Piezoelectric energy harvesting for airships and investigation of bio-inspired energy harvesters

Omair Riaz, Rahul Shah*, Bankim Patel*, Farbod Khoshnoud*, Georgios Pissanidis*, Yong K. Chen*,Amir Shahba*, Ray Shimura*, and Giorgio Gaviraghi***

**School of Engineering and Technology, College Lane Campus,*

University of Hertfordshire, Hatfield, AL10 9AB, UK

***Exponential design lab-Europa, Via Troubetzkoy 130, Verbania, Italy*

Abstract

The research in this paper is specifically carried out to obtain alternative ways of powering small electronic components. In the first phase of the paper the effects of air and water flow when induced on the piezoelectric harvesters is discussed. An array of aeroelastic flutter energy harvesters closely spaced together is investigated which can harvest relatively more energy in comparison with an isolated harvester. The spacing of the harvesters is inspired by formation flight of birds and fish schooling. In the second phase, an experiment is conducted in regards with inducing vibrations to piezoelectric cantilevers through rotational kinetic energy caused by wind or rain.

1. Introduction

Over the last decade, the attention on vibration based energy harvesting is growing. There are many types of vibration based piezoelectric energy harvesters where the cantilever type is one of the main. A cantilever type piezoelectric energy harvester is developed for harnessing energy from flow induced vibrations. By getting a better understanding of the dynamic forces that oscillate the cantilever at its natural frequency, the system can be improved by matching the magnitude of flutter frequency which will allow the power coefficient to increase. The aim of the project is to generate electricity with the use of a cantilever type piezoelectric harvester. As the cantilever flutters, it will leave a wake (Tip Vortices) downstream, and hence more of these harvesters can be placed into the flow downstream of the leading harvester in such a way that they can harvest more energy by arranging them in a formation that represents the flight of migratory birds and fish schooling. Both the methods were used to harvest the energy.

1.2 Bird Formation

In nature bird flocks are frequently observed and many reasons for this behaviour have been proposed. It can be said that flocking can be natural social behaviour of birds or it can also be driven by them in need to avoid, detect, and to defend against the marauders. [2]

A V-formation flight of the bird is the symmetric v-shaped flight and also it improves the flying efficiency of birds. Birds use this formation because it greatly boosts the efficiency and also helps in increasing the range of flight. They all fly except first bird in the up wash from the wing-tip vortices of the bird ahead. Opposite rotating line vortices were generated by the leading bird which moves downstream. As they create downwash as well as induce drag it is undesirable for the leading bird, however it is beneficial for trailing bird wing as it is accompanied by upwash behind the leader. The upwash assist each bird in supporting its own weight during flight as each bird can achieve a reduction of induced drag of up to 65%, resulting in an increase of flying range by 71%.[1] The amount of contribution of upwash from the leader depends on tip vortices generated by the wing which is influenced by its position and shape. The combination of highly controllable flight of bird with the variability of bird’s wings allows obtaining the full advantage of bird formation. In V-formation the leader save much less energy than the trailing birds in that formation

1.3 Flutter

Flutter is a phenomenon that occurs between an object and fluid when they are in contact with each other. Flutter happens when the fluttering body has enough fluid flow around it and the body starts moving as it interacts with the fluid. It is a two way movement with positive feedback that occurs to all bodies exposed to sufficient flow. Flutter

can be understood by studying the interaction of the body and the fluid flow around it in terms of aerodynamics, stiffness and inertial forces of the structure.
Structures like cantilevers have flutter effect and it's very common as the structure is able to regain its own form with no aerodynamic force applied to it. The forces that are caused by the movements give rise to an overshoot; this overshoot disturbs the flow to the standard sequences. This continues until the aerodynamic forces lose hold and the structure gets itself ready for next set if sequences. There is a specific flow speed and for any speed above that at the tip deflection the cycle proceeds
There is a lot of research going on flutters as they pose some serious problems under specific conditions. The most serious type of problem is that when the natural frequency of oscillations is superimposed with the structure oscillation which has dire consequences.
Although flutter is a potentially dangerous phenomenon, it does induce energy which can be used. . One of the uses is to use the flutter induced electricity generation (Energy harvesting). It's a very simple and profitable solution of using flutter effect. Investigation on the pairs and groups of deformable bodies flapping in the fluid flow has been done recently. Multi-body flow interactions have been uncovered by these studies which is an advantageous aero elastic energy harvesting device arranged together. The trailing harvester can extract more power with the help of wake generated by leading harvester for certain spatial configuration which develops an 'inverted drafting' with an increase in drag force and larger amplitudes for the trailing harvester. But there is no change in motion or power output of leading harvester; it is as same as the power extracted by the isolated harvester.

In order to harvest energy from wing, utilizing the flexible piezoelectric is one of the way from which energy can be harvested along with the higher rate of saving energy. Energy harvesting by using piezoelectric is becoming more suitable rather than generating from the complex structures and system like windmill or some which totally depend on design; when it all come to structural constrain. Energy harvesting could be achieved by piezoelectric cantilevers. These piezoelectric cantilevers are able to perform in 2DOF (degree of freedom) system. This system works in opposite direction of flow of air and when attached to piezoelectric it improves its efficiency. For this specific experiment the degree of freedom are plunge and pitch. If entire electromechanical mode is to be achieved the study should consist of lumped parameter of flutter vibration.
The aim in this research is based on fundamental plan to affect bio inspiration in practise by using flutter boundary as principal parameter. The system in here was linear and its assessed nodes are assumed for formulations to examine linearity and non-linearity effects, in piezoelectric which were connected to cantilever.
In paper from Erturk et al, particular approach in energy harvesting has been proposed, and it is focused on output from harmonic pattern of piezoelectric are working based on lumped parameter is method of using a section of a wing in a flow of air. According to the rules of 2-Degree of freedom the energy harvesting of this system is done, formulating by means of variables which are related to each other from a piezoelectric scheme.

