Intelligent control of smart actuators in a new closed loop morphing wing mechanism

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Publisher's version / Version de l'éditeur:

ICAST2011, The 22nd International Conference on Adaptive Structures Technologies [Proceedings], 2011

Intelligent control of smart actuators in a new closed loop morphing wing mechanism

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The objective of the research presented here is to develop a new morphing mechanism using smart materials such as Shape Memory Alloy (SMA) as actuators and fuzzy logic techniques. These smart actuators deform the upper wing surface, made of a flexible skin, so that the laminar-to-turbulent transition point could move close to the wing trailing edge. The ultimate goal of this research project is to obtain a drag reduction as a function of flow condition by changing the wing shape. The transition location detection is based on pressure signals measured by optical and Kulite sensors installed on the upper wing flexible surface. Depending on the project evolution phase, two architectures are considered for the morphing system: open loop and closed loop. The difference between these two architectures is given by the use of the transition point as feedback signal. This research work was a part of a morphing wing project developed by the Ecole de Technologie Supérieure in Montréal, Canada, in collaboration with the Ecole Polytechnique in Montréal and the Institute for Aerospace Research at the National Research Council Canada (IAR-NRC).

Recently, morphing wing system studies have branched out into new research directions. Extremely complex and catalogued as inter- and multidisciplinary studies, morphing wing studies continue to 'push' the science, up to the extreme boundaries of mathematics and physics. These multidisciplinary studies therefore require knowledge in the following disciplines: aerodynamics and computational fluid dynamics, aeroelasticity, automatic control, intelligent materials, signal detection using the latest miniaturized sensors, high computer-time calculations, wind tunnel and flight testing, instruments, and signal acquisition - these signals have such speed that they are raising serious problems for the existing calculus technology. Consequently, real-time system functioning is conditioned (in addition to other factors) by the obtaining of the best data processing algorithms, easy to implement software within the command and control unit. Fuzzy logic theories, which offer remarkable facilities, may therefore be used in these algorithms. They facilitate signal processing by allowing empirical models to be designed based on experimental data; and thus, the complex mathematical calculus currently in use can be avoided. In addition, fuzzy logic can be used to model highly non-linear, multidimensional systems, including those with parameter variations, or where the sensors' signals are not accurate enough for other models. This research project included the following: optical sensor selection and testing for laminar-to-turbulent flow transition validation (by use of XFoil code and Matlab), smart material actuator modeling, aeroelasticity wing studies using MSC/Nastran, open loop and closed loop transition delay controller design, integration and validation on a wing equipped with SMAs and optical sensors.

A first phase of this project involved the determination of optimized airfoils available for 35 different flow conditions expressed in terms of five Mach numbers and seven angles of attack combinations. The optimized airfoils, derived from a laminar WTEA-TE1 reference airfoil (Fig. 1), were calculated and were used as a starting point in the actuation system design. Two steps were completed in the actuation system design phase: optimization of the number and positions of flexible skin actuation points, establishment of each actuation line's architecture (Fig. 2). The next phase of the project was about the design of the actuation control in open loop architecture of the morphing wing, for which an integrated on-off versus a fuzzy PID architecture was chosen (Fig. 3 to Fig. 5). In this design, numerical simulations of the open loop morphing wing integrated system, based on a SMA non-linear model, were performed; as subsequent validation methods, a bench test (Fig. 6, Fig. 7) and a wind tunnel test were conducted (Fig. 8, Fig. 9). In the final phase a closed loop controller was developed and experimentally validated (Fig. 10-Fig. 13).

