NACELLES

ACOUSTIC METAMATERIALS FOR AERONAUTIC INDUSTRY

genierie
2017

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Safran Nacelles

SAFRAN

AGENDA

Safran and Safran Nacelles

Acoustic treatments for nacelles

Challenges for next engine generation

Metamaterials for nacelles

Passive metamaterial

Adaptive metamaterial

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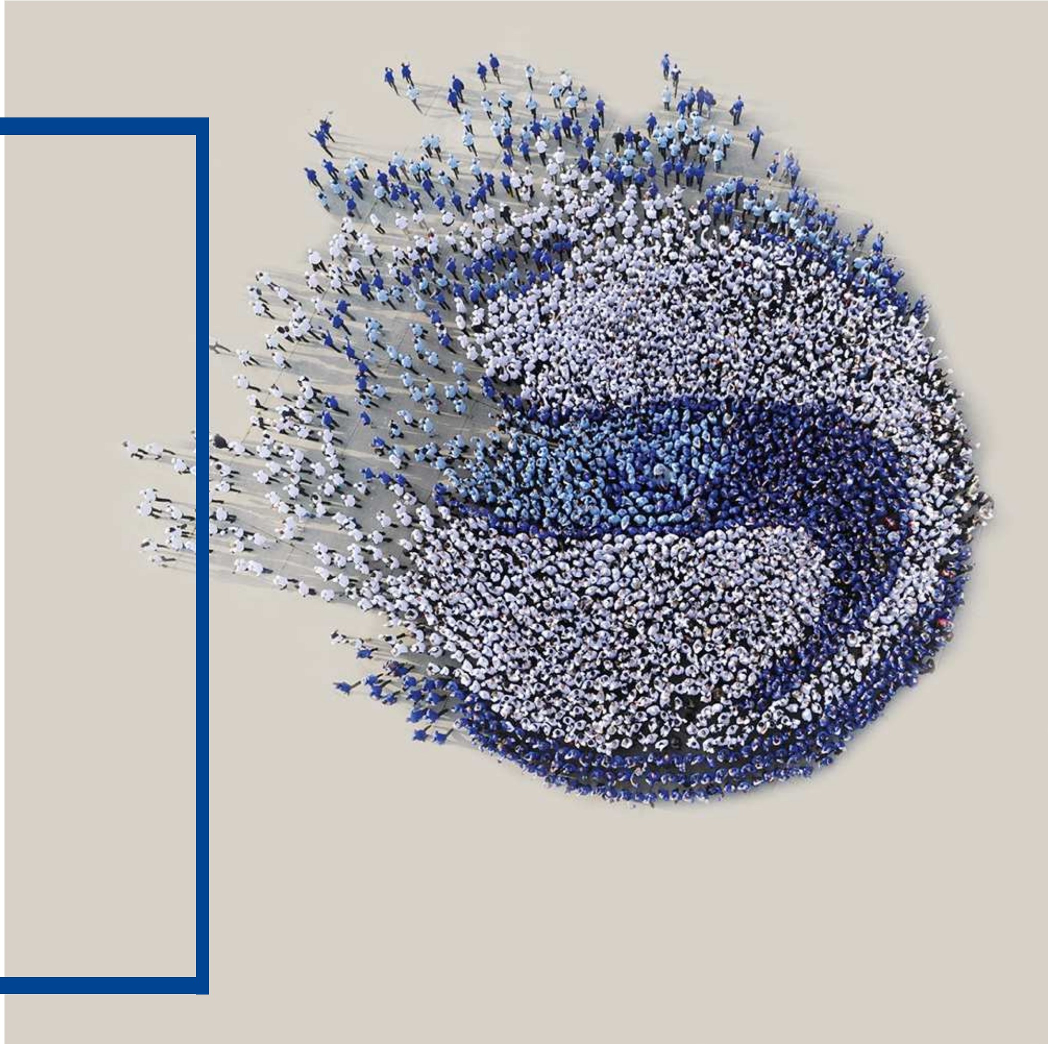
SAFRAN AND SAFRAN NACELLES

