# Aerodynamic Study of Delfy Hovering Flapping Wing

By

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Dissertation submitted in partial of the requirement for the

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# CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
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(MECHANICAL ENGINEERING)

Approved by,

________________
(Ir Idris b Ibrahim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Muhamad Hanafi b Abd Rahim

# ABSTRACT

Flapping wing mechanism is undergoing an extensive application nowadays but not yet commercialized for its limited technology to fulfill such a high energy propulsion system with limited power source. However, data gathering on the aerodynamic aspect can be useful to the future generation, during the time when the technology is available. My thesis is to study the aerodynamic characteristic of hovering flapping wing generally on commercial Delfly.

This study will reveal the mechanism used in Delfly and explain the data gathered from aerodynamic fundamentals such as lift, thrust, drag and weight using model equipped with flapping wing mechanism. For a practical research, an optimum angle of attack and frequency of flapping wing also will be counted to provide a maximum lift or thrust. Another parameter important in simulation is energy efficiency by analyzing power input and lift/thrust output. Lastly, characteristic flow of air during observation will be recorded to provide a comprehensive data for future reference.

The result obtained that lift and thrust are synchronize with the flight lift height and velocity in on air. The optimum thrust generated for Delfly is found at tilted angle of $60^o$ forward. This is due to force generated is dived to lift and thrust simultaneously. The efficacy graph force versus voltage input reveal the efficacy is highest starts from 6volt and above. Meanwhile the overall mechanical efficiency is 19.3%. From the slow motion sequences, the air flow characteristic is obtained and shows how the air is drawn due vacuum region created during high speed opening wing phase and generate thrust during flapping close phase.

# ACKNOWLEDGEMENTS

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# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

Aerodynamic studies of hovering flapping wings have been a phenomenon since a decade ago as the US research and defense agencies was funded to develop a small sized aircraft that simulate the insect or the light weight bird such as the humming bird. These new tech are called Micro Air Vehicles (MAVs). Generally the technology was introduced to enhance the application of military surveys and intelligent purposes. This research will be focusing on commercial Delfly. But hopefully this research can be applied for general purpose maybe to stimulate a wider production and application of this interesting new field of air locomotion.

## 1.2 Problem Statement

Flapping wing mechanism have been a great research value for a steady or hovering flying mechanism but very limited to the current technology as there are still no concrete research to generalize the flapping wing mechanism to be able for public purpose. A multi-tasking simulation with various tools and software also made a barrier for the researchers to develop such a risky and new technology that are still not well known about their true potential. For a complete analysis, a detail aerodynamic study to develop an ideal wing for a maximum thrust is needed. Simulations on the other hand need to be started as a kinematic analysis to find a proper mechanism to simulate a certain frequency to produce an ideal amount of thrust needed to synchronize with the previous aerodynamic study and also weight resistance of the mechanism itself.

### 1.3 Objective

- To study the mechanism used in Delfly
- To investigate aerodynamic data such as lift, weight, thrust and drag from the model/bird.
- To analyze optimum angle of attack and frequency of flapping wing to determine the maximum lift or thrust from the model.
- To analyze energy efficiency by monitoring power input and lift/thrust output
- To understand characteristic flow of air during simulation to provide a comprehensive data for future development.

### 1.4 Scope of Study

High time constraints (7-8 month) with multiple engineering subjects taken along with the research period seem to be a major contributor for the limit scope. The scope of study is limited to a certain factors:

i. This research is focused toward practical observation method only and limited to the simple available model in Malaysia.

ii. The data gathered maybe valid limited to the specific mechanism and actuator used in the prototype acquired.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Aerodynamic Study of Delfly Mechanism

The DelFly is one of Micro Air Vehicle (MAV), an extremely small, remote-controlled aircraft. With its two pairs of flapping wings, the DelFly resembles a dragonfly. Some larger variants of the DelFly can hover in the air like a hummingbird, and even slowly fly backwards.

Figure 2.1: Commercial Delfly available in Malaysia (E-Bird)

This DelFly weighs 15 grams and has a size of 28 cm from wing tip to wing tip. But, the smallest DelFly , Delfly Micro only weighs 3 grams and has a size of 10 cm from wing tip to wing tip. This makes it the smallest flying ornithopter carrying a camera in the world.

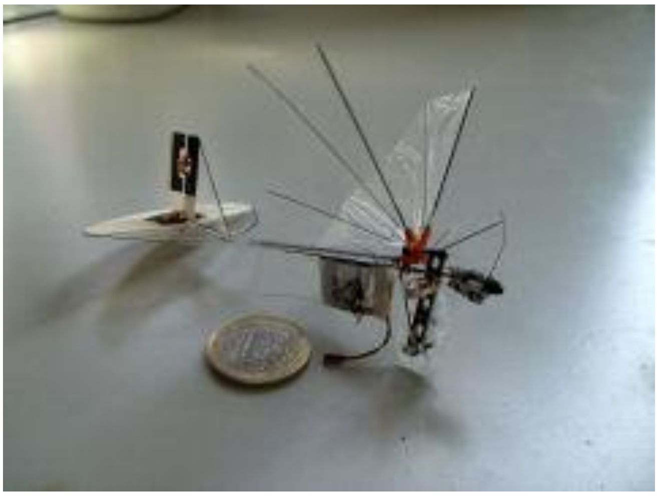

Figure 2.2: Delfly Micro

One of the goals of research on Micro Air Vehicles (MAVs) is to arrive at fly-sized MAVs that can fly autonomously in complex environments. Such MAVs form a promise for observation tasks in places that are too small or too dangerous for humans to enter. Their small size would allow the MAVs to enter and navigate in narrow spaces, while autonomous flight would allow the MAV to operate at a large distance from its user.

## 2.2 Previous Research on Flapping Wing Aerodynamic

Research in the aeroelasticity of flapping wings has substantially increased recently though a full understanding is still lacking. For example, investigations by Daniel and Combes[1] suggested that aerodynamic loads are relatively unimportant in determining the bending patterns in oscillating wings.

Subsequently, experimental investigations by Combes And Daniel[2] found that the overall bending patterns of a Hawkmoth wing are quite similar when flapped (single degree-of-freedom flap rotation) in air and helium, despite a 85% reduction in fluid density in the latter, suggesting that the contribution of aerodynamic forces is relatively minor compared to the contribution of inertial-elastic forces due to flapping motion. However, they mentioned that realistic wing kinematics might include rapid rotation at the stroke reversal that may lead to increased aerodynamic forces due to unsteady aerodynamic mechanisms.

Other research by Hui Hu [3] on performance of different wing type of flapping wing (wood, nylon and latex) suggest that latex wing is better in term of ift to drag ratio. This means the flapping wing which is flexible and elastic contribute more toward lift force and mechanical power that the stiff one.

For the mechanical power data, we can quote a research by R.D Bullen and N.L McKenzie [4]. It adopts mechanical power equation from Norberg (1993) to calculate the mechanical power at any given flight speed for bat. Thus, we implement the method to calculate the Delfly mechanical power after we get all the basic data such as lift, weight, thrust and drag.

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### 2.2.1 Aerodynamic Data Gathering Calculation

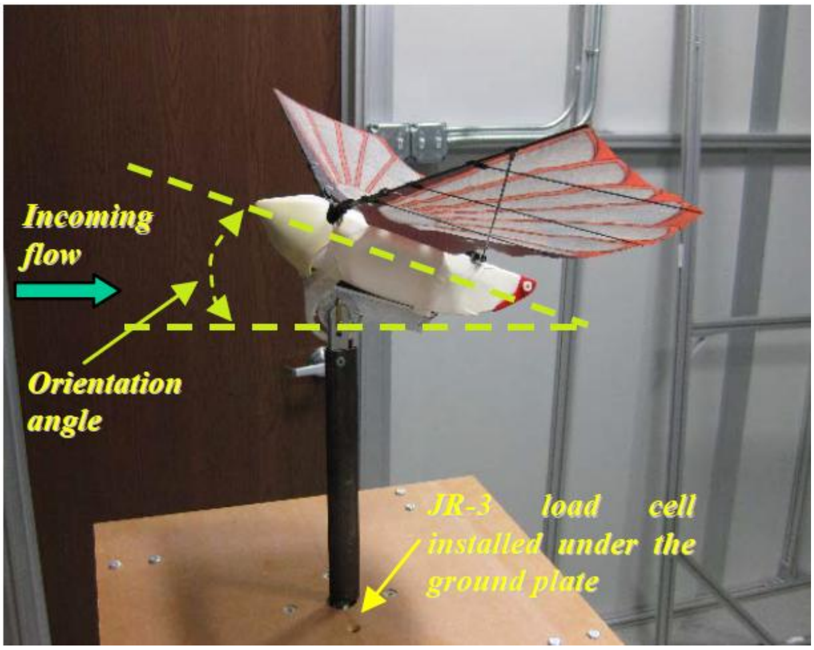

Figure 2.3: Test

Fig 3.3 shows the test rig and flapping mechanism used in the present study. Similar to the work of Hong & Altman[7] , the flapping mechanism used in the present study was adapted from a Delfly remote control ornithopter model, which is powered by a DC power supply. During the experiments, the flapping frequency of the mechanism is adjustable by changing output voltage of the DC power supply.

