# A miniature airflow energy harvester from piezoelectric materials

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## Introduction

This paper describes design, simulation, fabrication, and testing of a miniature wind energy harvester based on a flapping cantilevered piezoelectric beam. The wind generator is based on the oscillations of a cantilever that faces the direction of the airflow. The oscillation is amplified by interactions between an aerofoil attached to the cantilever and a bluff body placed in front of the aerofoil. A piezoelectric transducer with screen printed PZT materials is used to extract electrical energy. To achieve the optimum design of the harvester, both computational simulations and experiments have been carried out to investigate the structure. A prototype piezoelectric wind harvester was fabricated by thick-film screen printing technique and tested in wind tunnel to determine the optimum structure and to characterize the performance of the harvester. The significance of this work lies in obtaining the optimum structure for the harvester that achieves the widest possible range of operating air speeds.

## Theory

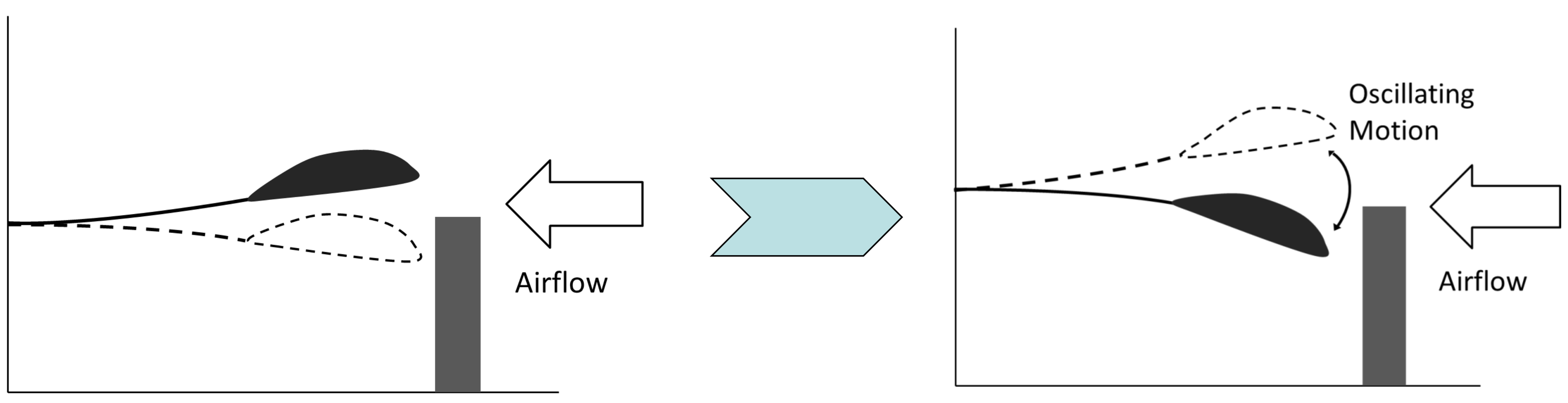


*Figure 1. Operation principle of the flapping generator*

In order to oscillate the cantilever, a bluff body is placed in front, which reduces the airflow behind the bluff body and increases the lift force, causing the cantilever to operate primarily under inertial effects and spring back. When the cantilever springs back to the initial position, the wing is exposed to the full airflow again, energy is once again extracted from the airflow, and the cycle is repeated.

## Design and Fabrication

### Design Model Variables

| Mechanical Structure | Transducer |
|---|---|
| Attacking angle of the wing | Length |
| Distance of the bluff body from the wing | Width |
| Height of the bluff body from the wing | Thickness |
| Shape of the wing | |

