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Energy Harvesting from Fluttering Membranes

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ABSTRACT

Research has shown that vibration energy harvesting using piezoelectric generators have been preferred due to the higher power output. The main advantage of energy harvesting is the possibility of powering wireless sensor nodes while extracting energy from environmental sources. This research focuses on study of the self-sustained oscillations (panel flutter) for energy generation with the use of flexible piezoelectric materials (MFC). Mylar sheets with a thickness of 100 μm and aspect ratios of 1, 1.5 and 2 were evaluated. The addition of fins at the trailing edge has been analyzed as well since it decreases the speed at which the fluttering starts. Wind speeds ranging from 10 to 16 mph caused the tested Mylar membrane to flutter, producing open-circuit voltages from 1-2.5 V.

Keywords: Fluttering Membranes, Energy Harvesting, Piezoelectric Generation

1. INTRODUCTION

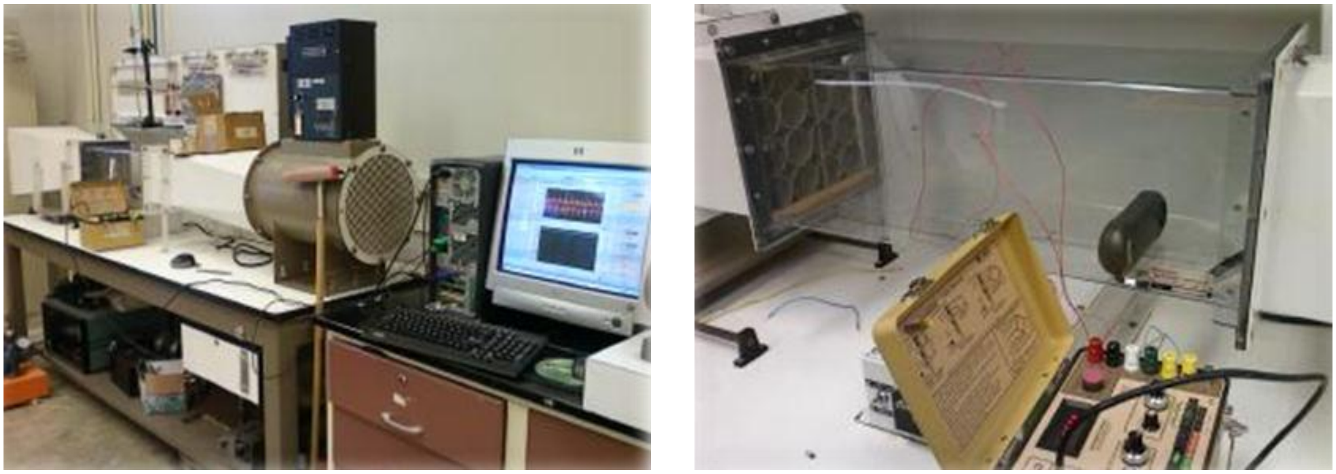
In recent years many studies focused on energy harvesting from the surroundings. These energy harvesters have a number of military and civil applications since they are self-powered, can be used in remote locations, and require almost no maintenance. From an evaluation of all available ambient energy harvesting sources, vibration-based power generation is found to produce the higher power output (Roundy, 2005). For converting vibrations to electricity several transduction technologies can be employed, such as electrostatic, electromagnetic, and piezoelectric generation. Among all these methods, piezoelectric conversion is preferred considering the higher power density (Erturk, 2009). Considering the rapid development of piezoelectric films, and the thin film batteries for storage, this method of energy harvesting is being given greater attention.

Most researchers have considered machine vibrations as a source of energy, but lately a number of investigators have used the fluid induced vibrations. The piezoelectric polymer strips oscillating (due to the Karman vortices generated behind a bluff body) is used to harvest energy by Taylor et al. (2001), Allen and Smith (2001) and Pobering et al. (2009). Robbins et al. (2006) have used the fluttering of membranes with flexible piezoelectric material to harvest energy. Aeroelastic vibration of an airfoil section clamped to a cantilever is used by Erturk et al. (2010). Kwon (2010) has used a T-shaped cantilever with attached piezoceramic patches under airflow for generating electric power. An aeroelastic flutter energy harvester using a cantilevered piezoelectric beam connected to a flap at the free end is proposed by Bryant and Garcia (2011).