The aerodynamic forces (lift, and thrust or drag) acting on the tested wings were measured by using a high-sensitive force-moment sensor cell. The force-moment sensor cell is composed of foil strain gage bridges, which are capable of measuring the forces on three orthogonal axes and the moment (torque) about each axis. The precision of the force-moment sensor cell for force measurements is about ±0.05% of the full scale (40 N). During the experiments, the output signals from the force-moment sensor cell were scanned at 1,000 Hz for 60 seconds for each tested cases. The time-averaged lift and thrust produced by the tested wings in soaring and flapping flight were determined based on averaging the acquired data samples.

### 2.2.2 Relevan Formula For Basic Calculation

In order to quantify the aerodynamic benefits of flapping flight more clearly, we introduce the concepts of lift augmentation and thrust augmentation for further data reduction of the flapping flight measurement results. The lift or thrust augmentation is referred to the increase of the time-averaged lift or thrust generated by a tested wing in flapping flight compared with those of the same wing in soaring flight (i.e., without flapping motion) with the same forward flight speed and same orientation angle[8]. The augmentations of the lift and thrust forces due to flapping motion can be expressed as:

$$\Delta Lift = F_{lift} - F_{weight} \tag{2.1}$$

And

$$\Delta T_{thrust} = F_{Thrust} - F_{Drag} \tag{2.2}$$

$F_{Lift}$ and $F_{Thrust}$ are measured using force cell meanwhile $F_{weight}$ is measure using electronic scale. For the $F_{Drag}$, the formula is:

$$F_D = \frac{1}{2} \rho v^2 C_D A \tag{2.3}$$

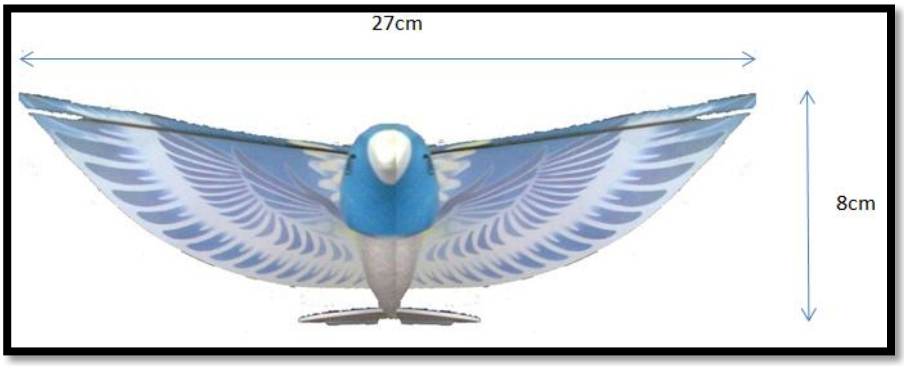

Figure 2.4: Area Exposed During Flight

Drag coefficient = 0.2

Herein we adopt a value for $\delta$ of 0.2 after Pennycuick (1975, 1989) and Grodzinski *et al*. (2009). This is because bats have lifting bodies and near-elliptical wing-planforms (Bullen & McKenzie 2007), and the flight speeds where the induced drag contribution is most interesting are those just above the minimum flight speed of the wing.

### 2.2.3 Relevan Formula For Mechanical Power

The equation for calculating flight mechanical power at any given flight speed (Norberg *et al.* 1993) is:

$$P_{\mathrm{mech}} = P_{\mathrm{ind}} - P_{\mathrm{drag}} \tag{2.4}$$

Its four elements are calculated using data on:

· airframe morphology (including geometry, wing inertia),

· aerodynamic cleanliness attributes (including lift and drag coefficients), and

· dynamic factors (such as wingbeat frequency and amplitude at various speeds).

The ‘Induced Power’ component is required to overcome the induced (or lift dependent) drag at a given speed. From aerodynamic theory, the drag induced by the wing/body/head/tail is well understood and is given in Hoerner (1965) as:

$$\boldsymbol{C_{D\ \mathrm{ind}} = C_L^2\,(1 + \delta) / (\pi\, AR\,)} \tag{2.5}$$

Where $C$D, $C$L and $AR$ represent drag coefficient, lift coefficient and wing-body aspect ratio, respectively. Herein we adopt a value for $\delta$ of 0.2 after Pennycuick (1975, 1989) and Grodzinski *et al*. (2009). This is because bats have lifting bodies and near-elliptical wing-planforms (Bullen & McKenzie 2007), and the flight speeds where the induced drag contribution is most interesting are those just above the minimum flight speed of the wing.

Induced power is:

$$P_{\mathrm{ind}} = D_{\mathrm{ind}}\, V \tag{2.6}$$

where $V$ is the flight speed of the bat, and after Norberg *et al*. (1993), Pennycuick (2008) and Grodzinski *et al*.(2009):

$$P\mathrm{ind} = [(m\,g / V_{\mathrm{w}})^2]\,(1 + \delta)\,V / (\,\rho\, S\mathrm{wd}\ 2\,) \tag{2.7}$$

### 2.2.4 Optimum Angle Determination

To determine the thrust from the Delfly model, firstly the optimum angle which exert the highest value of thrust need to be determined. The figure shows the angle manipulated during experiment. Then the axial force is determined to find out the actual force exerted at the optimum angle.

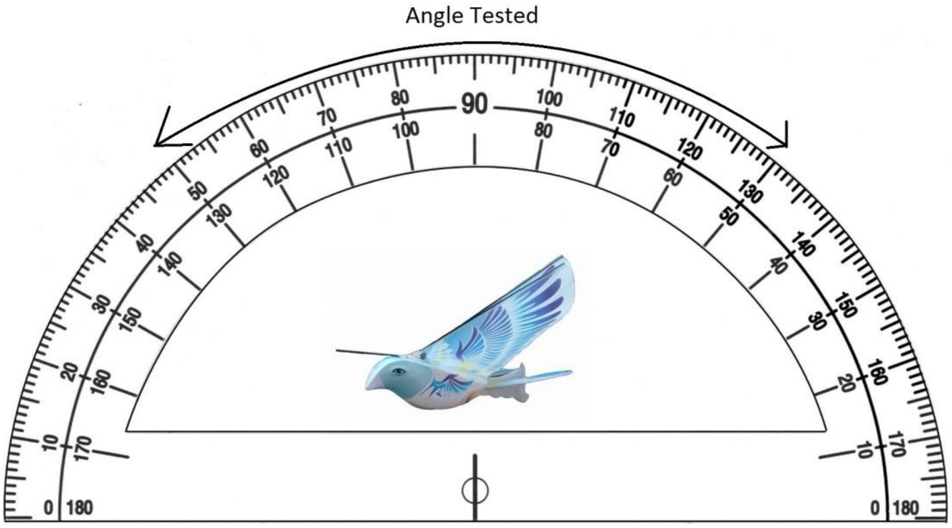

Figure 2.5: Angle Manipulated

# CHAPTER 3

# METHODOLOGY

## 3.1 Flowchart of the experimental study of Delfly

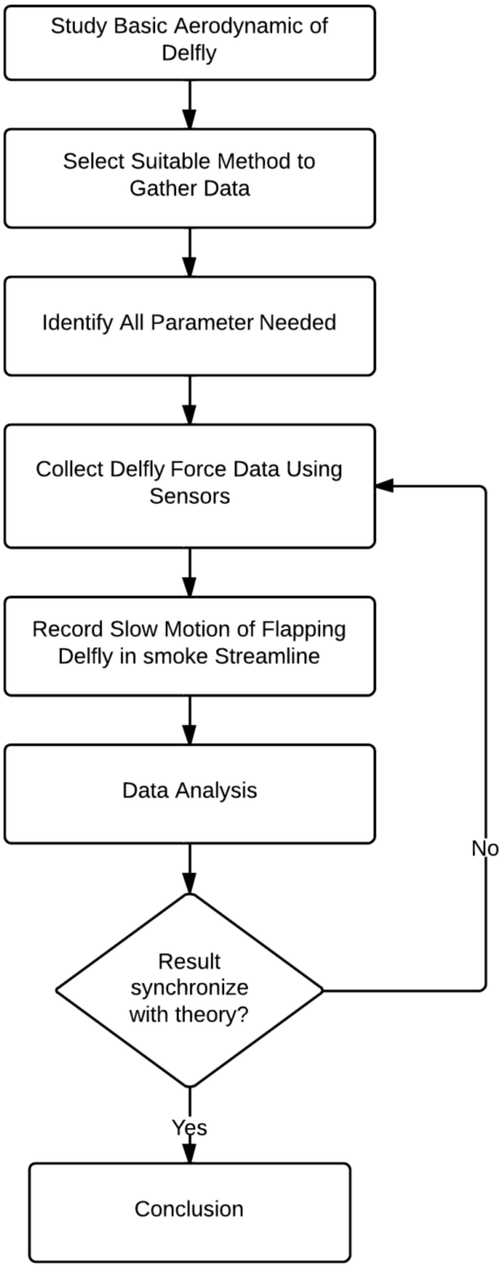

Figure 3.1: Flowchart of the Project

## 3.2 Study Basic Aerodynamic of Delfly

### 3.2.1 Delfly Specification

A commercial delfly bird remote control is acquired to simulate the flapping mechanism.