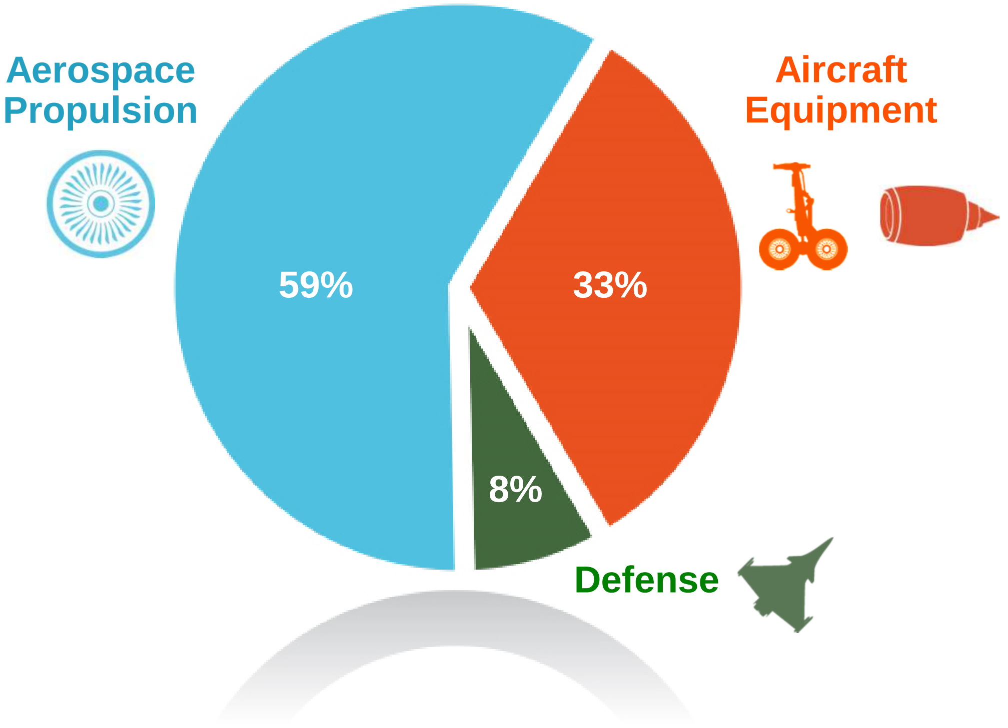


SAFRAN AT A GLANCE

3 CORE BUSINESSES: Aviation, Space & Defense

Nearly 58,000 EMPLOYEES in nearly 30 COUNTRIES

€15.8 BILLION in sales



SAFRAN NACELLES

Main activities

Design & development

Manufacturing and aircraft integration

Services to operators

The nacelle functions

Aerodynamic: flow ducting

Braking: thrust reverser

Acoustic: engine noise reduction

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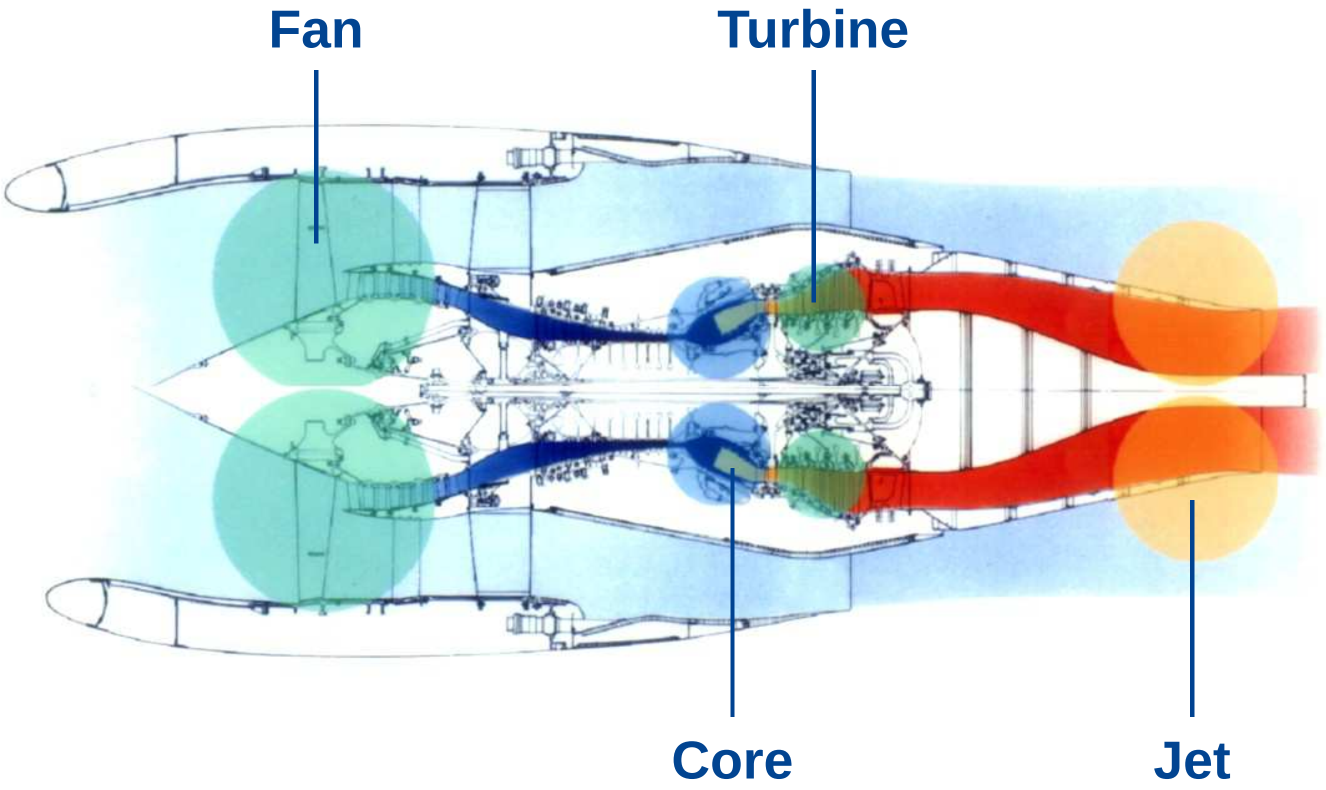
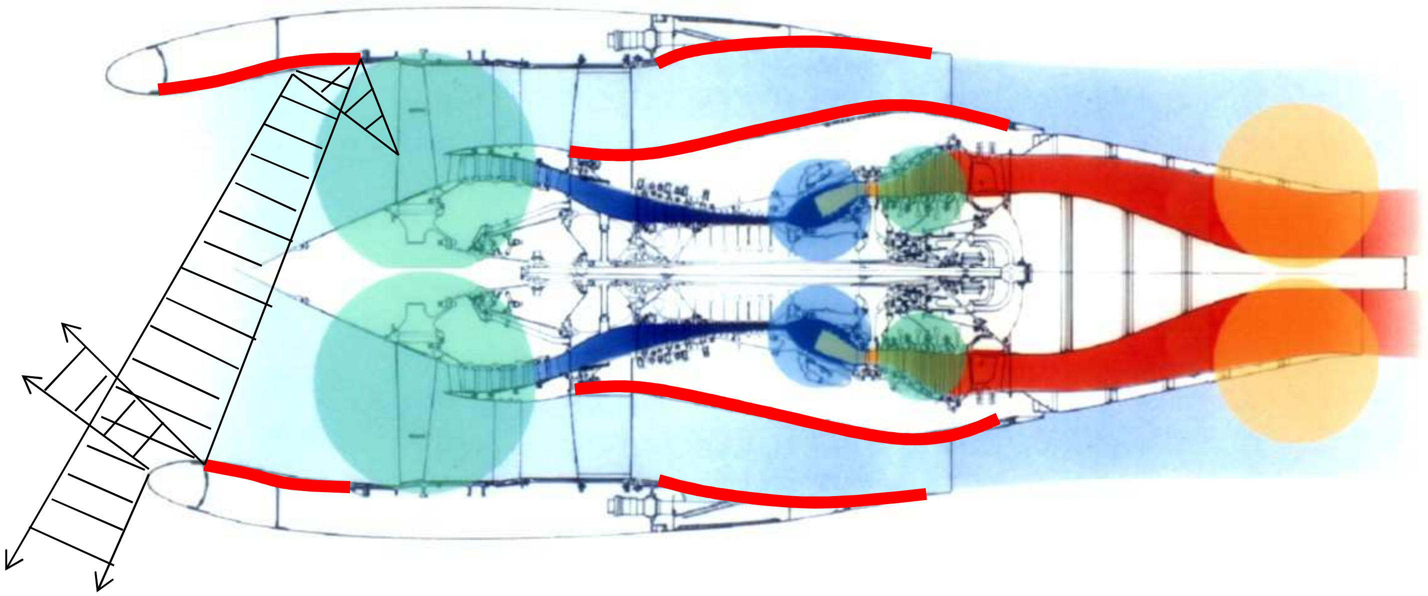
ACOUSTIC TREATMENTS FOR NACELLES

ENGINE MAIN NOISE SOURCES



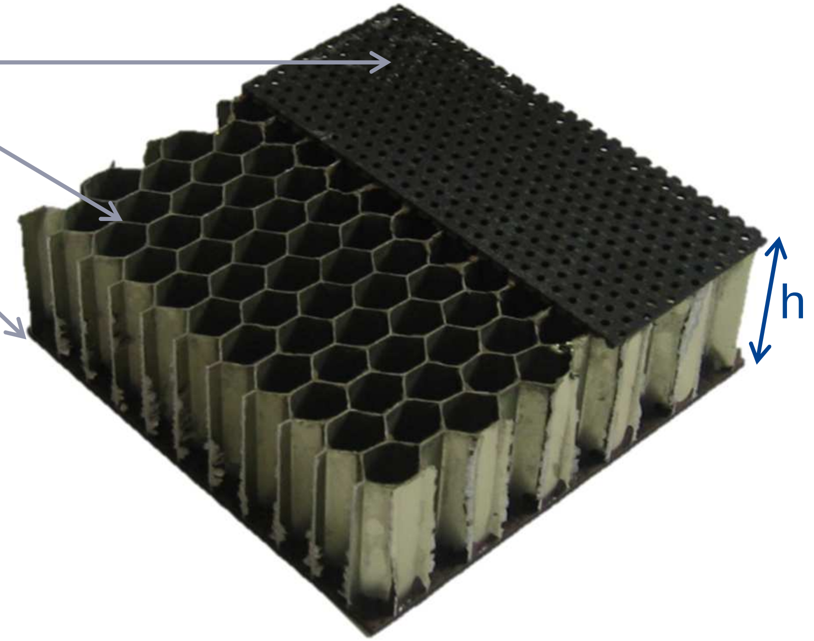
ACOUSTIC TREATMENTS LOCATION

Acoustic materials are integrated to nacelle walls to damp noise



CONVENTIONAL ACOUSTIC TREATMENT

Common acoustic treatments are made of:



