Noise and vibration control in aerospace composite structures

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Sustainable aviation

Fuel efficient engines and lighter structures

Reduced noise pollution around airports

Acceptable noise and vibration levels inside aircraft cabins

Innovative solutions
- Intelligent use of added mass
- Increase structural damping
- Reduce noise level
- Reduce emissions
- Increase the payload

Engine noise and vibration

Main noise and vibration sources in aircraft
- Engine (fan, turbine, jet)
- Interaction fluid-structure
- Hydraulic systems
- Landing gear

Structural vibrations
- Propagation through aircraft fuselage
- Propagation through flooring system

Structure-borne noise
- Transmission in solid structures (fuselage, flooring systems)
- Radiation from vibrating structures

Airborne noise
- Displacement of mass particles in the air (cabin)
Engine noise and vibration

**Main objective:** Reduce the noise and vibration level in aircrafts without detrimental impact on its composite structures

**Acting on source**

**Reduced noise level**
- Reduce noise level inside cabin
- Reduce noise annoyance to communities
- Mechanism: *Acoustic absorption*

**Acting on media**

**Reduced vibration level**
- Reduce noise level inside cabin
- Increase structure durability
- Mechanisms: *Mechanical damping and acoustic transmission barrier*
Start from the beginning:
- Define the problem quantitatively
- Understand the needs and context
- Limit the domain
- Define statement of work
- Identify people (Controlled goods)

Investigation:
- Define requirement specifications
- Understand technical parameters
- Use knowledge and expertise
- Explore innovative ideas

Small scale development:
- Fabricate lab demo samples
- Test preliminary concepts
- Select solution concepts
- Model concept and optimize
- Validate final concept

Implementation:
- Check for air worthiness
- Check for certification
- Evaluate impact on performance
- Develop integration procedures
- Complete proof of concept
Micro-Characterization

NSERC-Safran chair on 3D composites for aerospace

Micro-characterization
thermosets

Mechanical and
dynamic testing

Manufacturing
and prototyping

DMA

MDSC

DMA-450 Metravib

Pressclave with acquisition system

HP TGA-FTIR
spectrometer

Rheometer

DMA
Acoustics/vibration

Laboratory for acoustic and vibration analyses (LAVA)

Vibration ↔ Acoustics ↔ Vibro-acoustics

Anechoïc room:
$4.3 \times 4.6 \times 3.5 \text{ m}^3$

Tube à impédance
Absorption + Transmission

Reverberation chamber $0.8 \text{ m}^3$
Additive manufacturing

Laboratory of multiscale mechanics (LM2)


3D printing of complex microstructures (Lewis, White, U of Illinois at Urbana-Champaign)

UV assisted freeform 3D printing (L. Laberge Lebel)
**Motivations**

- High flexural stiffness/weight ratio
- Applications in transportation industry
- Transmission of mechanical and acoustic vibrations
- Discomfort or mechanical damages
Passive damping

Constrained layer damping (CLD)

Shearing of viscoelastic material through flexural motion of the structure

Damping increase through energy dissipation
Structural Vibration

Passive damping (face sheets)

- Take advantage of the laminated structure of composite
- Interleaved viscoelastic material
- Insertion of viscoelastic material before curing
- Limited risk of delamination

- Variable position viscoelastic material through the thickness
- Multiple shearing locations

- Multiple positions along the structures
- Target areas of maximum deformation (modal node)
Experimental vs model

Increase of damping ratio at the modal nodes

Structural Vibration

Passive damping (core)

- Core stiffness modification
- Cells filled with viscoelastic materials
- Embedded damping device in the core
- Metamaterials in the core

Mapping of the whole structure along the nodal lines (high shear deformation)

- Increase of structural damping
- Increase of acoustic transmission loss
- Reduction of the added mass

Risk of altering locally the mechanical properties of the structure
Modelling of passive damping

Sandwich structure

Core

Displacement field
Deformation
Stresses
Energies

Skins

Top skin

Bottom skin

Viscoelastic material

Displacement field
Stresses
Energies

Displacement field
Deformation
Stresses
Energies

Assumed modes method

Total energy (kinetic and potential)

Harmonic response
Eigenvalue problem

Natural frequencies

Damping
Engine noise

Motivations

- Several sources of noise
- Fan noise important during take-off and landing
- Annoyance to communities around airports
- Discomfort for passengers
- Reduced durability of the structures

- Engine length reduced
- Nacelle diameter increased
- Areas for acoustic treatment narrowed
Engine noise

Locally reacting acoustic liner (Helmholtz resonators)

- Composite perforated face sheet
- Metal or composite honeycomb
- Micro-perforated Septum
- Honeycomb
- Rigid back sheet

- Target only one octave band centered on fan blade passage frequencies
- Not suitable for critical areas such as OGVs
- Too cumbersome and heavy
- Development possibilities exhausted

- Need for new technologies breakthrough
- Development of new absorbing materials
- Development of new acoustic concepts
- Development of new integration procedures
Absorbing materials

Non-locally reacting acoustic treatment

- High porosity metallic/carbon foams available
- Dissipation phenomena involved
- Broadband absorption frequency range
- Integration in composite environment