1.4 Power density and power coefficient

Power density is the main subject of this project along with the power coefficient. Power density is the amount of harvested power per unit swept area occupied by the energy harvester depending on the different formations. Power coefficient is the power generated divided by the wind energy through energy harvester. Usually the horizontal axis wind turbine (HAWTs) are placed in the wind farms as the power coefficient is high. But when the numbers of HAWTs are positioned next to each other in an array the power coefficient reduces in single turbine. Hence, the HAWT harvester can be used for energy harvesting where single isolated turbine is used or when numbers of HAWTs are placed in one straight line. While in case of VAWTs when they are placed narrowly in an array same as to fish schooling the power coefficient increase in single turbine. Therefore, the power output for a particular area of land is much higher in VAWTs compared to HAWTs. The power density is also generally higher in the VAWTs when compared to HAWTs [6].

1.5 Bio-inspired design

Justifying the title, design configurations of the piezoelectric harvester in this project are arranged in the formations as in the fish schooling. All the processes involved in this project aim to harvest the energy from the cantilever type flutter structure when placed in the formation as fish swims in schools.

Many researches and theories have been proposed related to fish schooling since 1960 and the effects of fish schooling to the fish have been investigated till today. The interest of the researchers amends from biology to fluid dynamics, and in recent times it has been transformed to engineering. The interest of harvesting energy from the wind has been increased in the last 50 years for the economic and social sectors. Currently the horizontal axis wind turbines (HAWTs) are used in all wind farms providing the power coefficient is higher in these types of wind turbines. Though the energy extracted from isolated turbine decreased when the spacing between the HAWTs is decreased in an array arrangement. However an isolated vertical axis wind turbine (VAWT) generate comparatively low power coefficient and is more costly than a HAWT with less power output. Whittlesey, Liska and Dabiri carried out an experiment spacing the VAWTs in the configuration similar to the wake of fish schooling due to the shedding vortices [6].

1.5.1 VAWT array formation

When VAWTs are arranged according to the school of fish, the shed vortices form a reversed Karman vortex street in front of the fish . The wake effects of the shed vortices were analysed on a fish school by Weihs where the potential flow model was used. The same model was used by Whittlesey, Liska and Dabiri with similar configurations to investigate VAWT arrays. This model was inspired by the reversed Karman vortex street on fish schooling propulsion which was highly beneficial to analyse VAWT arrangement. Semi- empirical model was constructed to understand the effects on VAWT when placed in arrays [6].

1.5.2 Modelling

As the effects of alignment and configuration of VAWTs in an array was to be analysed, a prospective flow model was first introduced for an isolated wind turbine. The dipole and a point vortex were superimposed to the model for representing one VAWT with the uniform flow. The dipole represents flow obstruction due to existence of the turbine in the flow and the point vortex denotes the rotational flow affected by the turbine. Parameter which represents the power output was defined to estimate the power generated by a single turbine in an array. The power output for a simple drag based VAWT was represented by,

$$P1 = C1\frac{\rho R}{2\pi}\oint (u\ \hat{s})^3 ds \qquad \textbf{(equation1-1)}$$

Where,

P1 = Power output of turbine, ρ = Density of air, C1= VAWT dimensionless parameter, R = Wind turbine radius, ŝ = unit vector tangent to the contour of integration.

The other expression was used for representing power output for a lift based VAWT, where the array performance coefficient, C_{AP} was introduced to assess the effects of turbines spaced closely in an array,

$$C_{AP} = \frac{P(Array)}{P1} \qquad \textbf{(equation1-2)}$$

Where,

P (Array) was the average effectiveness parameter for an array. It was indirectly assumed that C1 was same for all the turbines. When C_{AP} <1, the average VAWT performance in an array was less effective than an isolated VAWT. But when C_{AP} >1, the inter –VAWT aerodynamic interactions were improved in the array configuration and the average power output was also increased [6].

Although to understand the flow physics comparison of C_{AP} is necessary. A power density parameter was introduced later to compare the performance of an array formation with regards to unit land area used by the VAWT farm to produce the power. The power density parameter C_{PD} is expressed by,

$$C_{PD} = \frac{P(Array)}{A(Array)} / \frac{P1}{A1} = \mathrm{K} \times C_{AP}\frac{A1}{A(Array)} \qquad \textbf{(equation1-3)}$$

Where, A(Array) is the total area of wind farm, A1 is land area for one turbine and K is the total number of turbines in an array.

1.5.3 Overall analysis

A comparison was made for the total power density C_{PD} for an array in a wind farm between HAWTs and VAWTs. The spacing between the turbines in a fish schooling array formation was adjusted to obtain the maximum power density. The power density obtained in the VAWT farms was considerably higher than that of HAWT farms, which was believed to higher by one magnitude. As the VAWTs are arranged very close to each other the power generated in each turbine is significantly high. The average turbine power output experience a decrease as the turbines are spaced following the similar formation of shed vortices. Conversely these minimal drops in power output can be neglected when the overall power density of the arrays for closely placed turbines increases [7].

If the spacing between the turbines is allowed to reduce than seen in fish schooling there is a possibility of harvesting more power from these turbines (C_{AP} >1). Naturally fish align themselves in a particular position to enhance their propulsion whereas the main aim of placing the turbines in various array configurations is to obtain maximum power output. The results obtained in the discussed paper appears to be dominated by the vortex association rather than the disruption caused by the neighbouring turbines. Finally the paper concluded that the power output can be increased with different array configuration and specified timely observations.

2. Piezoelectric energy harvesters

Firstly the energy harvesting based on vibrations with the application of piezoelectric transduction was discussed in this section. The simple transduction mechanics that can be useful to convert the vibrations into electrical power was summarised. The other benefits for piezoelectric transduction over electromagnetic and electrostatic effects were also discussed. Besides the historical summaries, the linear piezoelectric theory was looked over with necessary mathematical equations which are based on the first law of thermodynamics.

2.1 Piezoelectric transduction as a base of vibration-based energy harvesting

Energy harvesting though vibrations has been a key intention for the researchers and scientists since last decade. Small electronic equipment based on wireless sensor technology requires very low power and the research in the obtaining the electricity from the vibrations is the chief motivation for these types of low power devices. In this process the concentration is mostly on the bio inspired energy harvesting. If the success is achieved due to these types of researches, the replacement of inbuilt batteries is likely possible and the external source of power is also not required to the device. The piezoelectric material plays an important role in harvesting energy compared to electromagnetic and electrostatic transduction as they provide high power densities [8].