A perforated face sheet

Cavities

An impervious back skin

The skin is optimized to maximize the noise absorption

The cavity height *h* is defined according to the target frequency

$$h \approx \frac{\lambda_{target}}{4},\ \lambda_{target} = \frac{c}{f_{target}}$$

This kind of treatment is usually characterized by its acoustic impedance *Z*

$$Z = R + iX$$

Resistance R $\sim \frac{1}{\text{Skin porosity}}$

Reactance $X \approx -\text{cotan}(kh)$

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CHALLENGES FOR NEXT ENGINE GENERATION

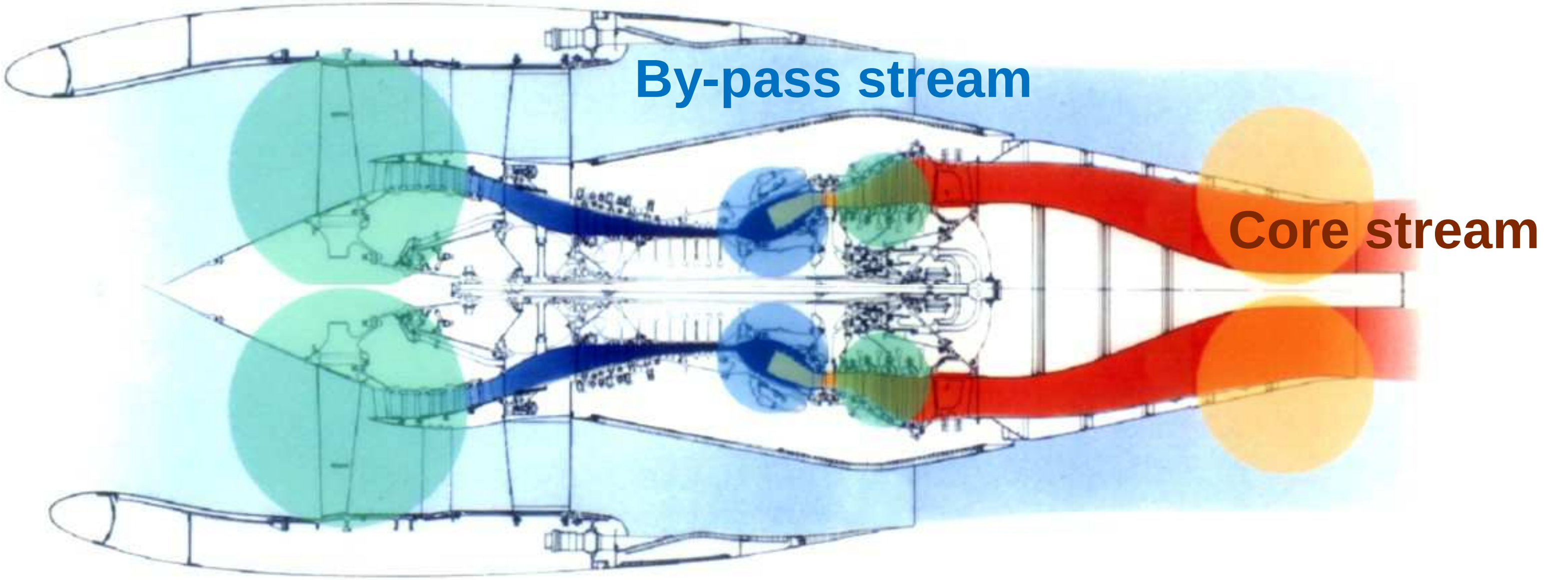
NEXT ENGINE GENERATION

To decrease fuel burn and environmental impact

- Engine by-pass ratio will going on increasing

$$\text{By}-\text{pass ratio} = \frac{\text{By}-\text{pass mass flow}}{\text{Core mass flow}}$$

- The nacelle will be slimmer and shorter (drag reduction)



NOISE IMPACT OF BY-PASS RATIO INCREASE

By-pass ratio increase

⬇

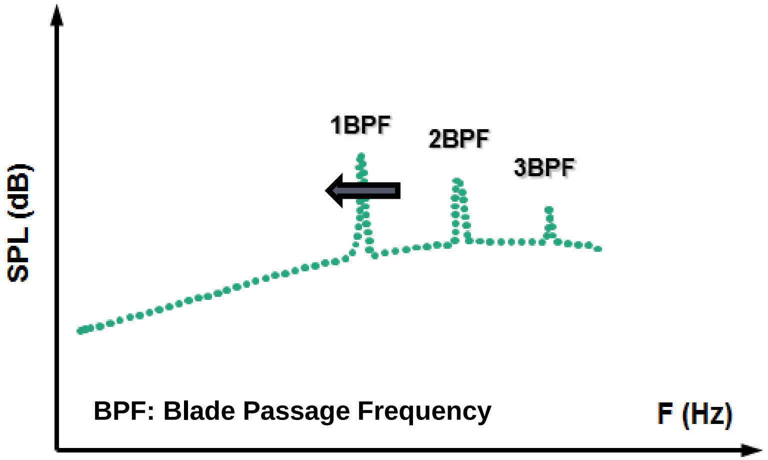
Larger fan

⬇

Lower fan rotation speed

⬇

Fan tones shift to lower frequencies



BPF: Blade Passage Frequency

Thicker acoustic treatments will thus be required. Available space is limited though…

Technologies to damp low frequency noise in limited space are thus needed

POTENTIAL OF METAMATERIALS

Metamaterials can be defined as periodic artificial materials including structuring on a scale smaller than the wavelength they influence

For aircraft engine, target frequencies are ~1kHz, i.e. λ_{target}~34cm

To efficiently damp this frequency range, conventional acoustic liners should be ~50mm to ~80mm thick

Two examples will be given in the following

- A passive material behaving as a conventional 50mm thick liner, but with a thickness of ~30mm ~ λ_{target} / 10
- An adaptive material composed of 25mm thick cells efficient below 1kHz, i.e. with a thickness < λ_{target} / 10