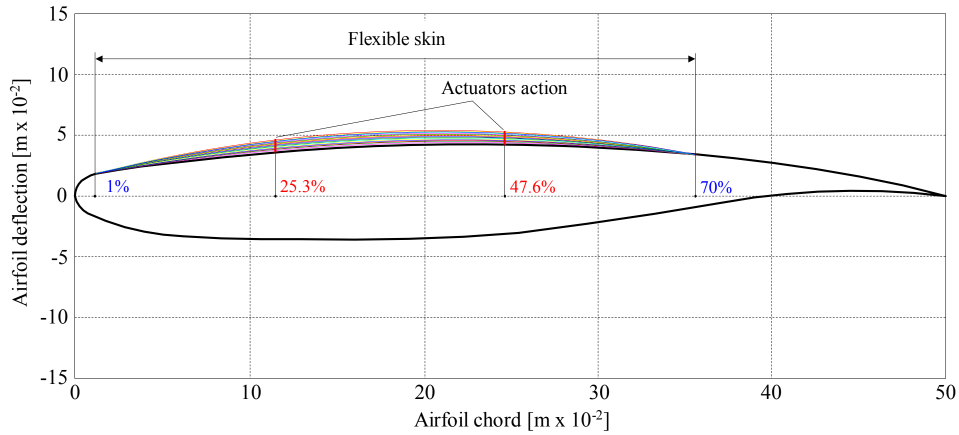

Fig. 1 Morphed airfoil shapes for different flow cases

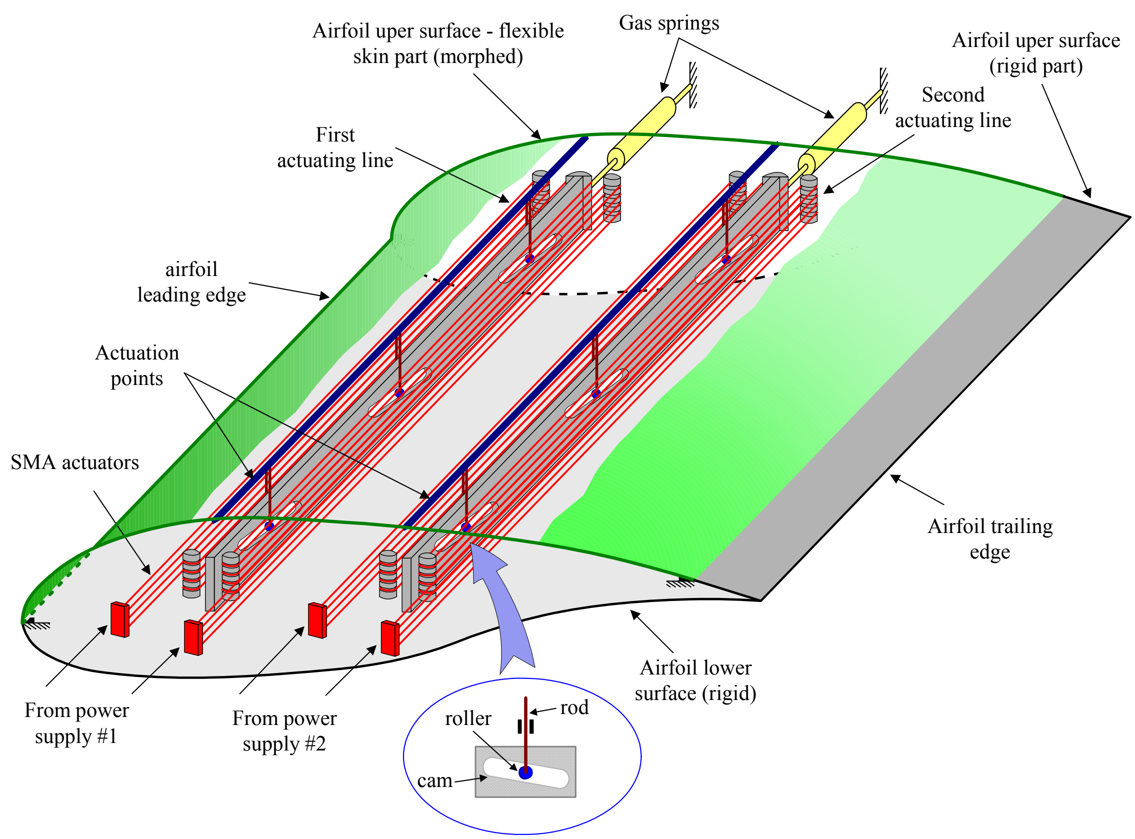

Fig. 2 Model of the flexible structure