In piezoelectric energy harvesting, the piezoelectric materials directly generate utilizable voltage as behaviour of the material is clearly expressed. The other advantage of the piezoelectric materials is that they can be assembled into extremely small scale due to fabrication assembly methods such thin-film and thick-film. Mostly the cantilever beams are used in the piezoelectric energy harvesters. They are formed of either unimorph or bimorph piezoceramic layers. The cantilever beam acting as a harvester is placed on a vibrating platform and the fluctuating voltage output is measured through electrodes as the active strain is hatched in the piezoceramic layer(s).

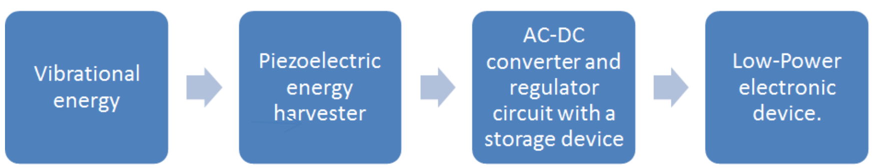

Figure 1 : schematic diagram of general piezoelectric energy harvesting system

The fluctuating voltage should be transformed to steady corrected voltage from an electrical engineering view point. This can be done by a rectifier circuit or a capacitor which consists of AC to DC converter to charge the capacitor through energy harvested in the process. The converted power to the loading device can develop to maximum if the DC-DC converter is inserted in the system.

3. Wind tunnel experiment

An experiment was carried out to examine the effects observed on the piezoelectric energy harvester fixed with the cantilever beam under free stream air-flow in the wind tunnel shown in figure 15. The cantilever beam harvesters were placed on the adjustable platform, where their positions can be altered in both the stream direction and cross-stream direction. The variations in the flutter effects and power output were also analysed by placing the harvesters in different arrangements.

Three formations were considered to extract higher amount of energy in this experiment, which were then compared to the principal isolated harvester. The three cases were as follows:

1) Inverted V formation 2) V formation 3) Echelon formation

When the power output for the isolated harvester was measured, the sole cantilever harvester was placed in the path of air flow in wind tunnel and the air speed was increased gradually to check whether the power output was improved. The values of power output were noted down for every speed and the speed where maximum power was generated was kept constant for rest of the formations. The speed was kept constant at that particular value as it was believed that these formations would harvest more energy compared to the single harvester.

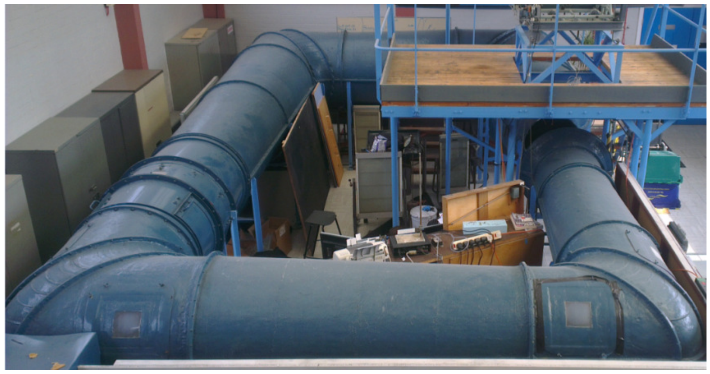

Figure 2: Wind Tunnel Area

As shown in figure 2 the wind tunnel is a closed loop system. For test section the air flow is diffused after passing through the flow straighteners situated upstream. The flow speed is supervised on the computer screen and the air flow speed is sensed by the flow sensors which depend on pressure difference.

3.1 Setup

Before noting any measurements the fluttering effect on the cantilevered harvester was tested and all the tightening parts were rechecked for the equipment. The frequency of the flutter can be obtained from the plot for raw signal in the computer system.

To begin with two tests were performed in the test section of wind tunnel where the harvester was placed in the path of air flow and results were noted and ensured that these results are accurate and errors are not incurred. The experiment setup and conditions were to remain consistent throughout the sub-experiment cases for which awareness at each stage was displayed keeping in mind the health and safety factors.

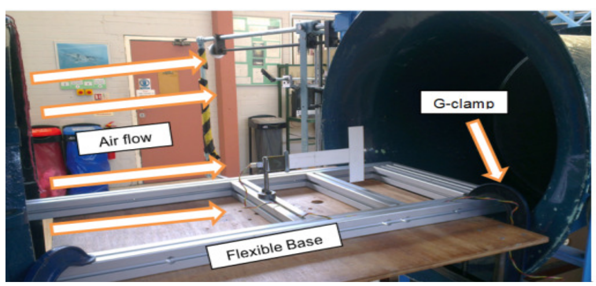

Figure 3 - Working setup for the test

As shown in figure 3 the flexible base is mounted to the table stand with the G- clamps to make sure none of the parts gets detached from the base. The arrows seen on the left side of figure 3 displays the direction of air flow in the wind tunnel. A duct tape was applied on the cantilever beam at opposite end of piezoelectric harvester and a small gap was left between the horizontal and vertical section of the beam to reduce the stiffness and enhance the flutter effect.

3.2 Results

The power outputs obtained from all the experiments performed have been found to be at par with previous researches done by other researchers. A summary of the results has been provided below. The power was harvested from the last piezoelectric harvester against the flow in all formations.

In all the cases the output result are compared with all the different separation distance in each phase, the power output is plotted against the time. Than at the end of each case the power output of that case is compared with an isolated energy harvester power output. Besides this, all the power output in all the cases is derived from the last

piezoelectric energy harvester in the direction of the flow in any of the three cases. The power output which is evaluated, that is the Root Mean Squared (RMS) value of the raw value of the harvester which is conditioned by the Data Acquisition System. T0 evaluate the power output the speed was kept constant at 18.3ms^{-1} because the maximum power output for isolated harvester was achieved at this speed.
Here, a single piezoelectric energy harvester was placed in the test section. The flutter parameters were noted during the process of investigation. The maximum power for an isolated energy harvester was achieved at the speed of 18.3ms^{-1}.