This works studies the flutter on flexible membranes for wind energy extraction using flexible piezoelectric films. The surface of a thin membrane in fluid flow is subjected to in-plane tension and aerodynamic forces normal to the membrane. Lateral deflection of the plate changes the pressure acting on the membrane and the tension in the membrane tends to bring the membrane back the equilibrium position. When the flow velocity exceeds a critical value, called the onset flutter speed, energy is continuously extracted from the surrounding fluid sustaining the flutter motion. Large amplitude of the membranes is related to high strains for piezoelectric materials. Since piezoelectric materials require to be under strain in order to generate a charge, it is desirable that the critical wind velocity is as low as possible for energy generation. It has been found that this "cut in" speed can be decreased by the use of fins added at the trailing edge.

2. EXPERIMENTAL SETUP

Experimental investigation was conducted to determine the effect of onset and higher flutter speed with (i) the aspect ratio (length/width) of the membrane, (ii) the effect of fins attached at the downstream end of the membrane, and (iii) to determine the relation between the output voltage and the flow speed. The experiments were performed in a low speed suction type wind tunnel with a test section of 8" x 8" and with a length of 24" (Fig. 1a). The tunnel has a maximum speed of 29 mph. Mylar membranes with a thickness 100 µm (0.04") and aspect ratios of 1, 1.5, and 2 were tested (Fig. 2). Strain gages (Omega Precision Strain Gages SGD-6/129-LY 11) were affixed to the membranes to measure the strains and the frequencies (Fig. 1b). MFC (Micro Fiber Composites, Smart Material Corp.) piezoelectric film with a thickness of 180 µm (0.007 in), 1"x 0.5 in size and polarized in the d_{31} direction was placed longitudinally along the membrane length (Fig. 3). The output of the MFC piezoelectric films and the strain gage readings were measured using NI Data Acquisition Equipment and processed using LabView. The wind speed was measured using a Pitot-static tube. In the experiment, the tunnel velocity speed is increased gradually till it reaches the onset flutter speed at which the membrane starts to flutter. Measurements of the strain were obtained with strain gages placed centered along the membrane length at different wind velocities and with and without added fins. Open circuit voltages were recorded as well with the MFC at different locations and wind velocities.

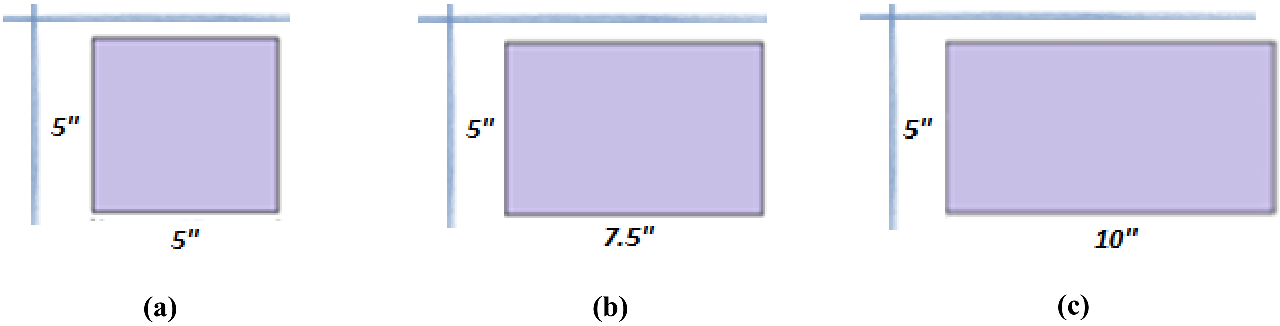


(a) (b)

Figure 1: Experimental Setup, a) Wind Tunnel, b) Strain measurement in the wind tunnel section.

3. EXPERIMENTAL RESULTS

Figure 4(a) and 4(b) shows flutter frequency and the membrane strain in the midpoint of the membrane at and after the onset flutter speed. Strain units are in micro strains while frequency readings are in Hz. In these figures, the flutter frequency increases with the wind tunnel speed. The higher the aspect ratio the onset flutter speed is lower. Also, the strains reduce with speed as the deflection of the membrane reduces. The effect of fins attached to the downstream end of the membrane is shown in Fig. 4(c) and 4(d). In this case the flutter frequency and the strains increase with the tunnel speed. The onset flutter speed is observed to be reduced dramatically. The onset speed reduces still further with increase in the aspect ratio. It is reduced by 33% for the 1.6 aspect ratio to 50% decrease for aspect ratio of 2 when a fin is added to the trailing edge. The added flap is placed at 90º with respect to the membrane, with dimensions of 0.5" x 2" (with negligible added weight to the membrane).