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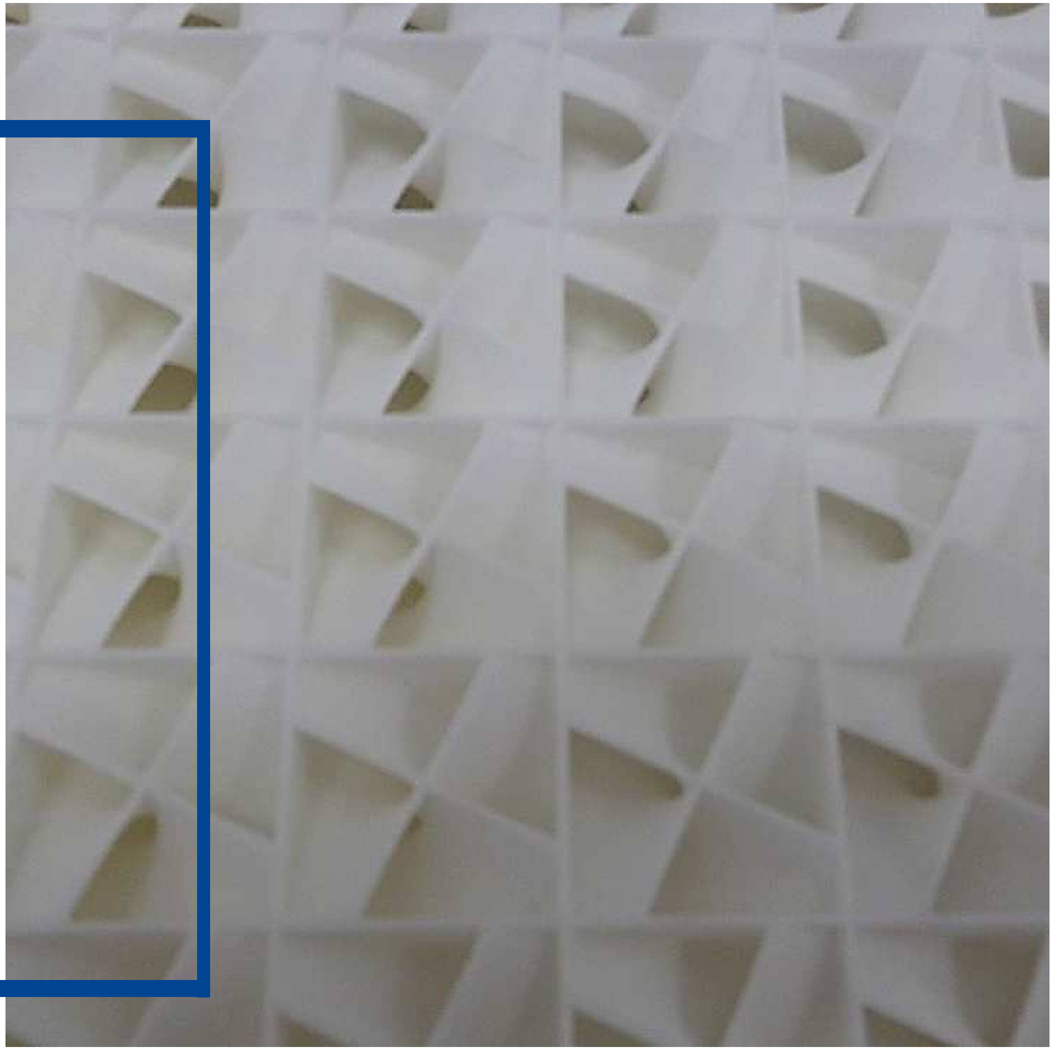
METAMATERIALS FOR NACELLES

EXAMPLE OF A PASSIVE SOLUTION



FOLDED CAVITY LINER CONCEPT

The folded cavity concept consists in designing a cavity shape, in which the acoustic length is higher than the core thickness

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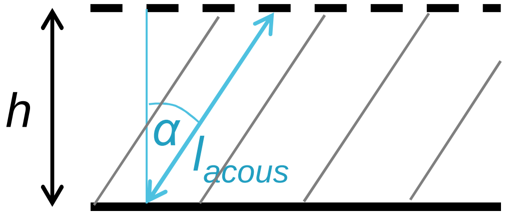
“Bowed” cavity



$$l_{acous} = \frac{h}{cos(\alpha)}$$

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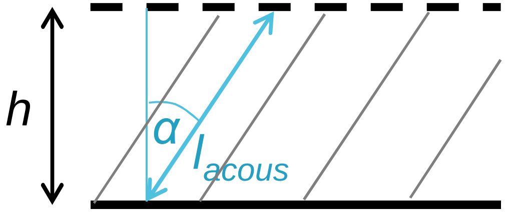
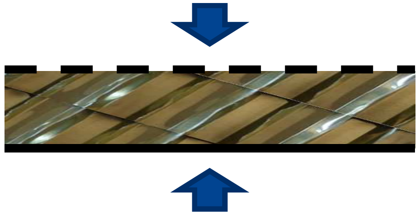


$$l_{acous} = \frac{h}{cos(\alpha)}$$

…but what about mechanical properties?



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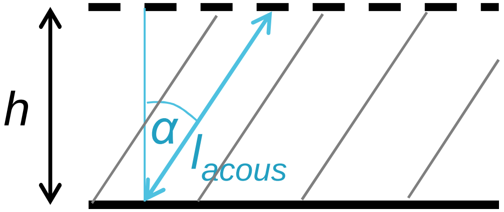

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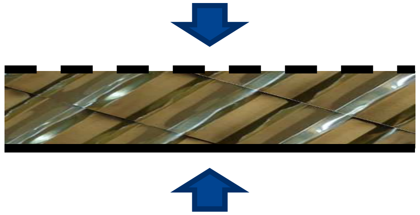
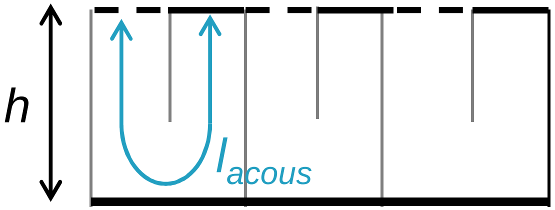


“U-shape” cavity



$$l_{acous} = 2h$$

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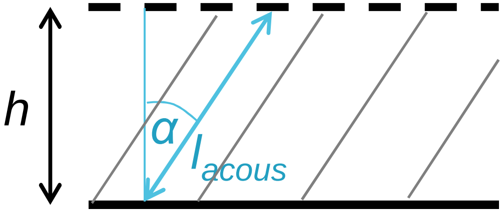

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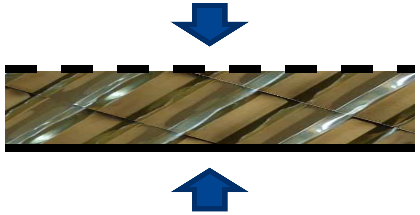

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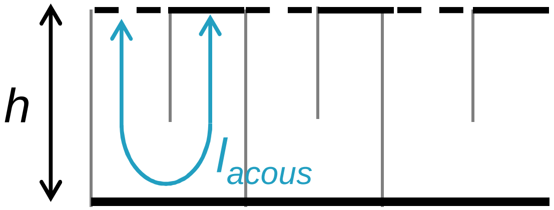

$$l_{acous} = 2h$$

…but acoustic area is divided by 2!

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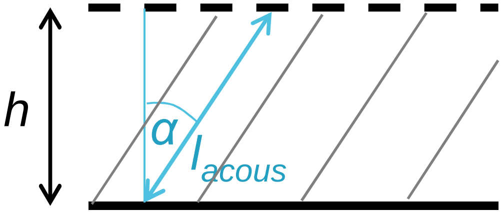

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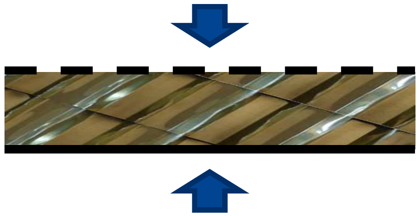
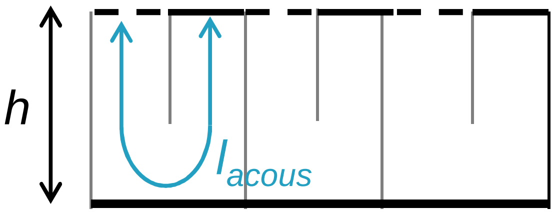


“U-shape” cavity



$$l_{acous} = 2h$$

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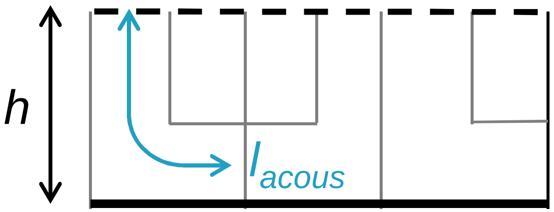
“L-shape” cavity



$$l_{acous} \approx 1.5h$$

FOLDED CAVITY LINER CONCEPT

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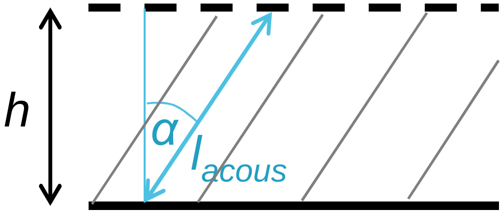
“Bowed” cavity



