

## **ED SMAER**

### **Sujet de thèses 2013**

Laboratoire : Institut Jean Le Rond d'Alembert – Equipe MISES

Etablissement de rattachement : CNRS UMR 7190 - Université Pierre et Marie Curie Paris

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Titre de la thèse :

Contrôle de forme de coques multistables : modélisation, optimisation et mise en oeuvre

Collaborations dans le cadre de la thèse :

Federica Daghia, MCF ENS Cachan, Laboratoire de Mécanique et Technologie (LMT) & Département de Génie Mécanique (DGM)

Stefano Vidoli, Professeur, Università Roma 1 “La Sapienza” & Institut d’Alembert

Rattachement à un programme :

Le sujet peut être publié sur le site web de l'ED SMAER : OUI

#### **Résumé du sujet :**

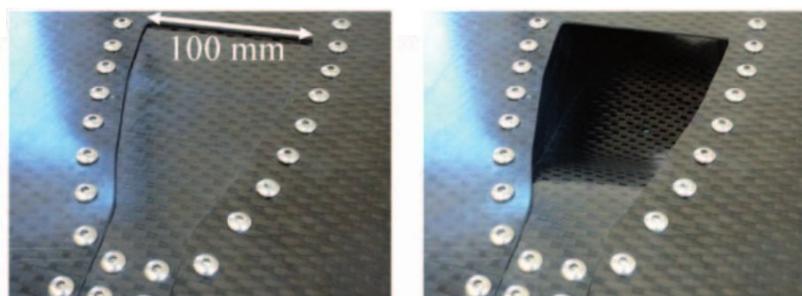
L'objectif de cette étude est la recherche dans le domaine des structures composites multistables, c'est-à-dire possédant plusieurs configurations distinctes d'équilibre stable : ces structures, soumises à des changements de formes importants par les chargements externes et une actuation appropriée, sont les éléments constitutifs de systèmes dits « intelligents » et « adaptatifs ». Une liste non exhaustive d'exemples d'applications : en aéronautique, des panneaux flexibles pour le contrôle d'écoulements, des ailes à géométrie variable ; dans les structures aérospatiales, des panneaux solaires flexibles qui peuvent s'enrouler/dérouler lors du lancement ; des dispositifs électroniques flexibles et pliables ; en architecture moderne, des panneaux à géométrie variable intégrés dans les toitures et les façades pour le contrôle de l'ensoleillement et de la ventilation.

La conception de structures multistables à géométrie variable dotées d'une actuation appropriée est un problème difficile, aussi bien d'un point de vue scientifique que technologique. Cela demande une profonde modification des règles et modalités courantes d'analyse et conception autant au niveau des modèles utilisés, que des techniques numériques.

L'objectif de la thèse sera de mettre en place une approche intégrée de modélisation, conception optimale et mise en œuvre de coques composites multistables. Une hiérarchie de modèles non linéaires de coques, plus ou moins simplifiés, nous permettra d'étudier l'influence des propriétés matériau, des courbures initiales et des éventuelles précontraintes sur les positions d'équilibre stable d'une coque et sur le différentiel énergétique entre ces positions (paramètre qui détermine l'énergie nécessaire à l'actuation). Des techniques numériques de simulation et optimisation seront appliquées pour la conception de structures multistables. Finalement, on se concentrera sur l'étude de l'actuation pour le passage d'un équilibre à l'autre : dans ce but, on envisage l'utilisation d'alliages à mémoire de forme.

