# PIEZOELECTRIC SYNTHETIC JETS AS VIRTUAL SURFACES

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**Abstract:**
Fuel consumption has become an important issue on all transportation areas. For aircraft applications for instance, an important tool that can reduce fuel consumption and improve manoeuvrability is active flow control. Active flow control for aircraft applications however, is still relatively new because of the added weight and complexity to a structure. One method that has been proven an effective way to provide active flow control is through the use of piezoelectric synthetic jets. These devices consist of a piezoelectric diaphragm placed in a cavity that has a slit to allow flow in and out of the cavity. The oscillation of the diaphragm allows the air to enter and exit through the same orifice hence not requiring tanks or additional plumbing. The goal of this research is to determine the feasibility of synthetic jets modifying the flow around a vehicle by creating a virtual surface. This virtual surface will be tested at low speeds by using flow visualization techniques and the use of pressure measurements around a ramp fitted with synthetic jets. In this manner, a feasibility study of using the synthetic jets to create suction that might aid on keeping a vehicle to the ground and prevent "lift-off."

Keywords: piezoelectric actuators, synthetic jets, flow control

## Introduction

In the last decade synthetic jet actuators have been studied extensively for aerodynamic flow control applications such as, control flow separation and turbulence in the boundary layer[1,2,3], cause separation over bluff bodies[1,4], in internal flows[5], and to the control the maneuverability of unmanned aerial vehicles[6]. A number of non-flying applications have also been investigated, where active flow control techniques have been used to augment or modify flow fields for unique purposes[7,8,9] such as cooling of electronics. Although synthetic jets have been mainly considered with a focus on aerospace applications, experimental and numerical investigations of plane and rounded jets prove their feasibility in other applications as well[10]. Automobile manufacturers such as Renault have been successful in using these jets to reduce the drag by approximately 15%[11].

Investigations on synthetic jets have employed a variety of jet drivers including piezoelectrically driven diaphragms[2,12], electromagnetically driven pistons[13], and acoustically driven cavities[14]. Mossi et al. have characterized synthetic jets which used piezoelectric composites as the active diaphragms in the synthetic jet cavity[12,15]. Several factors affecting the jet design and performance have been quantified and the relevant factors. In the current study, synthetic jet actuators driven with a Bimorph diaphragm in a cross-flow are measured with the aim of investigating the feasibility of utilizing these devices to alter the flow over a bluff body.

## Experimental Setup

A bluff body model based on an airfoil section is constructed (see Fig. 1). The model is equipped with two synthetic jet cavities with a slit 35mm by 0.5 mm for an opening. These synthetic jet cavities are placed at 92mm from the leading edge of the model. The model is placed in an open loop wind tunnel with a test section of width, height, and length of 15.24 by 30.48 by 60.96 cm respectively. Wind tunnel velocity is controlled using a variable frequency drive Cutler-Hammer HVX9000. Pressure changes at the surface of the model are monitored using eight differential pressure transducers, All Sensors 442022-ND, which are connected to pressure taps distributed across the surface of the model as indicated in Fig. 1.

The synthetic jet cavities, Fig. 2, are equipped with Bimorph actuators, Piezo Systems T216-A4NO-573X. The cavities have neoprene rubber around the perimeter to serves as a seal, allow the actuator to displace without failure, and reduce vibrations to the structure itself.

The actuators are driven using a signal generator, HP3194A, and an amplifier, TREK PZD-700. Driving frequency, waveform type, and applied voltage were previously determined on quasi-static flow[12], such that the actuators are driven at 80Hz and 150Vpp, with a sawtooth waveform. Velocity, measured with a Pitot probe and pressure are monitored using a data acquisition card and a PC using LabView as shown in Fig. 3.

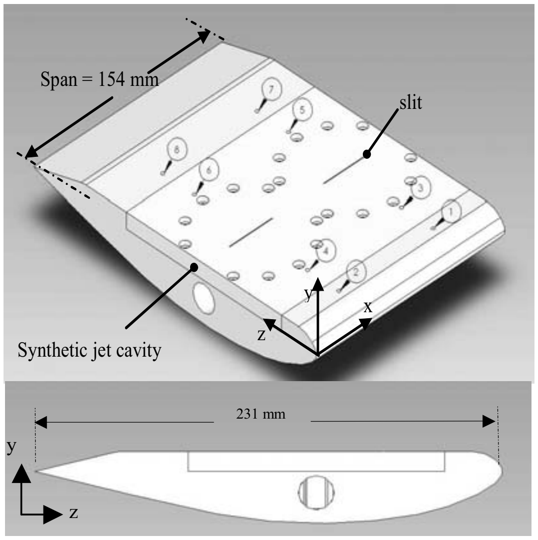


***Fig. 1:*** *Experimental Setup*

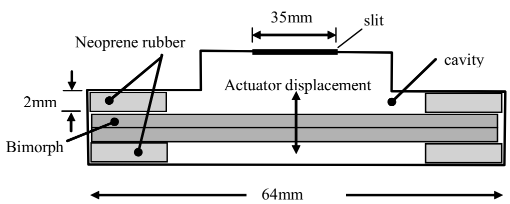


***Fig. 2:*** *Synthetic Jet Cavity*

In addition a flow visualization system is utilized that utilizes a smog machine with a high speed digital camera and a strobe light across the test section.

