



HAL
open science

Experimental investigation of electro-active morphing for aeronautics applications

Johannes Scheller, Maxime Chinaud, Jean-François Rouchon, Eric Duhayon,
Marianna Braza

► **To cite this version:**

Johannes Scheller, Maxime Chinaud, Jean-François Rouchon, Eric Duhayon, Marianna Braza. Experimental investigation of electro-active morphing for aeronautics applications. 21e Congrès Français de Mécanique (CFM 2013), Aug 2013, Bordeaux, France. hal-03439831

HAL Id: hal-03439831

<https://hal.science/hal-03439831v1>

Submitted on 22 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Experimental investigation of electro-active morphing for aeronautics applications

JOHANNES SCHELLER^{a,b}, MAXIME CHINAUD^{a,b}, JEAN-FRANÇOIS ROUCHON^a, ERIC DUHAYON^a, MARIANNA BRAZA^b

a. LABORATOIRE PLASMA ET CONVERSION D'ENERGIE

b. Institut de Mécanique des Fluides de Toulouse

Résumé :

La présente étude vise à étudier l'effet physique d'un actionnement hybride piézoélectrique-alliage à mémoire de formes sur un écoulement à des nombres de Reynolds élevés. L'objectif est de montrer les effets de l'activation piézo-électrique à haute fréquence, faible amplitude du bord de fuite d'un prototype hybride de profil d'aile d'avion. À cette fin, la conception du prototype hybride sera détaillée, et les principes de fonctionnement des mécanismes d'actionnement seront mis en évidence. Après la description de la conception de l'actionneur, des résultats expérimentaux seront présentés. L'étude expérimentale est effectuée à l'aide de PIV tomographique. Il est montré à l'aide d'analyse spectrale que la faible amplitude imposé par le mécanisme d'actionnement piézo-électrique au niveau du bord de fuite de la structure étudiée, est capable d'influencer l'écoulement.

Abstract :

The present paper aims at investigating the physical effect on the flow via a hybrid piezoelectric-shape memory alloy actuation at high Reynolds numbers. The aim is to show the effects of the high-frequency low amplitude piezoelectric actuation at the trailing edge of a hybrid prototype of an airfoil. To this end the design of the hybrid prototype will be detailed, and the functional principles of the underlying mechanisms will be highlighted. Following the description of the design the experimental results are presented. The experimental investigation is carried out by means of tomographic PIV. It is shown that the low amplitude of the piezoelectric actuation mechanism at the trailing edge of the structure under study is capable of influencing the flow.

Mots clefs : electro-active morphing, piezoelectric actuation, turbulence

1 Introduction

Conventional fixed wing airfoil geometries are usually the result of a design compromise optimizing the shape only for some parts of the mission profile. Control surfaces while modifying the aerodynamic profile of the wing and thereby extending the mission profile are usually characterized by poor aerodynamic performance and efficiency [19]. Adaptive or morphing structures hold the potential to solve this problem and studies on wing deformation are subject of much interest in the aerospace domain. Recent advances made in the field of smart-materials have renewed this interest [15].

The Electro-active morphing for micro-air-vehicles (EMMAV) research program, which was created as part of the French foundation of «Sciences et Technologies pour l'Aéronautique et l'Espace»'s effort to develop micro- and nano-air-vehicles and is composed of three French laboratories (IMFT, LAPLACE, ISAE), aims at optimizing the performance of micro-air-vehicles in realistic environments via electro-active morphing [17]. During the course of this project a deformable structure was developed with embedded Shape memory alloys (SMAs) ensuring high deformation. The SMA technology, which in the case of the EMMAV research program was a structure of Nickel and Titanium (NiTi), was able to create large deformations over a large range of stresses but was limited to a low frequency of actuation.

These characteristics make it especially suitable to optimize the shape of the wing and to control the flight. The SMA actuators were activated using the Joule effect. This mechanism is well understood and was for example implemented by Barbarino [1] and Manzo [14] in order to modify the shape of an airfoil. The developed plate allowed to study the fluid-structure coupling via wind tunnel experiments [5].