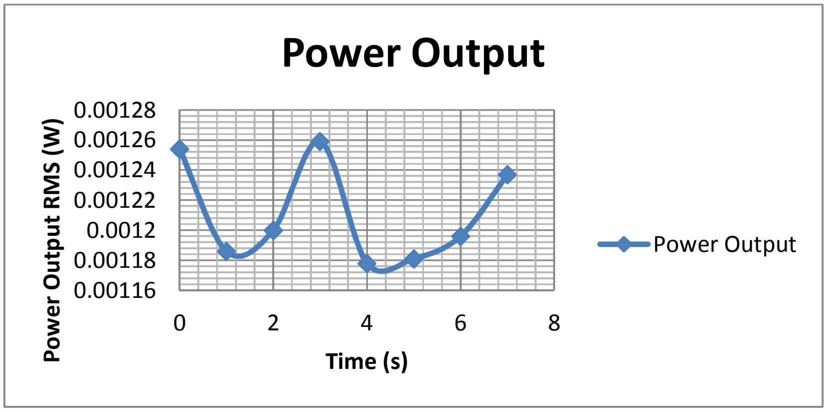

Figure 4 Graph of the Maximum Power output of an Isolated Energy Harvester

The values in the graph are not that much fluctuating with the time. The maximum value that is obtained while performing the experiment for isolated energy harvester was 1.25mW.

3.2.1 The Inverted V-Formation

In beginning it has been discussed about the three cantilevered based energy harvester placed in the inverted V-Formation.

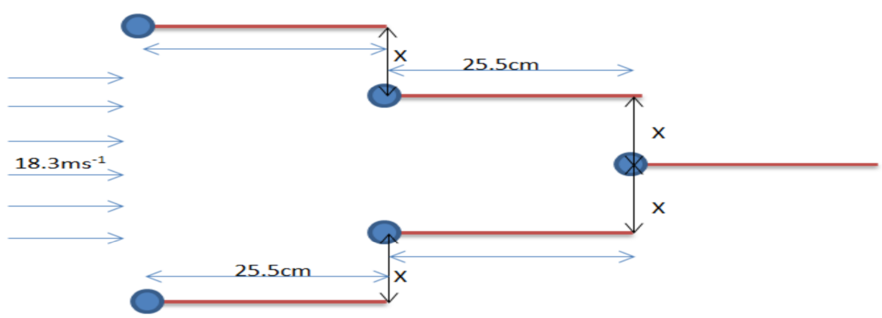

Figure 5: Inverted V formation

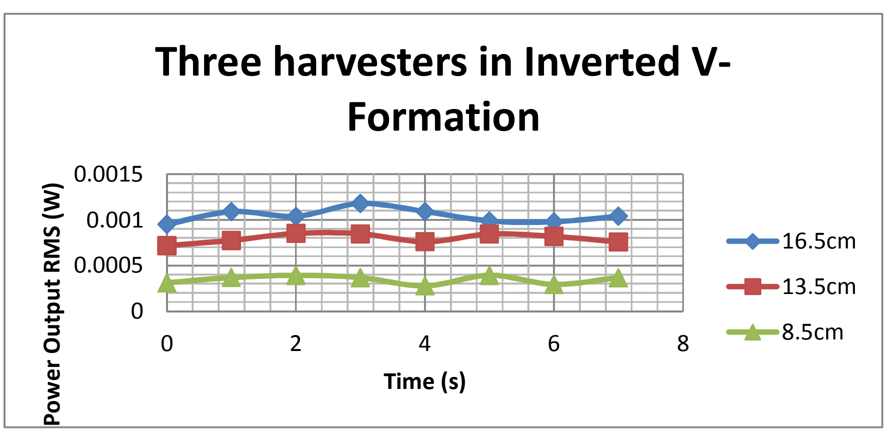

Figure 6: Graph of the three harvesters in inverted V-Formation at different separation distance

As it can be noted in the graph that, at the separation of 16.5cm the output power is at maximum and at the separation distance of 8.5cm is least. The maximum power output at the separation distance of 16.5cm, 13.5cm and 8.5cm are 1.178mW, 0.85mW and 0.39mW respectively. This graph indicates that as the cross-stream separation distance is decreased between the leading and the trailing harvester the effect of the leading harvester on the trailing harvester decreases.

Now, the other two harvesters at the beginning of the formation are added and the power output is being noted. As discussed above in the 'Case I', these two harvesters become the first two harvesters against the flow and this will affect the leading two harvesters, similarly the effect of those two harvesters will have a significant affect in the leading harvester. The separation distance of the leading harvester to the trailing harvester in cross-stream harvester was set at 8cm and 8.5cm between the middle harvesters and the last harvester.

The graph indicates that, as the number of the harvesters is increased in the formation the power output in the last harvester decreases. It can be noticed in the graph that the maximum output power of this formation is 0.36mW.

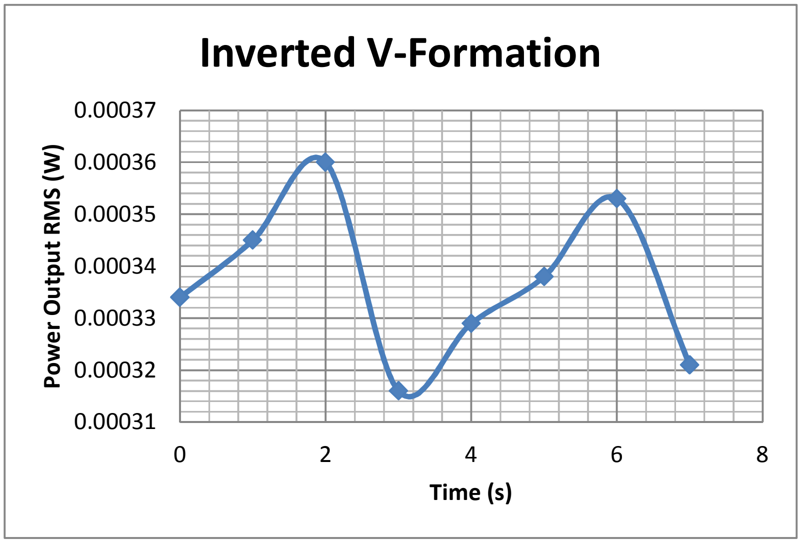

Figure 7: Graph of power output Inverted V-Formation (Five Harvesters)

Hence, comparing the last harvester in the inverted V-Formation with five energy harvesters to the isolated energy harvester gives a power output which is much less than the isolated harvester. The value is decreased upto 71.4% of the isolated energy harvester. Similarly, the performance for inverted V-Formation with three harvesters is almost as good as an isolated harvester but as the separation distance decreases the power output also decreases.

