Investigation of an active flow control system by multi-physics simulation and experimental validation.

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ABSTRACT

Flow control in aeronautic field plays significant role. Increasing lift by dumping of flow separation and drag reduction using active flow control system, piezoelectric (PZT) synthetic jet actuators, has been investigated. Results from multi-physics simulations and from measurements are presented in this paper. The potential of drag reduction and application fluid related systems (e.g. highlift systems) is very promising if one considers that a 1 percent saving in world consumption of jet fuel was worth about 1.25 million dollars a day of direct operating costs (in 2002) [1]. Therefore, proper determination of actuator's parameters, geometry and working conditions will help to increase effectiveness of flow control system. Total system configuration used in a synthetic jet actuator simulation is presented in Figure 1.

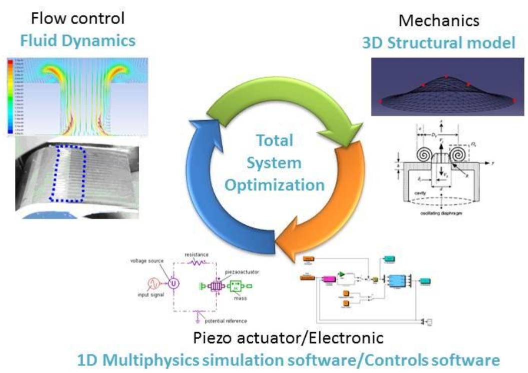

Figure 1 Total system scheme [2].

The synthetic jet is a jet-like mean fluid motion obtained by an alternate suction and ejection of fluid through an orifice bounding a small cavity. This is generated by a time periodic oscillation of a diaphragm built into one of the cavity's wall (Figure 2 left).

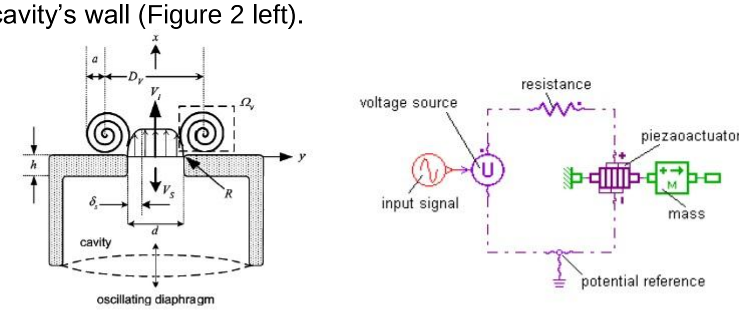

Figure 2 Scheme of a synthetic jet (left) [3] and 1D PZT model (right).

In this paper results from multi-physics simulation of a synthetic jet actuator for active flow control (piezoelectric material, structure and fluid dynamics) are presented. Furthermore, the validation of numerical models is presented.

Actuator's geometry has been defined. Piezoelectric membrane diameter is D=25 mm, orifice exit *d* and actuator height *H* are 1 mm. Simulations were performed for wide range of forcing frequencies up to 3 kHz and driving voltages up to 100 V. The PZT behavior is simulated using 1D model in LMS Imagine.Lab AMESim (Figure 2 right). The actuator device is described starting from the input signal, piezoelectric properties up to the diaphragm mass. The moving diaphragm is represented as a single mass mounted to the piezoactuator. The PZT material is changing its shape as a response to applied voltage. Deformation of a moving diaphragm is simulated in LMS Virtual.Lab using 3D Finite Element (FE) model (Figure 3 left). Results from 1D PZT simulation are used as an input in FE model (membrane deformation in the center). Material properties and boundary conditions on the membrane edge are applied. From the nodes located on the diameter, diaphragm displacement profile is exported and used as an input for a Computational Fluid Dynamics (CFD) simulation (Figure 3 right).

