RESEARCH ON STRUCTURAL DYNAMICS AND AEROELASTICITY

FAPESP France Week 2025

Domingos A. Rade
(rade@ita.br)

Aeronautics Institute of Technology
Division of Mechanical Engineering
Laboratory of Dynamics & Vibrations

June 2025

OUR RESEARCH GROUP AT THE AERONAUTICS INSTITUTE OF TECHNOLOGY

FAPESP France Week 2025

MEMBERS:



Domingos A. Rade
(Professor)



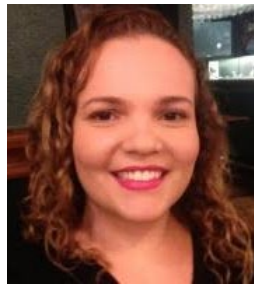
Thiago de P. Sales
(Assistant Professor)



Leandro R. Cunha
(Assistant Professor)



Vinicius G. Cleante
(Post-Doc Researcher)



Thaís L. A. Montanheiro
(Post-Doc Researcher)

COLLABORATORS:



Carlos De Marqui Jr.
(EESC-USP)



José R. de F. Arruda
(UNICAMP-retired)



Paulo J. P. F. Gonçalves
(UNESP-Bauru)



Leopoldo P. de Oliveira
(EESC-USP)



José M. C. dos Santos
(UNICAMP)



Ijar M. da Fonseca
(INPE - retired)



Cairo L. Nascimento Jr.
(ITA)



Daniel de A. Pereira
(Forza Composites)



Morvan Ouisse
(Univ. Bourgogne Franche-Comté/ France)



Michael J. Brennan
(ISVR/UK - retired)



Timothy Waters
(ISVR/UK)



Jandro L. Abot
(UCA/USA)



Rui A. da S. Moreira
(Univ. Aveiro/Portugal)

OUR CURRENT RESEARCH TOPICS

- Dynamics/aeroelasticity of advanced composite materials (variable-stiffness)
- Passive vibration/aeroelastic control using viscoelastic materials
- Vibrations and wave propagation in periodic structures and metamaterials
- Uncertainty quantification and stochastic modeling in structural dynamics and aeroelasticity
- Morphing aircraft components using shape memory alloys
- Structural health monitoring using carbon nanotube-based integrated sensors
- Piezoelectric energy harvesting from vibration motion
- Vibration control of satellite panels using piezoelectric transducers

OUR RESEARCH DIRECTIVES

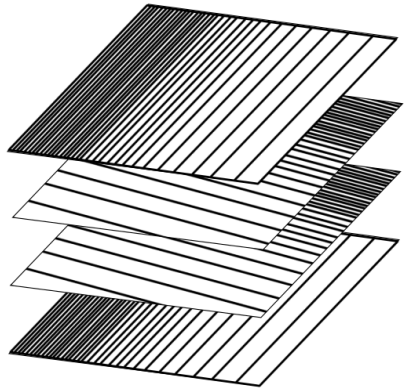
- Search for new/improved solutions to scientific/engineering problems.
- Mixed theoretical/numerical/experimental approaches.
- Projects funded by research agencies and industrial compagnies, with strong participation of graduate students and post-doc fellows.
- Collaboration with national and international partners.

DYNAMICS AND AEROELASTICITY OF VARIABLE STIFFNESS COMPOSITE MATERIALS

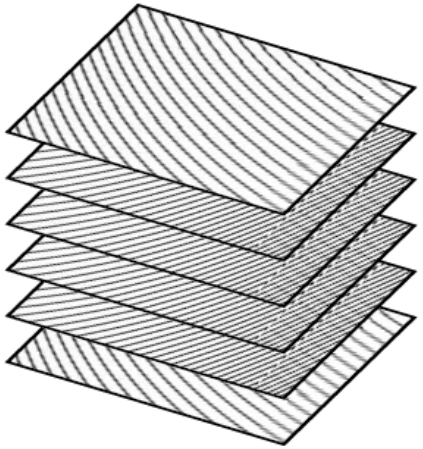
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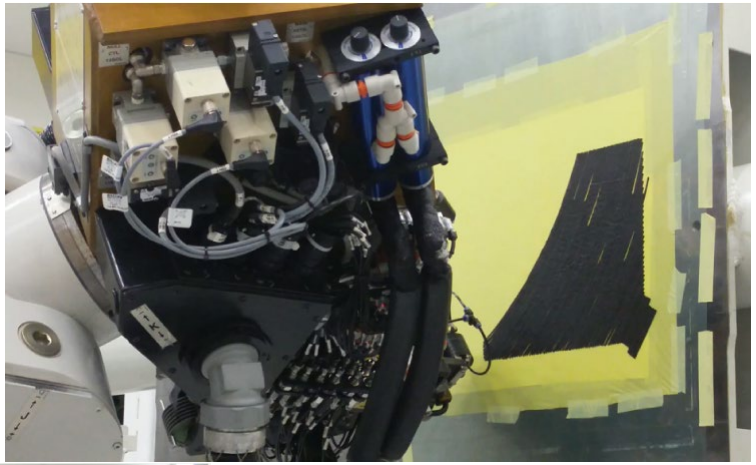
Novel (variable stiffness) composite laminates

Variable fiber spacing (VFS) laminates



Variable angle tow (VAT) or tow steered laminates







(From: Lightweight Structures Laboratory, São Paulo State Institute of Technological Research-IPT, São José dos Campos, Brazil)

Design variables:

- material properties
- number of plies
- relative orientation of the plies
- gradient of fiber/matrix fractions (VFS)
- fiber trajectories (VAT)

DYNAMICS AND AEROELASTICITY OF VARIABLE STIFFNESS COMPOSITE MATERIALS

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Specific research topics:

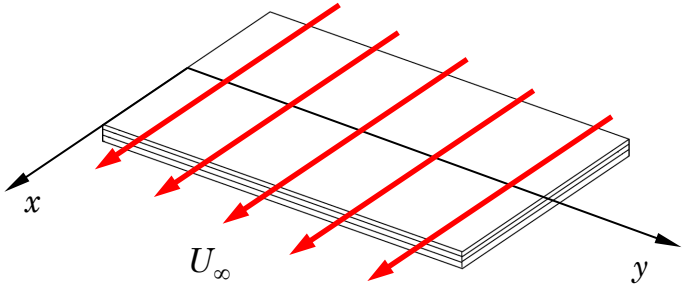
- Development of numerical models (Rayleigh-Ritz, Finite Elements)
- Validation of numerical models from laboratory vibration tests
- Uncertainty quantification (buckling loads, vibration responses, flutter speeds)
- Optimization of the vibrational and aeroelastic features of VAT composite plates

DYNAMICS AND AEROELASTICITY OF VARIABLE STIFFNESS COMPOSITE MATERIALS

Optimization of the aeroelastic behavior

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Aeroelastic model



$$\mathbf{M}\ddot{\mathbf{q}}(t)+\left(\mathbf{K}+\lambda\mathbf{K}_a\right)\mathbf{q}(t)=\mathbf{Q}(t)$$

$$\left(\mathbf{K}+\lambda\mathbf{K}_a-\chi_i^2\mathbf{M}\right)\boldsymbol{\phi}_i=\mathbf{0}$$

$$\Delta P=\lambda\frac{\partial w(x,y)}{\partial x};\ \lambda=\frac{\rho_\infty U_\infty^2}{\sqrt{M_\infty^2-1}}$$

ρ_∞ : air density

U_∞ : flow velocity

M_∞ : Mach number

Problem:

