Study into Utilization of Synthetic Jet Actuators for Flow Control

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The present experimental study into flow control utilizing synthetic jet actuators (SJA's) focusses on the application to flow separation control as well as on aerodynamic load control of aircraft wings and of blades of wind turbines. A synthetic jet actuator consists of a piezo-electric diaphragm placed inside a cavity, embedded inside the wing or blade, through a narrow slot in the surface of the wing or blade, connected with the outside. The cycle of the oscillating diaphragm consists of an instroke and an outstroke. During the instroke low momentum fluid is inhaled from the boundary layer along the surface. During the outstroke this fluid is expelled from the actuator through the same slot. The cyclic action forced by the oscillating diaphragm results in a time-averaged outflow of the SJA that closely resembles a continuous jet. The utilization of synthetic jets as flow-control devices is attractive because they are zero-mass flux devices, not requiring tubing for air supply. SJA's are also favorable due to their small response time and low power requirements.
The presentation reports on results of wind tunnel tests performed in an open return wind tunnel at the University of Twente. This wind tunnel has a closed test section (cross section of 0.455 x 0.455 m^2) and achieves velocities up to 25 m/s.
Flow separation control has been applied on a non-swept 2D NACA0018 wing (chord of 0.165 m) using SJA's with tangentially directed outflow. First a stand-alone prototype of the actuator has been designed and tested. Volume displacement is generated by a bimorph piezo-electric diaphragm producing a synthetic jet which exists through a 0.25 mm by 30 mm slot. Hot-wire anemometry (HWA) measurements have shown that maximum centerline jet velocities up to 65 m/s can be achieved at an optimum actuation frequency of 900 Hz using an actuation (peak-to-peak) voltage of 100 V_{pp}. At this actuation frequency and voltage the maximum displacement of the center of the piezo-electric diaphragm is determined to be 0.24 mm using a laser Doppler vibrometer. Then ten actuators are placed inside the wing. Their spanwise slots cover about 66% of the span of the wing and are located at 30.9% chord, upstream of the most forward location of flow separation. They exit at about a 15-degree angle relative to the airfoil tangential direction at that point. At the slot exit the surface is rounded, enabling the Coandă effect that forces the jet to remain tangential to the airfoil surface. In the wind tunnel experiments lift, drag and pitching moment have been measured using a balance. The free stream velocity was set to 25 m/s, which corresponds to a chord Reynolds number of 2.73×10^5. A parametric study has been performed invoking various actuation frequencies and jet velocities. It is shown that for a given actuation frequency a higher jet velocity results in a higher maximum lift coefficient and a corresponding higher stall angle. However, for the performance of the synthetic jet actuation, the actuation frequency proves to be of greater importance than the jet velocity. The best actuation frequency in combination with the maximum jet velocity possible with the current actuator corresponds to a dimensionless frequency F^+ of 5.9 (1300 Hz) and a momentum coefficient c_μ of 0.0014 (maximum jet velocity 32.9 m/s and Velocity Ratio of 1.32). Using these actuation parameters the lift coefficient is increased by 12% and the stall angle by 22%.

For aerodynamic load control the jet exits in the direction perpendicular to the surface of the airfoil also from a narrow slot, parallel to the trailing edge, now at chord wise distance x_j/c = 0.975. Also for this type of SJA first, a stand-alone prototype version has been manufactured and the jet velocity has been measured using HWA. These measurements have shown that for this type of SJA maximum centerline jet velocities up to 45 m/s can be achieved at an optimum actuation frequency of 700 Hz using an actuation (peak-to-peak) voltage of 100 V_{pp}. Due to the non-optimal geometry of this SJA the measured maximum jet velocity is lower than the maximum jet velocity achieved by the SJA's used for flow separation control.

For the purpose of load control a second non-swept 2D NACA0018 wing fitted with a module containing ten span wise distributed actuators has been designed and manufactured. Wind tunnel tests have been performed to measure the obtainable shift in the lift curve of the wing, i.e. the lift coefficient as function of the angle of attack of the wing, within some range of the actuation parameters. In the presentation results will be shown for the wing at α = 5 deg for three values of the reduced frequency $F^+ = f_{act}c/U_\infty$. This illustrates the load control performance of the wind-tunnel model equipped with SJA's blowing perpendicular to the surface. The highest relative increment in lift coefficient of

0.06 has been obtained for a freestream velocity of U_∞ = 12.4 m/s, combined with an actuation frequency of f_{act} = 750 Hz, corresponding to F^+= 10.