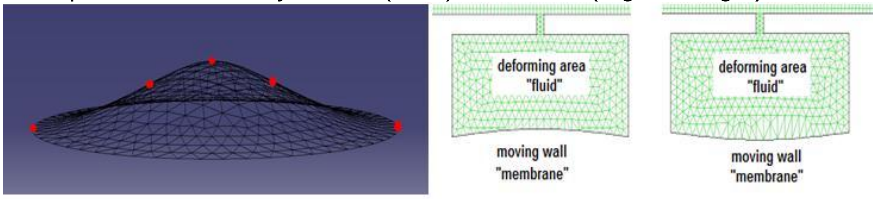

Figure 3 FE 3D deforming membrane model (left) and demonstrative 2D CFD model (right).

Preliminary 2D CFD simulations of a vortex structure on the orifice exit were performed using ANSYS FLUENT. Moving Deforming Mesh method for the more accurate simulation of the volume change as a result of a membrane oscillation was applied. Turbulence model is a Shear Stress Transport k-ω. Two arrangements were investigated – actuator with perpendicular and with parallel membrane (Figure 4). Based on the preliminary CFD simulation results and Constant Thermo Anemometry (CTA) measurements, arrangement with perpendicular membrane has been selected for further investigations as a flow controller to reduce flow separation thus pressure drag.

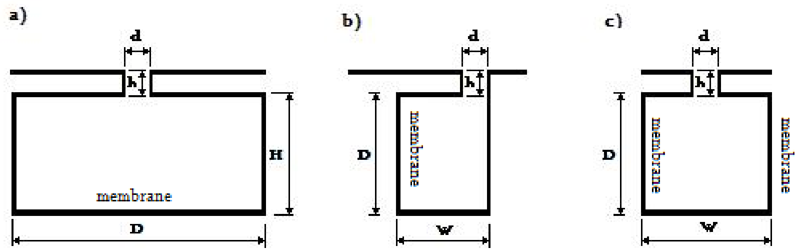

Figure 4 Actuator arrangement a) one parallel b) one perpendicular and c) two perpendicular membranes.

Numerical simulations of a flow separation behind a bump body are to be validated in the wind tunnel measurements using CTA hot-wire probe, pressure distribution measurements, smoke and Particle Image Velocimetry flow visualizations. Test section and manufactured model are presented in Figure 5.

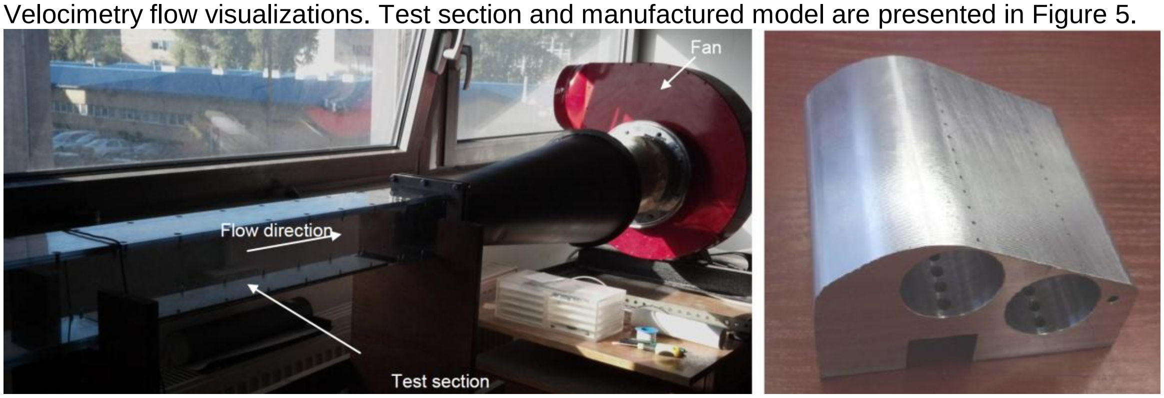

Figure 5 Wind tunnel (left) and manufactured bump model for synthetic jet actuators (right).

References

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