Experimental Studies and Parametric Modeling of Ionic Flyers

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Abstract—**This paper describes a novel indoor flyer, called the Ionic Flyer, that does not contain any mechanical moving parts and uses only high-voltage electrical energy to produce thrust. Experimental studies were parametrically carried out to understand the performance of the Ionic Flyers such as the force-to-power ratio at different input voltage. Through the experimental results, we propose a simple model to explain the physical phenomena that dictates the thrust generation mechanism for the Ionic Flyers.**

Keywords: Ionic Flyer, Ion-Propulsion, Micro Flyer.

I. INTRODUCTION

Helicopters and airplanes use the principles of aerodynamic to produce lift and thrust. Miniaturized helicopters and planes are now widely used for indoor and outdoor surveillance by embedding them with sensors and cameras. These flyers basically contain powerful rotating mechanical parts in order to move the air around them, and this may cause damages to objects or endanger human subjects around them.

This paper presents a new kind of flyer that does not require moving mechanical parts to provide thrust. i.e., it uses ionic momentum exchange to provide thrust. We will refer to these flyers as Ionic Flyers in this paper. The Ionic Flyer is basically an asymmetrical capacitor which uses high voltage (usually higher than 10kV) to produce thrust. It works without moving parts and convert electrical energy directly to mechanical energy for propulsion. The Ionic Flyers do not contain any dangerous rotating components and the working principle is not aerodynamics but probably related to electrohydrodynamics, i.e., its exact operational principles are unknown at this time to the best of our knowledge.

A basic Ionic Flyer contains two primary elements that are essential for its proper functioning. They are an emitter and a collector. The emitter is usually a thin wire that is connected to high voltage. While the collector is typically a plate foil and is connected to ground. Insulating materials like balsa wood is used to create the frame in order to isolate the emitter wire and the collector foil. Thus, the basic Ionic Flyer can be considered as a capacitor with two asymmetrical electrodes and the air as the dielectric material.

The power input should be in high voltage in order to create a high electric field between the asymmetric electrodes and this is the main requirement of the Ionic Flyers.

Figure 1 illustrates the basic structure of the Ionic Flyer with the parameters *L, d,* r_w and *h* represent the total perimeter length, the separation distance between electrodes, the radius of the emitter wire and the collector height of the Ionic Flyer.

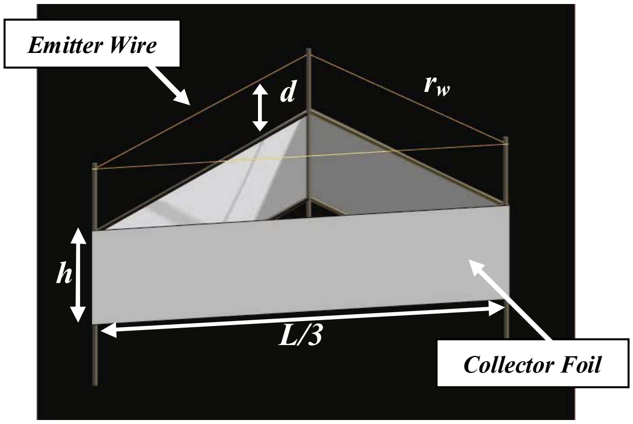

Figure 1. The structure of a basic Ionic Flyer

The working principle of the Ionic Flyers is under investigation. There are two prepositions, the electrohydrodynamic effect and the Biefeld-Brown effect, which are described below. Interested readers are urged to read the information collected by *Mr. Jean-Louis Naudin* [1] for the historical developments of the Ionic Flyer.

A) The Electrohydrodynamic Effect [2]

By applying a high voltage between two electrodes with sufficiently different radii of curvature, the electric corona discharge could occur. The high electric field generated by the emitter causes gaseous ionization and its partial breakdown to produce a high density of ions. As a result, ions with the same polarity of the emitter are drifted to the collector and this cause an electric current flow between the emitter and the collector. [2]

The movement of ions is probably under high-frequency collision with the electrically neutral air molecules. Momentum transfer from the ions to the air can be assumed to take place. Therefore, the Coulomb force acting on the ions becomes an electric body force on the air molecules [3]. By Newton's third law, the force acting on the Ionic Flyer is in the upward direction and this make the Ionic Flyer lift up.