**Results**

As this project was aimed at exploring the effectiveness of synthetic jet actuators, first the affected regions of the model are identified using flow visualization techniques. Although a number of factors such as actuator frequency, driving conditions and cavity specifications have an effect on the performance of the synthetic jet, these parameters are kept constant and are selected based on previous results[12]. Previous results however where performed in quiescent flow, Since in this case the jets are placed in a cross-flow, other factors such as windspeed, synthetic jet location, size of the slit are parameters that can significantly alter the results. To narrow some of this effect, flow visualization is used. A sample of the flow visualization results is shown in Fig. 4.

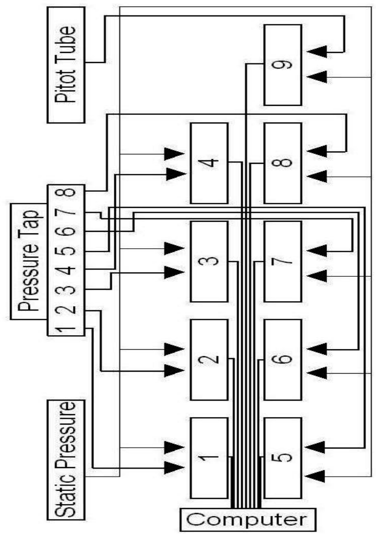


***Fig. 3:*** *Data Acquisition Schematic*

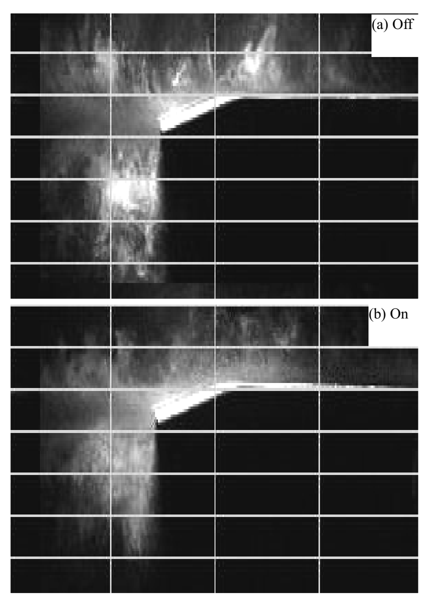


***Fig. 4:*** *Flow Visualization Results*

Careful inspections of the images indicate reductions in the turbulence regions and also show changes in the size of the wake. Though the effects on the flow are evident through the visualization techniques, they are too small to be measured using pressure sensors. To enhance the effects of the synthetic jets, so that pressure measurements and boundary layer profiles can be captured, the model is placed at an angle of six degrees with respect to the flow. This was determined as part of the flow visualization experiments. Once the zones and parameters offer some evidence of the effect of the synthetic jets, data is then collected. Since the model is equipped with pressure ports across its surface, average measurements of the pressure changes with the synthetic jets on and off are recorded. These results shown in Fig. 5 illustrate that the synthetic jet affect the pressure distribution upstream of the slits and a very small effect downstream of the slits.