3.2.2 V-Formation

In beginning it has been discussed about the three cantilevered based energy harvester placed in the V-Formation and then the other two were place later.

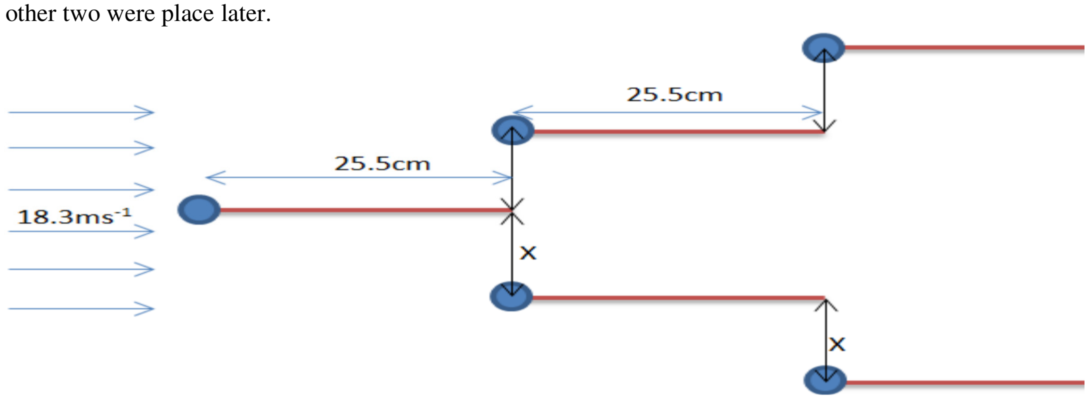

Figure 8: V formation

The power harvested in the change in the separation distance in the cross-stream direction has been shown.

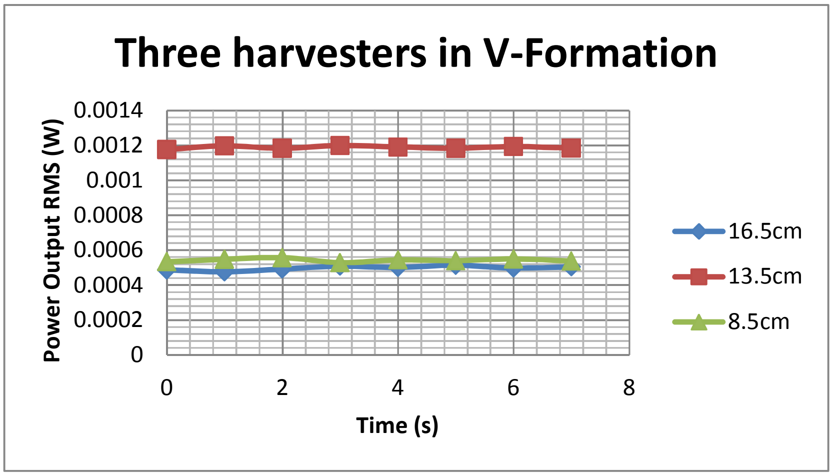

Figure 9: Graph of the three harvesters arranged in V-Formation

As it can be noted in the graph, at the separation of 13.5cm the output power is at maximum and at the separation distance of 8.5cm is least. The maximum power output at the separation distance of 16.5cm, 13.5cm and 8.5cm are 0.51mW, 1.2mW and 0.56mW respectively. The graph above indicates that the power output by the arrangement of three harvesters with a distance of 13.5 cm produces optimum power as compared to the other two.

Now, the other two harvesters at the beginning of the formation are added and the power output is being noted. As discussed above in the 'Case II', these two harvesters become the last two harvesters against the flow and this will be affected by the leading two harvesters, similarly the effect of a first harvester will have a significant effect on the two trailing harvesters. The separation distance of the leading harvester to the trailing harvester in cross-stream harvester was set at 8cm and 8.5cm between the middle harvesters and the last harvester.

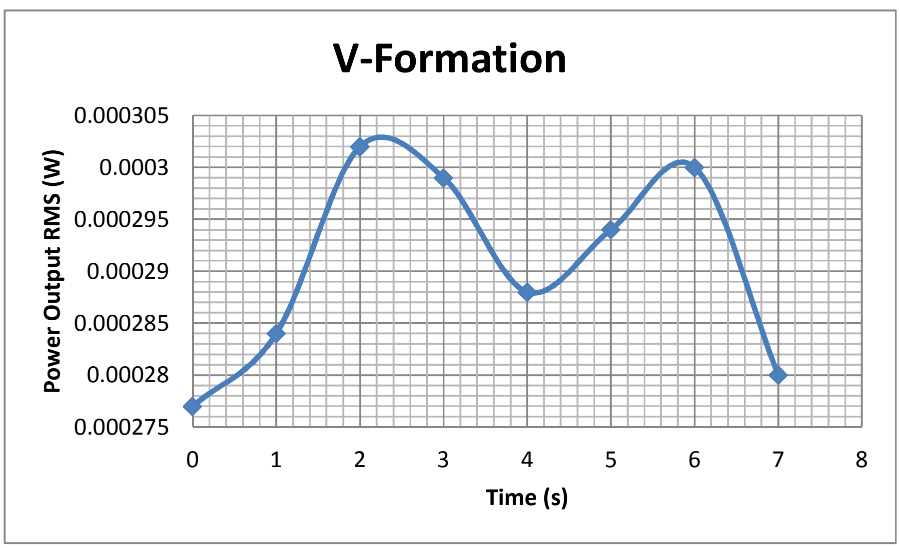

Figure 10: Graph of the Power output of V-Formation (Five Harvesters)

The graph indicates that, as the number of the harvesters is increased in the formation the power output in the last harvester decreases. It can be noticed in the graph that the maximum output power of this formation is 0.302mW.