Maximize: $\lambda_{flutter}$

Design variables: θ_{mn}

Subjected to: $\theta_{mn}\in\left[-90^o;90^o\right]$

Optimization scenarios

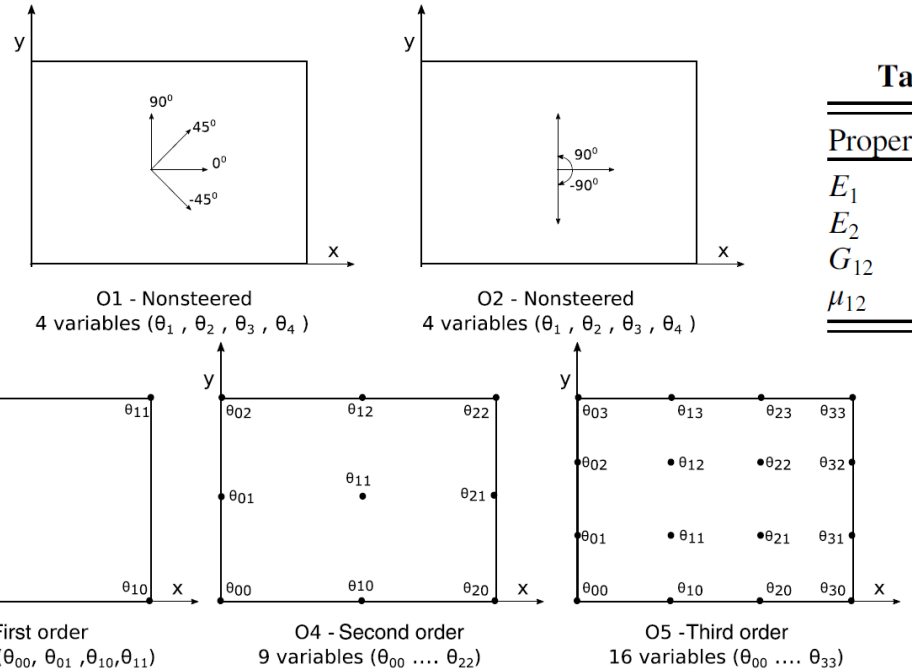


Table 1 Lamina physical properties and dimensions

Property	Value	Property	Value
E_1	129,500 MPa	a	400 mm
E_2	9,370 MPa	b	300 mm
G_{12}	5,240 MPa	ρ	1500 kg/m^3
μ_{12}	0.38	Ply thickness t	0.19 mm

$$\left(90^o,+45^o,0,-45^o,90^o\right)_s$$

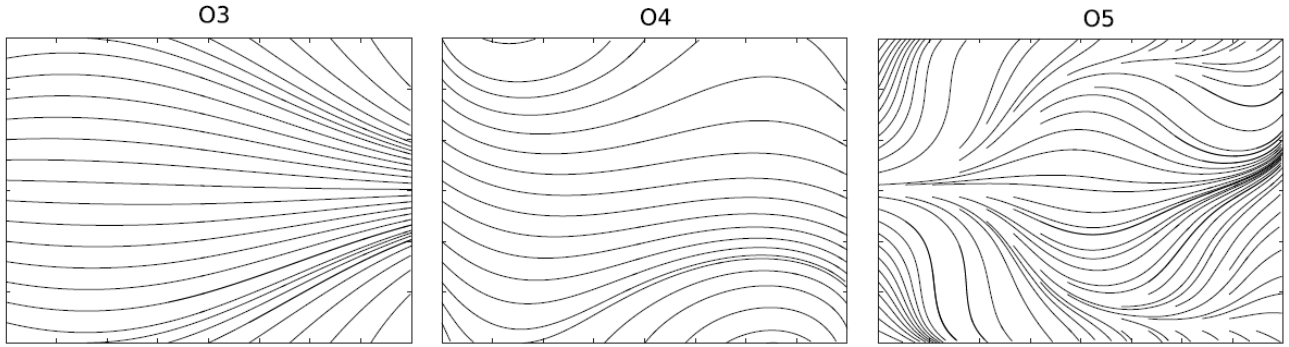
T.A.M. Guimarães, S.G.P. Castro, C.E.S. Cesnik, and D. A. Rade. "Supersonic Flutter and Buckling Optimization of Tow-Steered Composite Plates", AIAA Journal, Vol. 57, No. 1 (2019), pp. 397-407

DYNAMICS AND AEROELASTICITY OF VARIABLE STIFFNESS COMPOSITE MATERIALS

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Table 7 Optimization results

Configuration	Optimal values, deg	Flutter [λ^*]	Improvement[a], %
O1	[0 0 0 45]	779	— —
O2	[−24.24 31.79 31.67 24.95]	812	4.47
O3	$\begin{bmatrix} 64.98 & -64.56 \\ -15.23 & 11.34 \end{bmatrix}$	796	2.46
O4	$\begin{bmatrix} -77.57 & -26.31 & -83.35 \\ 50.71 & 7.88 & 53.40 \\ -74.33 & -34.21 & -63.44 \end{bmatrix}$	866	11.41
O5	$\begin{bmatrix} 39.95 & -75.60 & -69.75 & -14.01 \\ -32.67 & -10.82 & 8.23 & 30.14 \\ -49.58 & 11.18 & -11.42 & 55.71 \\ -15.15 & -55.95 & 60.09 & 1.65 \end{bmatrix}$	937	20.50



DYNAMICS AND AEROELASTICITY OF VARIABLE STIFFNESS COMPOSITE MATERIALS

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Composite Structures 256 (2021) 112932

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Multi-objective frequency and damping optimization of tow-steered composite laminates

D.A. Pereira [a,b], T.P. Sales [a], D.A. Rade [a,*]

[a] ITA – Aeronautics Institute of Technology, Division of Mechanical Engineering, Brazil
[b] IPT– Lightweight Structures Laboratory, São Paulo State Institute for Technological Research, Brazil

https://doi.org/10.1016/j.compstruct.2020.112932

Composite Structures 244 (2020) 112190

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Numerical and experimental analyses of modal frequency and damping in tow-steered CFRP laminates

D.A. Pereira[a,c], T.A.M. Guimarães[b], H.B. Resende[c], D.A. Rade[a,*]

[a] ITA – Aeronautics Institute of Technology, Division of Mechanical Engineering, Brazil
[b] UFU – Federal University of Uberlândia, School of Mechanical Engineering, Brazil
[c] IPT – Lightweight Structures Laboratory, Institute for Technological Research, Brazil

https://doi.org/10.1016/j.compstruct.2020.112190

VIBRATIONS AND WAVE PROPAGATION IN METAMATERIALS

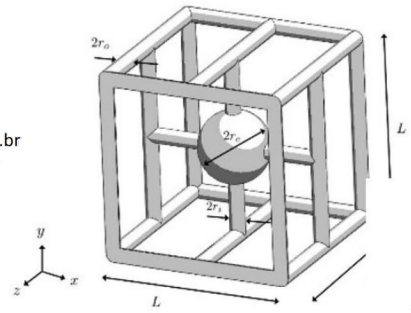
lajss.org
Latin American Journal of Solids and Structures
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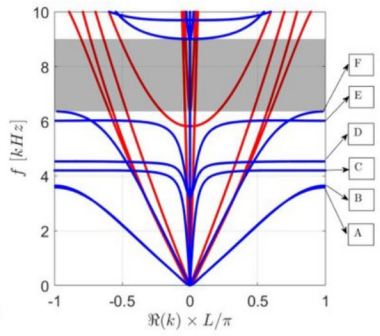
Optimization of Vibration Band Gaps in Damped Lattice Metamaterials

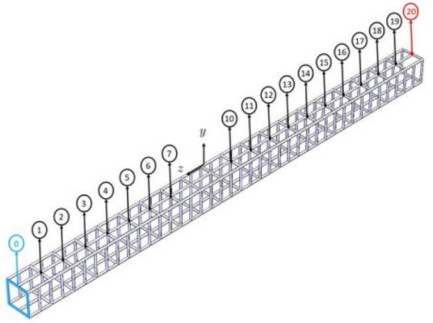
Rubens Gonçalves Salsa Junior[a]*, Thiago de Paula Sales[b], Domingos Alves Rade[c]