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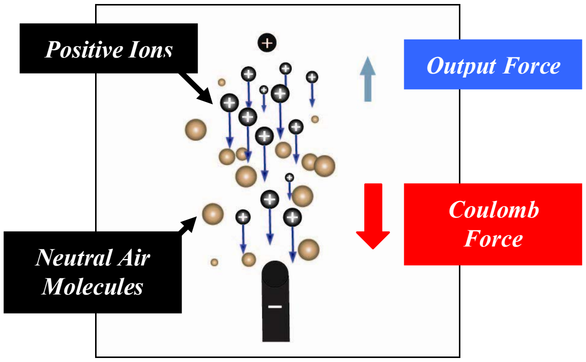

Figure 2. The microscopic view between the electrodes of the Ionic Flyers.

B) The Biefeld-Brown Effect

The Biefeld-Brown effect is a kind of antigravity effect but it cannot be explained by the conventional physics. It is proposed by Dr. Biefeld and Dr. Brown around the 1950's. They believed that when a strong uneven electric field is generated by a device, there will be an induced gravitational field. The induced gravitational field can interact with the Earth's gravitational field and either increase or decrease its strength. If the induced gravitation field is in the opposite direction and its strength is stronger than the Earth's gravitational field, the device will lift up. This effect can be experimentally studied by applying high voltage to a capacitor which is placed inside a plastic casing to reject the influence of electric wind. The weight of capacitor is measured to be reduced as Biefeld-Bown effect exists to reduce the gravity strength on the capacitor [4]. We will show in this paper that our Ionic Flyer does not operate under the Biefeld-Brown principle.

II. THE ELECTRICAL MODEL

When an electric corona discharge takes place in the air, space charge will accumulate in the air gap between the two electrodes and this will cause the electric current to flow. Thus, an electrical model was sought for the Ionic Flyers by obtaining their relationship. This is done experimentally by increasing the input voltage at 1kV increments to the Ionic Flyers and record the conducting current at the same time. The experimental setup is described in Figure 3.

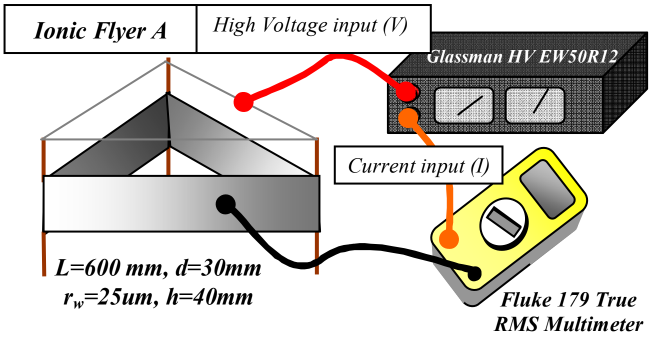

Figure 3. The experimental setup to measure the current-voltage relationship of Ionic Flyers

For the ease of explanation, Ionic Flyer A which has $L = 600mm,\ d = 30mm,\ r_w = 25\mu m$ and $h = 40mm$, as shown schematically in Figure 3, is taken as a representative flyer in the following discussion. The experimental measured current of Ionic Flyer A was plotted with the applied voltage as shown in Figure 4. By using the least square fitting method, we have developed a fitting curve $I = 0.001176(V-6.169)^2$ which is our proposed I-V relationship for Ionic Flyer A. A parametric analysis was performed and a general electrical model of the Ionic Flyers was determined and their properties are discussed below.

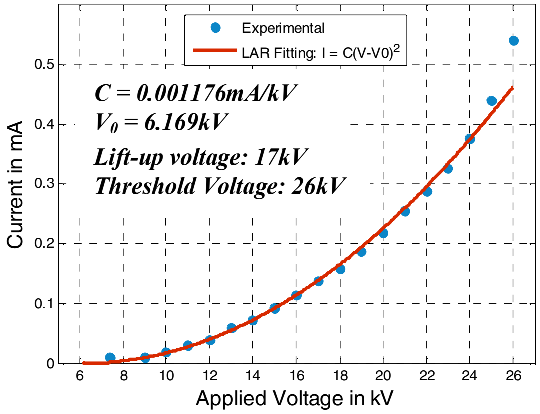

Figure 4. The variation of corona discharge current with applied voltage for Ionic Flyer A: experimental points (blue circle), the proposed I-V model $I = 0.001176\,(V-6.169)^2$ (full line)

A) The three stages of Ionic Flyers

When the applied voltage in the range of *zero* to about $6kV$ (depends on the configuration of the Ionic Flyer), no measurable current is record by the multimeter. (The minimum measurable current for Fluke 179 True RMS Multimeter is 10µA). The Ionic Flyer is in the insulating stage. Since the electric field generated by the Ionic Flyer is not strong enough to break down the air (the break down field strength of air is 30kV/cm). The Ionic Flyer in this stage can be considered as an insulator. Since the power input to the flyer is zero, no force is created.