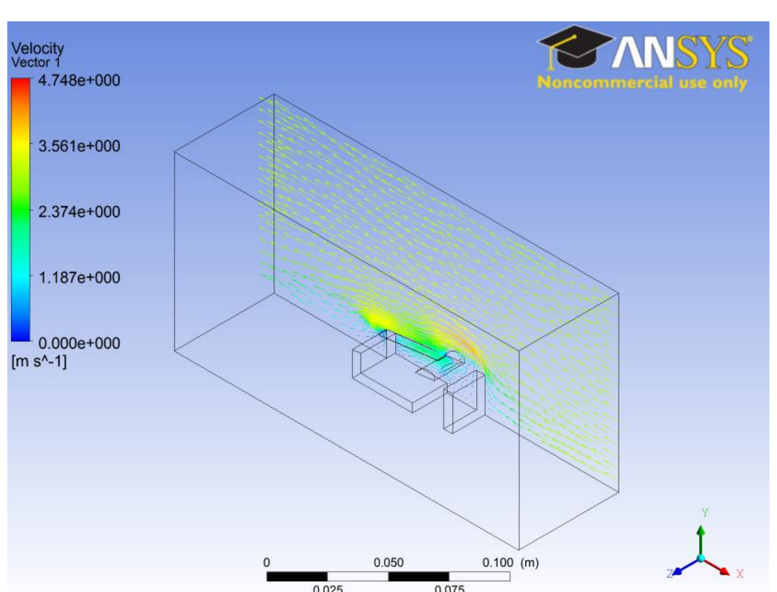


*Figure 2. Simulation model in ANSYS CFX*

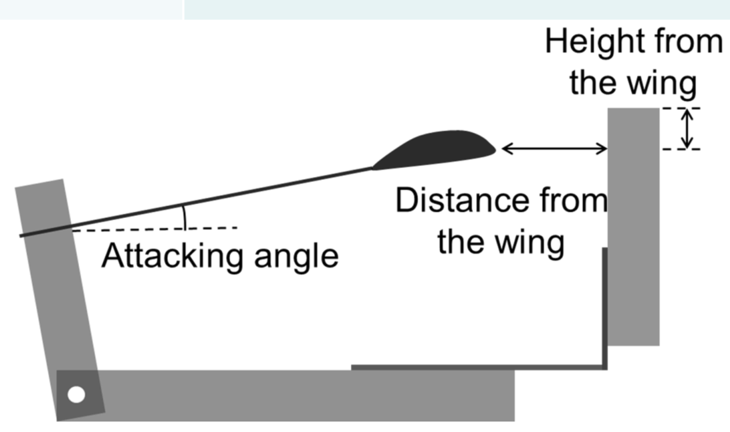


*Figure 3. Mechanical structure design variables*

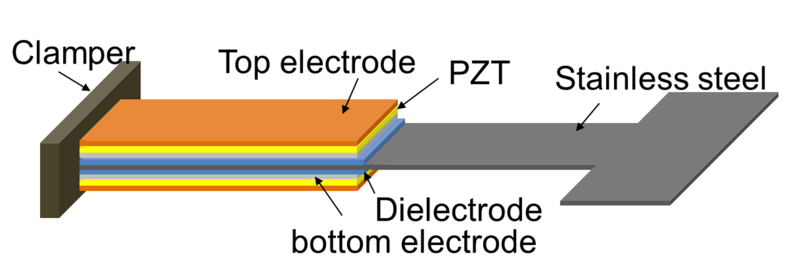


*Figure 4. Sketch of the piezoelectric transducer with bimorph structure*

### Fabrication Process

- ➢Thick-film Screen Printing
- ➢Sintering
- ➢Poling

Maximum $d_{33}$ value was around 130 pC/N

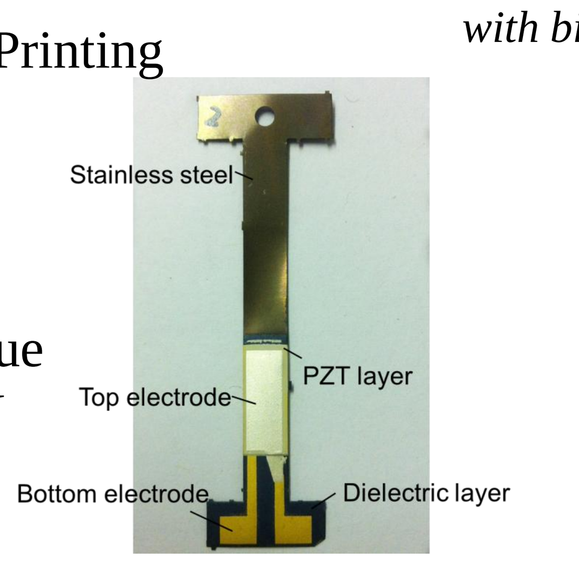


*Figure 5. Top view of the piezoelectric beam without wing*

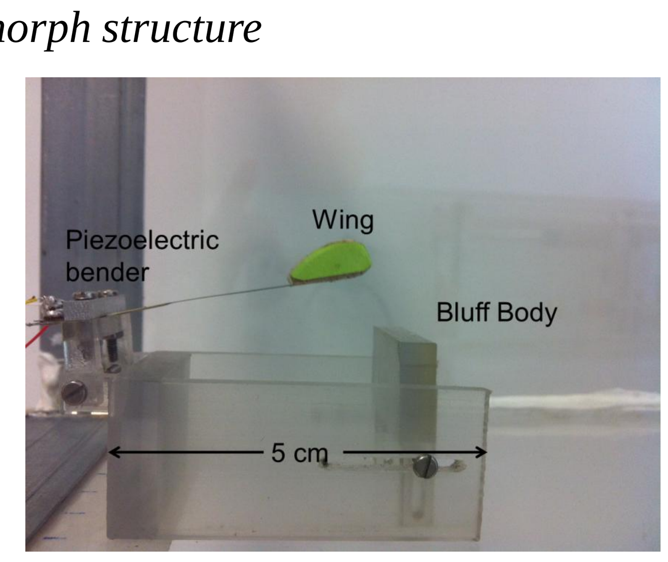


*Figure 6. Prototype harvester oriented with airflow from right to left*

## Test and Performance

Tests were carried out both in the centre of a wind tunnel and on a shaker. After testing, the experimental results were compared with the simulation analysis in ANSYS as shown in following table. Both results verify that to achieve the lowest threshold wind speed, optimum positions of the bluff body are approximately between 3 mm to 10 mm in horizontal distance and 18 mm to 20 mm in vertical distance with attack angle around 6° - 8°.

