Design of an experimental set-up to analyse compliant mechanisms used for the deployment of a panel

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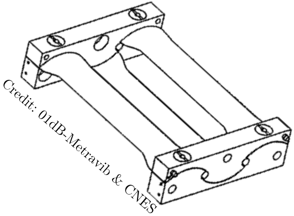
Outline

INTRODUCTION - TAPE SPRINGS

Definition: Thin strips curved along their width used as compliant mechanisms in replacement of common kinematic joints.



Space applications: deployment of solar panels, reflectors, antennas, masts...

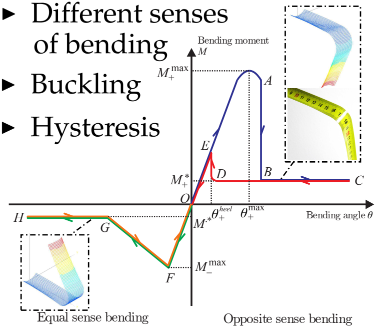
INTRODUCTION - TAPE SPRINGS

Assets:

- Storage of elastic energy
- Passive and self-actuated deployment
- No lubricant
- Self-locking in deployed configuration
- Possibilities of failure limited
- Versatility

Complexity:

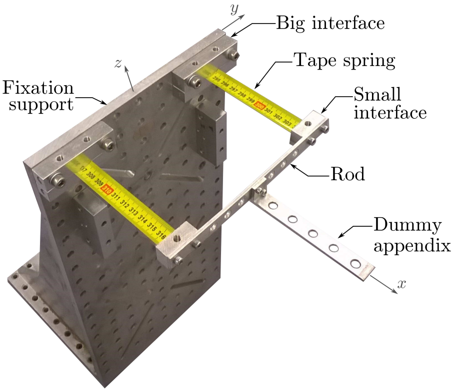
- Highly nonlinear
- Different senses of bending
- Buckling
- Hysteresis



Introduction - Objectives

- To design an **experimental set-up**
- To collect **experimental data** on tape springs
- To perform a **large variety of tests** (quasi-static, dynamic, small amplitude, large amplitude, ...)
- To evaluate the **parameters** required to develop a finite element model
- **To correlate** finite element models with the experimental results

EXPERIMENTAL SET-UP

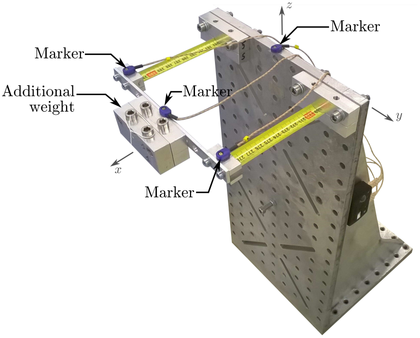


Constraints:

Despite the presence of the gravity field,

- No buckling under its own weight
- Passive deployment starting from a downwards folded configuration

EXPERIMENTAL SET-UP



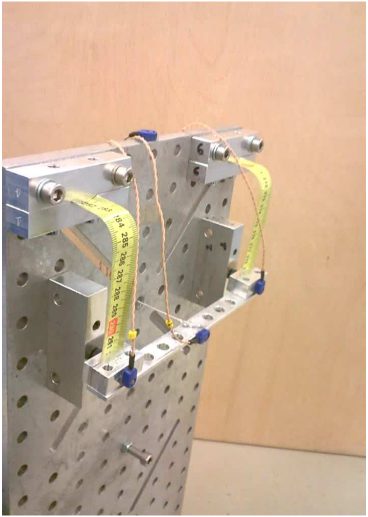
Acquisition equipment:

- 3D motion analysis system (CODAMOTION)
- Acquisition frequency: 800 Hz
- Triangulation of active markers (precision $\sim 0.3\ mm$)
- Force plate under the support (KISTLER)

Laboratoire
Analyse
Mouvement
Humain

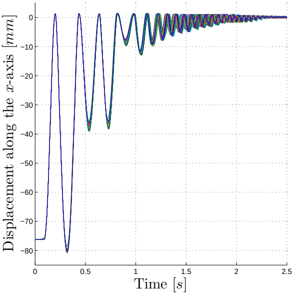
EXPERIMENTAL SET-UP

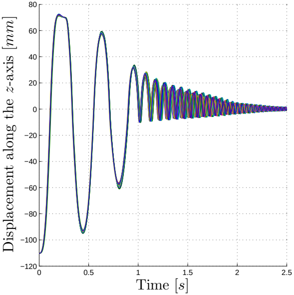
Deployment tests:
Initial downwards folding in opposite sense



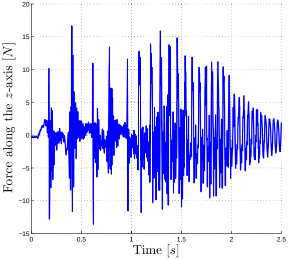
EXPERIMENTAL SET-UP

Positions: (superposition of 50 curves)