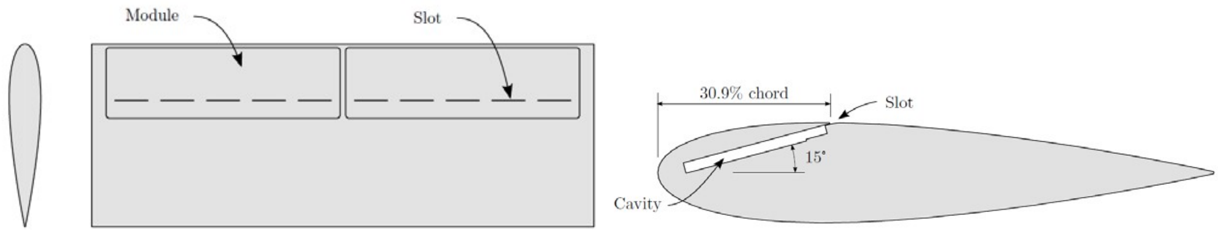

Figure 1: SJA for flow separation control. Schematic of NACA0018 airfoil section (chord 0.165 m) with the position of the cavity and the slot (drawing is to scale)

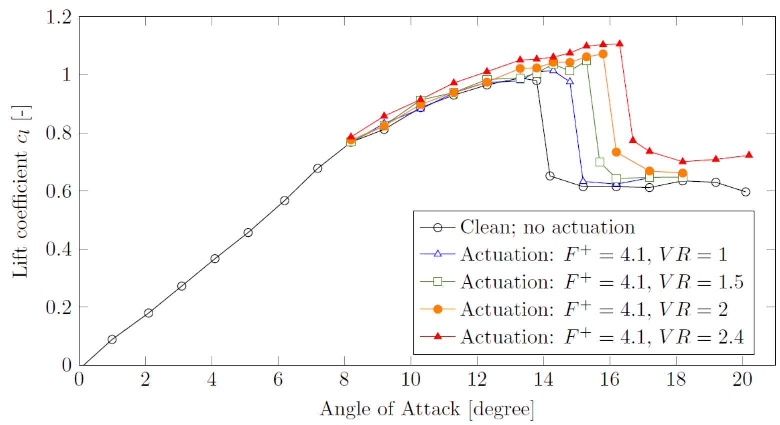

Figure 2: SJA for flow separation control. Lift curves for NACA0018 airfoil for different values of the relative jet velocity (F^+=4.1, Re_c =2.73×10^5).

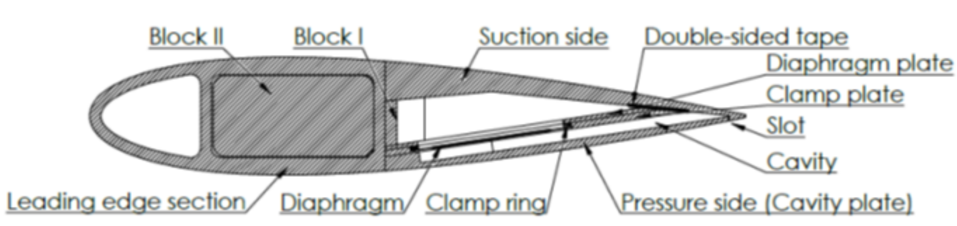

Figure 3: SJA for aerodynamic load control. Cross-section piezo-electric synthetic jet actuator integrated in NACA0018 wing.

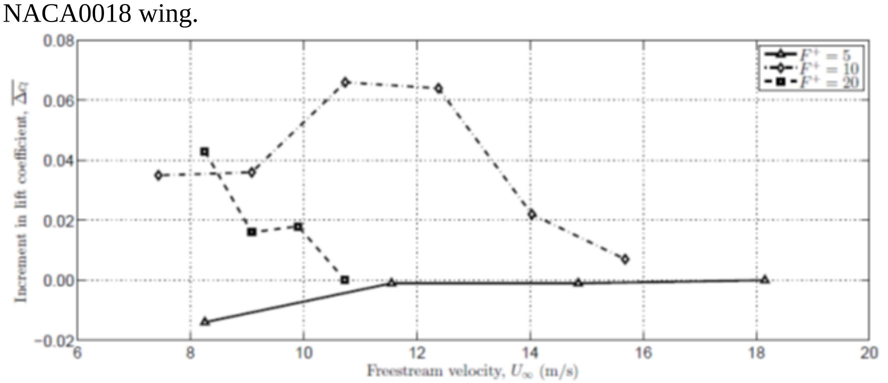

Figure 4: SJA for aerodynamic load control. Time-averaged increment in lift coefficient as function of free-stream velocity U_∞ for three values of reduced frequency $F^+ = f_{act}c/U_\infty$. E_{act} = 100V_{pp}, α = 5 deg.