Hence, comparing the last harvester in V-Formation to the isolated energy harvester the power output of the formation is much less than the isolated harvester. The value is decreased upto 76% of the isolated energy harvester. Also, a comparison between the harvester from a V-formation of three harvesters the isolated case yields an almost equal amount of power for a separation distance of 13.5cm but is halved for the rest of the cases.

3.2.3 Echelon Formation

As stated above, there are four main experiments to this case, the first one being an echelon formation with a stream wise distance of 25.5cm and cross stream distance of 13.5cm. Subsequently, two more cases with slight modifications were performed so that the performance changes could be studied.

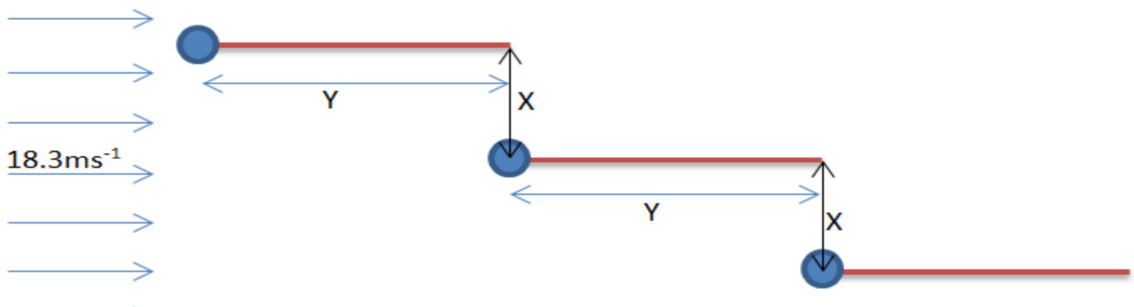

Figure 11: Echelon Formation

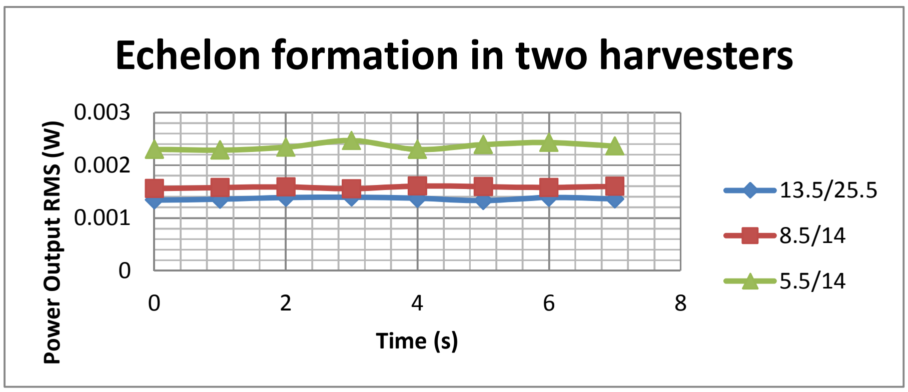

Figure 12: Graph of the Echelon formation of two harvesters

Note: the first values in the legend denote cross stream distances while the latter are the stream wise distances of separation.

The above graph shows how each experiment correlates. The best performance was obtained by the harvester placed at 5.5cm and 14cm in stream wise and cross stream distances respectively. The peak power obtained herein was 2.467mW. The peak powers for the other two cases were 1.606mW and 1.373mW.

Another set of experiments with three harvesters in an echelon formation was then carried out to expand the analysis. This set of experiments shows a stark difference as compared to the previous set of experiments as the values in the previous cases were relatively close together. Whereas, the peak power output found here was 1.35 mW for a separation distance of 5.5/14cm and the same for 16.6/25.5cm was 0.43mW. This meant a difference of 0.92mW.

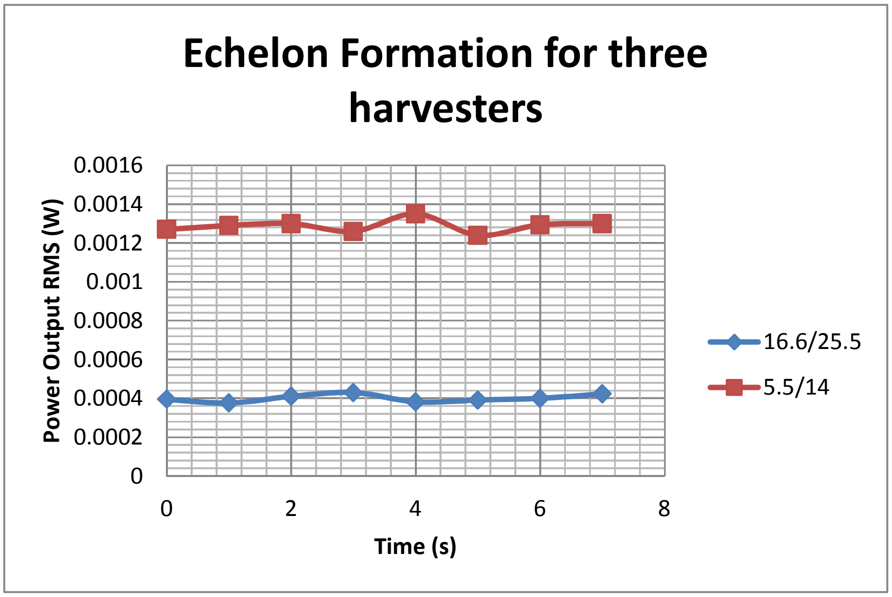

Figure 13: **Graph of Echelon formation with three harvesters**

Note: the first values in the legend denote cross stream distances while the latter are the stream wise distances of separation.

Using harvesters in an echelon formation can be proved to be advantageous as it can be observed by comparison that there is a 9.05% increase in the power output for the 13.5/25.5cm experiment while a 27.56% increase in the output for 8.5/14cm experiment. Also, a substantial rise of 95.95% was noted in the 5.5/14cm experiment. And, when three harvester echelon experiments were compared, a decrease of 65.84% and 7.23% was found for 16.6/25.5cm and 5.5/14cm respectively.