As voltage input becomes greater than $6.169kV$ (*conducting voltage* V_0), there are measurable current record by the multimeter. The Ionic Flyer becomes conductive at this stage (i.e., *conducting stage*) because the electric field strength is strong enough to break down the air between the electrodes. The Ionic Flyer is just like an asymmetrical capacitor that have very low capacitance and work under the breakdown voltage of the dielectric material (i.e., air). As the voltage increases, the resistance of the air will decrease because there are increasing number of ions that exist in the "dielectric material".

However, when the voltage input is beyond about $26kV$ (*threshold voltage*), the air is about to be totally broken down, noise comes out from the Ionic Flyer and the flowing current becomes fluctuating. Sparking can also be observed between the electrodes of the Ionic Flyers. Once this occurs, an ionic path is completed by the positive ions and connecting the positive and negative electrodes, making the Ionic Flyer

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short-circuited. At this moment, a large current is flowing through the Ionic Flyer and the thrust generation will be disabled. This is the *breakdown stage* since the Ionic Flyer may be possibly damaged by the sparking.

The Ionic Flyers can be defined with an *operating range* that they can work properly. The *operating range* is defined between the *conducting voltage* and the *break-down voltage* (*6.169kV* to *26kV* in this case). At this range, the air between electrodes is partially broken down and the Ionic Flyer can fly silently and relatively stable. The *lift-up voltage* is the minimum voltage input to lift up the Ionic Flyer. For a proper Ionic Flyer, the *lift-up voltage* should be in the range of the *operation stage*.

B) The formulation of I-V characteristic equation

The current-voltage relationship can be approximated by a quadric equation. The electrical model is therefore

$$I = f(L,d,k,\varepsilon)(V - V_0)^2 \tag{1}$$

where I is the *input current* in *mini-ampere*; V is the *input voltage* in *kilovolt*; V_0 is the *conducting voltage* of the Ionic Flyer in *kilovolt* and $f(L,d,k,\varepsilon)$ is the *current gain* to be deduced in the next section.

III. THE LIFT-FORCE MODEL

The basic lift-force model is done by investigating the power input to the Ionic Flyers and than record its upward lift-force. The result can be plotted in a force output vs. power input graph. The experiment was carried out by applying voltage with 1kV increments to the Ionic Flyer which is connected by a wire to an additional weight of 15 gram. The additional weight is being put on an electronic balance which has resolution of *10mg*. The lift-force is represented by the total weight of the Ionic Flyer plus the weight reduction of the additional weight record by the electronic balance. The experimental setup is described in Figure 5.

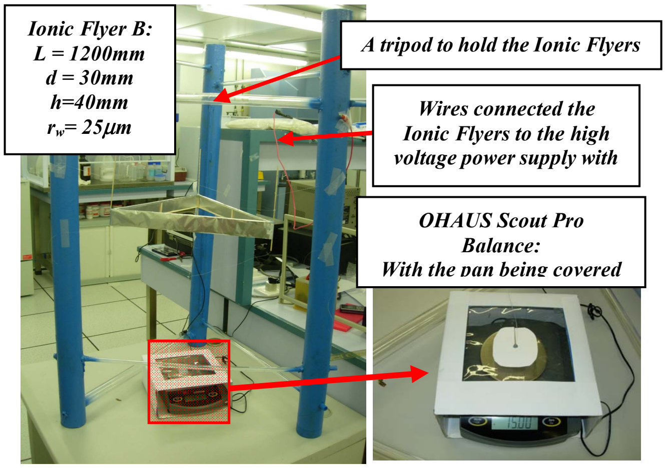

Figure 5. The experimental set-up used to measure the output force to power relationship of Ionic Flyers

We use the experimental data from Ionic Flyer B with *L=1200mm, d=30mm, r_w=25μm* and *h=40mm,* to discuss the formulation of the lift-force model below.