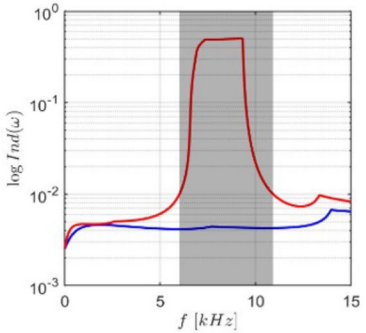
[a] Universidade Federal do Rio Grande do Norte, Departmento de Engenharia Mecânica, Natal, RN 59078-970, Brasil. Email: rubens.salsa@ufrn.br
[b] Instituto Tecnológico de Aeronáutica, Divisão de Engenharia Mecânica, São José dos Campos, SP 12228-900, Brasil. Email: tpsales@ita.br
[c] Instituto Tecnológico de Aeronáutica, Divisão de Engenharia Mecânica, São José dos Campos, SP 12228-900, Brasil. Email: rade@ita.br

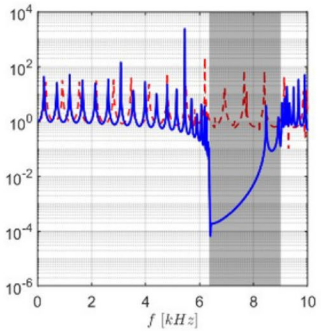
https://doi.org/10.1590/1679-78257486











Interest:

- Metamaterials exhibit anusual dynamic behavior (band gaps, negative refraction, non-reciprocal transmission, etc.), which can be explored to control wave propagation and vibration patterns.

Objective:

- Optimization of band gaps in damped resonating lattice metamaterials.

Result:

- Optimized band gap satisfying target bandwidth and central frequency.
- Optimal damped structure has a wider range of attenuation than the undamped counterpart, but with decreased level of attenuation.

VIBRATIONS AND WAVE PROPAGATION IN METAMATERIALS

International Journal of Mechanical Sciences 285 (2025) 109779

Contents lists available at ScienceDirect

International Journal of Mechanical Sciences

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Stochastic modeling of periodic beams under uncertain boundary conditions and environmental fluctuations

Vinícius M. de S. Santos [a,b], Yuri A. D. Martins [a], Henrique E. A. A. dos Santos [a], Thiago de P. Sales [a], Domingos A. Rade [a,*]

[a] Mechanical Engineering Division, Aeronautics Institute of Technology, Praça Marechal Eduardo Gomes, 50 - Vila das Acácias, 12228-900, São José dos Campos, SP, Brazil

[b] SUPMICROTECH, Université de Franche-Comté, CNRS, Institut FEMTO-ST, F-25000, Besançon, France

https://doi.org/10.1016/j.ijmecsci.2024.109779

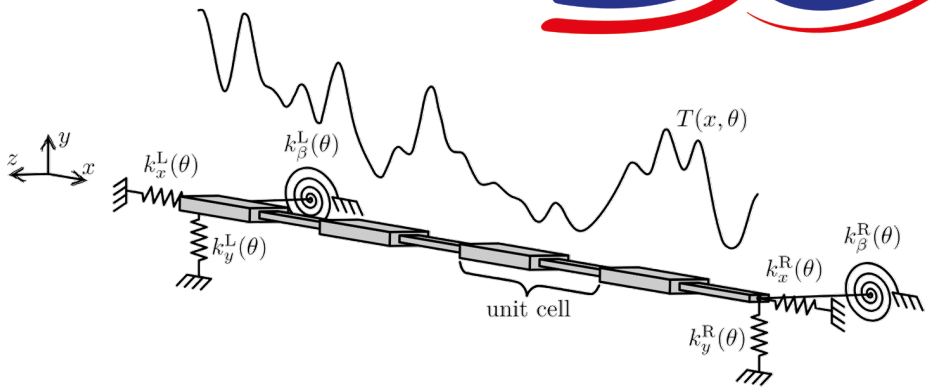


Fig. 1. Non-ideally supported periodic beam subjected to a temperature random field.

Objective:

- Investigate the influence of random uncertainties on the attenuation bands of periodic beams

Approach:

- Uncertainties affecting ambient temperature (random field) and BC (random variables) in the stochastic model of a periodic beam.

Conclusions:

- Both uncertainty sources exert significant influence on the characteristics of attenuation bands.
- Confirmation of the need to consider the interplay between the two sources of uncertainty.

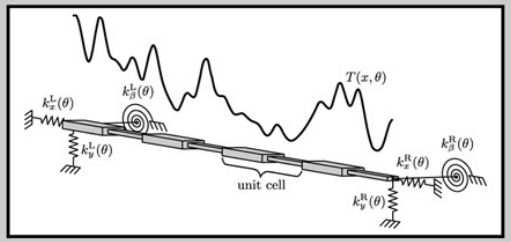
VIBRATIONS AND WAVE PROPAGATION IN METAMATERIALS

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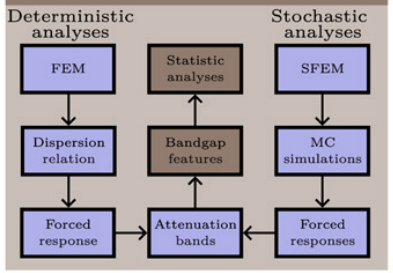
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Vinícius M.de S. Santos[a,b], Yuri A. D. Martins[a], Henrique E. A. A. dos Santos[a], Thiago de P. Sales[a], Domingos A. Rade[a]
[a] *Aeronautics Institute of Technology (ITA)*, [b] *Université de Franche-Comté (UFC)*

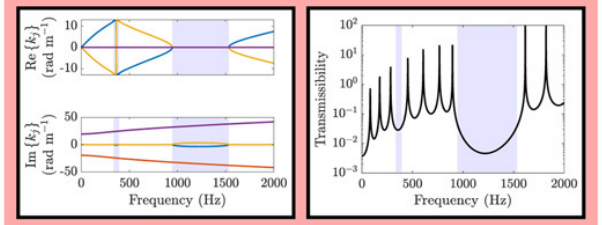
Non-ideally supported periodic beam subjected to a random temperature field



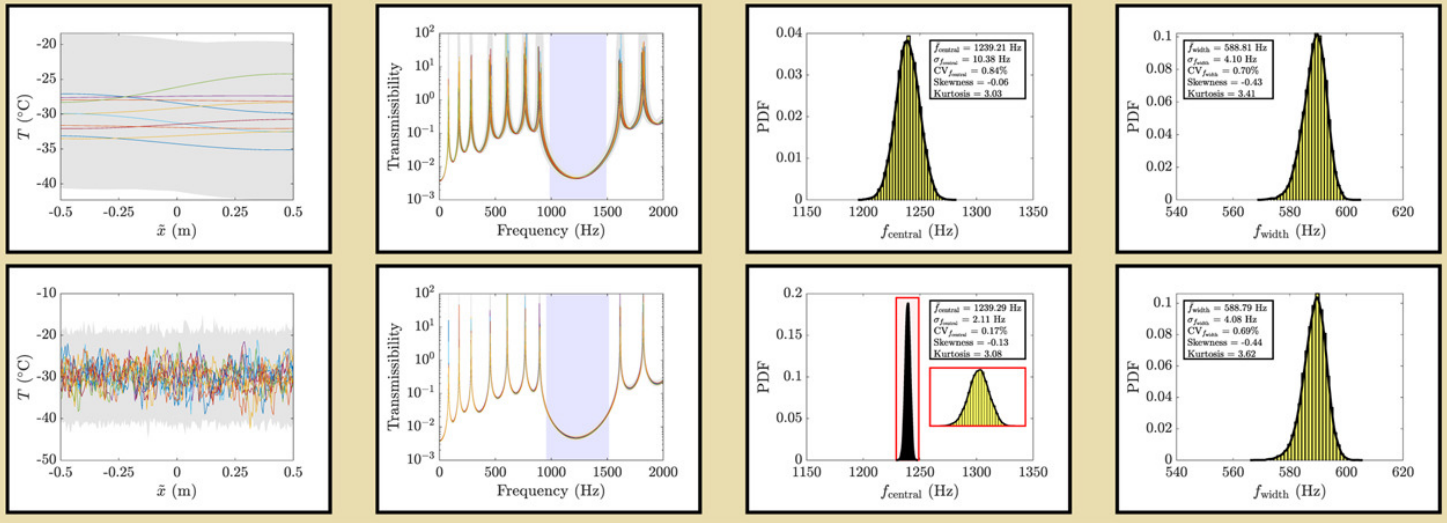
Methodology



Deterministic analyses



Stochastic analyses



PASSIVE VIBRATION CONTROL USING VISCOELASTIC MATERIALS

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DESIGN OF IMPROVED VISCOELASTIC DAMPERS EXPLORING 3D PRINTING TECHNOLOGY