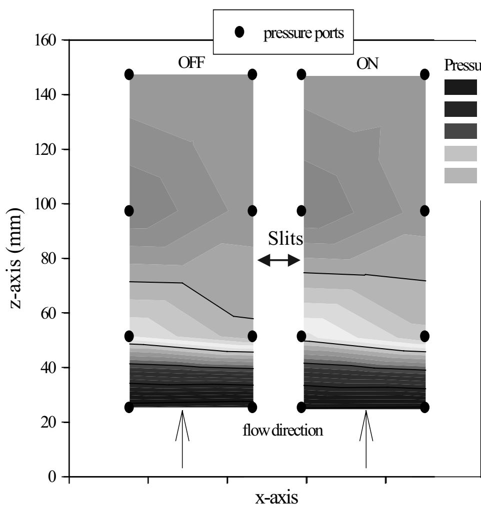


***Fig. 5:*** *Contour Static Pressure Data*

Boundary layer profiles are measured at selected locations along the surface of the model at four different speeds, 30, 36, 45, and 52 m/s, keeping the frequency and voltage of the piezoelectric actuators constant. Typical profiles at two speeds, 36 and 52 m/s are shown in Fig. 6a and 6b respectively. These boundary layer profiles are measured at 14mm from the leading edge of the model, that is, upstream of the location of the synthetic jets aperture. It is important to note that pressure coefficients are used to show the reverse flow regions and that the height is shown non-dimensional with boundary layer height. In the case boundary layer height, δ, is defined as the point where the boundary layer velocity reaches the value of free stream velocity. Results show that the effect of the jet is more significant at 36m/s that all the other tested speeds. Higher and lower speeds show a small reduction of the reverse regions, but it is not as significant as the 36m/s speed case. It is possible that frequency of the jets and cross-flow speed factor combination are factors to be considered but beyond the scope of this study. Other profiles measured downstream of the synthetic jet apertures across the surface of the model did not show significant effects reducing the separation region. This indicates that creating a surface upstream from the jets may be possible.

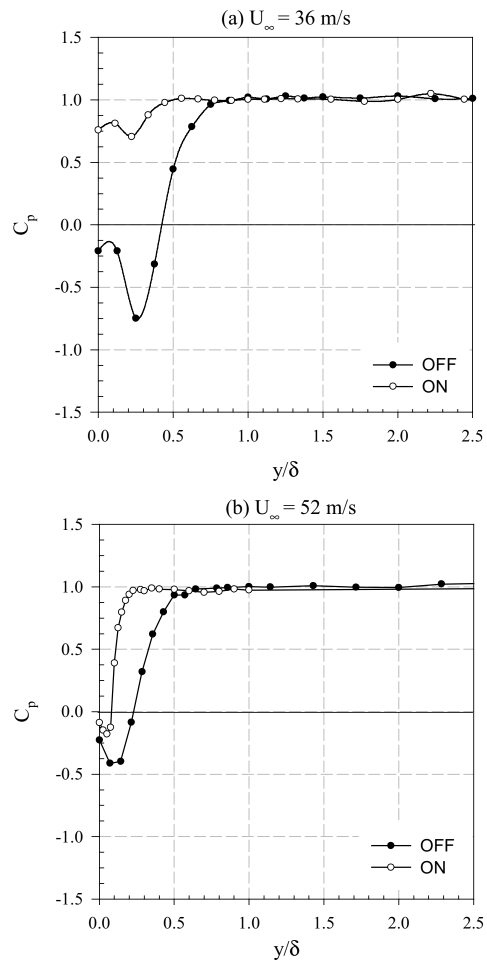


***Fig. 6:*** *Boundary Layer Profiles at z=14mm from the leading edge*

Furthermore, the effect on the model drag with synthetic jets on or off is also a concern, since altering the flow upstream of the jets may have an adverse effect on the model overall performance. To ensure that no significant effect on drag is caused, velocity profiles downstream of the model are measured.

To assess the overall effect on drag, velocity profiles of the wake of the model are measured at several locations downstream of the model. The different profiles show no significant effect between synthetic jets on or off. To illustrate a sample of these, results at 36m/s, at 0.16c distance of the leading edge, as shown in Fig. 7.

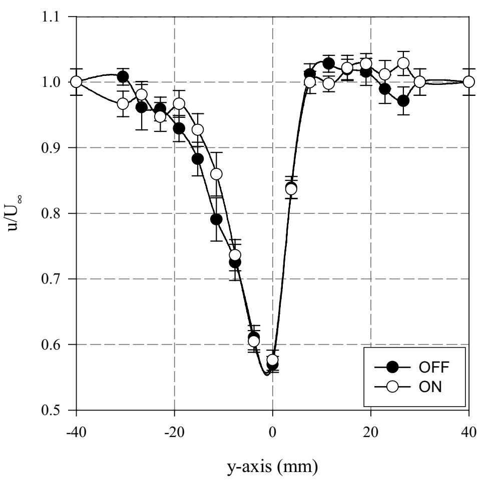


***Fig. 7:*** *Wake Profiles at z = 0.16c*

From these results, a profile drag, *D*, can be calculated by integrating the area under the curve, using Eq. 1[16].

$$D = c \cdot \rho \cdot \int_{y=0}^{\infty} u \cdot (U_{\infty} - u) \cdot dy \qquad (1)$$

Where $c$ is the cord of the model, $\rho$ is the density of the air at room temperature, $u$ is the local velocity and $U_{\infty}$ is the free stream velocity. The results for this particular case show that synthetic jets do not reduce or enhance drag significantly.

Results of this study demonstrate that synthetic jets can alter the flow at high speeds. Location of the jets, flow velocity, frequency of operation seemed to be strongly related and control algorithms that can adjust according to the speed may be needed for optimum operation.

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