4 Vibrations by Magnetic Force

The idea behind magnetic vibrations is that the vibrations are induced in the piezoelectric cantilevers through repulsive force of magnets. The design basis comes from the rotational phenomenon of the blades of a wind mill. As shown in figure 15, the rotating outer ring will have the piezoelectric cantilevers attached to the inner side and small permanent magnets be attached to the other end of the cantilevers. The fixed inner ring will house magnets to the out surface. The magnets on the inner ring and on the cantilevers will exert repulsive force, thus as the outer ring rotates the repulsive forces of the magnets deflect the cantilevers and hence induce vibrations. This design was proposed after testing a small scale piezoelectric windmill (figure 14) which followed the same principle of harvesting energy.

Magnetic Vibrations: The figure on the right is the model that was tested in wind tunnel to observe the deflection of the piezoelectric bimorphs induced by magnets and to measure the power output that can be achieved. Since the model built was to observe the vibrations, it was not built to be tested under high speed winds. Therefore the tests performed were at a maximum of 8m/s wind speed and it was recorded that the RMS power at this was 0.85mW. The output could have been increased by up to 50% if the build quality and the piezoelectric bimorph attachments were made to the industrial standards. The vibrations could also be increased by using magnets with higher pulling capacity, which are essential to keep the induced vibrations constant at higher rotational speeds.

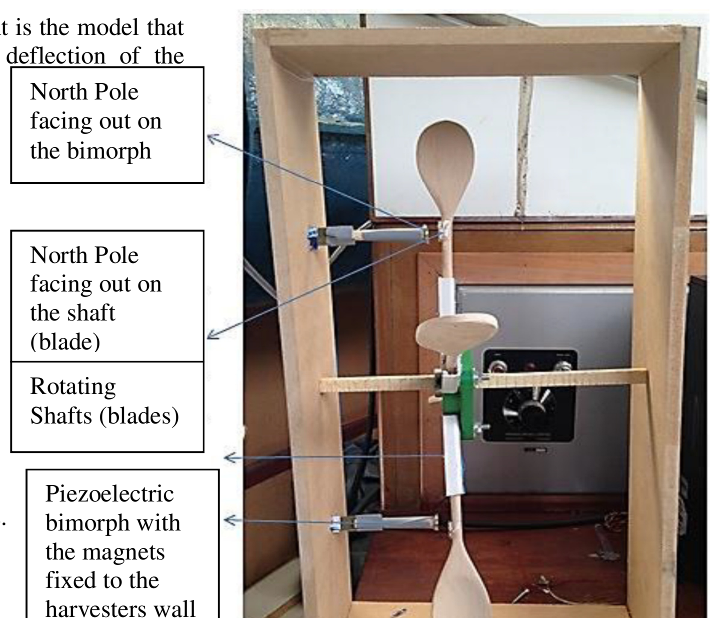

Figure 14: Harvester made to test the effect of magnetic vibrations.

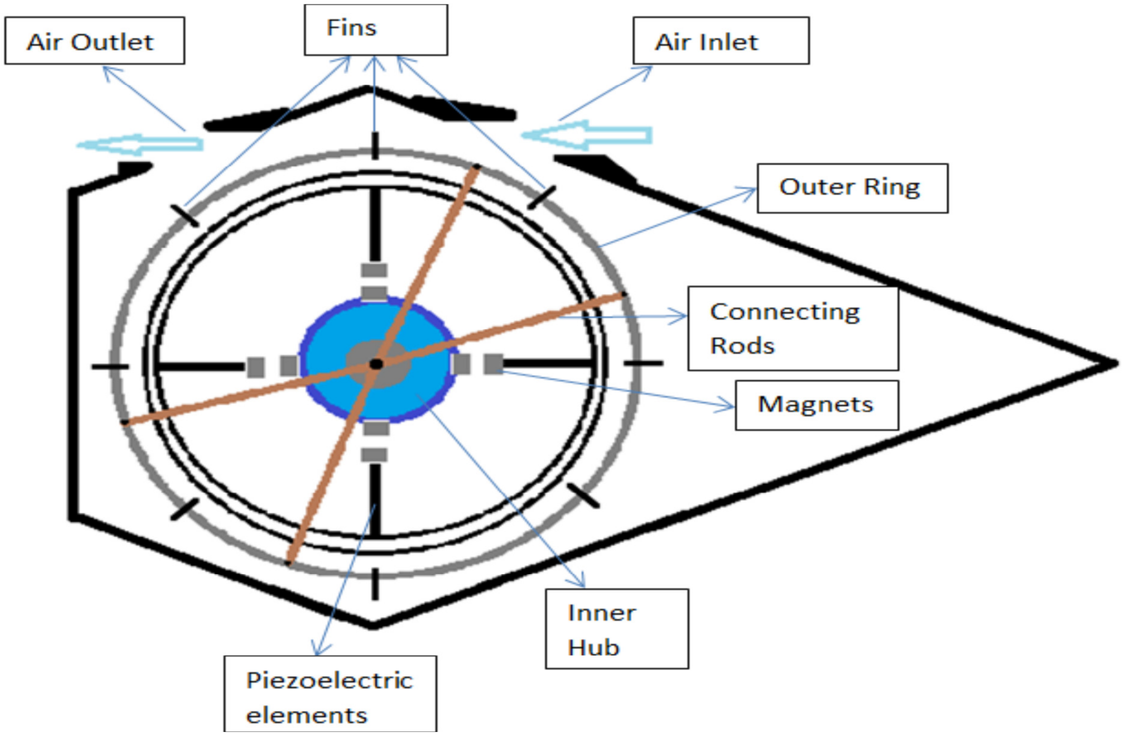

Figure 15: Harvester Proposed for the UAVs

As shown in the above figure, the harvester having an aerodynamic shape can be attached to the undercarriage of a UAV. The inner hub has magnets attached to it and is fixed to the outer ring. The outer ring has 6 fins on its surface which under the impact of high speed air rotate, which also rotates the inner hub. The magnets exert a repulsive force on the magnets fixed on the piezoelectric bimorphs and induce vibrations in the piezoelectric cantilevers hence producing electricity. The piezoelectric elements are attached to the fixed middle ring which does not rotate when the outer ring and the inner hub rotates.