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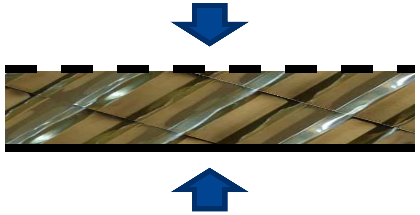
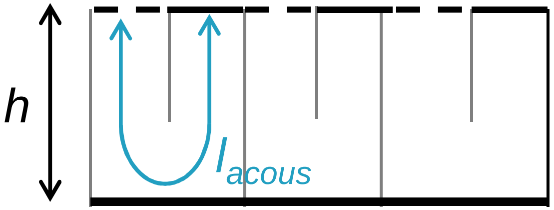


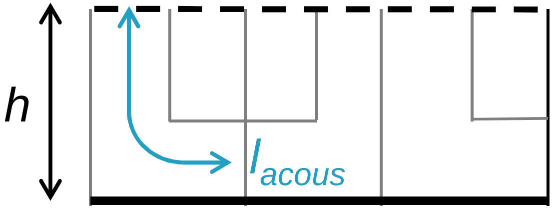
“U-shape” cavity



$$l_{acous} = 2h$$

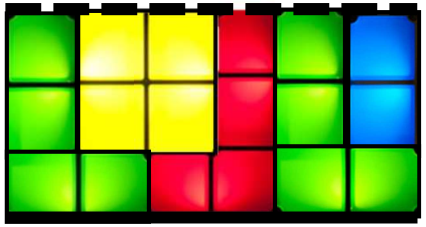
…but acoustic area is divided by 2!

“L-shape” cavity



$$l_{acous} \approx 1.5h$$

…but leads to a mixed acoustic impedance…



3D SPIRAL-SHAPED CAVITIES

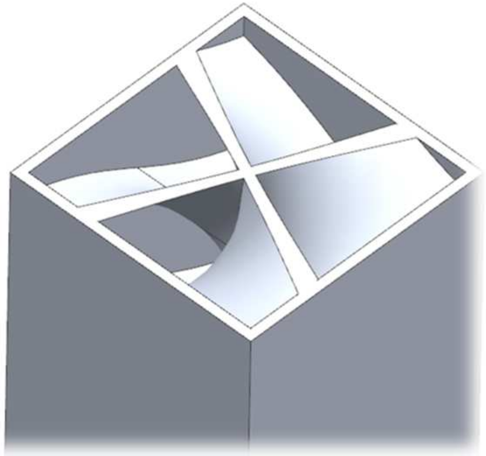
Objective: design a cavity shape with $l_{acous} \gg h$

Constraints:

- Keep correct mechanical resistance to compression
  - Cavity shape must include vertical foils
- No loss of acoustic area
  - Cavity shape must not turn back towards the acoustic skin
- Have an homogeneous acoustic impedance
  - Cavities must join together

The objective cannot be reached in respecting all the constraints with a 2D cavity shape

3D SPIRAL-SHAPED CAVITIES



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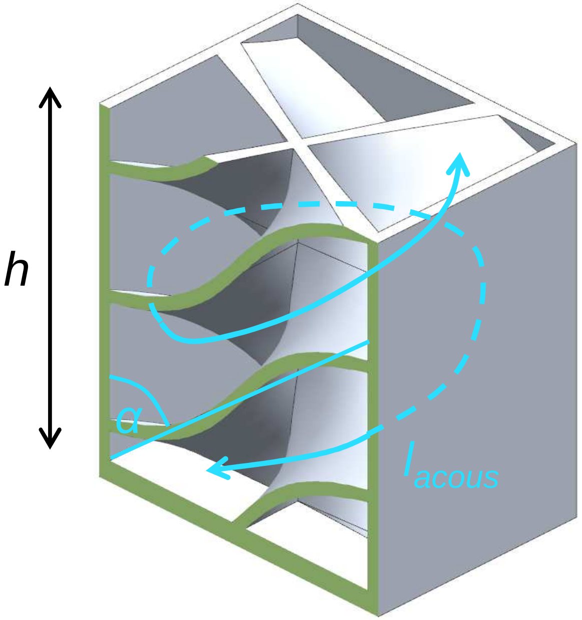
Acoustic length is expected to be close to:

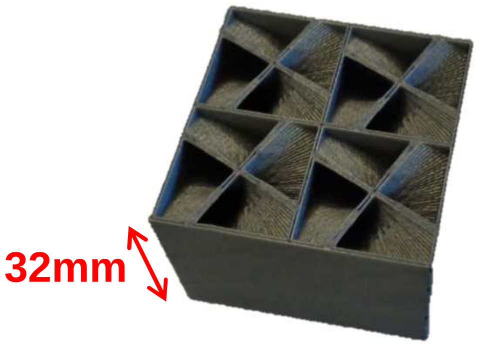
$$l_{acous} \approx \frac{h}{cos(\alpha)} \approx 50mm \text{ with } h = 32mm$$