Vertical force:

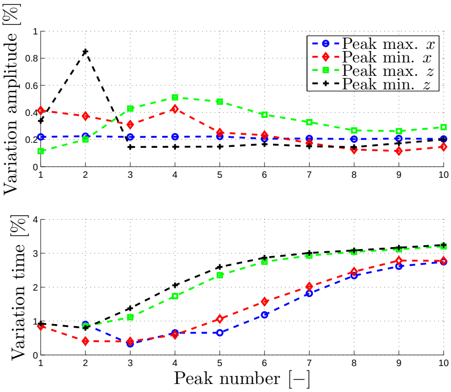


DEPLOYMENT TESTS

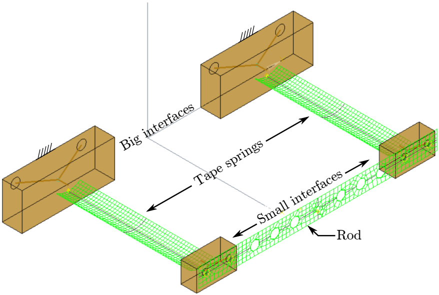
Reproducibility of the experimental results: for 170 tests with 4 pairs of tape springs

On the positions:

- Relative SD. $< 1\ \%$ for the peak amplitudes
- Relative SD. $\nearrow$ for the peak times



FINITE ELEMENT MODEL



- Shells for tape springs and rod
- Rigid interfaces
- Big interfaces clamped (fixation support not represented)
- Structural damping in the tape springs
- Nonlinear dynamic analyses
- Generalised-α method
- Low numerical damping
- Automatic time stepping procedure
- SAMCEF software

FINITE ELEMENT MODEL

Unknown parameters:

- Thickness t and Young's modulus E of the tape springs

Why?
- Small thickness ($\sim 0.14\ mm$)
- Tape springs cut out from a common measuring tape
- Composite (metallic layer + coating + plastic)
- Non uniformity

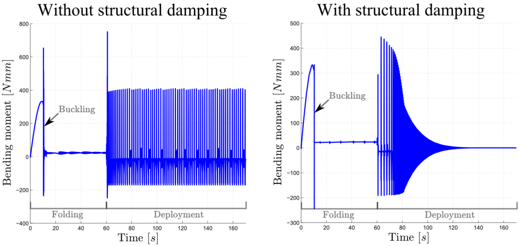
Strategy of identification: Quasi-static three points bending tests

FINITE ELEMENT MODEL

Unknown parameters:

- Structural damping ε

Why? ▪ Various sources (material, connections, air resistance, acoustic effects, ...)
▪ Important parameter to capture the physical behaviour

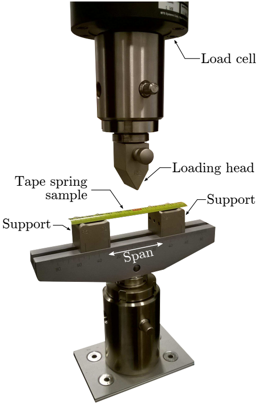


Source: Dewalque, Rochus, Bruls, Importance of structural damping in the dynamic analysis of compliant deployable structures, Acta Astronautica 2015

Strategy of identification: Small amplitude vibration tests

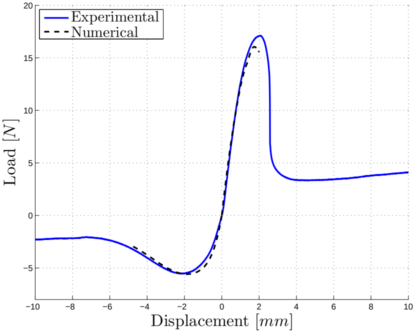
IDENTIFICATION OF t AND E

Three points bending tests:



Exp. relative SD. $< 5\ \%$

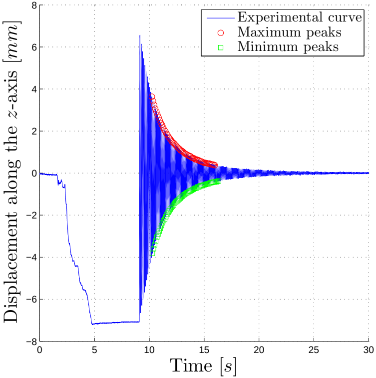
Use of an optimisation algorithm coupled to a FE model to determine t and E fitting the experimental results



$\Delta(exp - num) < 14\ \%$

IDENTIFICATION OF THE STRUCTURAL DAMPING

Small amplitude vibration tests:



Hypothesis: Exponential decay of the oscillations $Z \exp(-\varepsilon\omega t)$

$\Rightarrow$ Can be represented by a Kelvin-Voigt model in the FE model

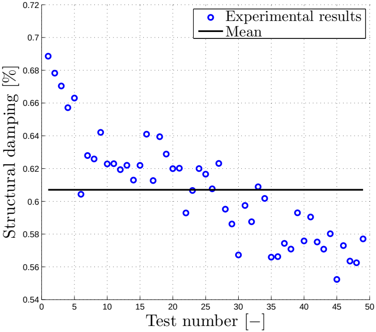
IDENTIFICATION OF ε

Small amplitude vibration tests: (510 tests in 11 sessions)

	Mean	Max. diff.	Relative SD.
ε	0.509 %	0.288 %	**20.67** %
Δt	0.100 s	0.003 s	**0.919** %

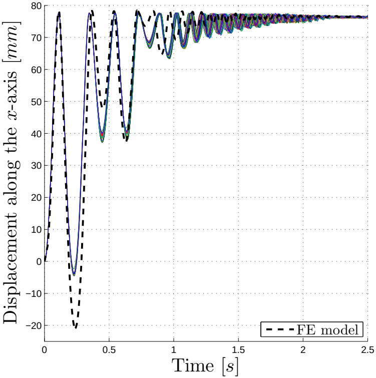
Challenging measurements:

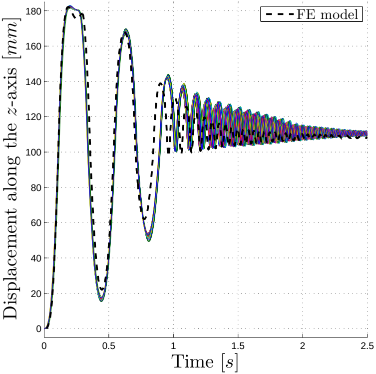
- Sensitivity to the assembly procedure
- Non-uniformity of the samples cut out from the same measuring tape
- Thermal effects within a session of tests



VALIDATION OF THE FE MODEL

Deployment tests: comparison with the experimental results





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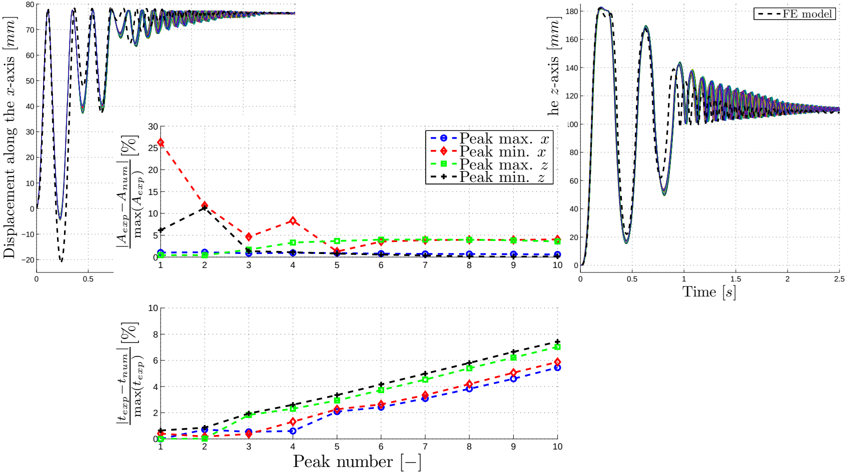
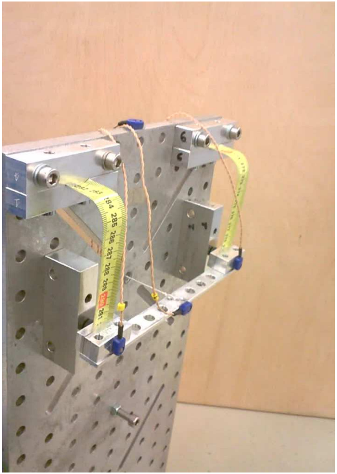
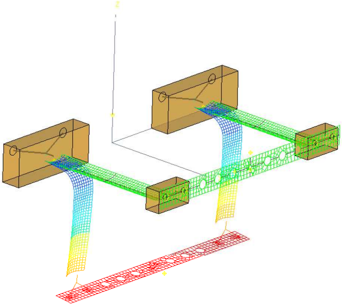


Validation of the FE model

Experimental



Numerical



Conclusions

- Design of an **experimental set-up**
- Acquisition of experimental data by the means of a **3D motion analysis system**
- **Good reproducibility** of the deployment tests
- Identification of the FE parameters based on **3PBT** and **small vibrations** (no use of the deployment tests)
- **Fair correlation** of the FE model ($\Delta < 15\ \%$)
- Good **basis for a prediction** of the behaviour in space environment

Conclusions

Perspectives:

- Perform experimental tests in equal sense
- Add markers on the set-up
- Improve the numerical model
  - Investigate other damping models
  - Represent the fixation support in the FE model

THANK YOU FOR YOUR ATTENTION

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fnrs FREEDOM TO RESEARCH