Figure 3.2: Commercial model as datum/model of project

Specification:

- Flapping Frequency: 3-7 Hz
- Control distance: Above 15~20 meters
- Aircraft batteries: 3.7V-70mAh polymer charging batteries
- Remote control batteries: LR6/AA 1.5V alkaline x4

### 3.2.2 How Delfly Operates

In a conventional aircraft lift and thrust are generated independently of one another. However in the case of the Delfly, which uses flapping wings, they are generated both together through a resultant force produce by impingement of wings during flapping on opposite direction. The force generated is divided into lift and thrust according to operating angle of Delfly.

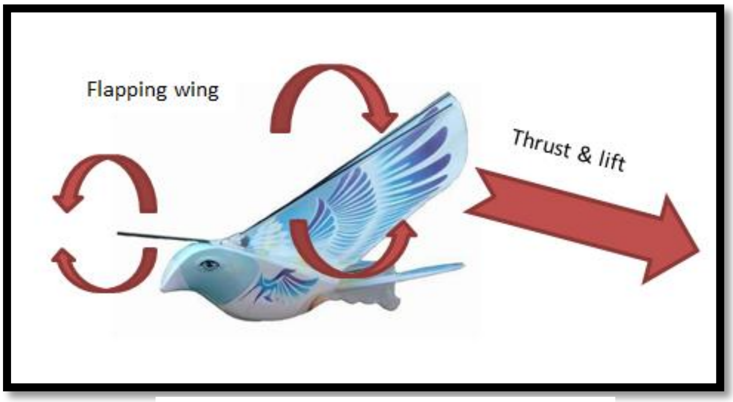

Figure 3.3: How Delfly Operates

The wings are powered by a motor that weighs 2 grams producing a power output of about 1W. It is in fact a motor that is used in mobile telephones. This motor feeds into a gearbox that reduces the rotational velocity of the engine. Two ‘conrods’ are placed that are themselves connected to the wing spars which turns rotational to linear motion, thus provides the flapping motion. This system illustrated in the diagram presented below.

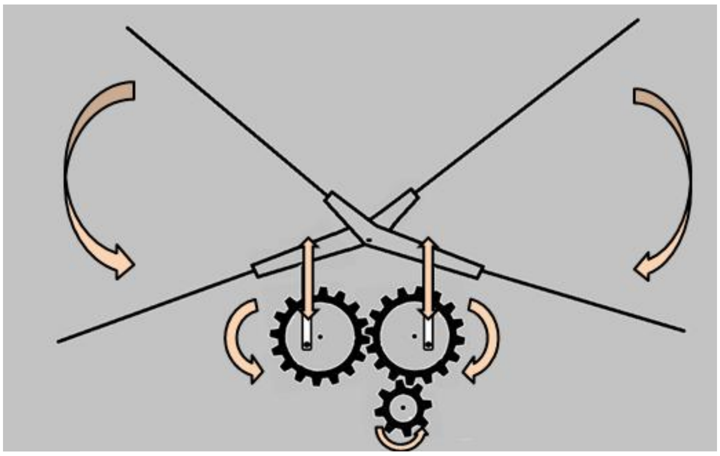

Figure 3.4: Illustration of mechanism in Delfly

## 3.3 Select Suitable Method to Gather Data

### 3.3.1 Aerodynamic Data Gathering Setup

The method used is similar to the work of Hong & Altman. The figure below shows how the set-up is made.

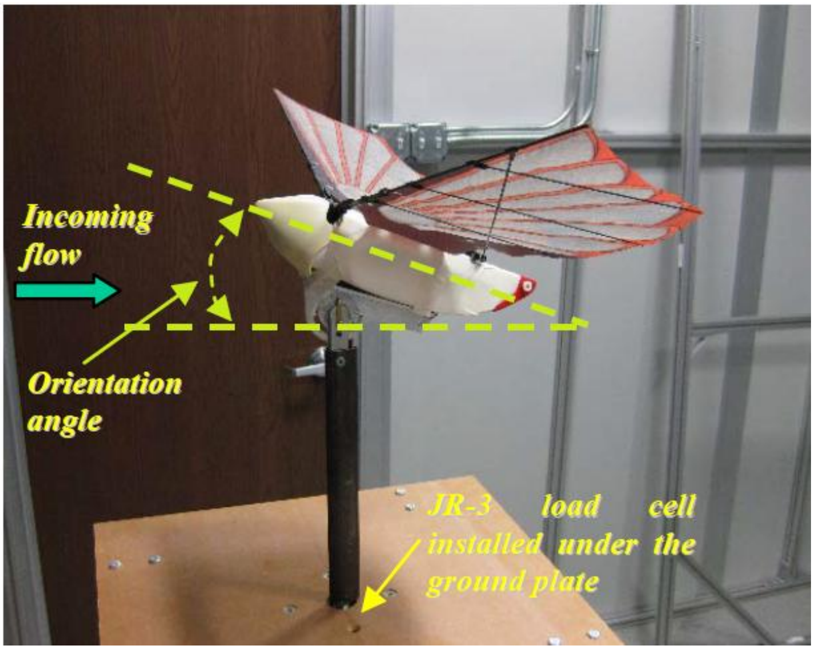

Figure 3.5: Test Rig

The angle of Delfly attached can be vary according to experimental requirement. For this research, the angle range is from 50° to 130°. The Delfly is attached to load cell as per picture above. This will enable data gathering in term of force exerted by the Delfly is recorded and analyzed. The load cell used is Pasco brand and it can detect range of force from 50 N to -50 N.

### 3.3.2 Air Flow Characteristic Setup

Figure 3.6: Test Rig Smoke Streamline

Motion taken at 1/400 fps shows the general flapping motion of Delfly. During this operatio, the flapping frequency of Delfly is around 2.4 Hz due to incapability of camera to capture high speed motion.

The smoke source is fom the smoke generator. It is placed exactly in front of Delfly and the smoke generated is released freely without any interference by other source. This is to enable observation of air at the wing of Delfly during its operation.

## 3.4 Parameter Identification

### 3.4.1 Relevan Parameter For Basic Calculation

**Lift , Thrust and Drag**

$$\Delta Lift = F_{lift} - F_{weight}$$

And

$$\Delta T_{thrust} = F_{Thrust} - F_{Drag}$$

$F_{Lift}$ and $F_{Thrust}$ are measured using force cell meanwhile $F_{weight}$ is measure using electronic scale. For the $F_{Drag}$, the formula is:

$$F_D = \frac{1}{2} \rho v^2 C_D A$$

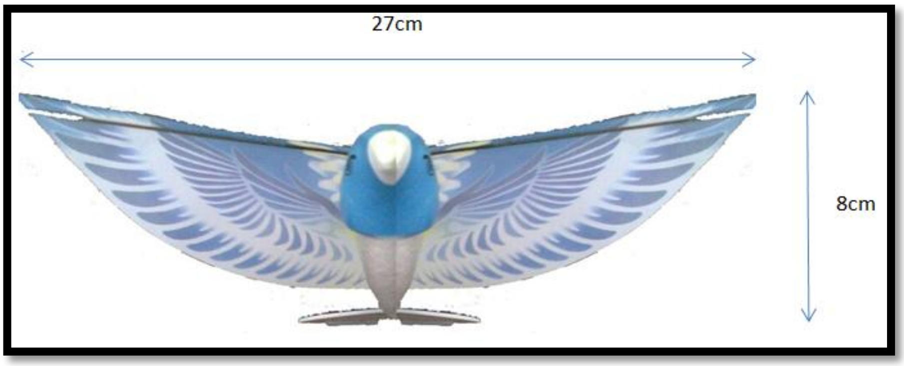

Figure 3.7: Area Exposed During Flight

Drag coefficient = 0.2 [Pennycuick (1975, 1989) and Grodzinski *et al*. (2009)]

### 3.4.2 Relevan Parameter For Mechanical Power

$$P_{\mathrm{mech}} = P_{\mathrm{ind}} - P_{\mathrm{drag}}$$

For Induced Power Calculation;

$$C_{D\ \mathrm{ind}} = C_L^2\ (1 + \delta) / (\pi\ AR\ )$$

m, mass = 0.013 kg

g, acc gravity = 9.81 m/s$^2$

$v_{W}$, wing speed = 5 m/s for 3.3 Hz (Wingbeat freq bird, Pennycuick 1990)

v, model speed = 1.5m/s

### 3.4.3 Optimum Angle Determination

To determine the thrust from the Delfly model, firstly the optimum angle which exert the highest value of thrust need to be determined. The figure shows the angle manipulated during experiment.