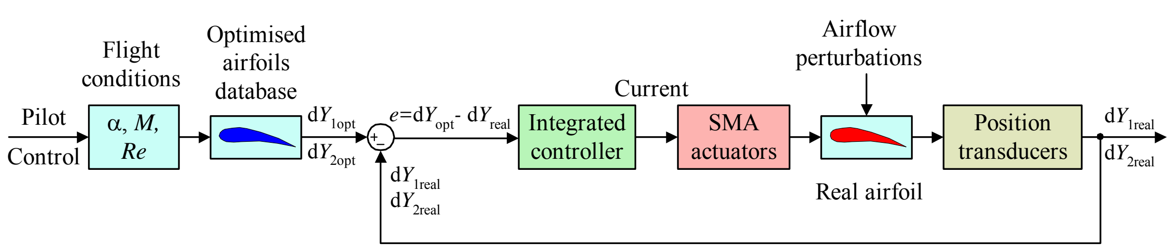

Fig. 3 Operating scheme of the SMA actuators control

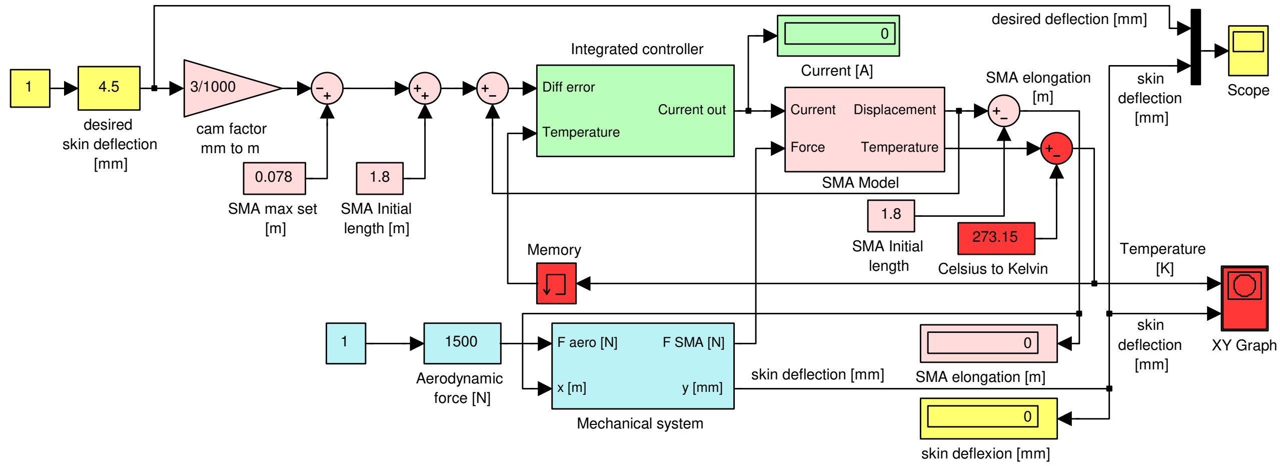

Fig. 4 The simulation model for the controlled SMA actuator