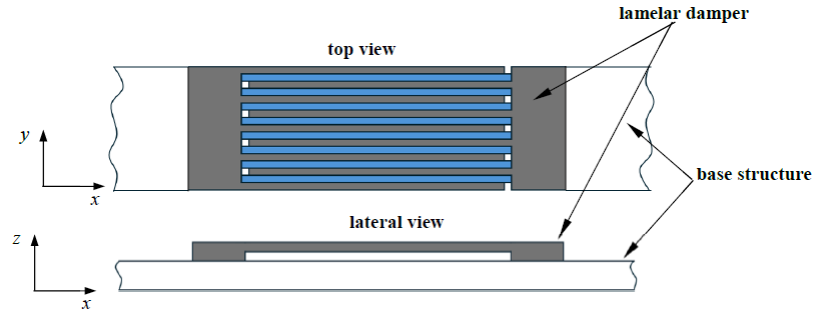
(accepted for publication)

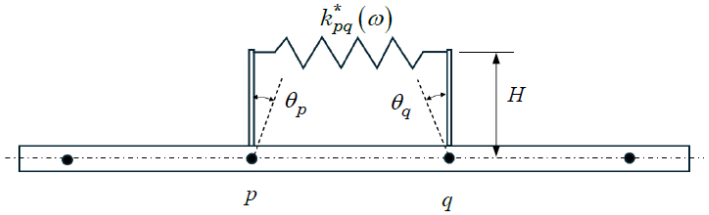
Domingos A. Rade[1,*], Rogerio Pirk[1], Inacio Regiani[1], Rui A.S. Moreira[2], Marcelo F. De Oliveira[3], Leonardo M. R. Machado[3]

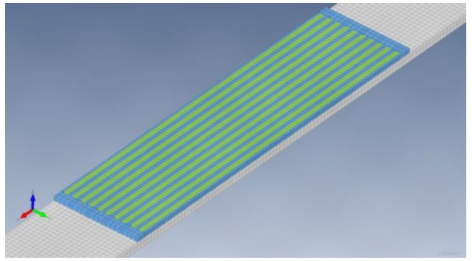
[1]Aeronautics Institute of Technology, Division of Mechanical Engineering, São José dos Campos, SP, Brazil

[2]University of Aveiro, Department of Mechanical Engineering/TEMA/LASI, Aveiro, Portugal

[3]Information Technology Center Renato Archer, Laboratory of Three-Dimensional Technologies, Campinas, SP, Brazil





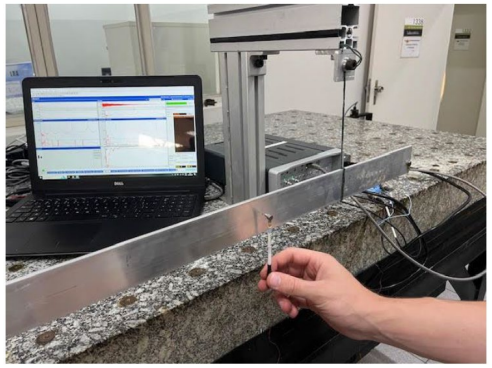


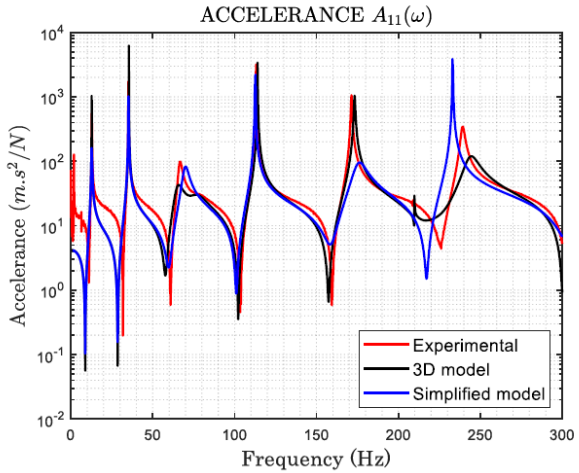
Interest:

- Exploration of modern 3D printing technologies for the design and manufacture of more efficient viscoelastic dampers

Objective:

- Numerical and experimental assessment of PolyJet™ for the design of a lamellar viscoelastic damper.





Conclusions:

- The lamellar damper perform better than traditional PCLD .
- PolyJet™ is very effective for the manufacture of dampers with complex geometry.

RESEARCH ON STRUCTURAL DYNAMICS AND AEROELASTICITY

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June 2025

RESEARCH ON SMART MATERIALS AND STRUCTURES

FAPESP France Week 2025

Domingos A. Rade
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June 2025

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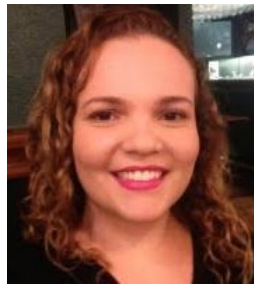
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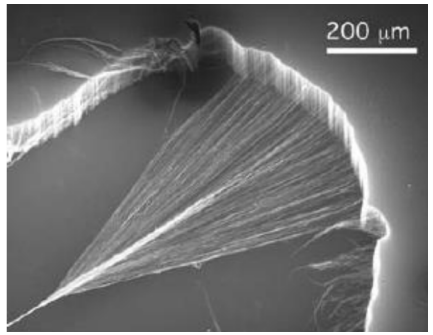
OUR CURRENT/RECENT RESEARCH TOPICS

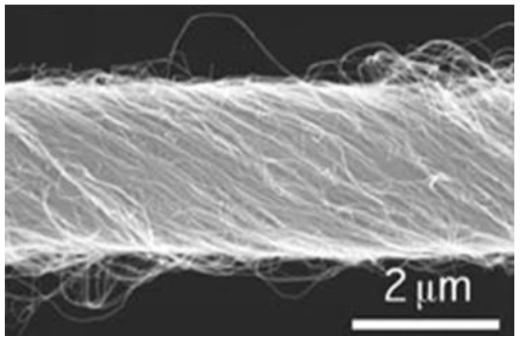
- Dynamics/aeroelasticity of advanced composite materials (variable-stiffness)
- Passive vibration/aeroelastic control using viscoelastic materials and vibration absorbers
- Vibrations and wave propagation in periodic structures and metamaterials
- Uncertainty quantification and stochastic modeling in structural dynamics and aeroelasticity
- Structural health monitoring using carbon nanotube-based integrated sensors
- Piezoelectric energy harvesting from vibration motion
- Vibration control of satellite panels using piezoelectric transducers
- Morphing aircraft components using shape memory alloys

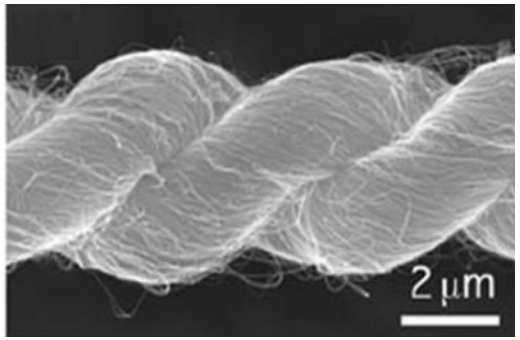
OUR RESEARCH DIRECTIVES

- Search for new/improved solutions to scientific/engineering problems.
- Mixed theoretical-numerical-experimental approaches.
- Projects funded by research agencies and industrial compagnies, with strong participation of graduate students and post-doc fellows.
- Collaboration with national and international partners.