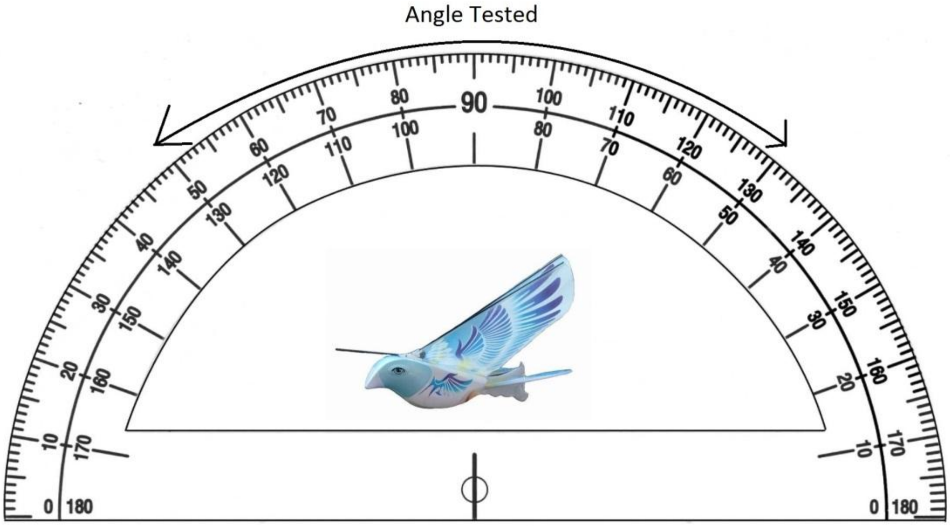

Figure 3.8: Angle Manipulated

The force result will be separated into two groups; the first group is the angle between 80$^o$ to 50$^0$, and the second group is the angle between 90$^o$ to 130$^o$. The Delfly model is attached directly to the sensor as before, but the angle is varied by 10 gap to observe the most thrust generated by the model.

### 3.5 Collect Delfly Force Data Using Force Sensor

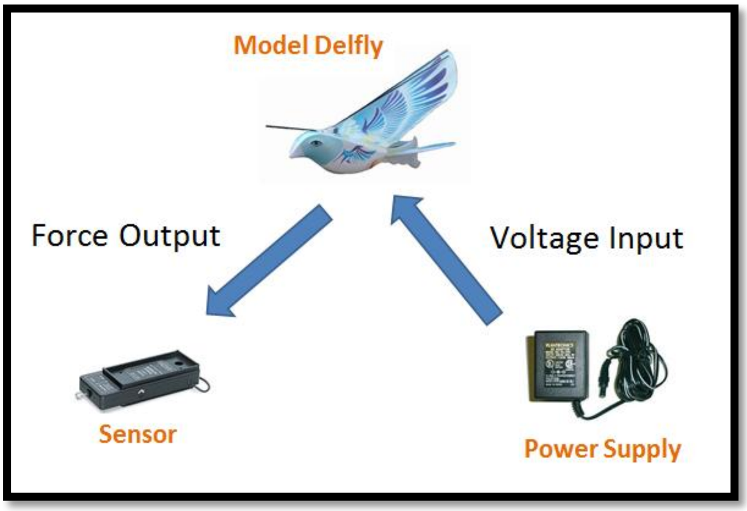

Figure 3.9: Connection power source – Delfly - sensor

The rig test is setup according to the figure above. The power source is connected to the Delfly in order to vary its input voltage. The sensor as mention before is attached to the Delfly through angle rod.

### 3.6 Record Slow Motion of Flapping Delfly in Smoke

In able to capture motion of high speed flapping wing, high speed camera is used. The frame speed is adjusted to 1/400 frame per second (fps) to generate slow motion sequences. The characteristic is observed by releasing coloured smoke (black) to trace the air flow in the wing region during flapping motion.

# CHAPTER 4
# RESULT

## 4.1 Aerodynamic Data Collection

### 4.1.1 Weight data collection

Using electronic scale, the Delfly model is weighted to obtain its mass. The picture above shows the process of weighting the Delfly.

**Mass = 13 g = 0.013 kg**

**Weight = Mass x Gravity = 0.013kg x 9.81ms$^{-2}$ = <u>0.128 N</u>**

### 4.1.2 Lift Data Collection

The data is collected using DataStudio software and the graph below is the result for force output from input 3volt with 500mA DC current.

**Positive mean = 1.70 N**

**Negative mean = 1.45 N**

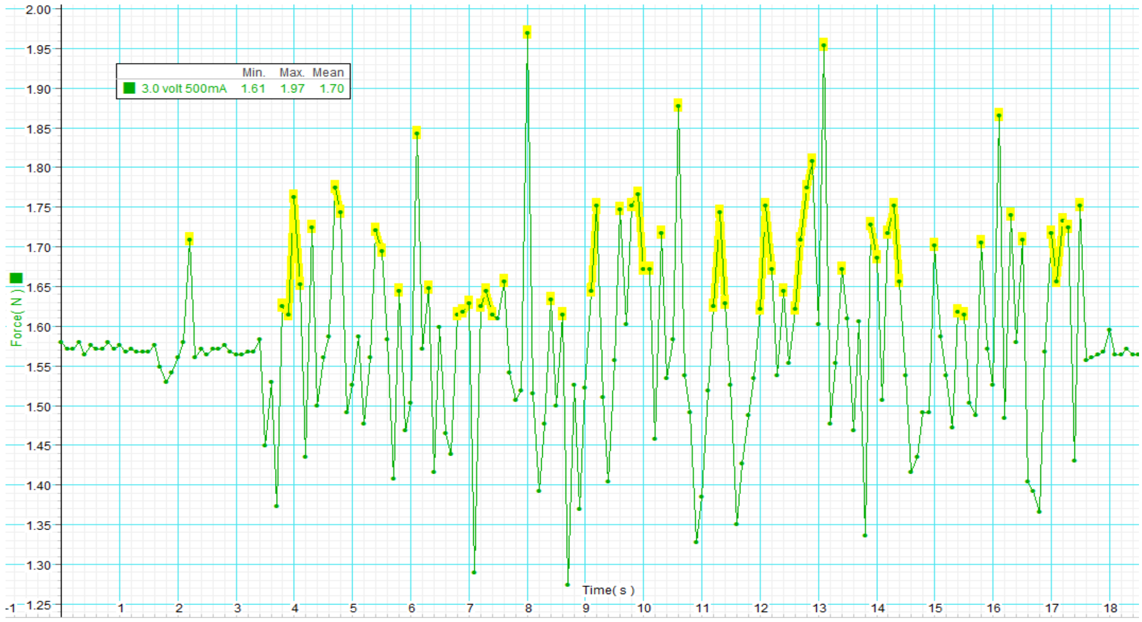

Figure 4.1: Lift Mean Data at Steady State

From the Positive and Negative Mean Lift graphs, the Lift force can be calculated by finding the difference between these two values:

**Mean Lift Force = Positive mean –Negative mean <u>= 0.25N</u>**

Meanwhile, the net lift force only valid after the weight is subtracted from the lift.

**Net lift Force = Lift Force – Weight = <u>0.122 N</u>**

Meanwhile, the net lift force only valid after the weight is subtracted from the lift. The lift data acquired is 0.122N. This is valid as we compare the data with the flight height of Delfly that is range from 3-7 meters height. This is enough lift to carry a mini surveillance camera weigh about 20 grams. The height also is the nominal flight for mid-sized bird.

### 4.1.2 Thrust Data Collection

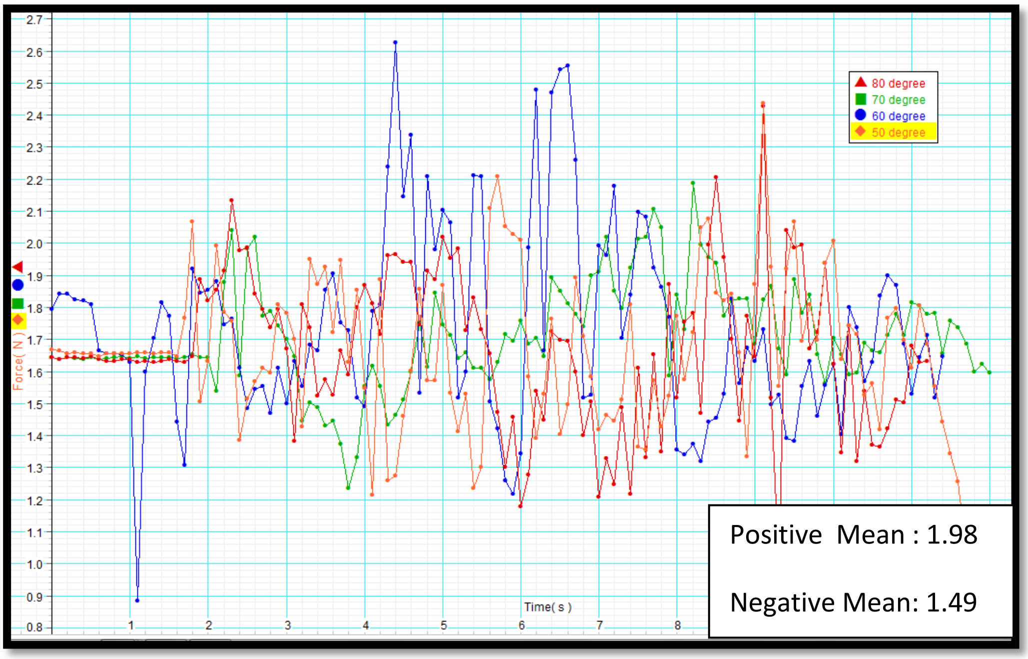

**Figure 4.2: Force Generated from 50$^{o}$ to 80$^{0}$ angle**

Based on the graph , the highest force generated is during Model is tilted 60$^{o}$ to the front.