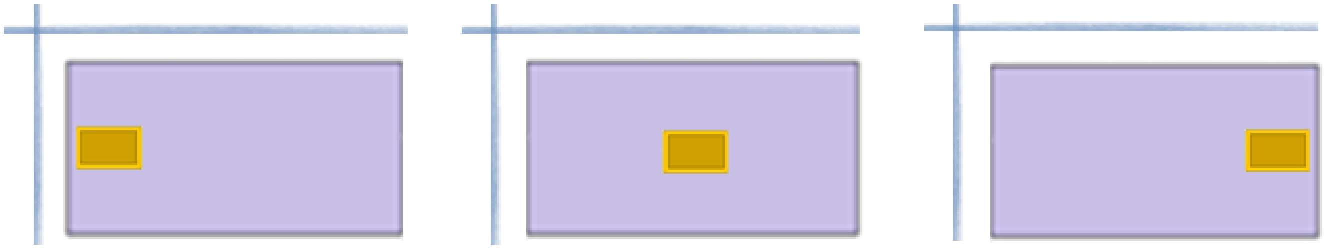
(a) **(b)** **(c)**

Figure 2: Mylar aspect ratio (AR), a) AR = 1, b) AR = 1.5, c) AR = 2.

Figures 5(a) and 5(b) shows the measured the open-circuit voltage variation with wind tunnel speed with and without the added fin. Placing the piezoelectric film at the downstream end is beneficial in both the cases of with fin and without fin. The cut in speed is the lowest at higher aspect ratio (Fig 5(b) and 5(d)). The MFC was tested at three locations, at the trailing edge, at the center of the Mylar sheet, and near the base of the membrane. Due to the addition of the MFC film, the stiffness of the membrane increased. This can be appreciated with the increase of the onset flutter speed for the same aspect ratio. For instance, for the aspect ratio of 2 (Fig. 4(b) and Fig. 5(b)) this speed increased by 33%. Only open-circuit voltage was measured at this time.

It is also interesting to observe the effect of the added fin to the membrane to the energy generation depending on the piezoelectric location. For the aspect ratio of 1.5 (Figs. 5(a) and 5(c)), the fin made it possible to generate energy at most wind speeds, although it reduced the maximum open-circuit voltage for higher wind velocities at the trailing edge location. This effect is more prominent at the aspect ratio of 2 (Figs. 5(b) and 5(d)).

The effect of aspect ratios on the voltage harvested is shown Figs 6(a) and 6(b). The higher the aspect ratio, the lower the "cut in" speed becomes. Two locations were analyzed, the trailing edge, and the center of the membrane. Up to a 44% reduction in the onset flutter speed was observed when comparing a membrane with aspect ratio of 1 to one with an aspect ratio of 2. It is to mention that no voltage saturation was observed for the test performed (piezoelectric films are expecting to produce voltage that is proportional to the induced strain).



(a) **(b)** **(c)**

Figure 3: Piezoelectric film placement along the Mylar sheet, a) close to post, b) center of Mylar, c) end of Mylar.