In order to control and influence the aero-elastic coupling effect inducing both noise and drag a more high frequent actuation was necessary. Therefore as a second pillar of the EMMAV research program an actuation mechanism based on piezoelectric stack actuators was developed. These actuators are able to achieve a very high frequency of actuation (in the order of kHz) useful to produce trailing-edge vortices breakdown but only provide a very limited amount of deformation (several μm). Hence, an amplification was necessary. With regards to piezoelectric stack actuators there is a diverse offer of currently available amplification mechanisms. Amplified piezoelectric stacks and flexion actuators are among the more common amplification mechanisms [12]. The X-Frame and double X-Frame actuators developed at MIT amplify the deformation via a «scissor»-like mechanism [16, 6, 7]. They were used in Boeing's SMART active flap [18]. EADS optimized an amplified stack actuator to be used for the active control of a helicopter rotor [11, 10]. Finally NOLIAC developed a diamond type amplification mechanism optimized for low weight and high energy density [13]. Since all the previously described mechanisms add a considerable amount of weight and only allow for unidirectional amplification a new PUSH-PUSH amplification mechanism was developed at LAPLACE [4].

This work is developed as follows : in a first part we recall the fundamental properties of piezoelectric actuators, shape memory alloys and the developed actuation mechanisms. Subsequently we present the control and instrumentation of both the SMA and piezoelectric actuation mechanisms. Then we present the results of the Particle image velocimetry (PIV) measurements in the windtunnel at $Re = 200000$ for the piezoelectric actuation mechanism. Finally we will summarize the obtained results and present the perspective for future work.

2 Smart materials

2.1 Piezoelectricity

In 1880 the brothers Jacques and Pierre Curie discovered that certain types of materials became electrically polarized when subjected to a mechanical force. This effect became known as the direct piezoelectric effect and is nowadays exploited in variety of sensor and energy harvesting applications. The inverse effect, that is to say the deformation of the material when an electric field is applied, is used in different actuators from image stabilizers in cameras to accelerometers and elements for vibration control [9]. Piezoelectric materials are defined by an electro-mechanical coupling which can be described by the following equations :

$$\{S\} = [s^E] \cdot \{T\} + [d] \cdot \{E\} \quad (1)$$

$$\{D\} = [d] \cdot \{T\} + [\epsilon^T] \cdot \{E\} \quad (2)$$

where $\{S\}$ is the strain vector, $[s^E]$ is the compliance matrix, $\{T\}$ is the stress vector, $[d]$ is the matrix of piezoelectric constants, $\{D\}$ is the dielectric displacement vector, $[\epsilon^T]$ is the permittivity matrix and $\{E\}$ is the electric field vector. During the course of this work, piezoelectric stack actuators were used. These actuators are made out of several layers of piezoelectric ceramics with alternating polarity bonded together as illustrated in Figure 1. This amplifies the deformation of a single piezoelectric element. The achievable deformation δl of these types of actuators can be approximated by $\delta l = N \cdot d_{33} \cdot V$, where N is the number of layers of the stack. While this actuator has a large blocking force the significant capacitance of the stacked piezoelectric elements has to be kept in mind.

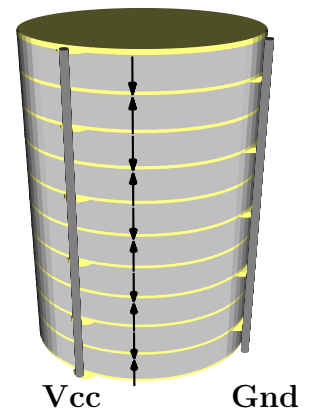


FIGURE 1 – Illustration of a piezoelectric stack actuator

2.2 Shape memory alloys

Whereas piezoelectric actuators are characterized by an electro-mechanical coupling, SMAs are defined by a thermo-mechanical dependance. In other words a change in the temperature induces a change in the intrinsic properties of the material. The material is able to produce large deformations (6% – 9%) over a large range of stresses (200Mpa) but at limited deformation speeds. The shape memory effect in these types of alloys is caused by a change in the crystalline structure of the material induced by a variation of the temperature. Two crystalline phases can be distinguished : the so called martensitic phase with a lattice crystal structure and the austenitic phase with a cubic crystal structure. Due to the reversability of the shape change this material is a good candidate for an actuator in smart structures. Amongst the various mechanical properties exhibited by these kinds of materials the hysteresis effect between the martensite-austenite transformations is certainly the most remarkable one. This effect has to be considered when precise structural control is desired. It can be shown that the resistance R of the alloy is a suitable control parameter for the displacement of a SMA wire [3].