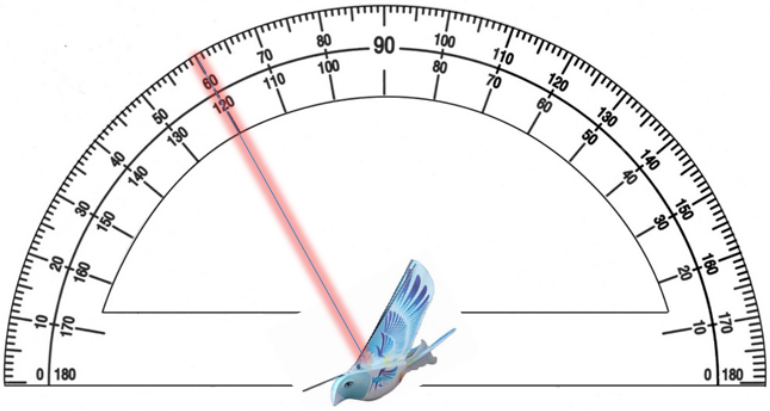

Figure 4.3: Optimum angle to generate highest thrust

Thus, at 60$^{o}$ the vertical lift generated: 1.98N – 1.49N = **0.49N**

So, the thrust = $\left(\dfrac{0.49N}{\sin 60}\right)\cos 60 = 0.28N$

### 4.1.3 Drag Data Collection

$$F_D = \tfrac{1}{2}\rho v^2 C_D A$$

Where:

$F_D$ is the drag force, which is by definition the force component in the direction of the flow velocity,
$\rho$ is the mass density of the fluid (air)
$v$ is the velocity of the object relative to the fluid,
$A$ is the reference area exposed to air during flight
$C_D$ is the drag coefficient – a dimensionless coefficient related to the object's geometry and taking into account both skin friction and form drag.

$\rho$ (air) = 1.225 kg/m$^3$

$v$ (normal) = 1.5 m/s

$A$ (exposed) = (0.27 m x 0.08 m) – (0.08cm)$^2$ = 0.0152cm$^2$

Thus Drag Force, $F_D$ :

$$F_D = \tfrac{1}{2}\rho v^2 C_D A$$

$$F_D = \left(\frac{1}{2}\right)\left(1.225kgm^{-3}\right)\left(1.5ms^{-1}\right)^2(0.2)\left(0.0152\,m^2\right)$$
$$= 0.0041895\,N \approx 0.004N$$

Net Thrust = Thrust – Drag

= **0.28N – 0.004N =0.276N**

From the data collected the optimum angle of Delfly during flying is $60^o$ and it shows that the configuration of existing flying position is not to the maximum usage of propulsion power. The normal operating position is similar to humming bird, this will enable the Delfly to hover itself during flight.

However, the hovering in principle does not produce a movement, meaning the velocity of the Delfly is zero. That is also contribute to inefficiency and has a great flaw in operating motion, but it all have to back to main objective of the Delfly; to imitate biological flight and thus enabling it to hover, accelerate and maneuver according to natures law. It is very different from the normal jet flight that using a simple linear propulsion system.

The thrust data shown revealed clearly that orientation angle would also affect the thrust generation of the tested wings in flapping flight greatly. The thrust generated by flapping the tested wing was found to decrease with the increasing orientation angle. This is due to the nature of Delfly mechanism. The main thrust generated is divided into two functions; to overcome weight and to generate forward thrust. It is logical explanation if the angle is increased, the lift decrease because the tilted Delfly will focus the main thrust downward to provide lift alone and vice versa.

## 4.2 Energy Efficacy

Delfly model is connected to an adjustable power source to be able to regulate power supply. The range of voltage is between 1.5v to 7.5v with a constant of 500mA of current.

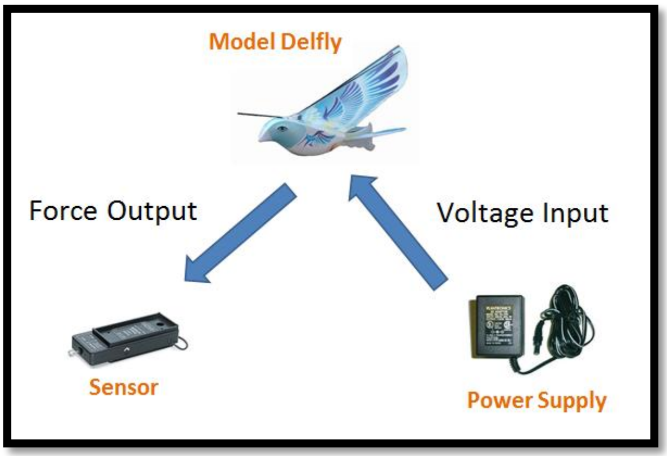

Figure 4.4:  Data Collection Configuration

The power supplied to the model will be compared to the power induced by the Delfly model to determine the energy efficacy of the flapping mechanism used by the Delfly model. The lift force is compared with an increment of voltage. The result is as follows:

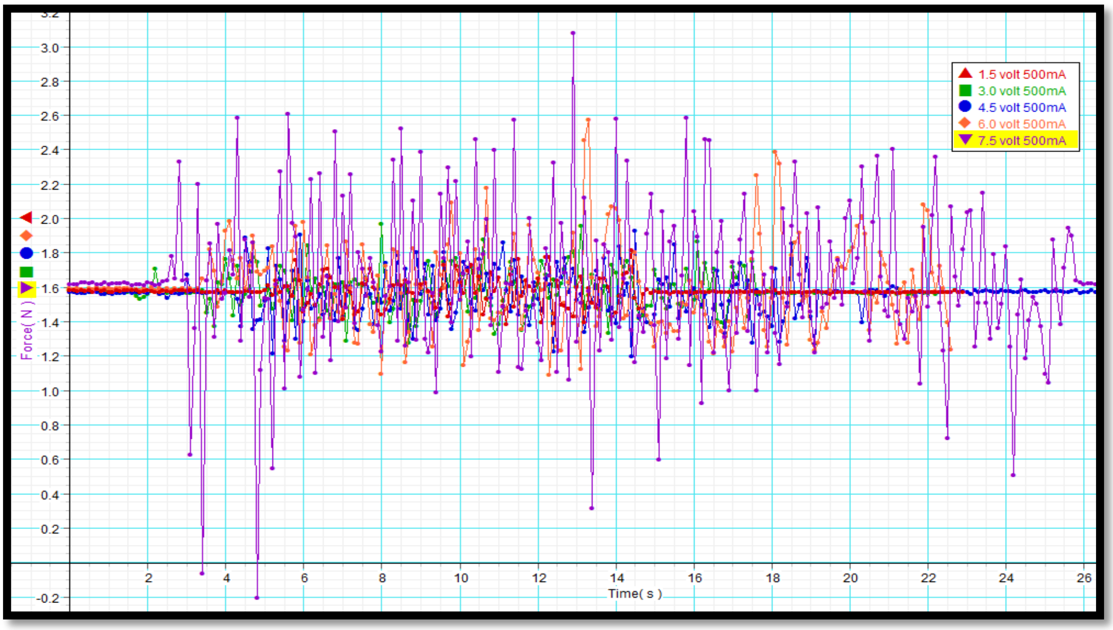

Figure 4.5: Lift Generated with respect to voltage

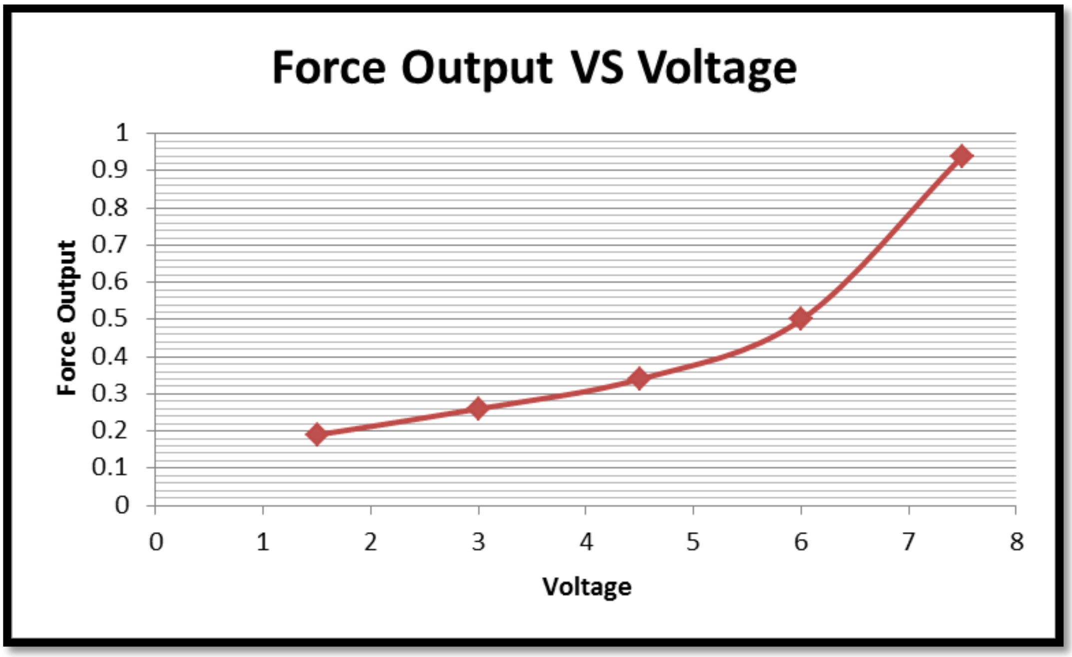

Figure 4.6: Force Output Vs Voltage Input(500 mA)

Due to insufficiency of power supply from the battery, the efficacy of the system is measured by plotting graph force versus voltage. This is to observed the pattern of output force due to increment of voltage input. The system seems to be increase in effectiveness starting from 6 volt and above.This is where the limitation of the Delfly can be observed. The power limitation is still the biggest barrier to achieve a high effectiveness of system.