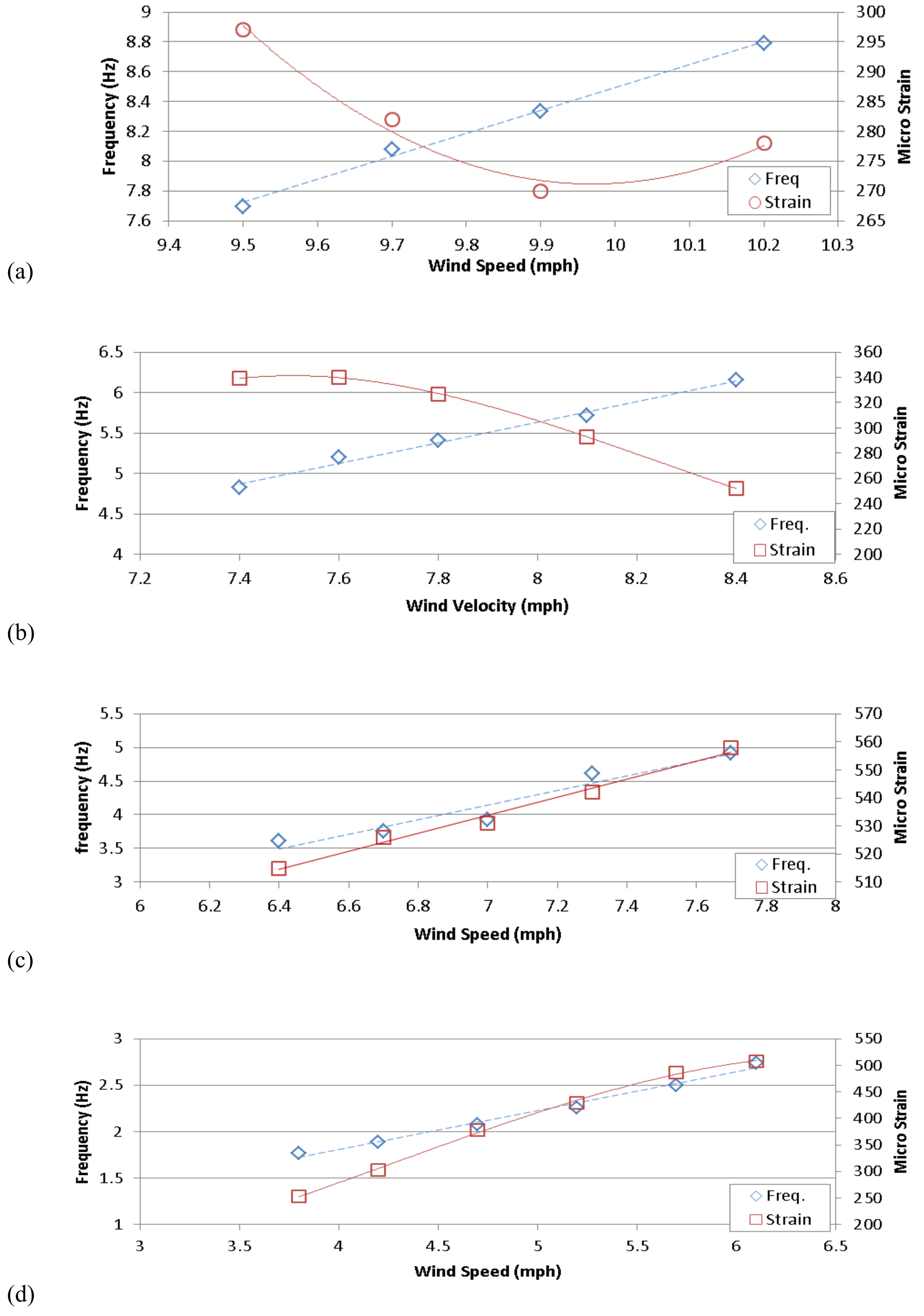


Figure 4: Effect of the aspect ratio and addition of fins.