STRUCTURAL HEALTH MONITORING USING CARBON NANOTUBE-BASED INTEGRATED SENSORS







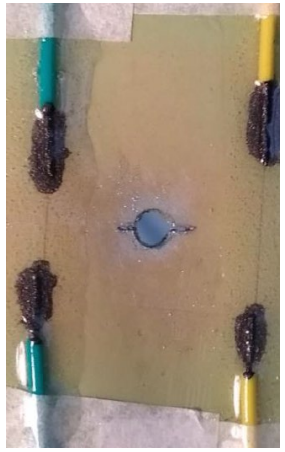
Monitoring principle: CNT yarns exhibit piezoresistive behavior

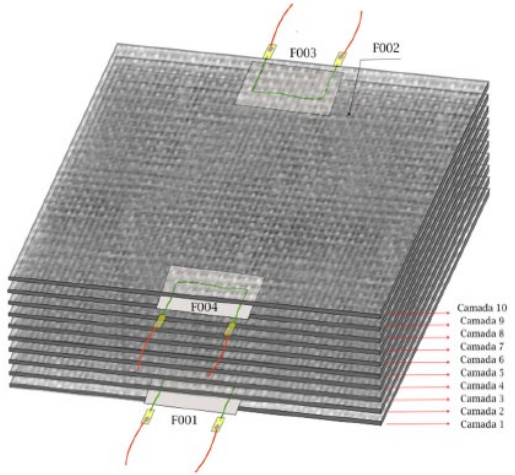
Advantages:

- Non-intrusive monitoring
- Monitoring of large areas
- Good sensitivity w.r.t strain and damage
- Full integration to the host structure

Objective:

- Increase the TRL aiming at industrial applications





Conclusions:

- Promising monitoring technique
- Problems being addressed: ageing, environmental influences

STRUCTURAL HEALTH MONITORING USING CARBON NANOTUBE-BASED INTEGRATED SENSORS

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Composites Science and Technology 254 (2024) 110694

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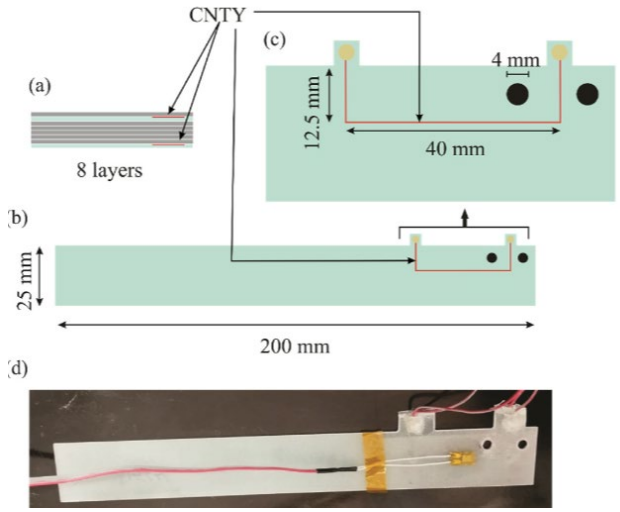
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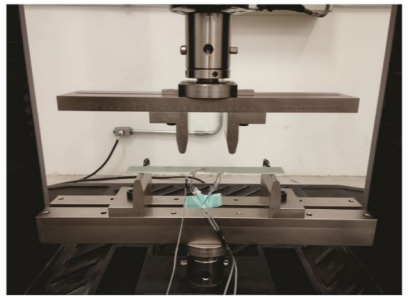
Monitoring of static and vibration responses of laminated composite materials using integrated carbon nanotube fibers

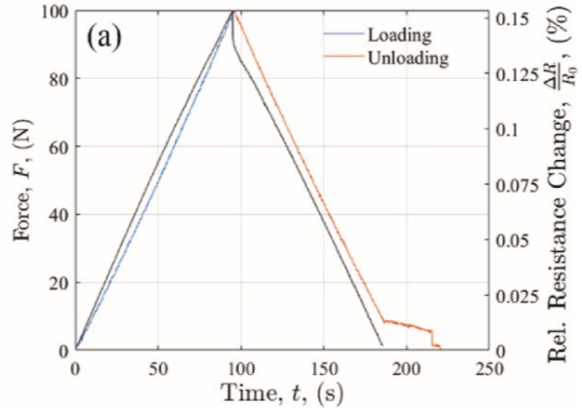
Jandro L. Abot [a,*], Thaís L.A. Montanheiro [b], Daniel de A. Pereira [c], Sérgio Nascimento Jr. [c], Cairo L. Nascimento Jr. [d], Juan R.B.F. Silva [d], Alexander H. Kasama [e], Domingos A. Rade [b]

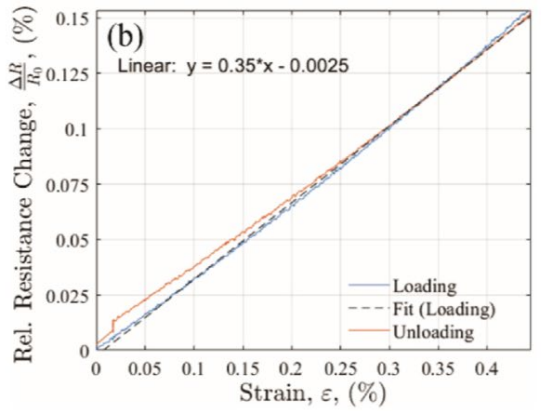
[a] Department of Mechanical Engineering, The Catholic University of America, Washington, DC, USA
[b] Instituto Tecnológico de Aeronáutica, Division of Mechanical Engineering, São José dos Campos, SP, Brazil
[c] Forza Composites, São José dos Campos, SP, Brazil
[d] Instituto Tecnológico de Aeronáutica, Division of Electronics Engineering, São José dos Campos, SP, Brazil
[e] CENPES, Petrobras, Rio de Janeiro, RJ, Brazil

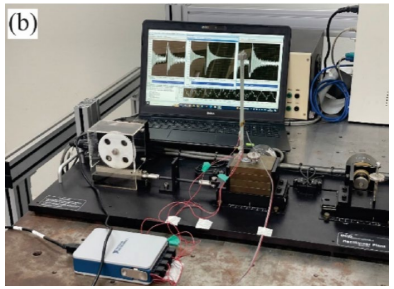
https://doi.org/10.1016/j.compscitech.2024.110694

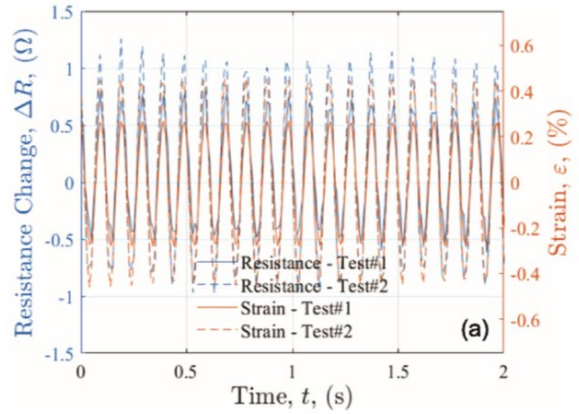


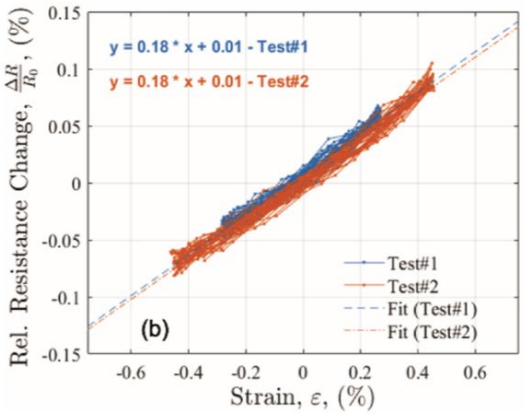












PIEZOELECTRIC ENERGY HARVESTING FROM VIBRATION MOTION

Mechanical Systems and Signal Processing 79 (2016) 141–148

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

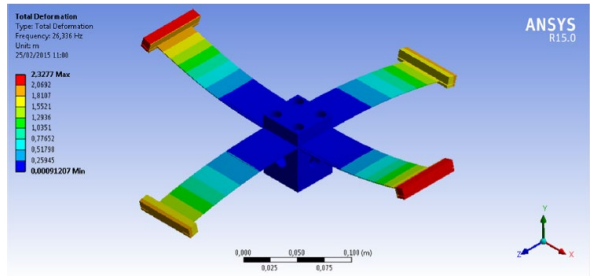
journal homepage: www.elsevier.com/locate/ymssp