### 4.3 Mechanical Power

$$P\text{ind} = [(m\, g \,/\, V_{\text{w}})^2]\, (1 + \delta)\, V \,/\, (\, \rho\, S\text{wd}\; 2\, ) \ldots\ldots\ldots\ldots \quad (4)$$

m, mass = 0.013 kg

g, acc gravity = 9.81 $m/s^2$

$v_w$, wing speed = 5 m/s for 3.3 Hz (Wingbeat freq bird, Pennycuick 1990)

v, model speed = 1.5m/s

$\delta$, = 0.2 (Pennycuick 1975, 1989) induced drag factor

$\rho$ = 1.225 $kg/m^3$ (air density)

$S$wd, = $( \pi\, b_{\text{ref}}^2 / 4) = ( 3.142 \times 0.27^2 /4) = 0.0573 m^2$

= (area of a lifting or draging surface or body)

F drag = 0.04N

**$P_{\text{ind}}$ = [(0.013x9.81 / 5)$^2$] (1 + 0.2) 1.5 / ( 1.225 x 0.0573$^2$ ) = 0.29Watt**

**$P_{\text{drag}}$ = v x drag force = 1.5m/s x 0.04N = 0.006watt**

**$P_{\text{mech}}$ = 0.29 – 0.006 = 0.284 Watt**

**$P_{\text{input}}$ = 3 v x 500mA = 1.5 Watt**

## Thus overall mechanical efficiency:

$$\eta_{mech} = \left[\frac{P_{mech}}{P_{input}}\right] \times 100\%$$

$$= \left[\frac{0.284}{1.5}\right] \times 100\% = 18.9\%$$

This shows that the existing mechanism has a low efficiency in relative to power input. Research on the wing characteristic may boost up the overall power generate by Delfly. This statement is based on biological characteristic of bird wings that has a flexible structure to blend with the air to reduce resistance and maximize thrust from flapping motion

The other option is to stiffen up wing in order to imitate the insect wings. The insect has a stiff but very light wings; it is almost negligible in mass. The weight of Delfly is mainly contributed by battery. Thus, a great limiting factor from the research is still the energy barrier.

## 4.4 Overall Result Delfly Data

| No | Result Type | Value |
|---|---|---|
| 1 | Weight | 0.128N |
| 2 | Net Lift | 0.250N |
| 3 | Net Thrust | 0.276N |
| 4 | Optimum angle for maximum Thrust | $60^o$ |
| 5 | Efficacy of input voltage | 0.067 N/Volt |
| 6 | Mechanical Power | 0.284 W |
| 7 | Mechanical Efficiency | 18.9% |

Table 4.1: Overall Result Data

## 4.3 Air Flow Characteristic

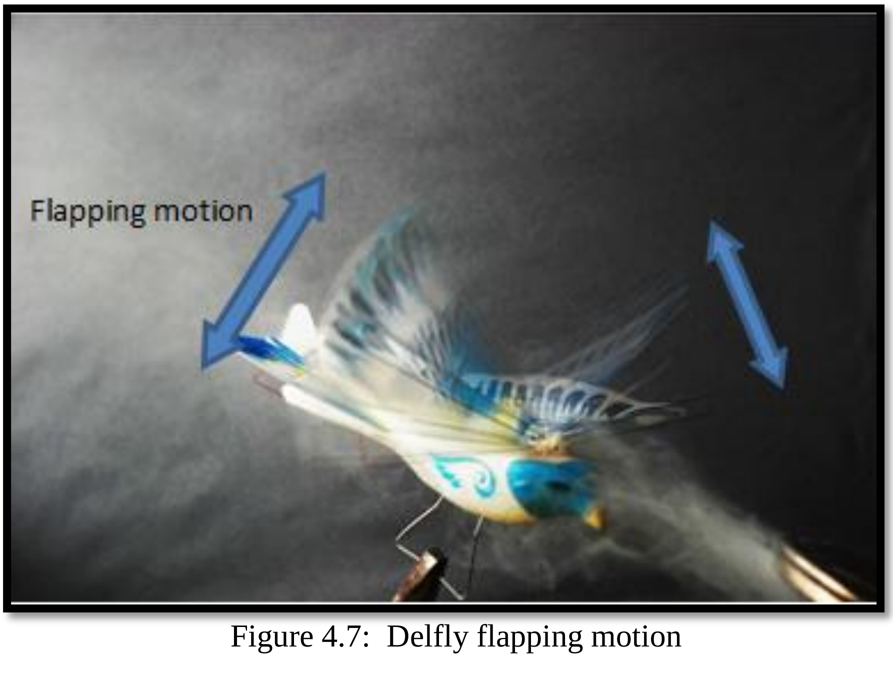

Figure 4.7: Delfly flapping motion

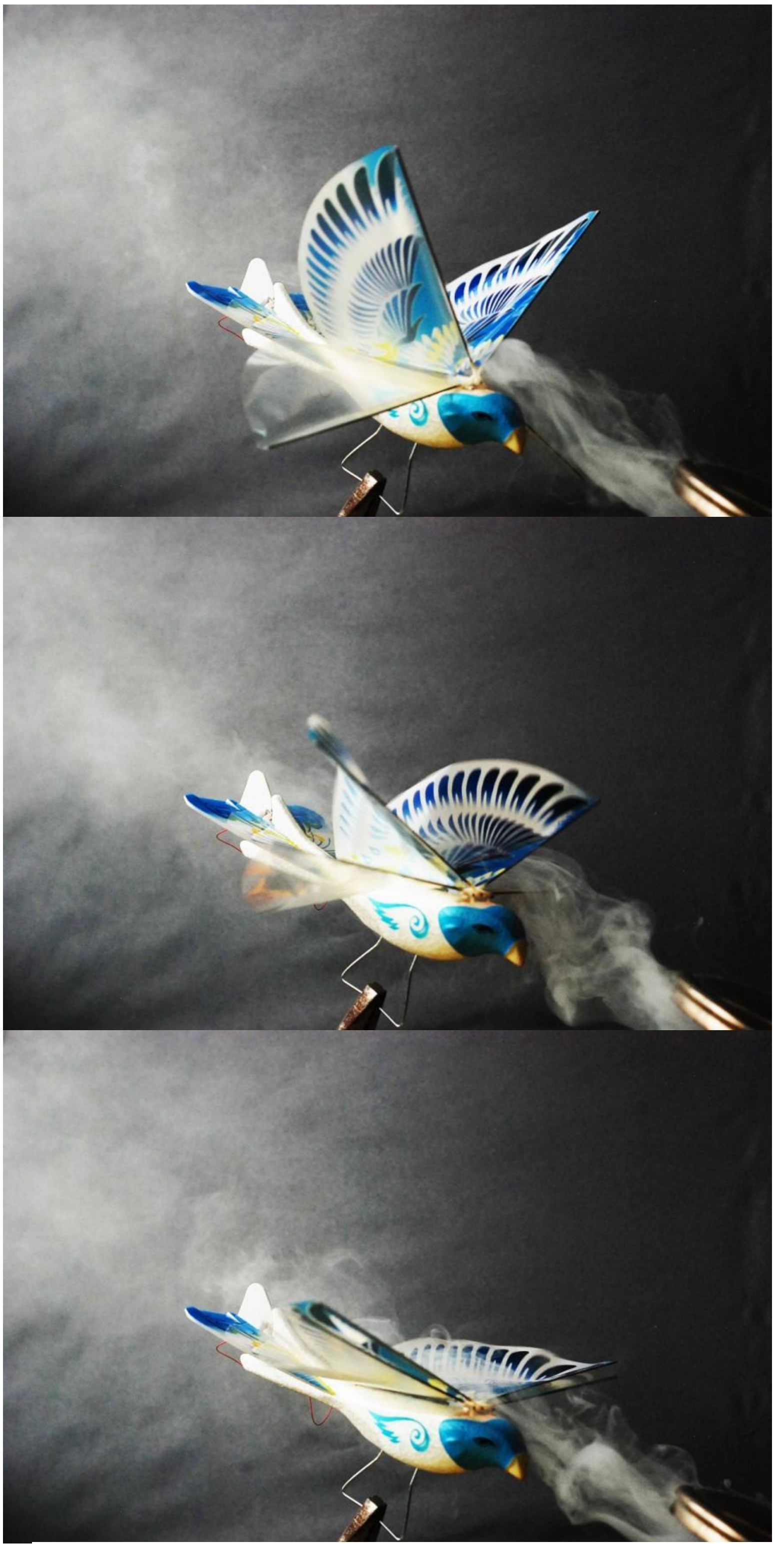

Figure 4.8: Delfly flapping sequences

Motion taken at 1/400 fps shows the general flapping motion of Delfly. During this operatio, the flapping frequency of Delfly is around 2.4 Hz due to incapability of camera to capture high speed motion. The general motion of the air flows can be visualized as below.