3 Actuation mechanism

Based on the previously described smart materials, an integrated actuation mechanism has been developed exploiting the benefits of both material types. Naturally, the mechanism is split in two parts, the large displacement low frequency actuation achieved by SMAs and the small displacement high frequency actuation achieved by piezoelectric actuators.

The proposed piezoelectric PUSH-PUSH actuation mechanism uses a lever in order to amplify the deformation of the stack actuators. By applying a force F at a distance δ_h to the neutral plane the flap can be deformed by δ_z as illustrated in Figure 2a. By placing two stack actuators at opposing sides of the neutral plane bidirectional flapping can be achieved (see Figure 2b). Hemispheric interfaces between the flap and the actuators enable the bidirectional motion when the stack actuators are driven in opposition.

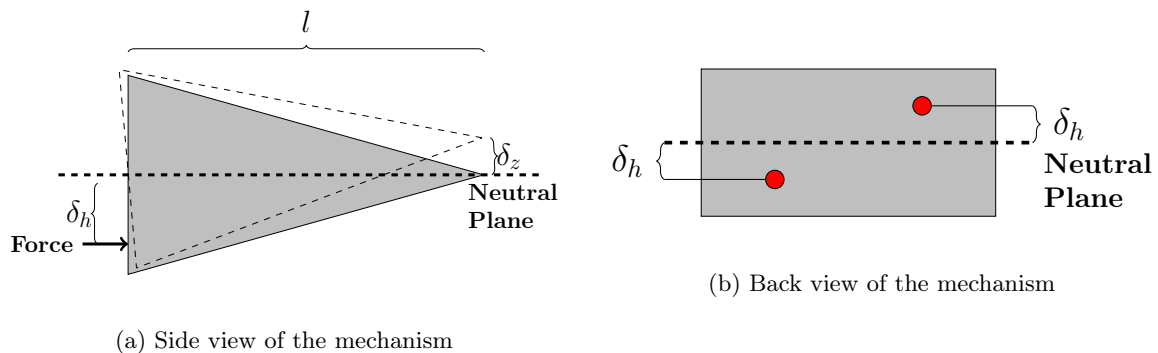


FIGURE 2 – PUSH-PUSH actuation mechanism

Whereas for the piezoelectric actuators an amplification mechanism had to be developed, the SMA based actuation mechanism works by simply embedding the wires into the structure above and below the neutral plane. Upon heating the wires contract and the structure is deformed. An integrated structure, shown in Figure 3a, has been developed combining both the piezoelectric actuation mechanism as well as the SMA based actuator.

4 Experimental investigation

The goal of the experiments were twofolds : the first goal was to show that the energy introduced from the low amplitude high frequency flapping of the piezoelectric part of the actuation mechanism is sufficient in order to influence the flow, building upon this work an optimization has to be performed. This paper will focus on the first part. To achieve this aim the flow past the integrated piezoelectric-SMA prototype (see Figure 3b) with an incidence angle of 10° and Reynolds number of 200.000 is considered (as shown in Figure 4). Using foam the prototype was given the structure of a NACA0012

airfoil. The present PIV measurements were being conducted in the S4 wind-tunnel of IMFT with the contribution of S. Cazin and M. Marchal of the IMFT signal and image processing service at a frequency of 1000Hz over a duration of 3s . The measurement zone (1024×1024 pixel) was at the trailing edge of the airfoil. The trailing edge Kelvin-Helmholtz vortices and response characteristics can be found in Hoarau et al. [8]. Laser Doppler velocimetry (LDV) experiments at high Reynolds numbers were carried out by Favier, Berton et al. [2] in the Marseille-Luminy wind-tunnel.