Experimental evaluation of a cruciform piezoelectric energy harvester

Karina M. Tsuruta [a], Domingos A. Rade [b,*], Roberto M. Finzi Neto [a], Aldemir A. Cavalini Jr.[a]

[a] Federal University of Uberlândia, Av. João Naves de Ávila, n. 2121, Uberlândia, MG, Brazil
[b] Technological Institute of Aeronautics, Praça Marechal Eduardo Gomes, 50, São José dos Campos, SP, Brazil

https://doi.org/10.1016/j.ymssp.2016.03.005





Objective:

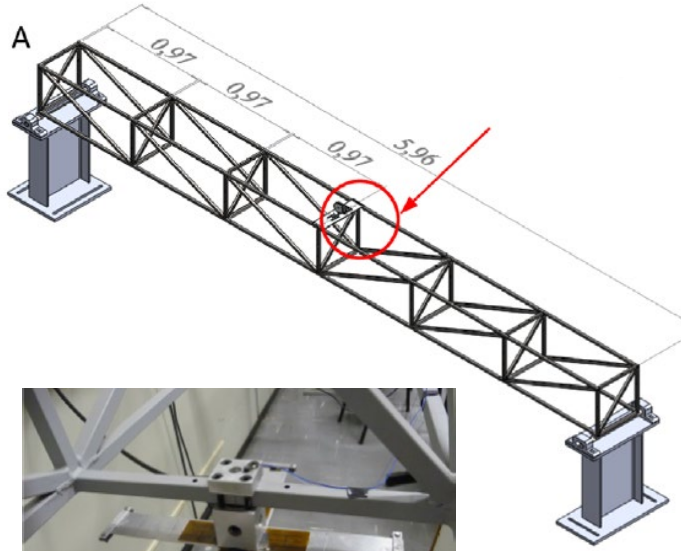
- Design and numerical/experimental evaluation of an enhanced piezoelectric energy harvester to be appended to vibrating structures.

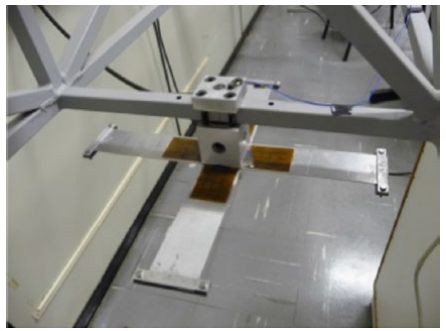
Interest:

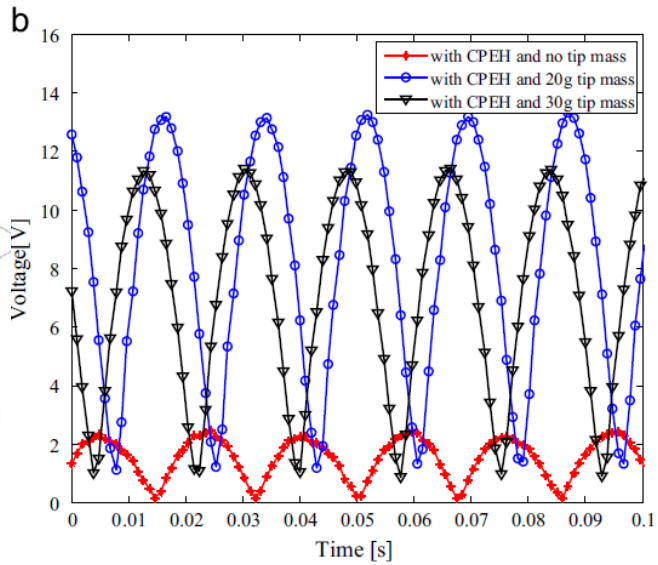
- Electric feeding of low-power remote sensing and signal transmission devices.

Conclusions:

- Validated concept
- Possible further improvements







VIBRATION CONTROL OF SATELLITE PANELS USING PIEZOELECTRIC TRANSDUCERS

Aerospace Science and Technology
Volume 29, Issue 1, August 2013, Pages 403-412

Passive vibration control of flexible spacecraft using shunted piezoelectric transducers

T.P. Sales [a], D.A. Rade [a] ✉, L.C.G. de Souza [b]

https://doi.org/10.1016/j.ast.2013.05.001

Objective:

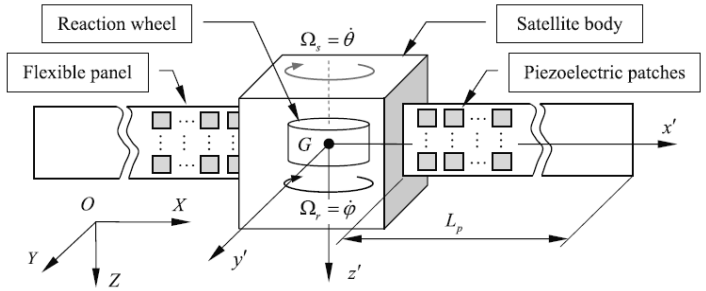
- Attenuation of the vibration of satellite panels induced by attitude correction maneuvers.

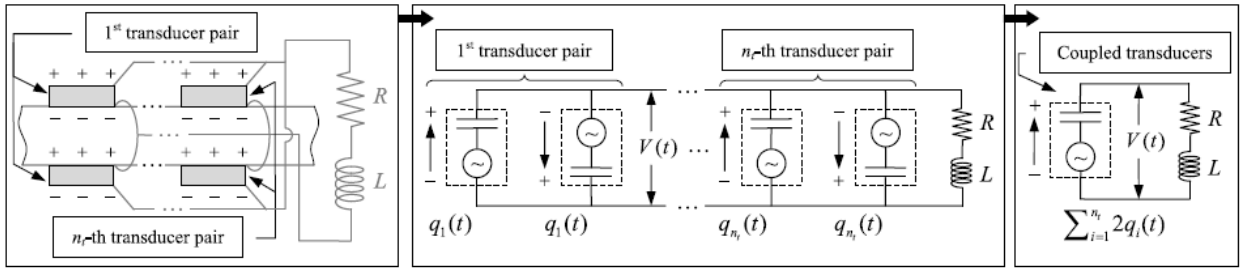
Approaches:

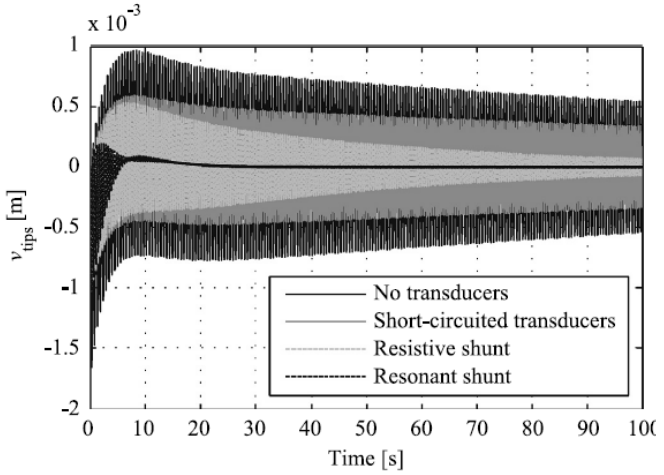
- Passive vibration control using piezoelectric transducers connect to resonant electric circuits (shunt circuits).