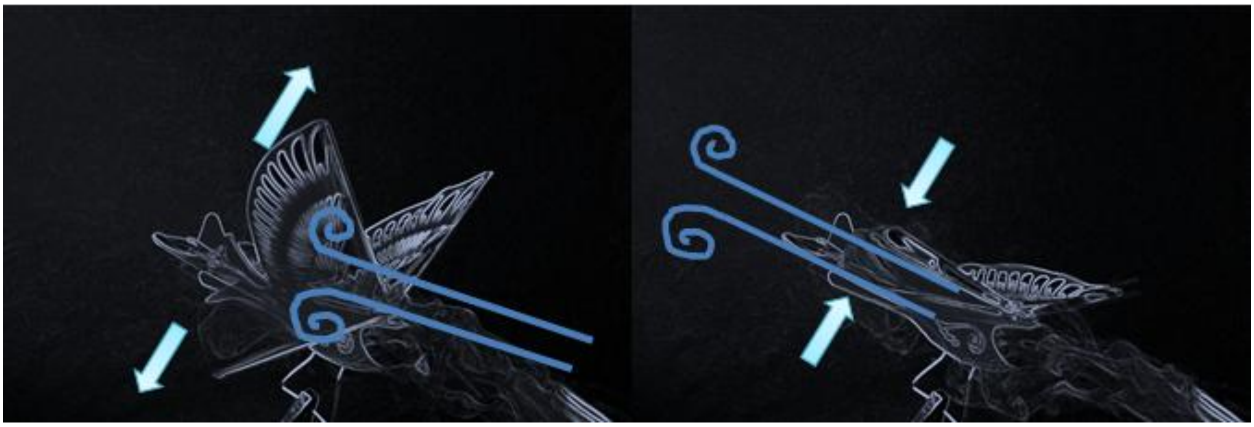

Figure 4.9: Air Motion during Flapping Motion

The figure above shows the simplified air flow motion during Delfly flight motion. During the opening phase, the high velocity of the wings create a low pressure region and pull in the air to the region between the wings. Then, the propulsion starts when the wings flap and force the air to the backward and thus generate a thrust for the flight. This cycle repeats itself at the rate 3- 7 times per second depends on the power input. This means the frequency af the flapping wing for this model of Delfly is 3Hz to 7Hz.

There are advantage of flapping wings for their low Reynolds number. The application for small area with obstacles is best for flapping wing because of the capabilities to hover in the air. It also enable maneuverability in the high constraint area compared to fixed wings.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In order to allow the Delfly to fly entirely independently, some work still needs to be done. The Delfly should, in other words, be able to analyze its surroundings and act accordingly. The battery on board of the Delfly is however both a blessing and a curse: it allows the Delfly to fly via remote-control, but it also hampers the miniaturization process. The problem is that the focus of battery industry is on volume reduction and not so much on weight reduction.

Trending indicates that toy industry currently benefits more from this research than any other industry. However, any possible military applications can never be prevented. In the future the Delfly will be deployed for saving lives, for instance, using the Delfly to look for signs of life under the rubble caused by an earthquake. Perhaps this inexpensive MAV can be further developed for a better application in the future.

## 5.2 Recommendation

With all the collected data, a new version of Delfly can be made for future research. This can be prove by try and error instead of inconclusive simulation which is not convenient for improvisation. The data from this research can be referred to create UTP Delfly as to start an aeronautic field of simple MAV.

# CHAPTER 6
# REFERENCES

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*“A Computational Study of Flexible Wing Ornithopter Flight,” AIAA Paper No. 2008-6397*