During the measurements the flap was actuated at different frequencies. The PIV measurements for the actuation at 60Hz and 90Hz are shown in Figure 5a and Figure 5c respectively. Using this data the Welch power spectral density estimate for both frequencies was created. The resulting spectra (for the point X :652 Y :396) are shown in Figures 5b and 5d. The higher frequency peaks are due to the Kelvin-Helmholtz vortices. The lower frequency peak is due to the von-Karman shedding, modulated by the strongly turbulent chaotic motion.

The low amplitude of the piezoelectric actuation mechanism at the trailing edge of the flap has a noticeable impact on the flow as can be seen from the spectra shown in Figures 5d and 5b. The change in the frequency of the actuation of the piezoelectric actuators leads to a shift in the peaks of the power spectral density corresponding to the actuation frequency of the piezoelectric PUSH-PUSH actuator. A detailed analysis of the forcing effect from the actuation by means of the piezoelectric actuators will be presented concerning the modification of the wave structure past the trailing edge as a function of the actuation frequency.

5 Conclusion

The goal of this study was to demonstrate the effect on the flow of a low amplitude, high frequency piezoelectric actuation mechanism integrated in a hybrid prototype. To this end, the design of the hybrid prototype was illustrated and the actuation mechanisms were explained. Using this hybrid prototype it was shown, that the energy added via high-frequent, low amplitude actuation of the piezoelectric stack actuators has a noticeable impact on the velocity field. The peaks in the velocity field spectra correspond to the actuation frequency of the piezoelectric PUSH-PUSH actuation mechanism. This is especially interesting as this high frequent actuation has the potential to influence the high-frequent Kelvin-Helmholtz vortices whereas the low-frequent high amplitude SMAs are more suited to control the flight and for quasi-static optimization of the form.

A detailed investigation of the forcing is being conducted with regards to the effects on the turbulent structures namely the lower-frequent von-Karman and the higher-frequent Kelvin-Helmholtz vortices. The data obtained from the PIV measurements will be fully exploited in order to identify the effect of the actuation on the vortex structures. Based on this data, a control law has to be developed for the coupled piezoelectric-SMA actuation mechanism in order to optimize the form in real time by ensuring reduction of the instability modes.

On the other hand, the actuation mechanisms have to be improved. This includes further investigation regarding the optimal driving waveform for the piezoelectric actuators as well as an adaptation of the structure with embedded SMAs.