**Sujet développé** (à présenter en 2 ou 3 pages maximum,  
en précisant notamment le contexte, les objectifs, les résultats attendus)

*Motivation.* Multistable structures appear to be an effective mean of compensating for the lack of active materials able to provide powerful muscle-like action. Beautiful and inspiring examples are found in several natural organisms, such as the Venus flytrap, a plant that captures its prey by triggering the snapping of its multistable leaves [1]. The bistable air inlet recently proposed in [2] and reported in Figure 1 provides a tangible example of application to fluid flow control: a composite shell with non-uniform stiffness distribution is able to maintain open and closed flush geometries without a holding force from an actuator. Even though the use of morphing multistable structures is attractive for a wide range of use cases and may potentially lead to a technological breakthrough in aeronautical engineering [3], only a few examples of actual design and manufacturing of demonstrators as in [2] can be found in the literature. The lack of simplified modelling tools and the lack of efficient actuation techniques constitute fundamental limits for their current applications.



*Figure 1 Morphing air inlet from Reference [2].*

*Scientific objectives.* Design and actuation of multistable structures require a global non-linear analysis, able to identify several equilibrium shapes and disclose their dependence on multiple material and loading parameters. This implies two main difficulties: (i) taking into account non-linear effects to design a structure with a set of assigned stable equilibrium configurations; (ii) conceiving efficient actuation techniques to control the transition among different equilibria. The starting point to tackle these issues is a careful study and a synoptic representation of the non-linear static behavior of the considered class of structures. This may be obtained only on the basis of simplified low-dimensional models, resuming the foremost qualitative properties of the system. Finite-element numerical studies may constitute a validation tool in a second step of the analysis, keeping in mind that the numerical analysis of non-linear systems with multiple stable equilibria remains a difficult task.

*Novelty.* The study of morphing multistable structures is a non-conventional research subject. It demands to put into work novel analysis and design methodologies. From the scientific point of view it demands to take into account in a design phase the influence of material non-homogeneities and anisotropy, pre-stresses, embedded actuation, material and geometrical non-linearities. The main novelty of this project is to propose an integrated approach to this problem, spanning from fine theoretical modelling to experimental validation, passing through advanced numerical analysis. We expect that this approach will provide a significant advance in the field and promote the use of novel multistable structural elements in the engineering practice.

### *Expected results.*

- An established methodology for the design and manufacturing of the morphing panels, including simplified analytical modelling, fine numerical validation and accurate reliable fabrication using fiber-reinforced composite materials.
- Realization of at least two different demonstrators pertaining to the cases of high and small energetic gaps between equilibria. These two classes indeed distinguish different operating regimes related to applications in which the transition is triggered by either suitable actuation forces or by small inputs as variations in the ambient conditions.
- Assessment of the use of SMA as actuation material for shape control of multistable shells.

*Potential applications.* Potential applications in aeronautics encompass shape-changing aerodynamic panels for flow control, variable geometry engine exhausts, and reconfigurable airplane wings. In defense, morphing composite structures are especially attractive for drone and micro-drone design. Flexible solar cells which are lightweight, can be rolled up for launch, and are easily deployable, are an example of application in space industry. Flexible electronics (flexible and folding electronic, such as smartphones) may benefit from a technological transfer from aeronautical and space applications. It is worth to mention the potential applications to some problems typical of architecture and civil engineering, as the control of ventilation and heat-exchanges (adaptive architecture). Other applications fields include optics (shape-changing mirrors for active focusing in adaptive optical systems) and microelectromechanical systems (micro-switches, mechanical memory cells, valves, micropumps).

### *Detailed program.*

1. Development of non-linear models of anisotropic laminated structures including SMA elements and investigation of their multistable behavior
2. Integration of analytical or semi-analytical non-linear modelling and optimization techniques for the study of multi-stability over simple reduced models
3. Integration of non-linear numerical simulations based on Föppl-Von Karman models and optimization techniques for the study of multi-stability over enriched models which can take into account different boundary conditions and distributions of material properties
4. Optimal design of laminates in the framework of the fully-coupled hygro-thermo-elastic behavior in order to define the feasible constitutive material of the laminated multi-stable structure
5. Finite-element validation of the proposed designs for multi-stable laminated structures
6. Manufacturing of simple multi-stable structures, which are issued from the design and optimization phase (in collaboration with F.Daghia at LMT ENS Cachan).

### REFERENCES

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