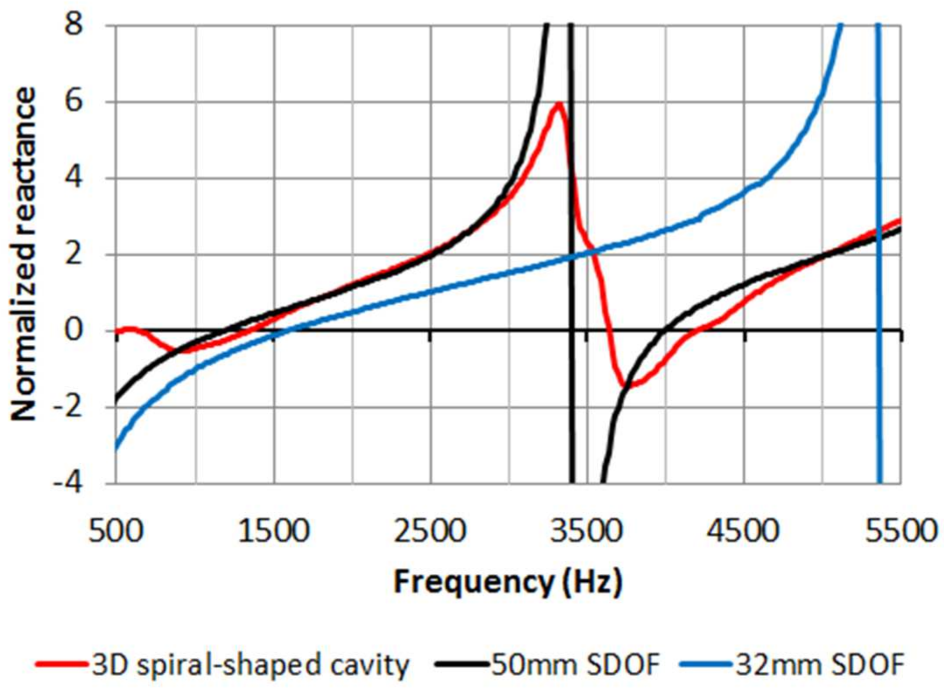


TEST RESULTS: IMPEDANCE MEASUREMENTS

For a SDOF liner, the reactance $X \approx -\textbf{cotan}(kh)$

32mm thick spiral-shaped cavities behave as a 50mm thick conventional liner





Equivalent acoustic length is increased by more than 50%

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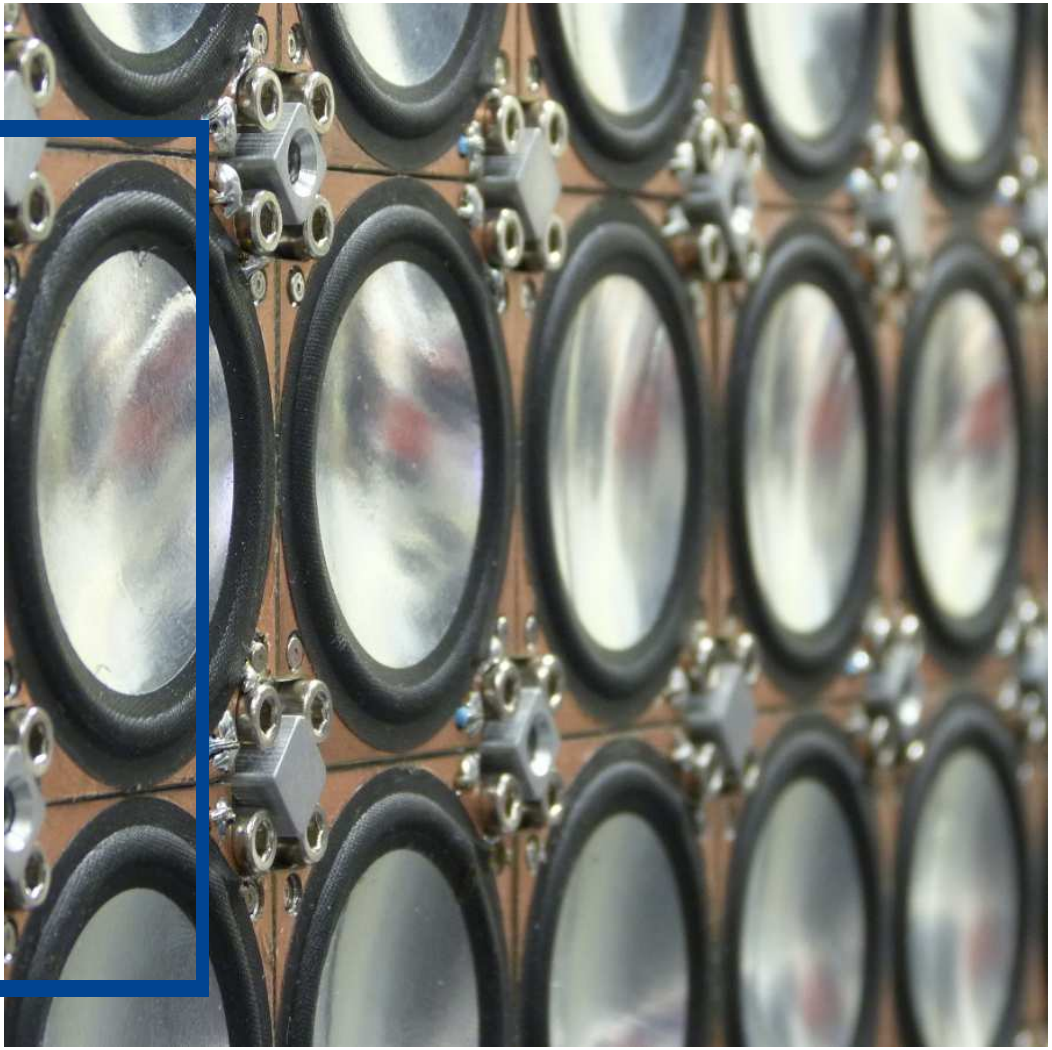
METAMATERIALS FOR NACELLES

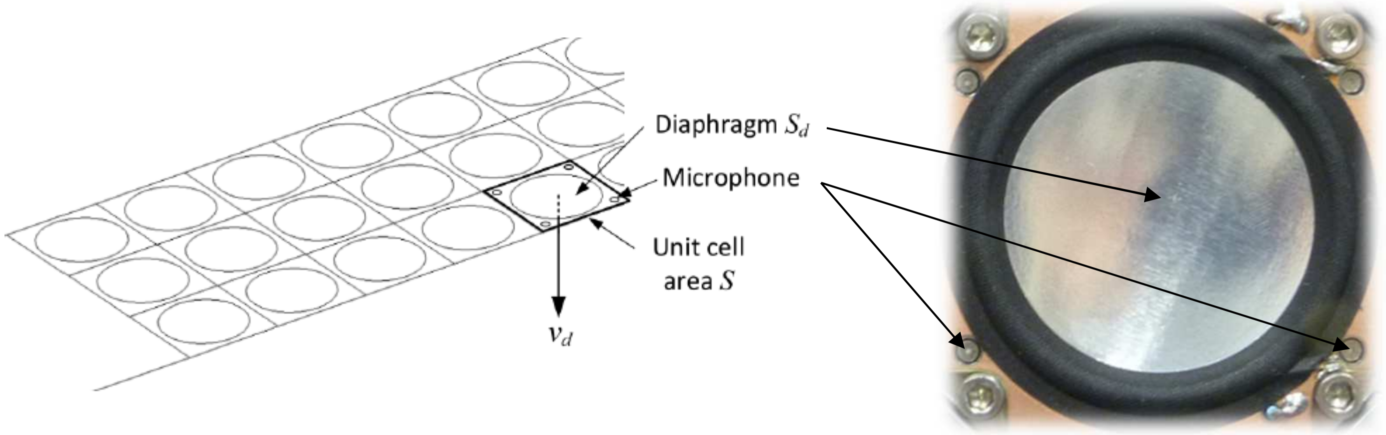
EXAMPLE OF AN ADAPTIVE SOLUTION



ADAPTIVE SKIN CONCEPT

The objective is to match a target acoustic impedance by controlling the local skin displacement

Proof of concept skin is made of electrodynamic speakers



This work has been made within the framework of the European project ENOVAL, in collaboration with FEMTO-ST, EPFL and CTTM

ENOVAL Ultra High Bypass Ratio Aero Engines · femto-st SCIENCES & TECHNOLOGIES · EPFL · CTTM CENTRE DE TRANSFERT DE TECHNOLOGIE DU MANS

CONTROL STRATEGY

Passive mechanical impedance

$Z_{ms} = sM_{ms} + R_{ms} + \frac{1}{sC_{ms}}$ with resonance frequency $f_0 = \frac{1}{2\pi\sqrt{M_{ms}C_{ms}}}$

Controlled acoustic impedance

$Z_{at} = \frac{1}{S_d}\left(s\mu_1 M_{ms} + R_{at} + \frac{\mu_2}{sC_{ms}}\right)$ with resonance frequency $f_t = \sqrt{\frac{\mu_2}{\mu_1}} f_0$

Current-driven pressure feedforward

$I = H_{loc}.p$, with $H_{loc} = \frac{S_d}{B_l}\left(1 - \frac{Z_{ms}}{S_d Z_{at}}\right)$