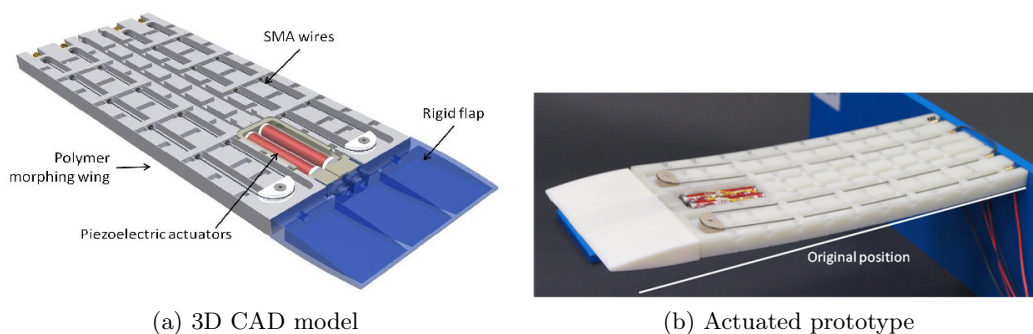


FIGURE 3 – Hybrid prototype

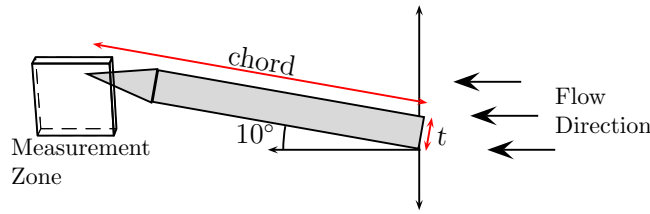
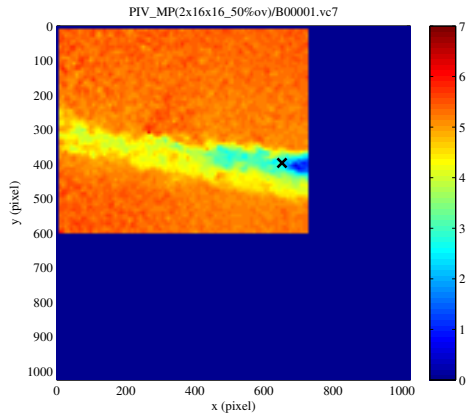
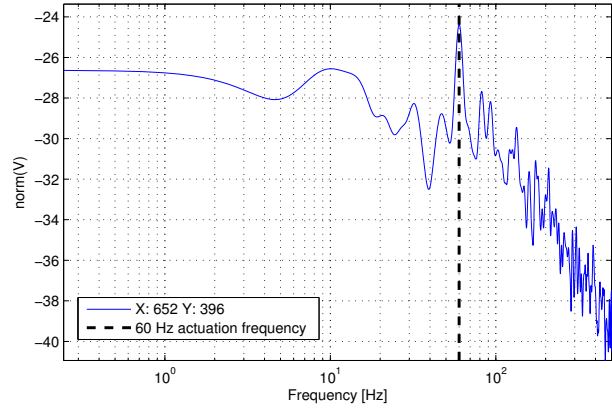


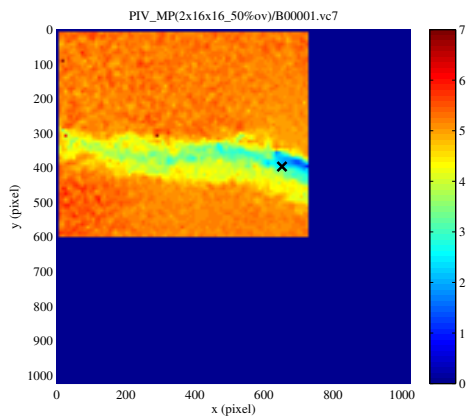
FIGURE 4 – Illustration of the experimental set-up



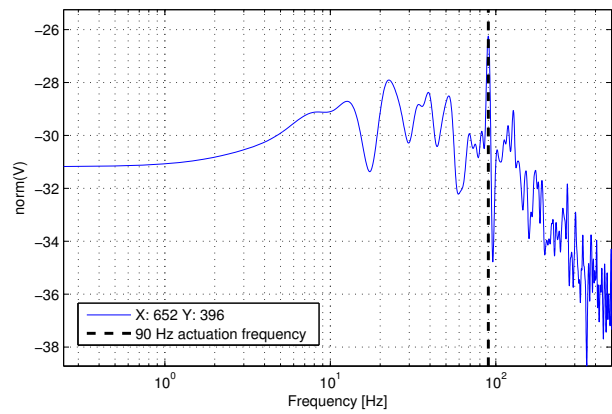
(a) PIV norm of velocity components at 60 Hz



(b) Welch power spectral density estimate at 60 Hz



(c) PIV norm of velocity components at 90 Hz



(d) Welch power spectral density estimate at 90 Hz

FIGURE 5 – Experimental results obtained via PIV measurements

Acknowledgements

The authors would like to thank D. Harribey from LAPLACE as well as S. Cazin, M. Marchal and C. Korbuly from IMFT for their help and support in realizing the present work.

Références

- [1] S Barbarino, R Pecora, L Lecce, A Concilio, S Ameduri, and E Calvi. A novel sma-based concept for airfoil structural morphing. *Journal of materials engineering and performance*, 18(5) :696–705, 2009.
- [2] E. Berton, C. Allain, D. Favier, and C Maresca. *Progress in Computational Flow-structure Interaction : Results of the Project UNSI, Supported by the European Union 1998-2000*, volume 81, chapter Experimental methods for subsonic flow measurements. Springer, 2002.