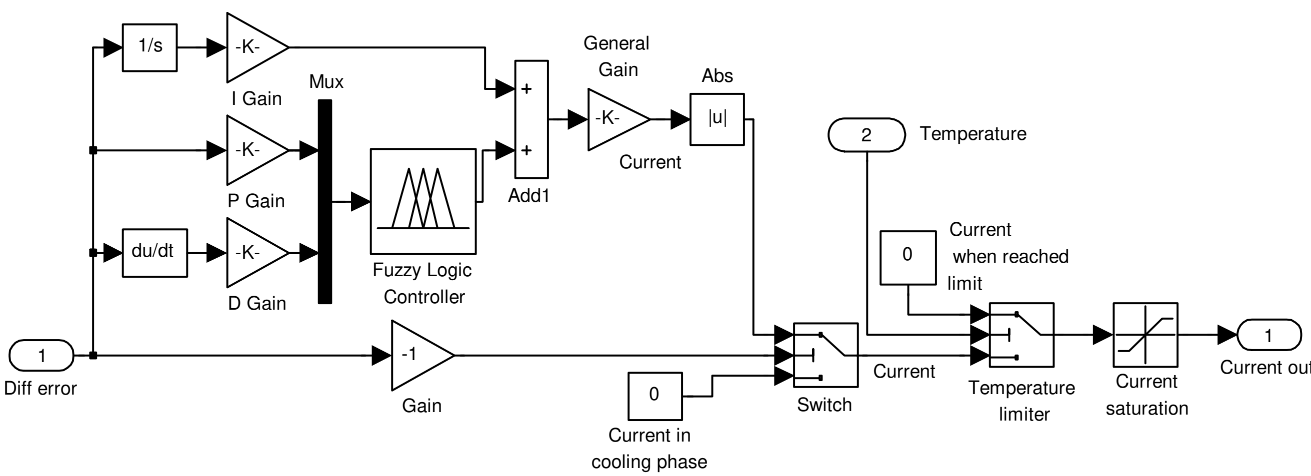

Fig. 5 The fuzzy PID architecture

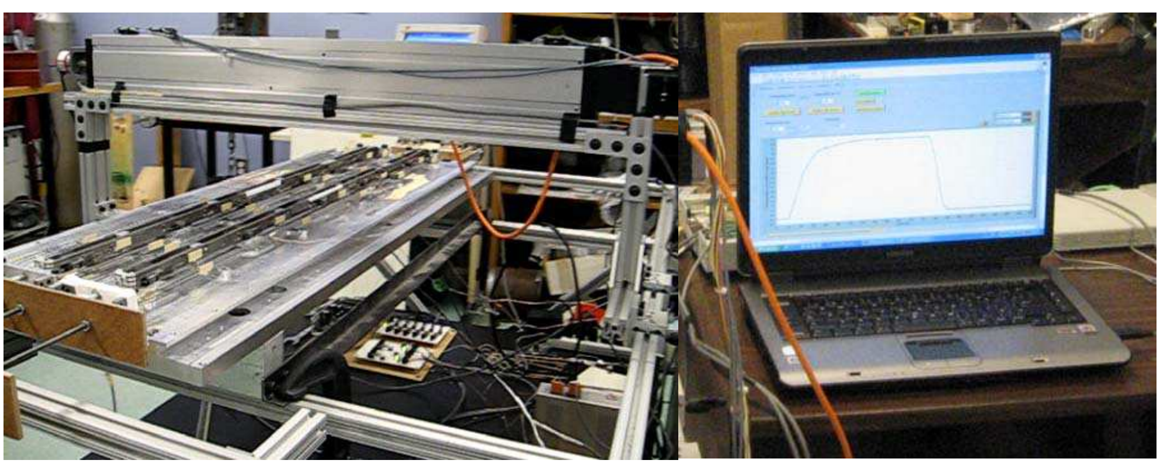

Fig. 6 Morphing wing system in the bench test runs