A) Output force is proportional to voltage input

The experimental data of the voltage input and force output fit very well using the linear equation $F = 1.019(V - 12.98)$ as shown in Figure 6. The general equation for output force and input voltage can be formulated by

$$F = J(V - V_f) \tag{2}$$

where F is the *lift-force* in *gram*; V is the *input voltage* in *kilovolt*; V_f is the *barrier voltage* in *kilovolt*, i.e., the force generation process begins when the applied voltage is greater than V_f,. J is the *force gain* in *gram/kilovolt* to be further deduced.

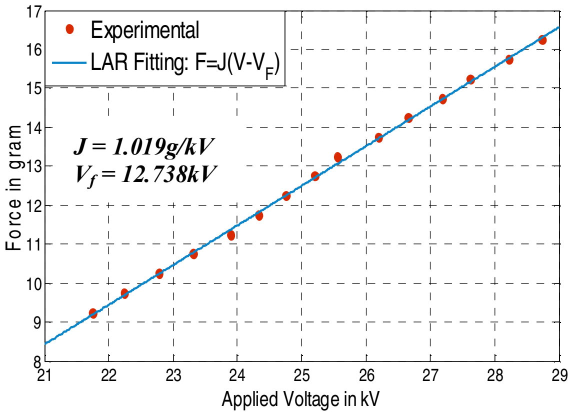

Figure 6. The variation of lift-force with applied voltage for Ionic Flyer B: experimental points (red circle), the proposed F-V model $F = 1.019(V - 12.738)$ (full line)

B) The maximum output force of the Ionic Flyers

The maximum force generated by the Ionic Flyer is limited by the maximum power input. Since every Ionic Flyer has a limited threshold voltage, the maximum force output is limited by this threshold voltage. When a voltage greater than the threshold voltage is applied to the flyer, the output force will drop abruptly to zero. All the input energy will be consumed in discharging.

C) The formulation of the lift-force model

The lift-force model of the Ionic Flyer in terms of power input and force output can be formulated by using the electrical model $I = f(L,d,k,\varepsilon)(V - V_0)^2$ that was discussed in section II.

By $P = IV$, we can get the following equation:

$$P = f(L,d,k,\varepsilon)V(V - V_0)^2 \tag{3}$$

By substituted with equation (2), we can formulate the lift-force model in terms of only power input and force output by the following equation:

$$P = f(L,d,k,\varepsilon)(J^T F + V_f)(J^T F + V_f - V_0)^2 \tag{4}$$

where P is the power input in *Watt*; F is the force output in *gram; J^F* is equal to the reciprocal of the force gain *J*.

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Figure 7 shows the experimental data and the deduced equation of the lift-force model of Ionic Flyer B with $f(L,d,k,\varepsilon) = 0.002405mA/kV$ and $V_0 = 5.604kV$, as deduced by the electrical model. From the force-voltage relationship, $J = 1.019\ g/kV$ and $V_f = 12.738kV$.

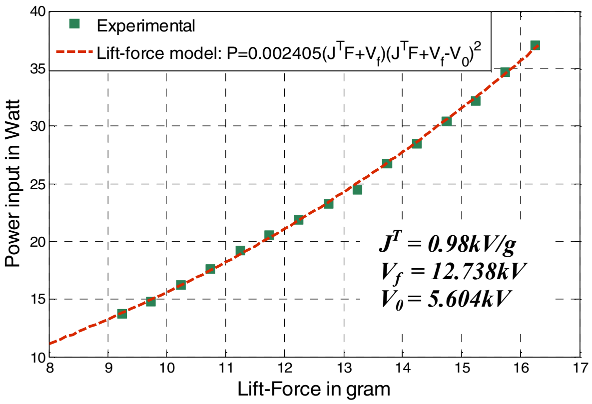

Figure 7. The variation of power input with lift-force for Ionic Flyer B: experimental points (green square), the proposed Lift-force Model $P = 0.002405(0.98F + 12.738)(0.98F + 7.134)^2$ (dash line)

IV. PARAMETRIC ANALYSIS AND FORMULATION

From the previous sections, we have formulated the electrical and lift-force model of the Ionic Flyers with some unknown parameters and a function that had to be determined. In this section, six primitive parameters have been identified and experiments were carried out to test how they affect the performance of the Ionic Flyers. They are 1) the total perimeter length of the Ionic Flyers (L); 2) the separation distance between the positive and the negative electrodes (d); 3) the height of the collector foil (h); 4) the radius of the emitter wire (r_w); 5) the dielectric permittivity of the dielectric materials (ε); 6) the mobility of ions of the dielectric materials (k). Each of these experiments is done by varying the testing parameter while kept all other parameters consistence. The results can be analyzed by investigating the *I-V curves* and the *F-P curves*.