5 The MAAT concept

Travelling at economical altitudes and cruise speeds, MAAT (Multibody Advance Airship for Transport) [9]-[13] gives rise to the possibility of long non-stop-flights. The on the whole frame work of the MAAT concept is dependent on two principle components:

1) PTAH (Photovoltaic Transport Aerial High altitude system) is the central airship cruiser.
2) Three ATENs (Aerial Transport Elevator Network) or feeder ships.

The feeder ships transport individuals and load to/from the cruiser throughout its operation. The feeder idea decreases ground movements for travellers, as the feeders can arrive in any area which additionally decreases vigor consumed to arrive at airports and Co2 outflows. The transport dependent upon the MAAT notion does not require imposing ground structures or runways. The point when MAAT lands to its end of the journey, ATENs transports individuals and freight to land. In the meantime, a different ATEN can prepare to leave individuals and go from area to the Ptah. The point when the ATEN feeder achieves the height of Ptah, the ATEN joins the Ptah in the spot cleared by the diving feeder. The unloading/loading of travellers and payload by the feeders can additionally be finished between two MAATs in the sky. One MAAT may take after an alternate track and in this way MAATs can trade ATENs to arrive at to their fancied ends comparable to the engineering extensively connected in the way and rail transportation. Operational elevation of the MAAT has been evaluated between 13000 to17000 feet relying on the air conditions. The average cruise speed of the MAAT cruiser is evaluated to be around the range of 200 km/h with the velocity of around the range of 100 km/h with heightened frontal winds and 300 km/h with elevated back winds.

The electric vigor for MAAT operation is supplied by a photovoltaic (Pv) framework, throughout daytime, and hydrogen based energy components, throughout night, utilizing the hydrogen transformed by Pvs. The transformed electrical vigor controls the impetus framework and the carrier flying. This vigor framework can give 24-hour operation for MAAT with no outflow and will radically lessen the effect of greenhouse gases.

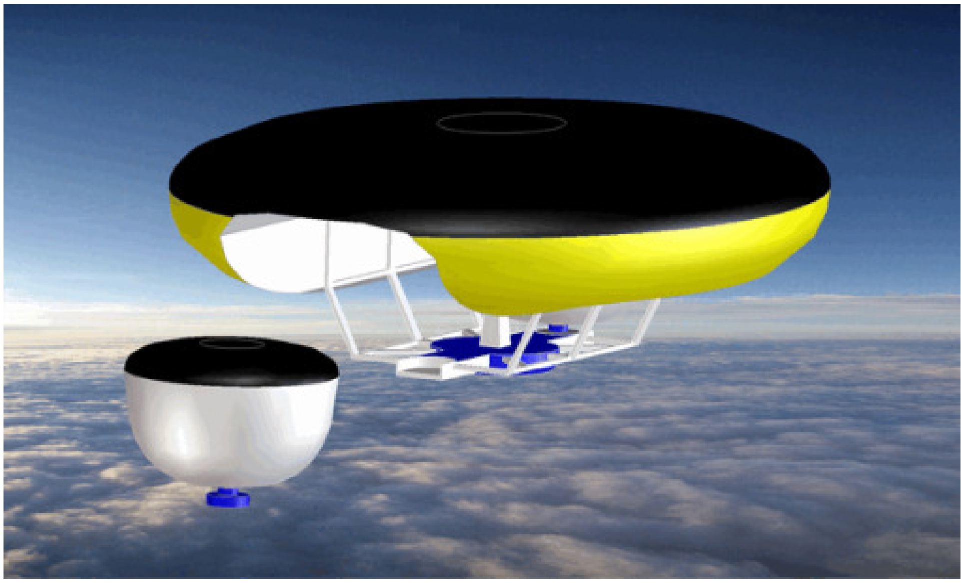

Figure 16: Proposed idea of a MAAT [12]

5.1 Power Generation of MAAT

Since one of the major objective of the MAAT concept is reduced emissions, the use of engines will be omitted, which means the use of natural resources to create the power required on board. At the cruising heights of MAAT, the best natural resources available for the generation of power are wind and solar energy. The MAAT will house solar panels on its roof which will generate power during the day and store the excess for using it during night. Since the solar panels harvest relatively high power than the piezoelectric materials, i twill only be used for the propulsion system.

Piezoelectric materials arranged in Echelon formation as discussed above will be placed on the wings of the MAAT, which will harvest enough power for the consumption of in cabin lighting, sensors and controllers.

As for the magnetic induced vibrations harvester, it can be housed on the undercarriage of the airship where it will have least effect on the total drag of the airship. Since piezoelectric materials do not require a specific time of day to harvest energy, they can work throughout the journey producing power by high speed wind flows. Piezoelectric elements also benefit for the ease of use and simple to replace compared to the high complexity of solar panels, and without having a high impact on the cost.

Conclusions

Performing several experiments in the wind tunnel, on the piezoelectric cantilevers arranged in Bio-Inspired formation, it was concluded that the best formation was the Echelon to harvest the maximum power. Hence using this idea of Bio-Inspired formation and housing the piezoelectric cantilevers on the wings of an airship, it is possible to generate power that can be adequate for the functioning of sensors and other low power controllers.

However, a harvester that uses magnets to induce vibrations can be ideal on land remote areas, where wind speeds are low for the start-up of the harvester. Thereby on an airship where the wind speeds are very high, the magnetic repulsion can induce vibrations in the cantilevers to their natural frequency and hence produce the maximum power for in cabin equipment use.

Considering the MAAT concept, the idea is to use minimum amount of fuel, produce low volume of harmful gasses and travel long distances without having to stop between the journeys. The MAAT's will use the power supply from solar energy and piezoelectric elements to reduce emissions by burning fuel. Another advantage of the MAAT concept is that the central ship houses the feeder ships which can separate from the central ship and land anywhere without the need for an air base or and airport. This concept if adopted can revolutionise the mode of transportation.

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