- Foaming processes difficult to control
- Foaming process expensive
- Mechanical behavior for high performance applications
- Ensuring long-term acoustic performance
- Certification compatibility
Absorbing materials

Foaming process PLA foams
Non Solvent Induced Phase Separation (NIPS)

PLA+DCM Solution → Hexane → Liquid-liquid Phase separation at various temp → Gel

Dry in air (12 h) → Magnetic stirrer → Solvent exchange in methanol

Absorbing materials

PLA foams
Absorbing materials

Microstructure PLA foams: Bimodal porosity

13 wt.%  @ room temperature

Porosity = 45%
Compressive Strength = 45 MPa

23 wt.%  @ room temperature

Porosity = 84%
Compressive Strength = 8 MPa

Rezabeigi et al, Production of PLA monoliths via NIPS, Polymer (55), 2014, 643-652
Absorbing materials

Microstructure PLA foams: Bimodal porosity

13 wt.% @ Freezer

Porosity = 91%
Compressive Strength = 1.8 MPa

23 wt.% @ Freezer

Porosity = 84%
Compressive Strength = 15.6 MPa

Nucleation & growth mechanism

Rezabeigi et al, Production of PLA monoliths via NIPS, Polymer (55), 2014, 643-652
Absorbing materials

Microstructure PLA foams: Bimodal porosity

Rezabeigi et al., Production of PLA monoliths via NIPS, Polymer (55), 2014, 643-652

Crystallization of PLA
Absorbing materials

PLA foams

- Foam1: [L-L] 18 wt.% @ 23°C
  - Thickness: 
  - Porosity: 88%
  - Average pore size: 10.3 nm
  - Comp. modulus: 14 MPa
  - Density: 0.14g/cm³

- Foam2: [S-L] 13 wt.% @ 23°C
  - Thickness: 
  - Porosity: 86%
  - Average pore size: 15.4 nm
  - Comp. modulus: 3.5 MPa
  - Density: 0.17g/cm³

- Foam3: [L-L] 18 wt.% @ -23°C
  - Thickness: 
  - Porosity: 91%
  - Average pore size: 12.7 nm
  - Comp. modulus: 1.8 MPa
  - Density: 0.12g/cm³

Resonance-like acoustic absorption (3000Hz and 3500Hz)
Absorbing materials

PLA foams

• Interesting transmission capabilities at low frequency
• Can be used as absorbing material and sound barrier

Fotsing et al., Acoustic properties of porous PLA monoliths produced via NIPS, ICTAM 2016 (Montreal)
Absorbing materials

Thermoset foams

Innovative process to produce thermoset foams
- Simple and flexible
- Cost effective
- Fully controllable

• Porosity greater than 85 % (ideal for acoustic treatment)
• Improved mechanical properties (up to 50 MPa compressive modulus)
• Porosity gradient through the thickness (ideal for non-locally acoustic treatment)
• Easy integration to composite structures (e.g. sandwich structures)

Foam #1
Commercial metallic foam (Recemat)
Foam #2
Absorbing materials

Thermoset foams

- Epoxy foam slightly more resistive than the metallic foam
- Absorption on a broad frequency range for epoxy foam
Absorbing materials

Characterization and modelling

Concept of equivalent fluid

\[ \Delta p + \omega^2 \frac{\tilde{\rho}_{eq}}{K_{eq}} p = 0 \]

JCA model

\[ \tilde{\rho}_{eq} = \frac{\alpha_\infty \rho_0}{\phi} \left[ 1 + \frac{\sigma \phi}{j \omega \rho_0 \alpha_\infty} \sqrt{1 + j \omega \frac{4 \alpha_\infty^2 \eta \rho_0}{\sigma^2 \Lambda^2 \phi^2}} \right] \]

\[ K_{eq} \]

Characteristic impedance \[ \tilde{Z}_c = \frac{\tilde{\rho}_{eq} K_{eq}}{K_{eq}} \]
Wave number \[ \tilde{k} = \omega \sqrt{\frac{\tilde{\rho}_{eq}}{K_{eq}}} \]
Normal surface impedance \[ Z = -j \tilde{Z}_c \cot (\tilde{k} e) \]
Absorption coefficient \[ \alpha = 1 - \frac{\tilde{Z} - Z_0}{\tilde{Z} + Z_0} \]

5 parameters to be characterized \( (\phi, \sigma, \alpha_\infty, \Lambda, \Lambda') \)

Direct method (experimental)
- Impedance tube \( (\alpha, Z) \)
- Resistivity meter \( (\sigma) \)
- Porosity meter \( (\phi) \)
- Tortuosity meter \( (\alpha_\infty, \Lambda, \Lambda') \)

Inverse method
Comparing the model with experimental values of acoustic absorption and acoustic impedance
Conclusion

Implement mechanical damping solutions
- Lightweight
- Non intrusive
- High performance
- Cost effective

Implement sound barrier solutions
- Lightweight
- Non intrusive
- High performance
- Cost effective

Implement acoustic absorption solutions
- Lightweight
- Non intrusive
- High performance
- Cost effective

Implement functionalities to existing structures at the design stage
Innovative concepts
No corrective patches!
Thank you