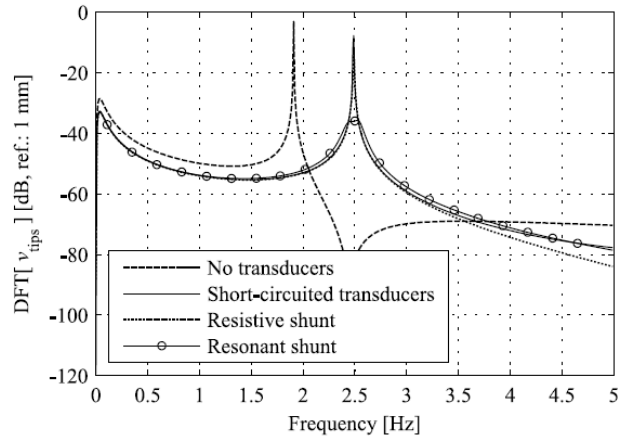
Conclusions:

- Effective vibration damping
- Need of TRL increase









VIBRATION CONTROL OF SATELLITE PANELS USING PIEZOELECTRIC TRANSDUCERS

Acta Astronautica 139 (2017) 357–366

Contents lists available at ScienceDirect

Acta Astronautica

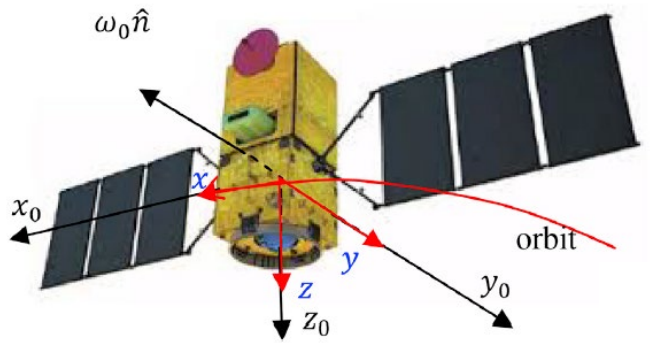
journal homepage: www.elsevier.com/locate/actaastro

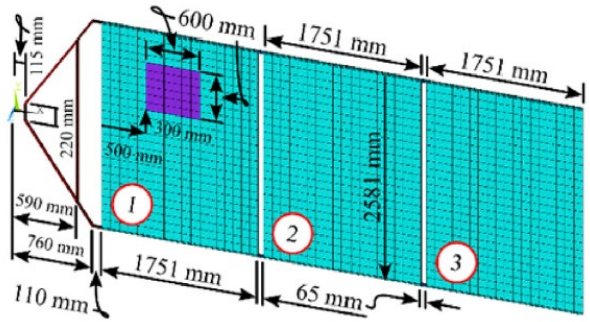
Attitude and vibration control of a satellite containing flexible solar arrays by using reaction wheels, and piezoelectric transducers as sensors and actuators

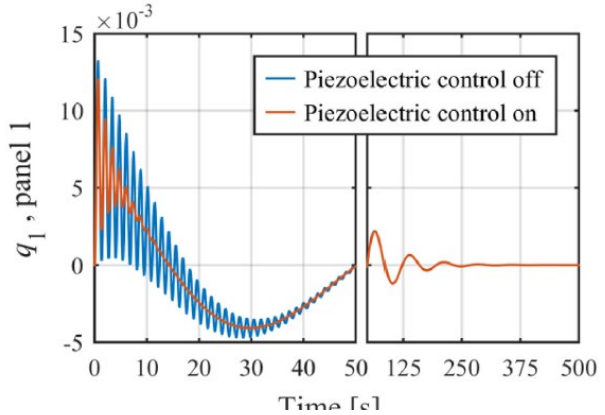
Ijar M. da Fonseca [a,*], Domingos A. Rade [b], Luiz C.S. Goes [b], Thiago de Paula Sales [c]

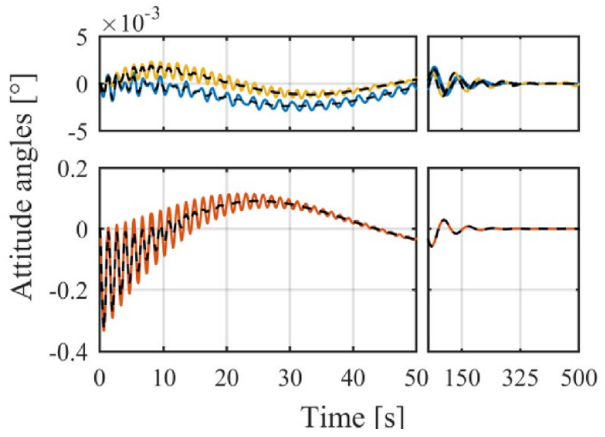
[a] Aeronautical Mechanics Division, ITA and Space Mechanics and Control Division, INPE, S. J. dos Campos, SP, Brazil
[b] Aeronautical Mechanics Division, ITA, S. J. dos Campos, SP, Brazil
[c] Federal University of Uberlândia, UFU, Uberlândia, MG, Brazil

https://doi.org/10.1016/j.actaastro.2017.07.018









Objective:

- Attenuation of the attitude/flexible vibration coupling induced by attitude correction maneuvers.

Approaches:

- Active vibration control using piezoelectric transducers as sensors and actuators.

Conclusions:

- Effective coupling mitigation
- Need of TRL increase

VARIABLE-CAMBER MORPHING WING USING SMA WIRES AND PERMANENT MAGNETS

FAPESP France Week 2025

Journal of the Brazilian Society of Mechanical Sciences and Engineering (2020) 42:122
https://doi.org/10.1007/s40430-020-2202-0

TECHNICAL PAPER

Check for updates

A morphing metastructure concept combining shape memory alloy wires and permanent magnets for multistable behavior

Thiago de P. Sales[1] · Domingos A. Rade[1] · Daniel J. Inman[2]

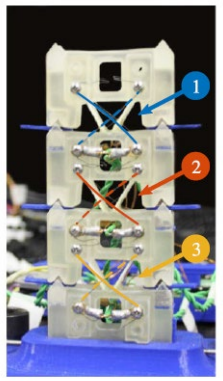
Received: 1 May 2019 / Accepted: 28 January 2020
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https://doi.org/10.1007/s40430-020-2202-0

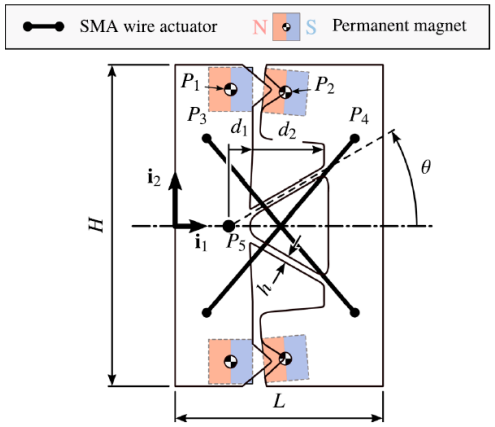
Objective: propose and assess strategies for the design of variable-camber morphing wings using SMA in association with permanent magnets to achieve multiple stable configurations.