- [3] M. Chinaud, A. Boussaid, JF Rouchon, E Duhayon, E Deri, D Harribey, and M Braza. Thermo-mechanical coupling in nitinol. application to an electro-morphing plate. In *Electrical Machines (ICEM), 2012 XXth International Conference*, pages 2580–2584. IEEE, 2012.
- [4] Maxime Chinaud, Johannes Scheller, Jean François Rouchon, Eric Duhayon, and Marianna Braza. Hybrid electroactive wings morphing for aeronautic applications. *Solid State Phenomena*, 198 :200–205, 2013.
- [5] E Deri, H Ouvrard, M Braza, J Hunt, Y Hoarau, S Cazin, E Cid, and G Harran. Capturing coherent structures and turbulent interfaces in wake flows by means of the organised eddy simulation, oes and by tomo-piv. In *Journal of Physics : Conference Series*, volume 318, page 092002. IOP Publishing, 2011.
- [6] Steven R Hall and Eric F Prechtel. Preliminary testing of a mach-scaled active rotor blade with a trailing-edge servo flap. In *1999 Symposium on Smart Structures and Materials*, pages 14–21. International Society for Optics and Photonics, 1999.
- [7] Steven R Hall, Theodora Tzianetopoulou, Friedrich K Straub, and Hieu T Ngo. Design and testing of a double x-frame piezoelectric actuator. In *SPIE's 7th Annual International Symposium on Smart Structures and Materials*, pages 26–37. International Society for Optics and Photonics, 2000.
- [8] Yannick HOARAU, Marianna BRAZA, Y Ventikos, D Faghani, and G Tzabiras. Organized modes and the three-dimensional transition to turbulence in the incompressible flow around a naca0012 wing. *Journal of Fluid Mechanics*, 496(1) :63–72, 2003.
- [9] T.O. Ikeda. *Fundamentals of piezoelectricity*. Oxford University Press, 1990.
- [10] P Janker, F Claeysen, B Grohmann, M Christmann, T Lorkowski, R Leletty, O Sosniki, and A Pages. New actuators for aircraft and space applications. In *The 10th International Conference on New Actuator*, 2006.
- [11] P Jänker, F Hermle, S Friedl, K Lentner, B Enekl, and C Müller. Advanced piezoelectric servo flap system for rotor active control. In *32nd European rotorcraft forum, Maastricht, The Netherlands*, 2006.
- [12] R Le Letty, N Lhermet, G Patient, F Claeysen, and M Lang. Valves based on amplified piezoelectric actuators. *online,[retrieved on Jun. 20, 2011]*, 2002. URL : <http://www.cedrat.com/fileadmin/user-upload/cedrat-groupe/Publications/Publications/2002/06/Actuator2002-A4-6-VALVES-BASED-ON-AMPLIFIED-PIEZOELECTRIC-ACTUATORS.pdf>.
- [13] Charles Mangeot, Bjørn Andersen, and Ross Hilditch. New actuators for aerospace. In *Conf. Piezoelectric Actuation at the Institute of Mechanical Engineers (IMEchE), London*, volume 22, 2009.
- [14] Justin Edward Manzo. *Analysis and design of a hyper-elliptical cambered span morphing aircraft wing*. PhD thesis, Cornell University, 2006.
- [15] Anna-Maria Rivas McGowan, W Keats Wilkie, Robert W Moses, Renee C Lake, Jennifer Pinkerton Florance, Carol D Wieseman, Mercedes C Reaves, Barmac K Taleghani, Paul H Mirick, and Matthew L Wilbur. Aeroservoelastic and structural dynamics research on smart structures conducted at nasa langley research center. In *5th SPIE International Symposium on Smart Structures and Materials, San Diego, CA*, 1998.
- [16] Eric F Prechtel and Steven R Hall. Design of a high efficiency, large stroke, electromechanical actuator. *Smart Materials and Structures*, 8(1) :13, 1999.
- [17] Jean-François ROUCHON, Dominique HARRIBEY, Enrico DERRI, and Marianna BRAZA. Activation d'une voilure déformable par des câbles d'amf répartis en surface. *20ème Congrès Français de Mécanique, 28 août/2 sept. 2011-25044 Besançon, France (FR)*, 2011.
- [18] Friedrich K Straub, Dennis K Kennedy, Alan D Stemple, VR Anand, and Terry S Birchette. Development and whirl tower test of the smart active flap rotor. *San Diego, CA, USA, March*, 2004.
- [19] Narcis M Ursache, Tomas Melin, Askin T Isikveren, and Michael I Friswell. Morphing winglets for aircraft multi-phase improvement. In *7th AIAA ATIO Conference*, 2007.