A) The total perimeter length of the Ionic Flyers

We have constructed five Ionic Flyers for this experiment. They all have $d = 30mm$, $r_w = 25\mu m$, $h = 40mm$ and the experiments were performed in the CMNS clean room with controlled 25°C temperature and 42% humidity. The five Ionic Flyers have the perimeter length *L = 300mm, 600mm, 750mm, 900mm and 1200mm,* respectively, as shown in Figure 8.

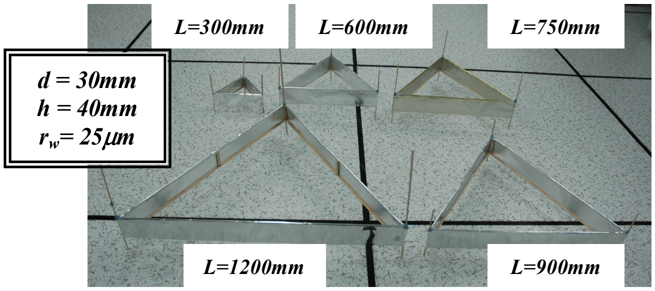

Figure 8. Five Ionic Flyers with *L=300mm, 600mm, 750mm, 900mm and 1200mm*

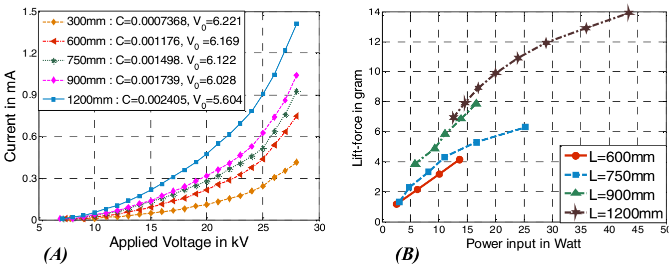

Figure 9. (A) I-V curves and (B) F-P curves for the Ionic Flyers with *L = 300mm, 600mm, 750mm, 900mm and 1200mm*

Based on the experimental result, we can draw the following conclusions.

i) Lift-up voltage decreases as the length increases

By comparing the *lift-up voltage* of each of the Ionic Flyer, we can find that the lift-up voltage will decrease as the total perimeter length of the Ionic Flyer increases. As the Ionic Flyers are supplied with the same voltage, the output force will be larger with a larger size flyer, which leads to a lower lift-up voltage.

ii) Current is proportional to the length

By investigating Figure 9(A), the flowing current of the Ionic Flyers can be found to be proportional to its perimeter length and this property can be formulated by

$$\frac{I_M(V_i)}{L_M} = \frac{I_N(V_i)}{L_N} \tag{5}$$

where I_M and L_M are the input current and the total perimeter length of the Ionic Flyer M; I_N and L_N are the input current and the total perimeter length of the Ionic Flyer N; V_i is any voltage input in the operating range.

When Ionic Flyers are supplied with the same voltage, the resistance of the Ionic Flyer is inversely proportional to its total perimeter length. The current gain can than be represent by $f(L,d,k,\varepsilon) = Lf(d,k,\varepsilon)$

iii) Force to power ratio increases as the length increases

By comparing their lift-force model as shown in Figure 9(B), the force to power ratio is larger for an Ionic Flyer with longer perimeter length.

B) The gap distance of the positive and negative electrodes

In this experiment, an Ionic Flyer with $L = 1200mm$, $r_w = 25\mu m$ and $h = 40mm$, was test for its performance by carrying out the experiments with different electrodes' separation distance of *30mm, 40mm, 50mm, 60mm and 90mm*. Figure 10 shows the I-V curves and the F-P curves of the experimental results. One obvious property is that the current will decrease as the separation distance increases. The current gain is plotted with the separation distance in Figure 11. The experimental data can be fitted very well with the curve $g(d) = 2.087\left(1/d^2\right)$, with all other parameters is being constant. By combining the result with the previous experiment, $f(L,d,k,\varepsilon)$ is equal to $\frac{L}{d^2} f(k,\varepsilon)$

