3-28-2019

Measurements of Forces on a Flapping Wing Micro Aerial Vehicle

Darnisha Crane

Measurements of Forces on a Flapping Wing Micro Aerial Vehicle

by

Darnisha Crane

An Honors Capstone
submitted in partial fulfillment of the requirements for
the Honors Diploma
to

The Honors College

of

The University of Alabama in Huntsville

March 28, 2019

Honors Capstone Director: Dr. Chang-kwon Kang
Assistant Professor of Mechanical and Aerospace Engineering

Darnisha Crane 4/2/19
Student (signature) Date

4/2/19
Director (signature) Date

4/17/19
Department Chair (signature) Date

4/22/19
Honors College Dean (signature) Date

HONORS COLLEGE
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Honors College
Frank Franz Hall
+1 (256) 824-6450 (voice)
+1 (256) 824-7339 (fax) honors@uah.edu

Honors Thesis Copyright Permission

This form must be signed by the student and submitted as a bound part of the thesis.
In presenting this thesis in partial fulfillment of the requirements for Honors Diploma or Certificate from The University of Alabama in Huntsville, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by my advisor or, in his/her absence, by the Chair of the Department, Director of the Program, or the Dean of the Honors College. It is also understood that due recognition shall be given to me and to The University of Alabama in Huntsville in any scholarly use which may be made of any material in this thesis.

Darnisha Crane
Student Name (printed)

Darnisha Crane
Student Signature

4/2/19
Date

Measurements of Forces on a Flapping Wing Micro Aerial Vehicle

by

Darnisha Crane

An Honors Capstone
submitted in partial fulfillment of the requirements for
the Honors Diploma
to

The Honors College

of

The University of Alabama in Huntsville

March 28, 2019

Honors Capstone Director: Dr. Chang-kwon Kang
Assistant Professor of Mechanical and Aerospace Engineering

____
Student (signature) Date

____
Director (signature) Date

____
Department Chair (signature) Date

____
Honors College Dean (signature) Date

HONORS COLLEGE
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Honors College
Frank Franz Hall
+1 (256) 824-6450 (voice)
+1 (256) 824-7339 (fax) honors@uah.edu

Honors Thesis Copyright Permission

This form must be signed by the student and submitted as a bound part of the thesis.
In presenting this thesis in partial fulfillment of the requirements for Honors Diploma or Certificate from The University of Alabama in Huntsville, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by my advisor or, in his/her absence, by the Chair of the Department, Director of the Program, or the Dean of the Honors College. It is also understood that due recognition shall be given to me and to The University of Alabama in Huntsville in any scholarly use which may be made of any material in this thesis.

____
Student Name (printed)

____
Student Signature

____
Date

Table of Contents

1 Acknowledgements 1
2 Abstract 2
3 Introduction 3
3.1 Background 3
3.2 Objective 4
4 Experimental Overview 5
4.1 Experimental Apparatus 5
4.2 Experimental Method 6
4.3 Data Collection & Processing 7
5 Results 9
6 Conclusion 13
7 References 14

1 Acknowledgements

Thank you to The University of Alabama in Huntsville College of Engineering, Office of the Provost, and Office of the President and Vice President for Research and Economic Development for providing financial support for this research project. I would also like to thank Dr. Hikaru Aono of Tokyo University of Science for donating the micro air vehicle. I would also Thank you to Dr. Brian Landrum of the Mechanical and Aerospace Department for the support they provided during the duration of the project. Also, thanks to Kabilan Nedunchezian and Daniel Aiken for their assistance with the data collection and analysis – this was very appreciated. Lastly, I would like to thank Madhu Sridhar and my mentor Dr. Chang-kwon Kang for assisting me with the development of this Capstone paper – I am not only grateful to them for helping me with this paper but also for introducing me to research!