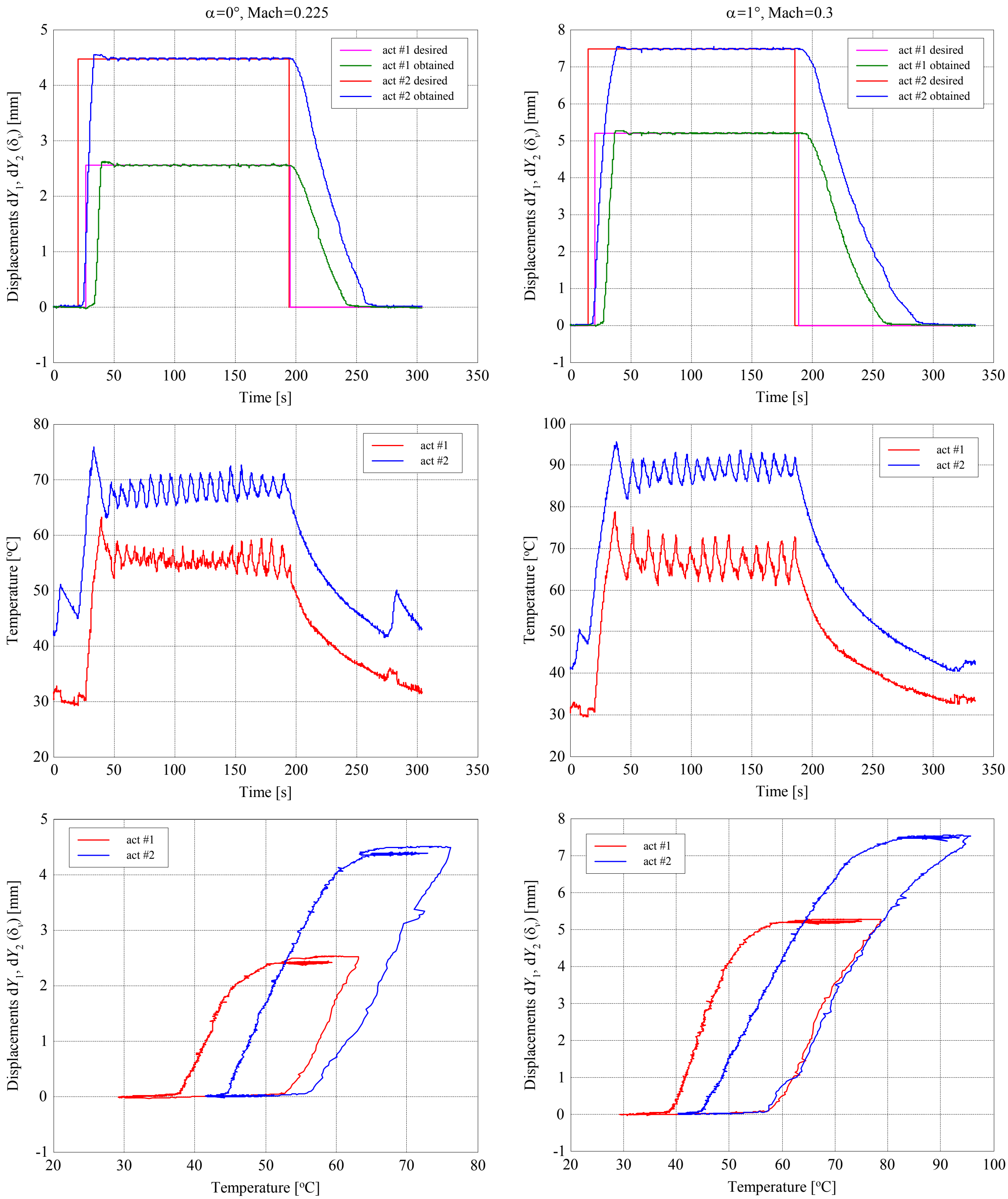

Fig. 7 Bench test results for α=0°, M=0.225 and for α=1°, M=0.3

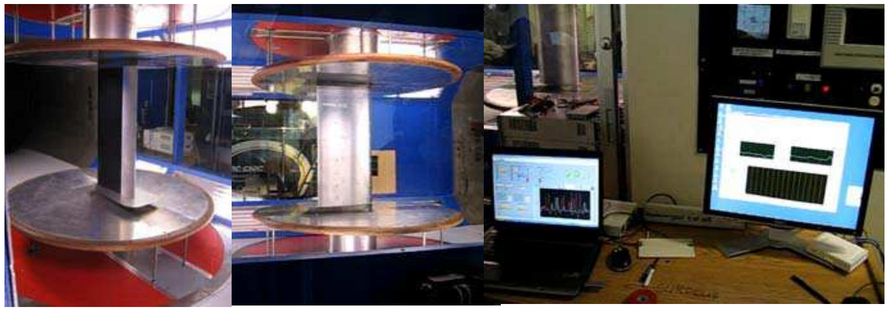