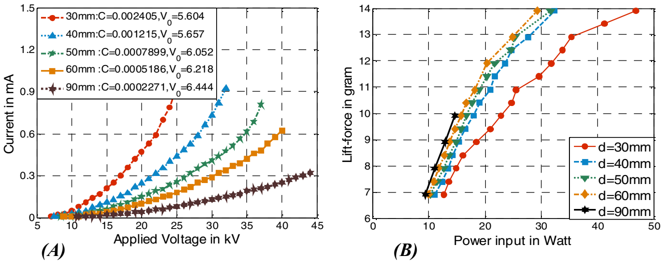

Figure 10. (A) I-V curves and (B) F-P curve for the Ionic Flyers with *d = 30mm, 40mm, 50mm, 60mm and 90mm.*

By investigating the force to power graph, by increasing the electrodes' separation distance, a higher force-to-power ratio can be obtained. To draw a conclusion, by increasing the distance, ion generation will be decreased. But, a higher force-to-power ratio could be obtained, and so the thrust is generated more efficiently.

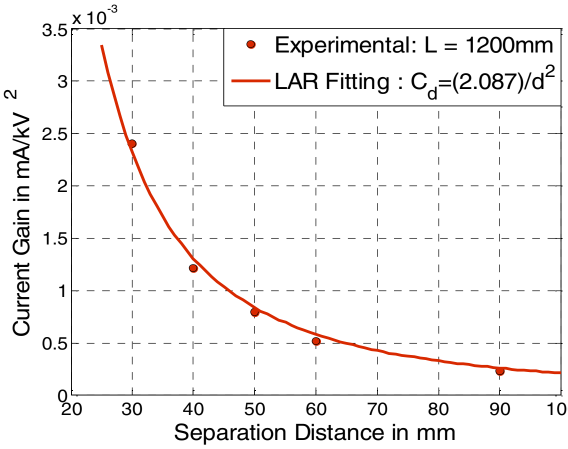

Figure 11. The variation of the current gain with electrode's separation distance d = *30mm, 40mm, 50mm, 60mm and 90mm.*

C) The depth of the collector foil

In the previous experiment, we considered the perimeter length of the Ionic Flyers. By increasing the length, the area of the electrodes will be increased. Another way to increase the area of electrodes is by increase the height of the foil. In this experiment, four Ionic Flyers with *L = 600mm, d = 30mm and* $r_w = 25\mu m$ but constructed with *h = 30mm, 40mm, 50mm, 60mm,* respectively, as shown in Figure 12, were tested.

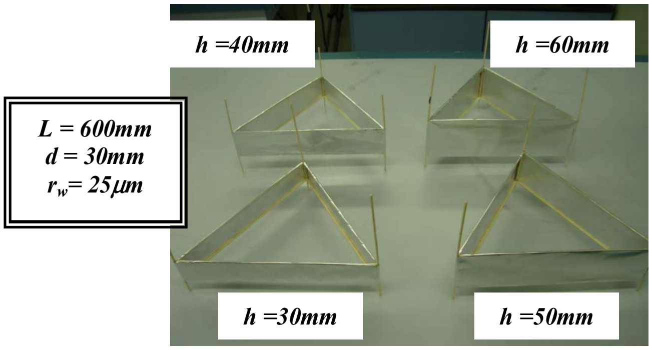

Figure 12. Four Ionic Flyers with *h = 30mm, 40mm, 50mm and 60mm*

The electrical and lift-force models are shown in Figure 13. Obviously, they have nearly the same I-V curve. Also, referring to the Force-to-Power Curve, they also have similar relationship. So, all these models, although configured with different foil depth, have the same electrical and lift-force model.

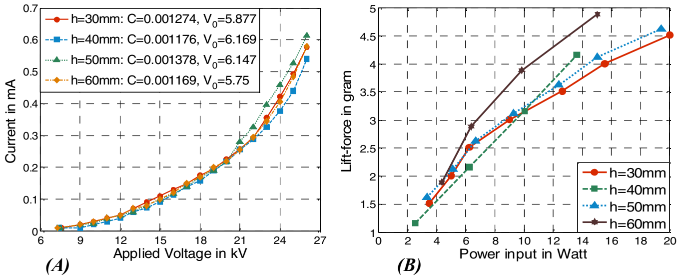

Figure 13 (A) I-V curves and (B) F-P curve for the Ionic Flyers with *h = 30mm, 40mm, 50mm and 60mm*

D) The radius of the emitter wire

The emitter wire played an importance role in ion generation. Since the electric field strength is the strongest around the surface of the emitter wire, so the radius of the wire is a critical property of the strength of the electric field. So, we constructed two Ionic Flyers with their emitter wire being different in radius. The two Ionic Flyers both have *L = 1200mm, d = 30mm, h = 40mm*. The radius of the emitter wires were $25\mu m$ and $10\mu m$, respectively. The experimental results showed that they have the same *current gain*. However, the two curves have a shift in the voltage-axis since they have different *conducting voltage*.