| Variables | Simulation Analysis | Wind Tunnel Test |
|---|---|---|
| Attack angle of aerofoil (θ) | 5°-8° | 6°-10° |
| Height of the bluff body (h) | 18 mm-21mm | 17 mm-20 mm |
| Distance between bluff body and aerofoil (d) | 3 mm-10 mm | 3 mm-11mm |

For further investigation of the performance, four configurations were designed using results above. As seen in following figure the power outputs with various bluff body positions were tested. The maximum output power occurred in 7m/s wind speed from configuration d, which was chosen for final tests. It can also be observed that at a bluff body distance less than 5 mm, performance at high wind speed was not stable, thus resulting in reduced power output.

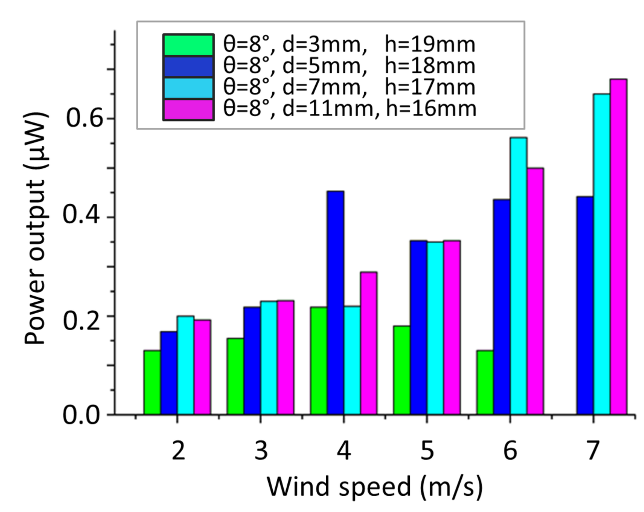


*Figure 7. RMS output power in varying flow speed conditions of four configurations*