Fig. 8 Wind tunnel morphing wing model

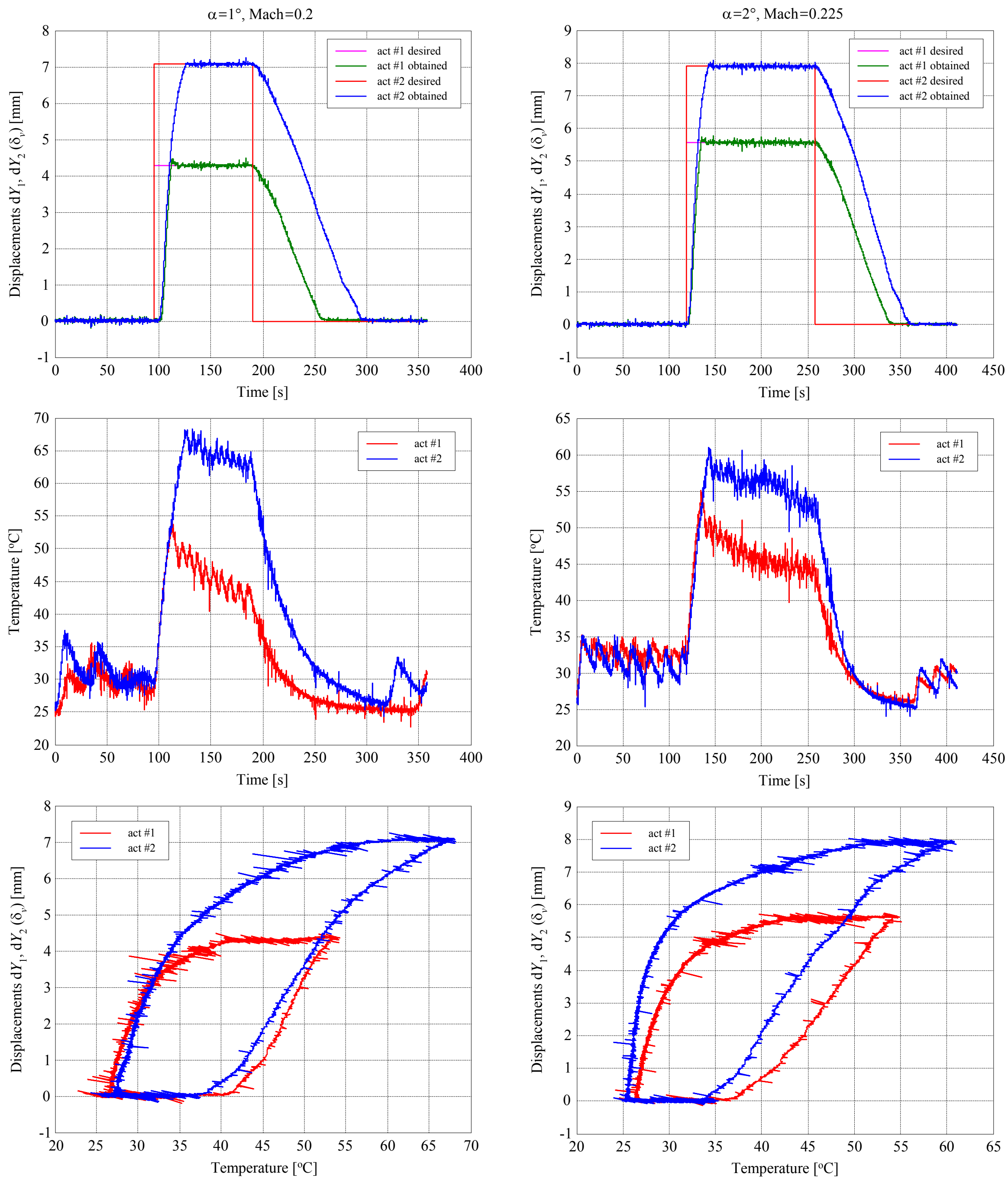

Fig. 9 Wind tunnel test results for α=1°, M=0.2 and for α=2°, M=0.25

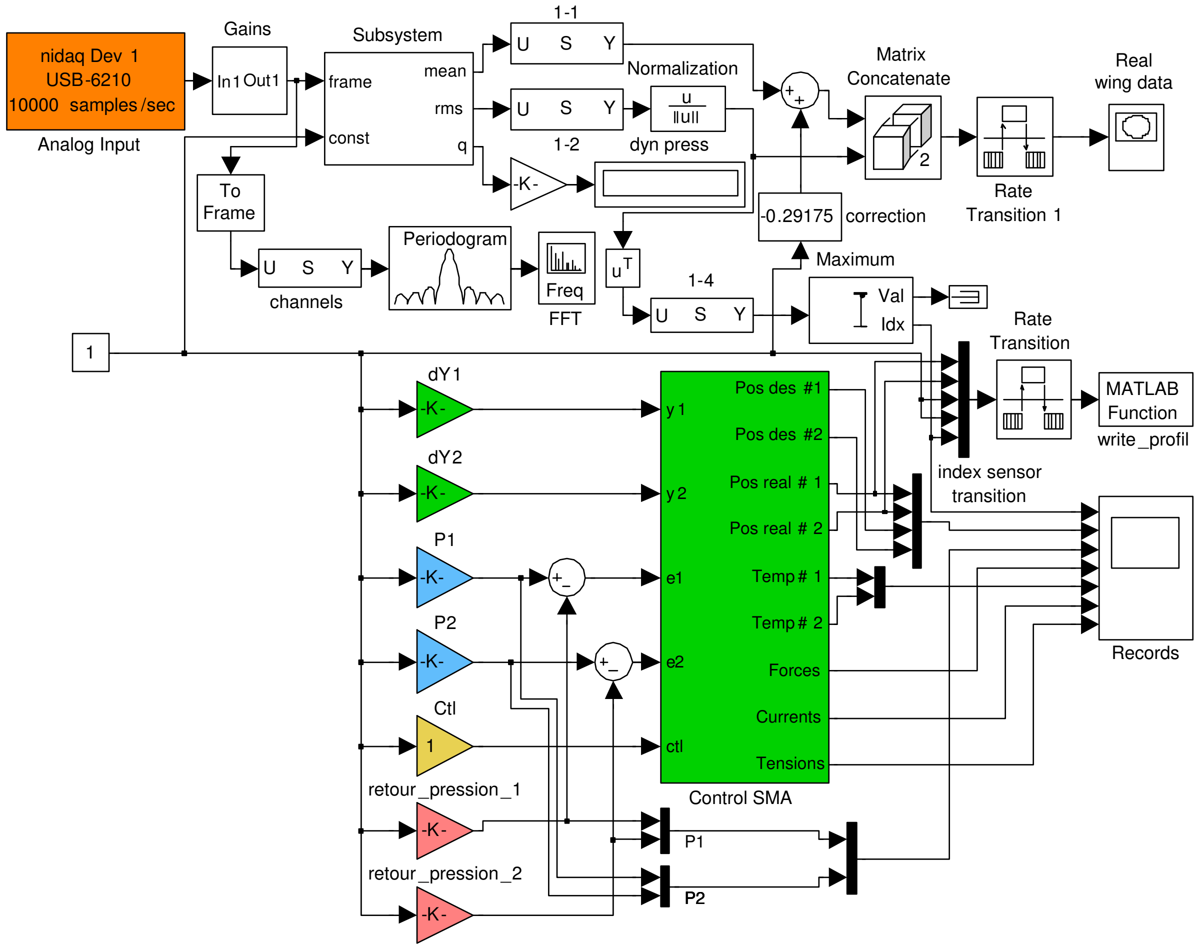