M_{ms}: dynamically moved mass

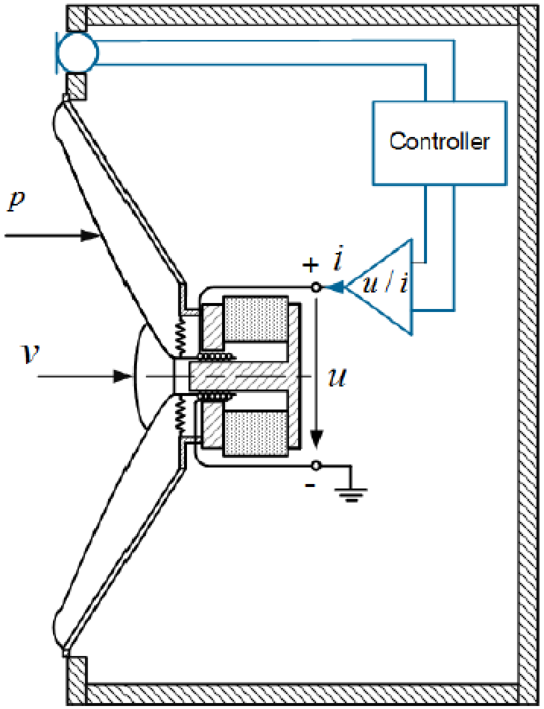
R_{ms}: mechanical resistance

C_{ms}: mechanical compliance

B_l: transduction coefficient

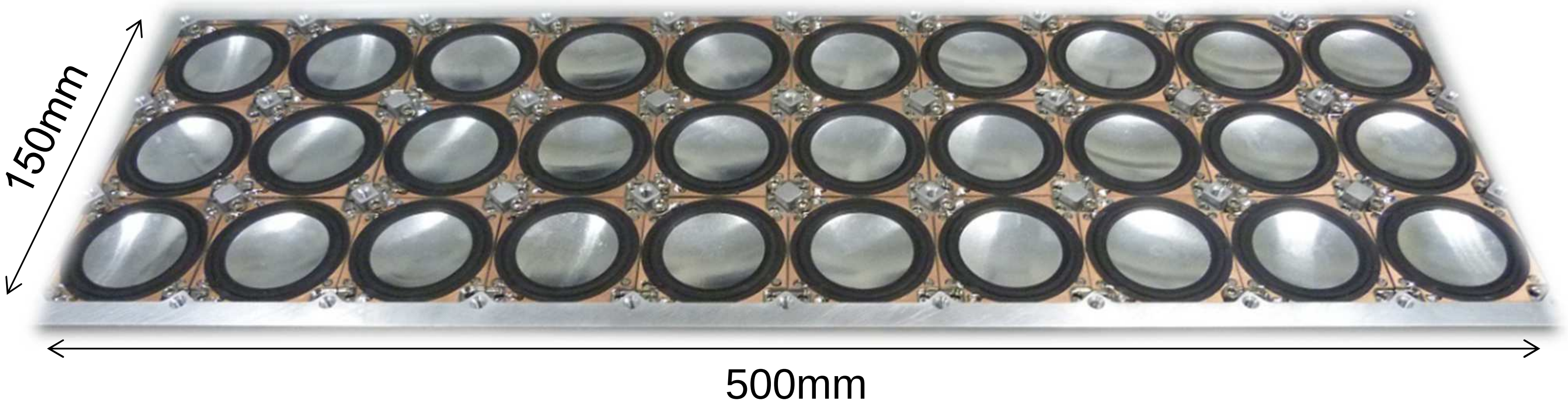
S_d: effective piston area

R_{at}: target acoustic resistance

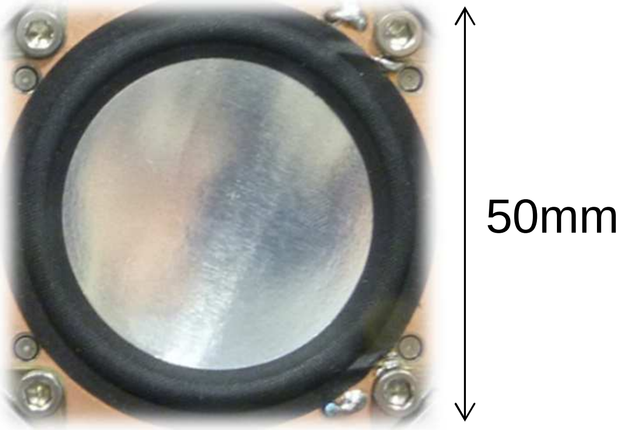


TEST HARDWARE

Panel of 30 cells (30 speakers & 120 microphones)



Total thickness of ~25mm



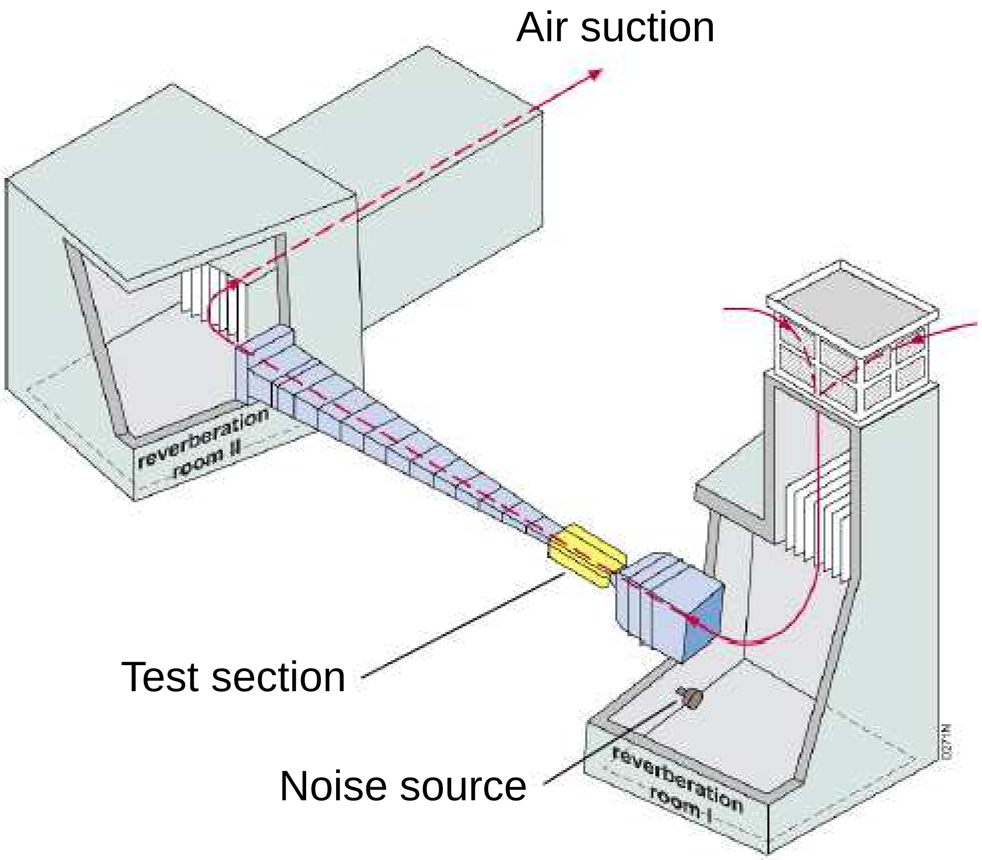
TEST BENCH

Insertion loss measurements (IL) have been carried out in the Flow Duct Facility of the Netherland Aerospace Centre (NLR)