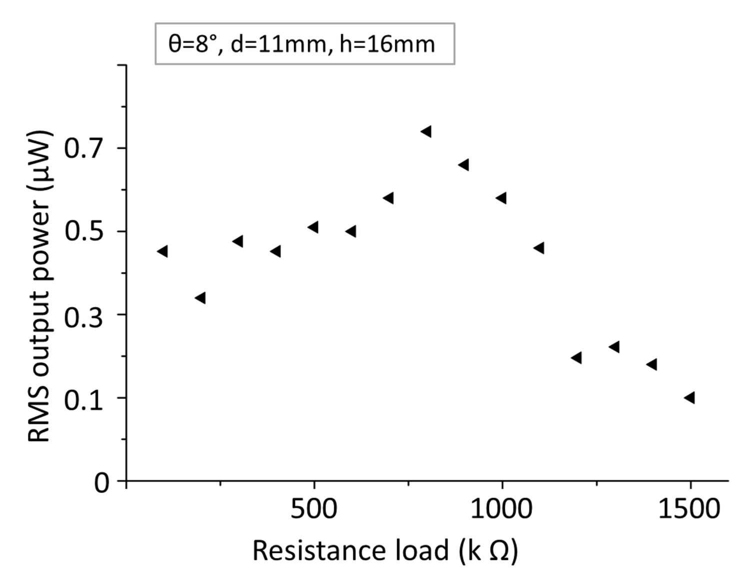


*Figure 8. Output power with varying resistive loads with optimal configuration*

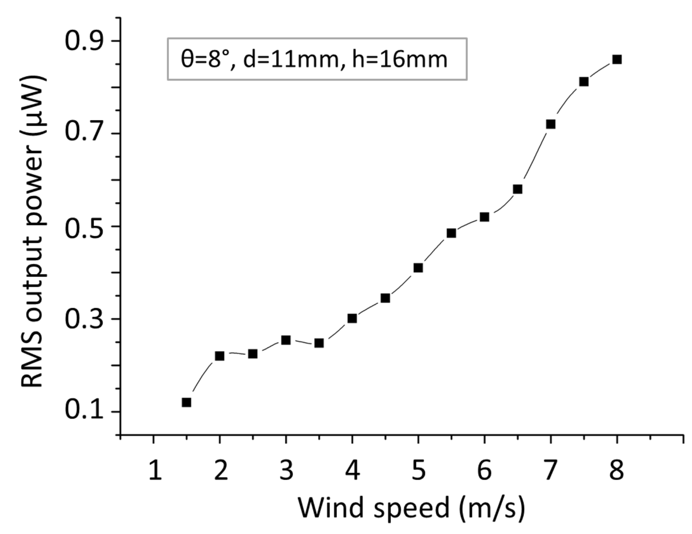


*Figure 9. RMS Output power in varying flow speed conditions with optimal configuration and load*

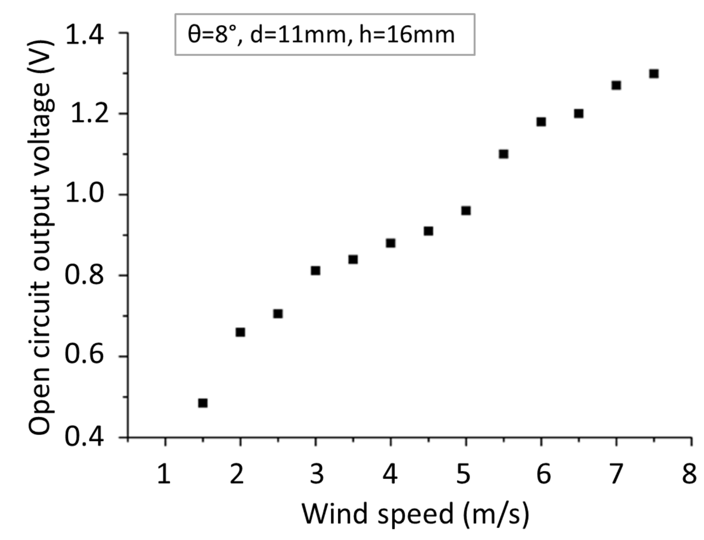


*Figure 10. Open circuit output voltage in varying flow speed conditions with optimal configuration and load*

### Final Performance of the harvester

- ➢Working wind speed range : 1.5 m/s to 8 m/s
- ➢Maximum power output : 0.86 μW
- ➢Maximum open-circuit output voltage : 1.32V
- ➢Optimal load : 800 kΩ

## Conclusions

- ➢ Experimental results generally showed good correlation with the simulation results
- ➢ The harvester operates from a lower wind speed of 1.5 m/s compared with traditional wind turbines.
- ➢ The harvester can effectively convert wind energy into large amplitude mechanical vibration without strict frequency matching constraints
- ➢ The power generated is lower than expected due to the added stiffness of the beam from the presence of the printed PZT layers, however further improvement will be carried out with increasing the length of the piezoelectric part of the beam or using more flexible materials.

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