They have different *conducting voltage* because the electric field strength should be constant around the wires during discharge, although they have different radius. This can be explained by the Peek's equation [5]. One of the most important concepts of the Peek's equation is the corona inception voltage (CIV). CIV represents the required voltage between two electrodes that can make the air between them to begin break down. So, Ionic Flyers begin to break down the air molecules when the supply voltage reaches CIV:

$$CIV = Gm_0 E_0 \delta \left(1+\frac{0.0301}{\sqrt{\delta \cdot r_w}}\right) r_w \cdot \ln\left(\frac{d}{r_w}\right) \qquad (6)$$

where m_0 represent the wire roughness factor; δ is the air density factor; d is the distance between two wires and r_w is the radius of the wires; and G is a modification factor for wires with radius smaller than *0.25mm.*

For all of our Ionic Flyers, the wire used is stainless steel polished wire, so m_0 is equal to one. All the experiments were done in a clean room with standard temperature and pressure, so δ is equal to one also. E_0 is the standard break down field strength of the air and is equal to *3MV/m*. G is the modification factor equal to *1.5* for wires with radius smaller than *0.25mm.* By using the Peek's equation to calculate the CIV for the two wires used in the experiment, we obtained $CIV = 5.113kV$ and $4.676kV$ for the $25\mu m$ and $10\mu m$ wire, respectively. Figure 14(A) shows their experimental conducting voltage is $5.064kV$ and $4.434kV$ respectively.

By observing the force to power curve at Figure 14(B), we can see that the data of the two Ionic Flyers nearly coincide. We can conclude by this experiment that the force generation efficiency is not related to the wire radius.

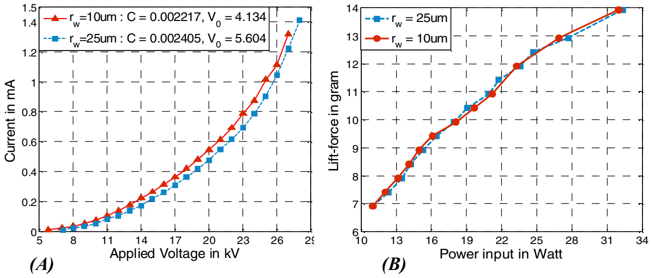

Figure 14 (A) I-V curves and (B) F-P curves for the Ionic Flyers with $r_w = 25\mu m$ and $10\mu m$

E) The dielectric materials

The force generation process of the Ionic Flyers can be divided into two parts. They are the ion-generation and the ion-transportation in between the electrodes. The lifting force generated may be somehow due to interactions and force offset between the ions and the neutral air molecules in the dielectric medium. The ion-generation process is related to the permittivity of the dielectric material while the ion-transportation process is related to the permeability of the dielectric materials.

The permittivity of dielectric material can not be modified because the Ionic Flyers are supposed to work under atmospheric air to have a wide variety of applications. The permeability is related to the air pressure and the temperature, and this will affect the ions' mobility in the dielectric material. So, the current gain $\frac{L}{d^2} f(k,\varepsilon)$ is a function of the ions' mobility and the permittivity of the dielectric medium. However, the detailed formulation is under investigation and will be reported in a different paper.

V. CONCLUSION

This paper presents a novel flying mechanism which uses no moving parts and only electrical energy to produce lift and thrust. Experimental studies were carried out to formulate the current-voltage characteristic equation and the force-to-power equation, which are critical to the understanding of the operational principles of the Ionic Flyer. Parametric analysis is further performed to figure out the effects of all primitive parameters that affect the performance of the Ionic Flyers. The force generation process is confirmed to be not only Biefeld-Brown effect since the direction of the output force is not defined by the direction of the gravitation field but in the direction from the collector to the emitter.

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