Test section: cross section of 150mm x 300mm

Noise level measured in reverberation room 2

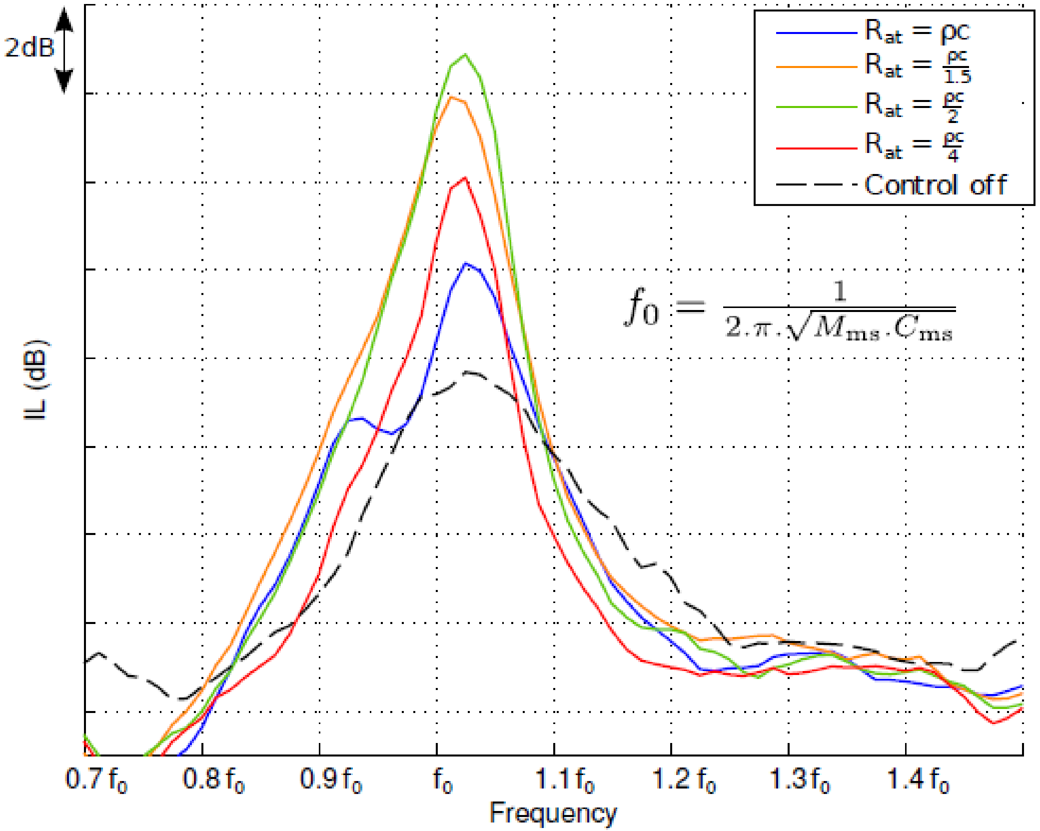
$$IL = SPL_{HW} - SPL_{lined}$$



TEST RESULTS: RESISTANCE CONTROL

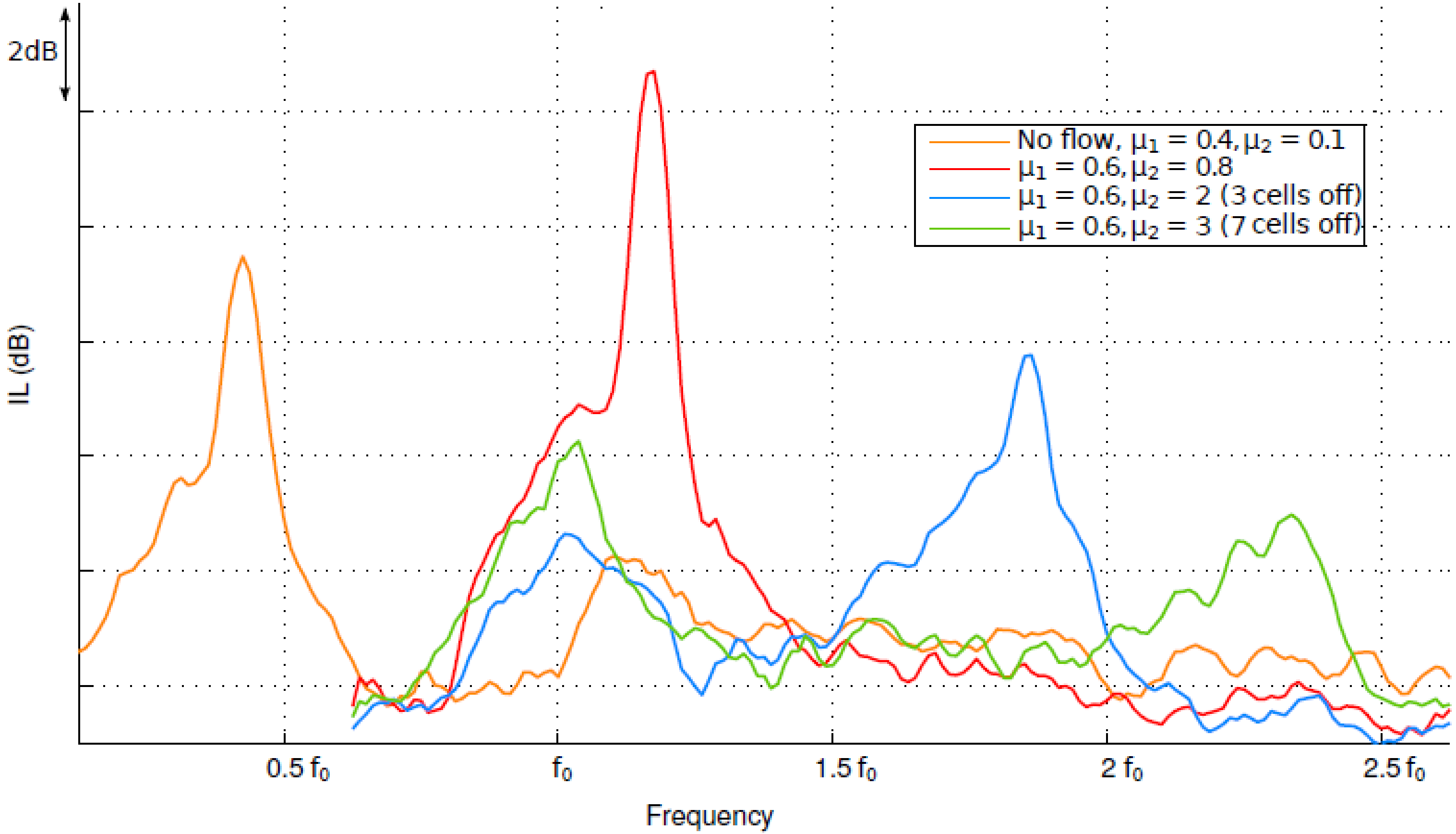
Validation of the ability to control the acoustic resistance R_{at}

IL can be maximized in properly setting R_{at}



TEST RESULTS: RESONANCE CONTROL

Attenuation peak frequency can be modified in properly setting the μ_1 and μ_2 parameters



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CONCLUSIONS

CONCLUSIONS

Acoustic materials are integrated to nacelles to contribute to engine noise reduction

A challenge for future commercial aircraft nacelles is to damp lower frequencies without thickening acoustic treatments

Acoustic metamaterials are a promising solution to achieve this objective

Passive materials

- Spiral-shaped cavities demonstrated their acoustic performance
- Their manufacturing has become much easier with the progress of additive manufacturing
- Such materials could thus be a mid-term solution

Adaptive materials

- A skin made of electrodynamic speakers demonstrated proof of concept
- The real-time control increases the acoustic performance compared to passive solutions
- Such concepts would be long term solutions (integration work to functionalize a skin to control its displacements)

THANK YOU FOR YOUR ATTENTION

POWERED
BY TRUST

REFERENCES

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Sugimoto R., Murray P. & Astley, R. J., Folded cavity liners for turbofan engine intakes, AIAA 2012-2291

Karker S., Lissek H., Ouisse M., Collet M., Versaevel M., Control strategies for a distributed active acoustic skin, INTERNOISE 2015