Fig. 10 Closed loop architecture of the morphing wing

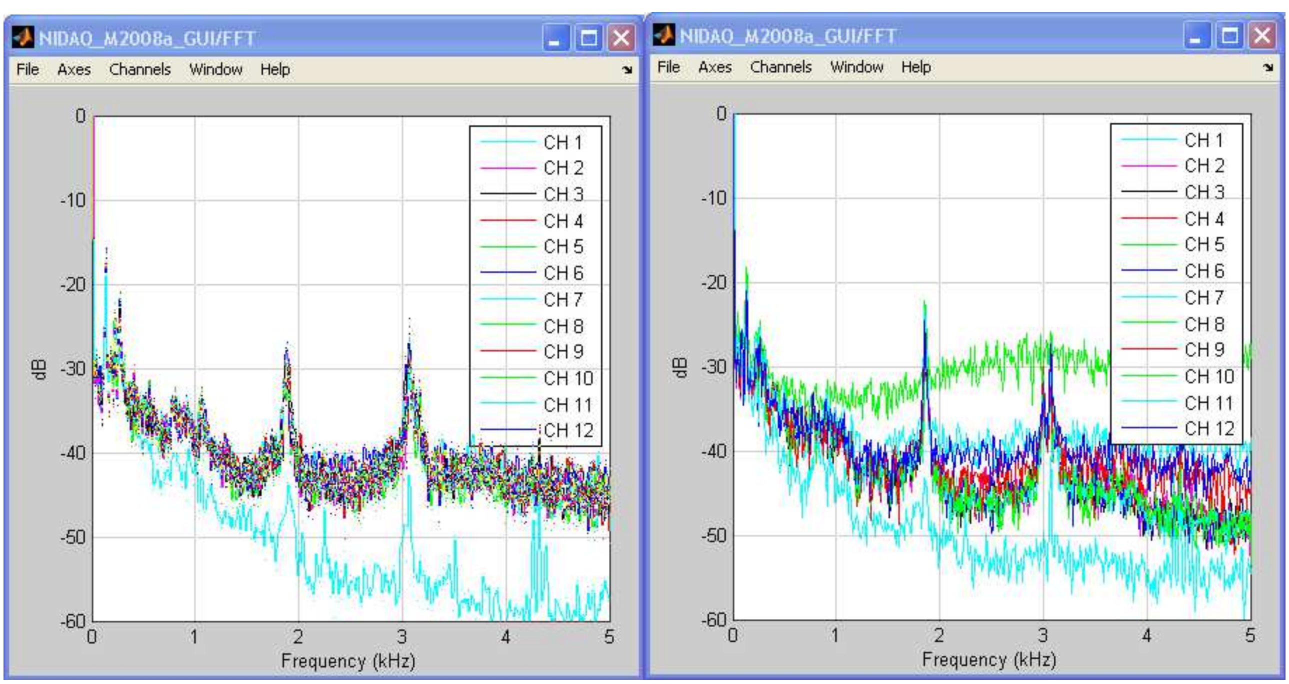

Fig. 11 Pressure signals FFT for un-morphed and morphed wing, for α=0°, M=0.3.