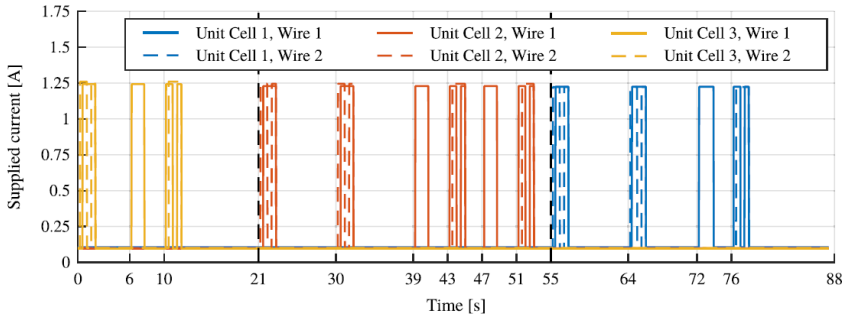
Conclusions:

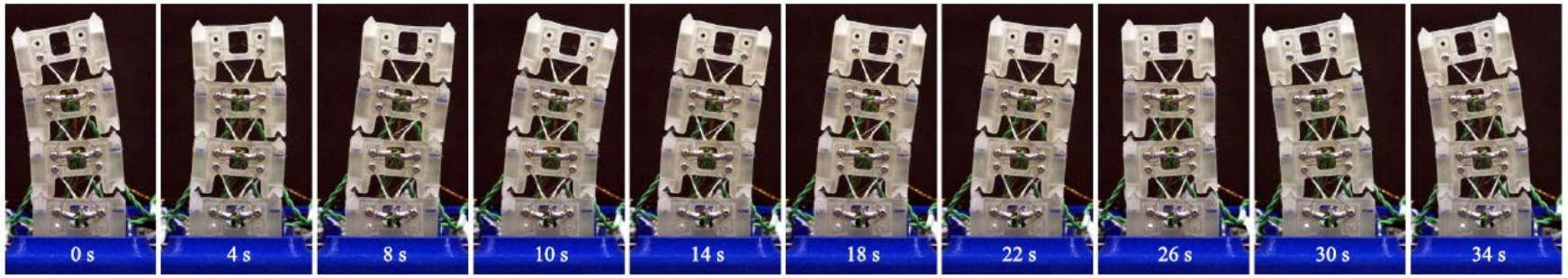
- Effective morphing capability
- Requires complex control procedures



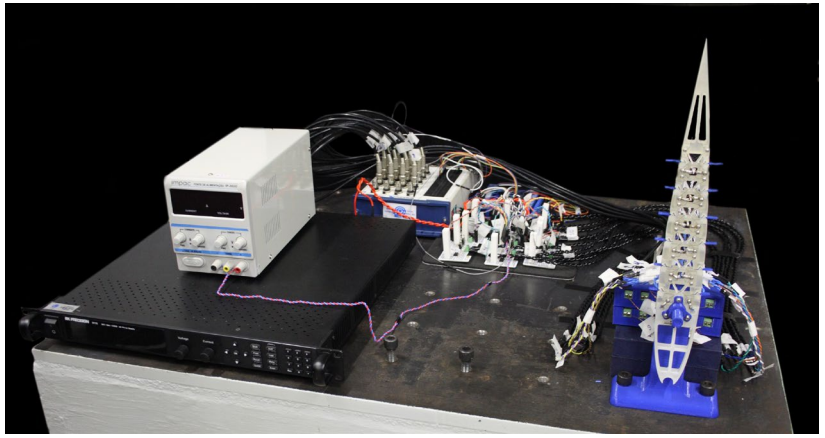
(b) Tested prototype

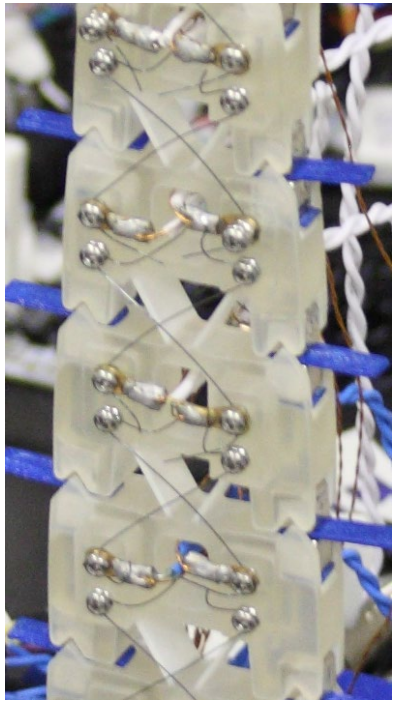


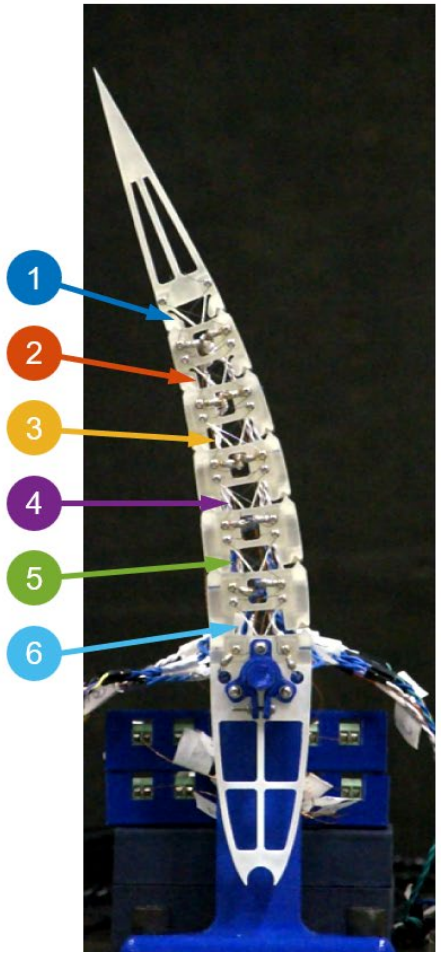


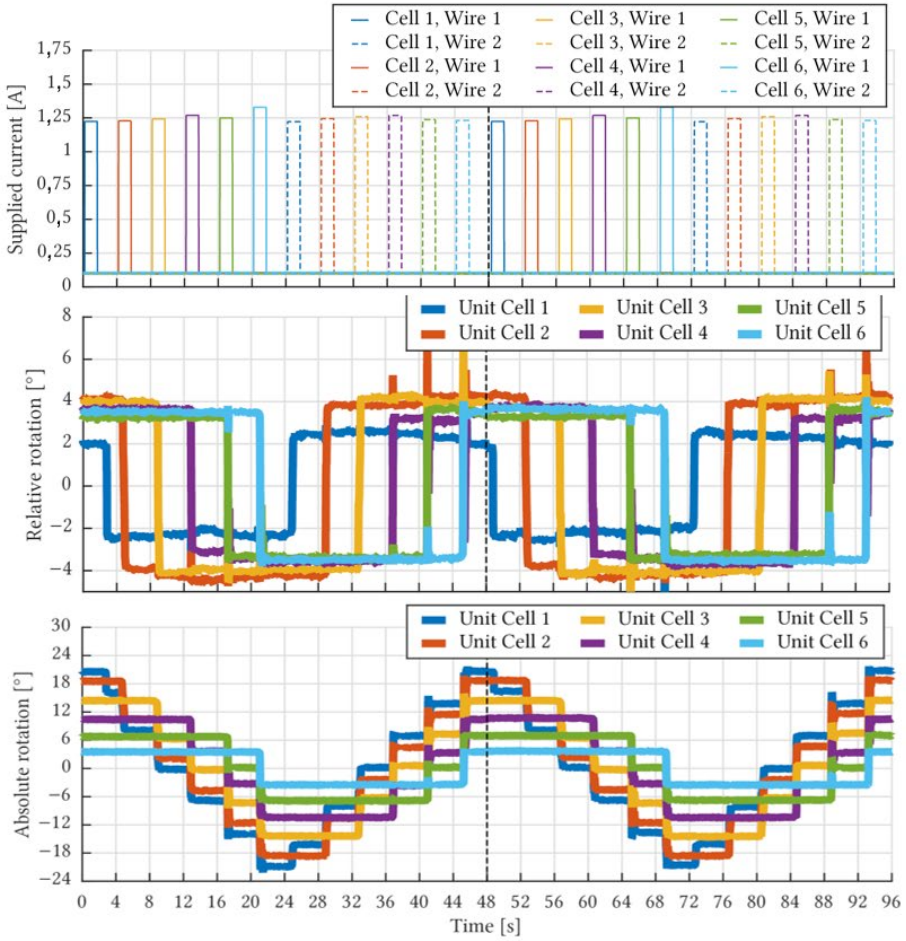


VARIABLE-CAMBER MORPHING WING USING SMA WIRES AND PERMANENT MAGNETS









RESEARCH ON SMART MATERIALS AND STRUCTURES

FAPESP France Week 2025

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Division of Mechanical Engineering
Laboratory of Dynamics & Vibrations

June 2025