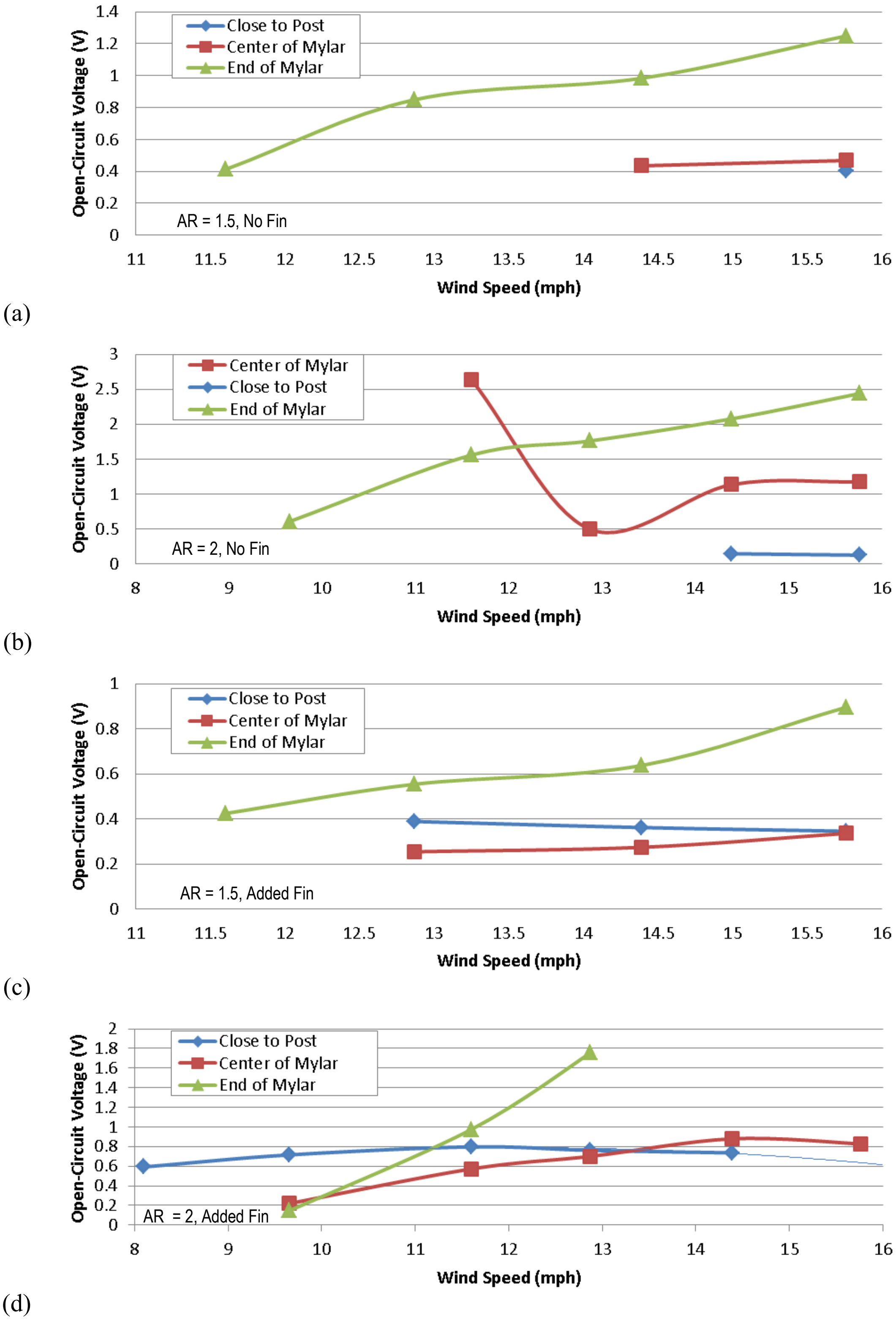


Figure 5: Induced voltage on the piezoelectric membrane.

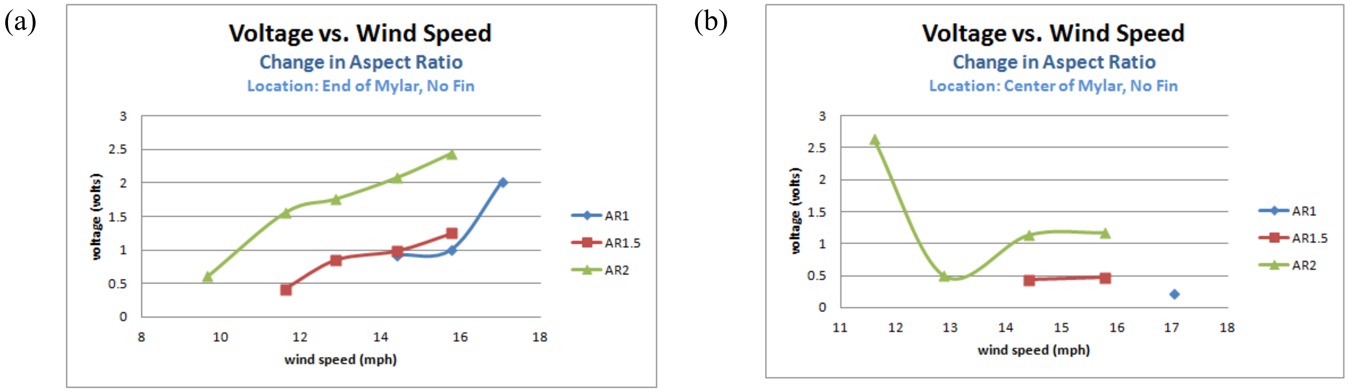


Figure 6: Effect of the change in aspect ratio

4. CONCLUSION

The experimental study found the trailing edge location as the one producing the higher voltage output under different wind velocities and membrane aspect ratios. In addition, the length-to-width ratio was found to affect more the onset flutter speed than the addition of flaps. The analysis of the added fins is not conclusive and requires further experimentation to investigate its contribution to reducing the critical fluttering speed. It was found that a relatively high aspect ratio of 2 was found to reduce the critical fluttering speed by almost 50%. At the same time, it produced open-circuit voltages as high as 2.5V when the MFC flexible piezoelectric film was affixed to the trailing edge. Further testing is required in order to understand better the relationship of these parameters for energy generation as well as thinner membranes to study the behavior at lower speeds.

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