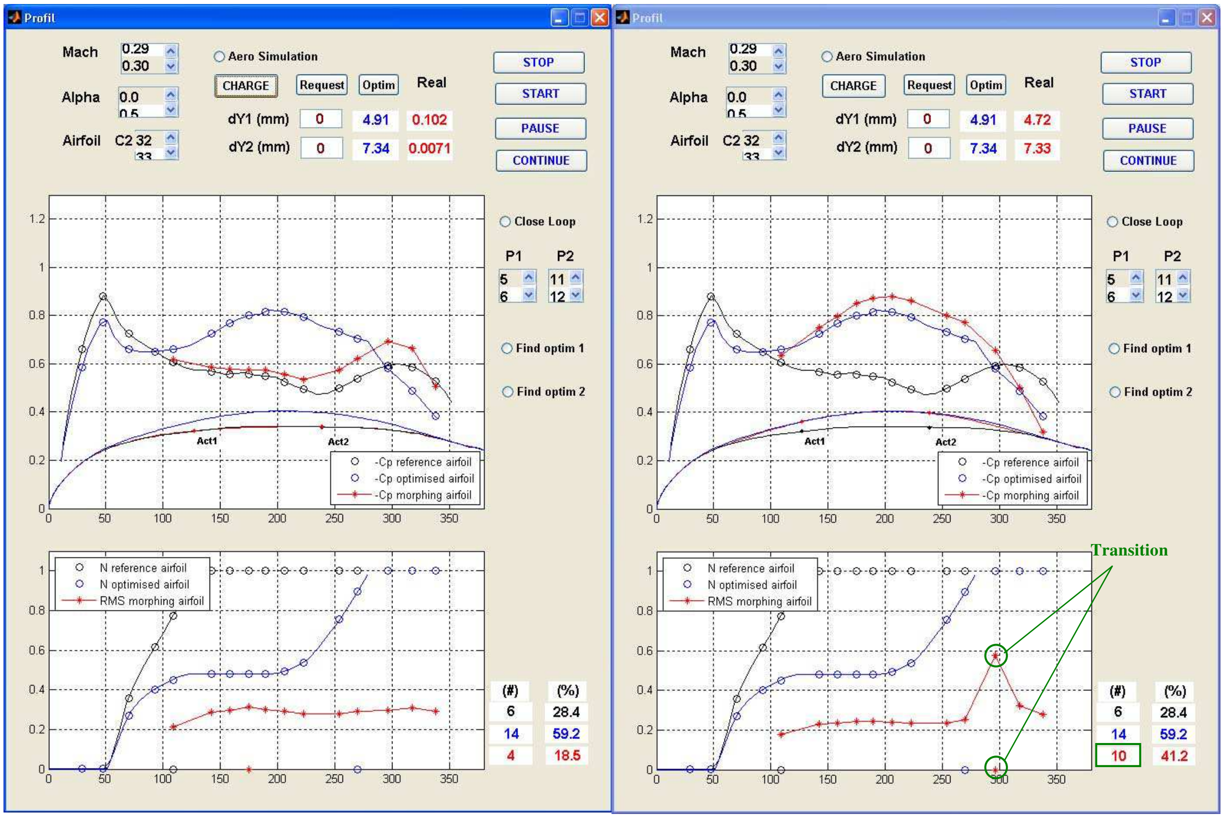

Fig. 12 GUI for un-morphed and morphed wing, for α=0°, M=0.3.

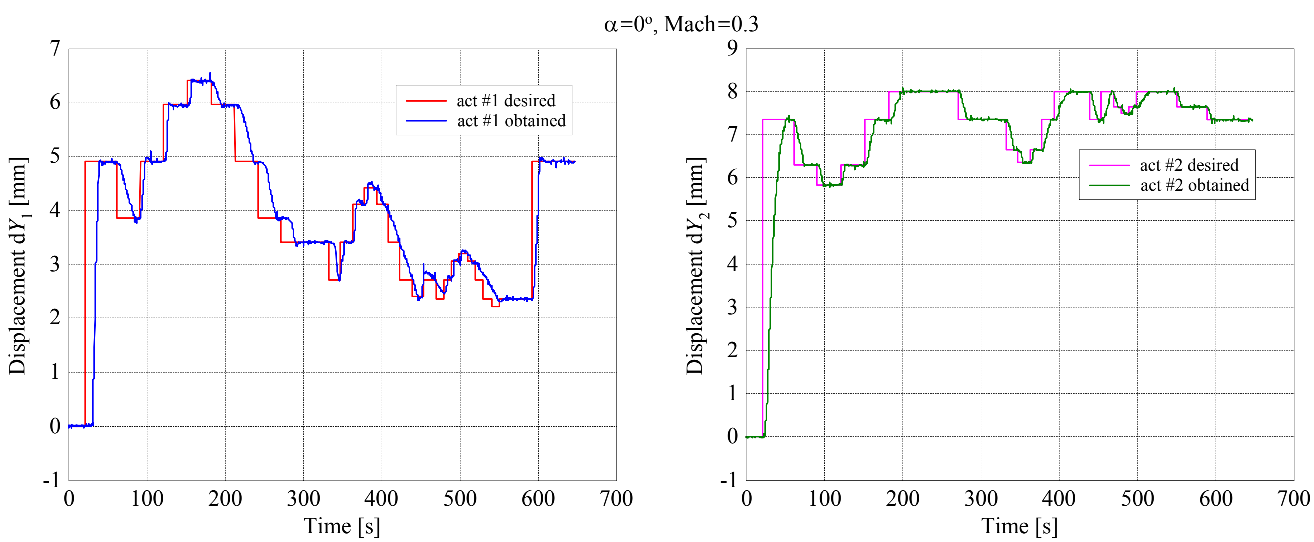

Fig. 13 Wind tunnel test for α=0°, M=0.3 flow condition