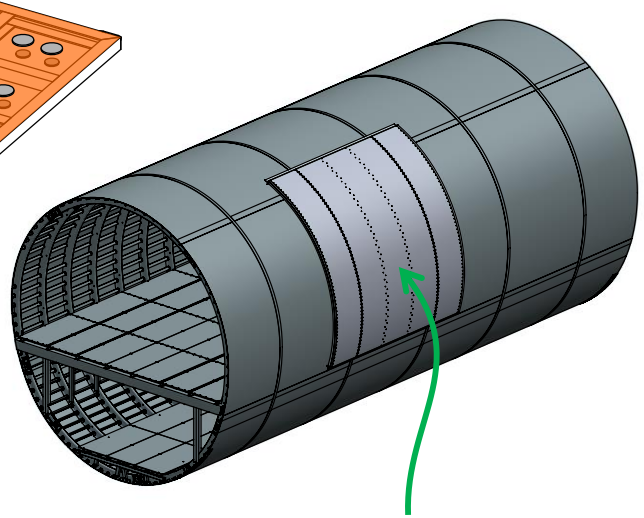
Analytical, numerical and experimental investigation of unit cells

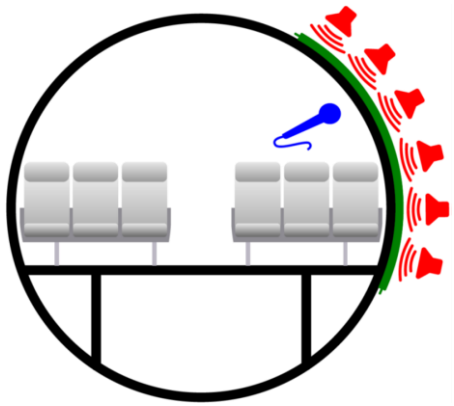
Numerical and experimental investigation of large-scale panels

NOISE SHIELD WITH INTEGRATED MAMS

TRL 5: validation in relevant environment

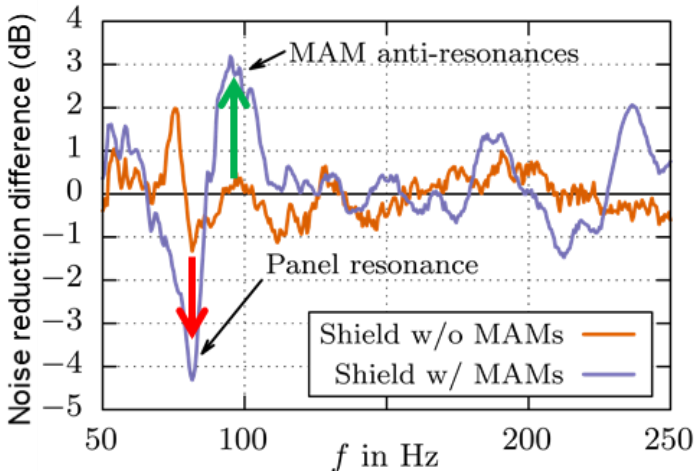


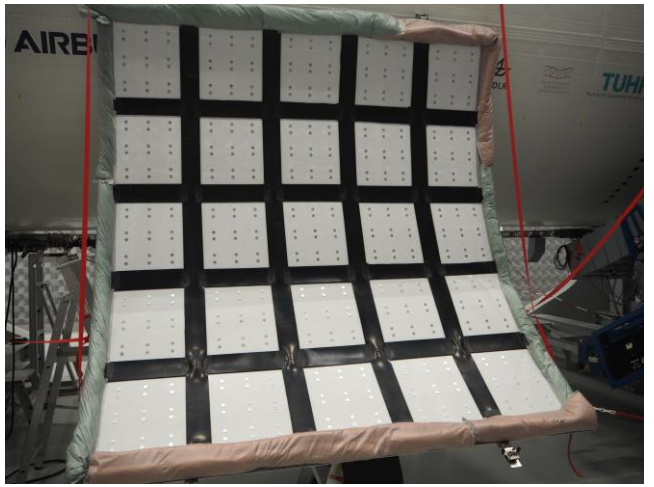




Preliminary experimental study:

- ~8 m² panel with 225 MAM unit cells
- Excitation with loudspeaker array
- Average cabin SPL measured @ 645 pos.
- First results: MAM anti-resonance identified @ 100 Hz, but only +3 dB improvement due to **flanking sound paths** around the noise shield!





Further experiments with minimized flanking sound paths are planned to reach TRL 5

SUMMARY

Aircraft cabin acoustics research at HAW

- Multi-disciplinary acoustic test facilities
- Sound insulation technologies in aircraft are subject to many non-acoustic requirements
- Technology research from TRL 1 to TRL 6
- Several research projects in close cooperation with Airbus

Acoustic metamaterials for aircraft cabin sound insulation

- Membrane-type acoustic metamaterials promising for aircraft applications
- Characterization in small-scale and large-scale test setups
- TRL 5 validation of noise shield concept planned on optimized Flight-LAB test setup

THANK YOU FOR YOUR ATTENTION!

The financial support of the following sponsors is greatly appreciated:

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

AIRBUS

SPONSORED BY THE

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HAW HAMBURG