Active flow control over a wind model using synthetic jet arrays

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Synthetic jet (SJ) technology has been proved to be a promising active-flow-control means in aeronautical applications. A typical synthetic jet actuator (SJA) consists of a cavity with an oscillatory diaphragm on one side and an orifice on another side. The oscillation of the diaphragm generates a succession of vortex structures that propagate away from the orifice, forming a so-called “synthetic jet”.Due to its well-known zero-net-mass-flux and compact features, SJA can beeasily applied in arrays to achieve better control effects. As a preliminary study towards realizing active feedback controland flight control for UAVs by applying the SJ technology, the current study aims to design and deploy suitable SJ arrays and utilize an appropriate feedback control scheme to actively control the possible flow separation over a wing model.

Firstly a single SJAis designed, fabricated and tested in quiescent conditions. This SJA includesfour 20mm-diameter piezoelectric ceramic diaphragmsattached on its four side walls and five 1mm holes arranged in a line on its top. Hotwire measurements show only one peak of the jet velocity at about 800 Hz withinthe operating frequency range 0 - 1000Hz, whichcorrespondsto this SJA’s Helmholtz resonance frequency.

Secondlytwo arrays of such SJAsare implemented on a wing model based on the low-speed LS(1)-0421MOD airfoil, one at 23% of the chord from the leading edge (denoted as Array 1), and the other at 43% of the chord (denoted as Array 2). This wing model is tested in a wind tunnel at the wind speed 10m/s, which is closed to the typical flight speed of small UAVs. The aerodynamic forcesand moments exerted on the wing model with and without the actuation of the SJ arraysat different angles of attack (AOAs) aremeasuredusing asix-component force balance.The SJ arrays are actuated with driving voltage of 200Vp at three different frequencies, i.e. 200Hz, 400Hz, and 600Hz. As an example shown in Fig. 1, the stall angle and the corresponding maximum lift coefficient for the wing model are significantly increased with the actuation of the SJ Array 1 at 400Hz and 600Hz, while they are almost the same at 200Hz as in the non-actuation case. The changes are associated with the delay of the flow separation on the upper surface of the wing model, indicating that the SJ array does effectively delay the flow separation. This flow-separation-control effectiveness of the SJ array is also demonstrated by flow visualization using tufts (as shown in Fig. 2).

Further investigations reveal that higher jet-to-freestream velocity ratio provides better lift enhancement and drag reduction, and moving the jets closer to the leading edge leads to better flow separation control.

Finally the power consumption of operating the SJ arraysismeasured to help assess whether the benefit brought by the SJ arrays is offset by the penalty associated with the additional power requirement. It is found that the power consumption by actuating both SJ arrays at 150Hz is less than 5W, indicating the low-power-consumption feature of the current SJ arrays.

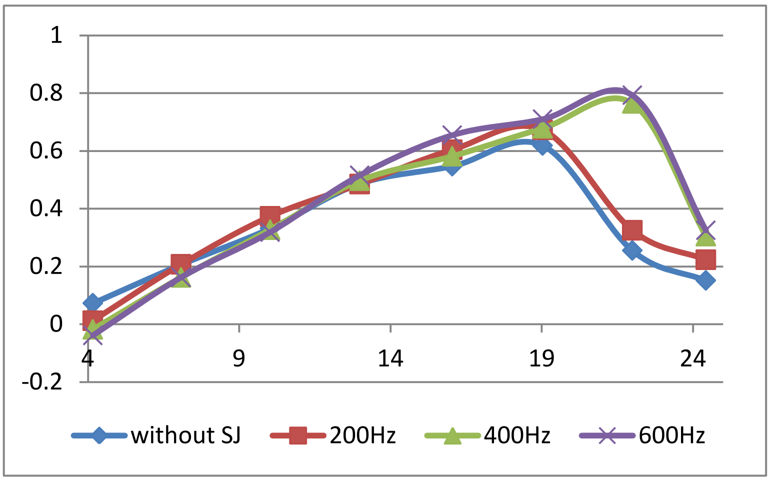

Figure 1. Lift coefficient curve at different operating conditions for SJ Array 1

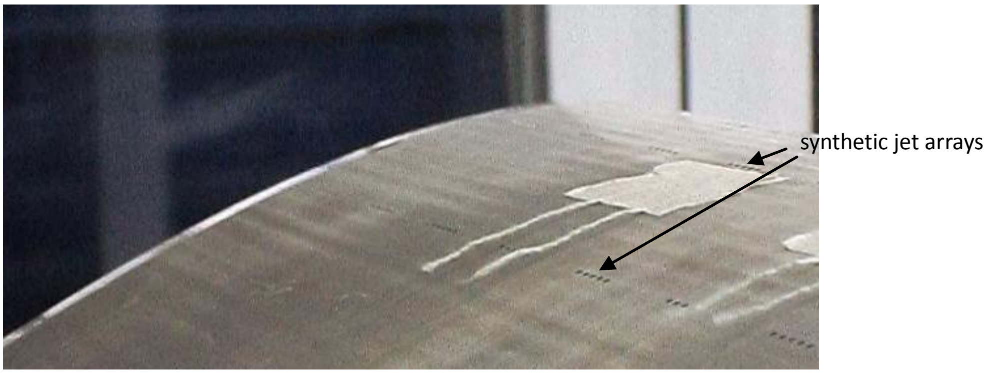

Figure 2. Visualization of flow separation control using SJ Array 1 (a video snapshot)

As this is an ongoing research, further investigations have been planned to quantitatively study the detailed flow fields around the wing model with/without the actuation of the SJ arrays. The measurement techniques to be involved include unsteady pressure sensors, hotwires, and PIV.In addition, it is also planned that a couple of shear stress sensors will be implemented on the supper surface of the wing model to “feel” the happening of flow separation,and a suitable feedback control scheme will be applied to help keep the flow attached at all times. More results and discussions in these aspects will be included in this paper.

Keywords

Synthetic jet array, active flow control, feedback control, UAV