# APPENDIX I

## FORCE RAW DATA

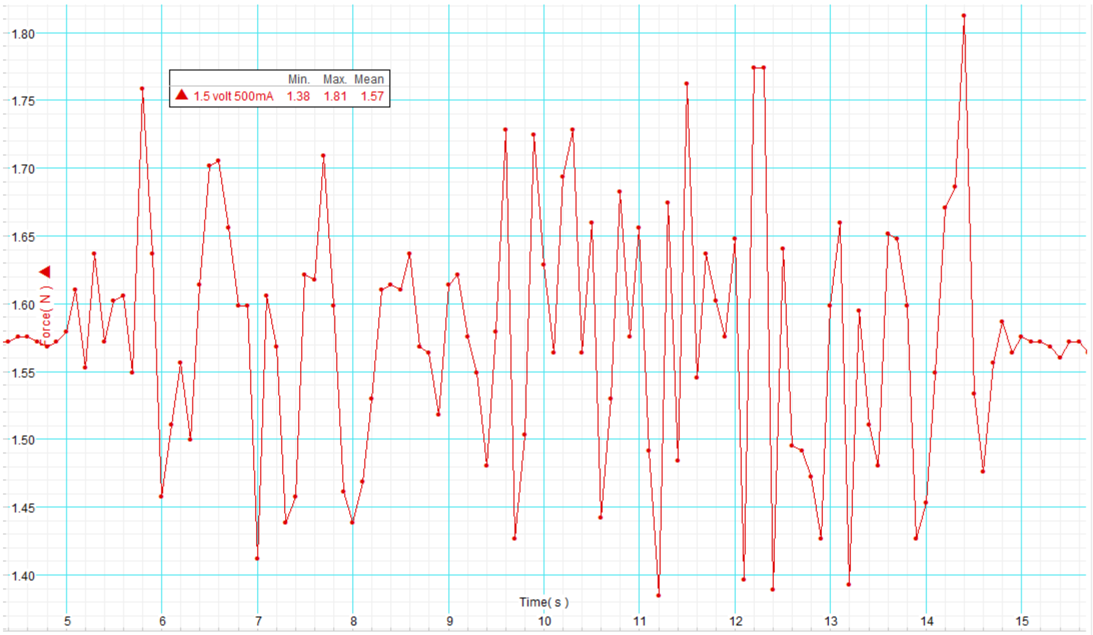

Figure 1: Force exerted with input 1.5 volt

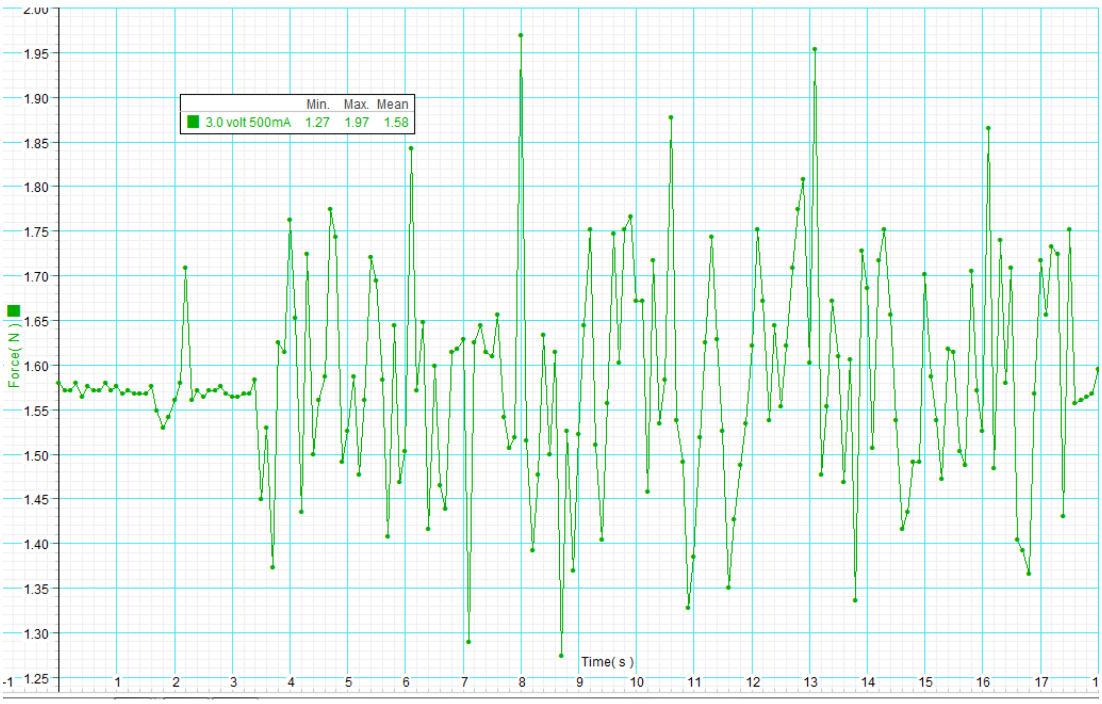

Figure 2: Force exerted with input 3.0 volt

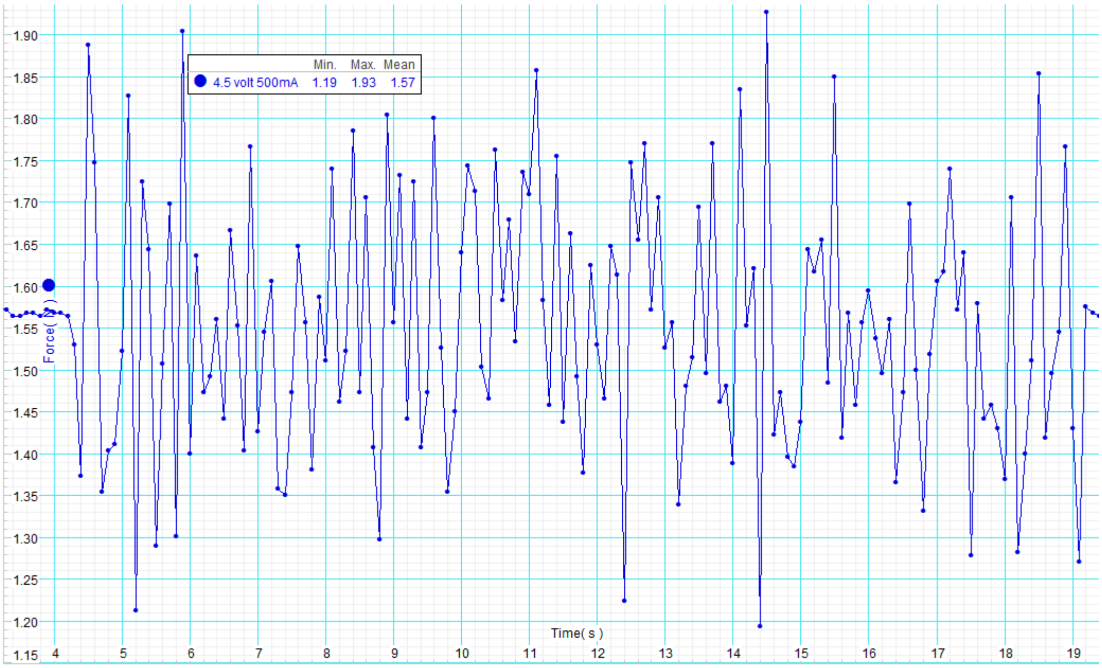

Figure 3: Force exerted with input 4.5 volt

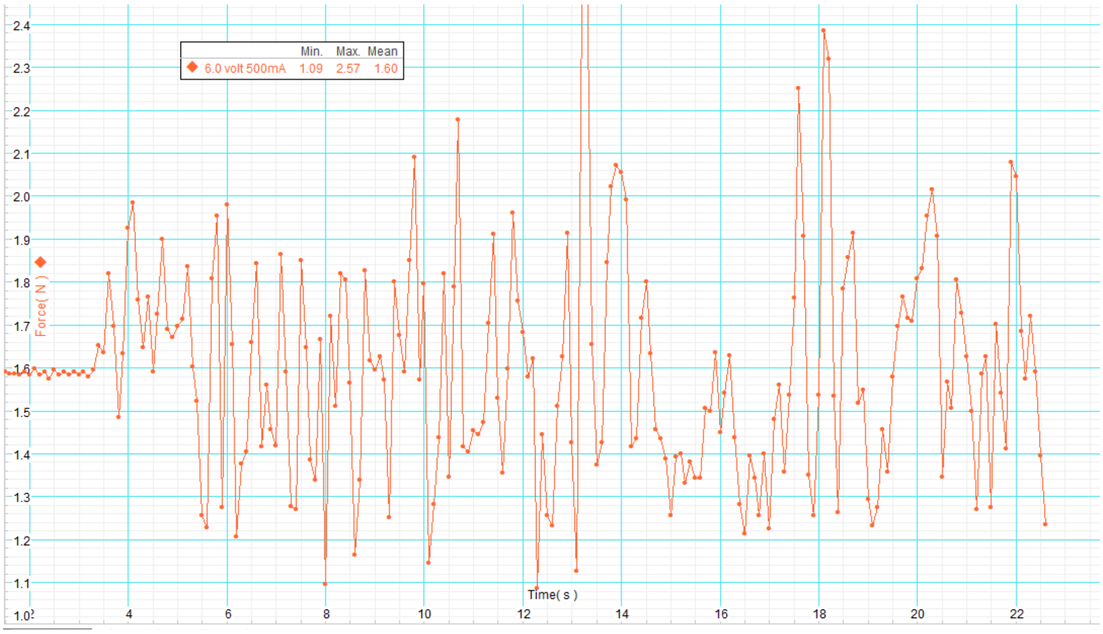

Figure 4: Force exerted with input 6.0 volt

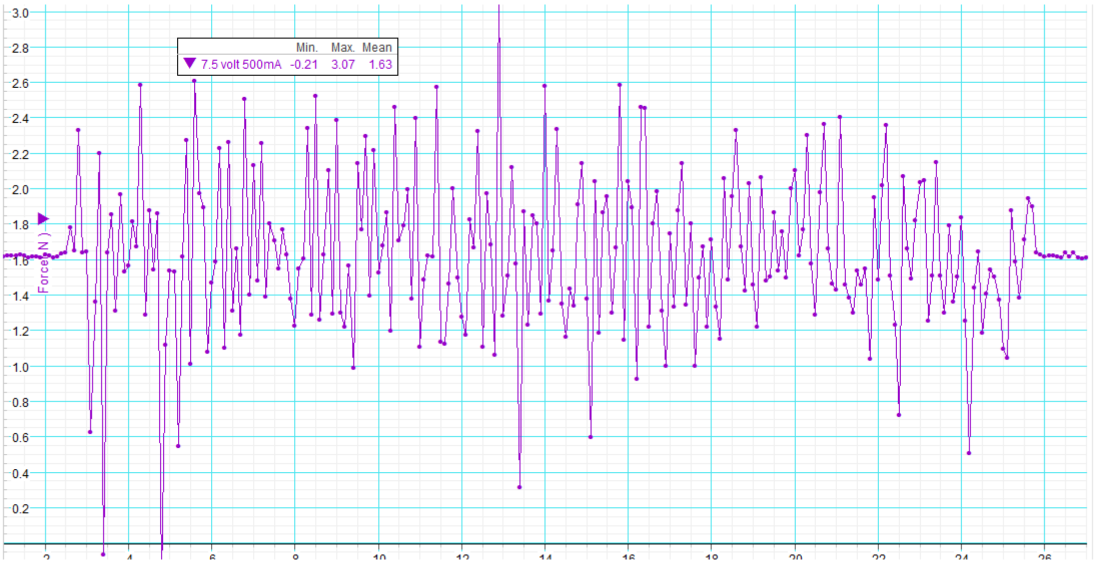

Figure 4: Force exerted with input 7.5 volt

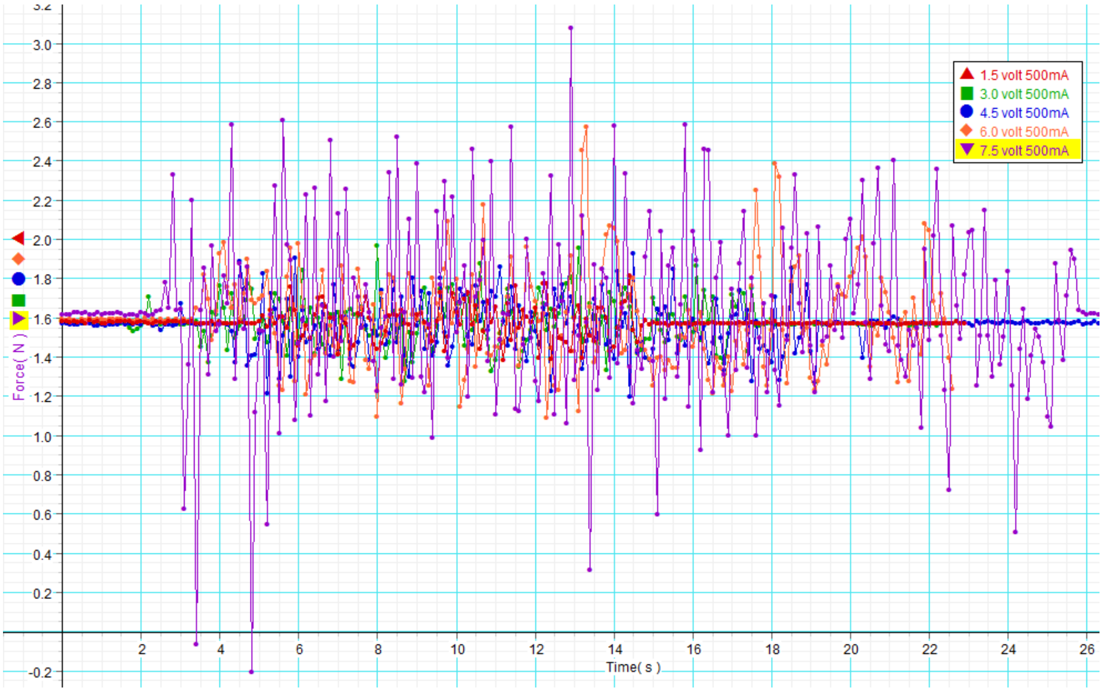

Figure 5: Force exerted with input 1.5-7.5 volt