____

Darnisha Crane

2 Abstract

The interest for the development of micro air vehicles (MAVs with the capability of desirable flight characteristics has been steadily increasing over the past decade. The ability of a MAV to successfully fly has implications for improving) military and commercial operations, possibly space exploration as well. An understanding of the forces generated by MAVs is an important step in achieving desirable flight. The objective of this research project is to measure and analyze the forces generated by a flapping wing MAV. It was achieved by using an ATI Nano17 Titanium Force/Torque transducer by measuring and recording the forces generated by the flapper in the x, y, and z directions. The recorded forces were processed using a low pass filter created in MATLAB and the average forces in the z and x direction were plotted for specific applied voltages. Additionally, a Fast Fourier Transform was also executed in MATLAB to determine the flapping frequency of the MAV; it was plotted against the maximum and average forces. The results of the data analysis concluded that lift increases with flapping frequency but drops off at higher frequencies. The flapper can lift a weight of approximately 14 grams at a flapping frequency of approximately 22 Hertz.

3 Introduction

The concept of the micro air vehicle (MAV) was proposed by the Defense Advanced Research Projects Agency (DARPA) in 1996. Micro air vehicles are small unmanned aircraft that can be autonomous or remotely controlled. Commercial and military use are some of the driving factors for the development of MAVs. The goal for these vehicles is to be less than 15 cm in any dimension. Currently, there are three core designs for MAVs: fixed-wing, flapping-wing, and multi-rotor systems. The area of interest for this research is the development of a flapping-wing micro air vehicle with the capability of desirable flight characteristics.

3.1 Background

Small natural flyers use unsteady aerodynamics mechanisms to produce lift and thrust, which is qualitatively different than large aircraft aerodynamics [1]. Scaling laws indicate that a reduction in the size of a flyer leads to an increase in environmental influence for smaller flyers – natural flyers overcome this by improving flight performance (force generation, flapping wings and wing tail coordination, etc.) [1]. Results of a study performed by Sane and Dickinson concluded that subtle alterations in stroke kinematics have large effects on force production [4]. An understanding of the relationship between the wing kinematics and resulting forces on a flapping wing is essential for the development and improvement of flapping wings - e.g., flexible wings can outperform rigid wings in terms of force production and vice versa depending on flight conditions [1,5].

Figure 1 shows a humming bird in flight – the inspiration behind the design of the MAV or flapper used for this research project. The MAV – shown in Figure 2 – mimics the flight of a hummingbird by recreating the clap-and-fling mechanism [6] that the hummingbird and various other birds and insects employ to enhance their flight. The process of clap-and-fling is as follows:

the wings clap above the insect and fling apart which increases lift production. A vortex is formed above each wing and moves across the wing in the clap becoming the staring vortex of the other wing – this increases circulation and in turn lift. The micro air vehicle mimics this mechanism using four wings, a gear box, and a motor.

Figure 1: Hummingbird in flight [2]

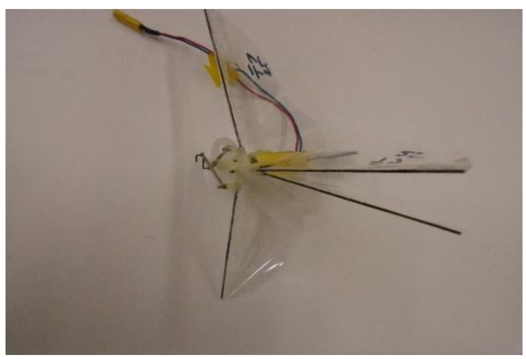

Figure 2: Flapper

3.2 Objective

The objective of this project is to measure and analyze the forces generated by the flapper in motion as an increasing amount of voltage is applied. An additional objective was to determine the flapping frequency of the flapper and to relate the frequency to the measured forces. The primary goal of the project is to gain a sufficient understanding of the force production of the flapper and apply that knowledge to improving the flapper and developing additional micro air vehicles.

4 Experimental Overview

4.1 Experimental Apparatus

Figure 3 shows the ATI Nano 17 force/torque transducer – it is directly placed underneath the flapper and measures the forces the flapper generates while in motion.

Figure 3: ATI Nano 17 Force/Torque Transducer

The experimental apparatus used for this project is shown in Figure 4. The flapper is inspired by hummingbirds and is composed of two upper wings, two lower wings, a motor, and a gear box. Unlike the hummingbird, the flapper has four wings made of which are necessary in recreating the clap- and-fling motion that a hummingbird uses to achieve flight. The wings of the flapper are made of polyethylene film and are 25 micro meters in thickness [3]. The length of the wings is 60 millimeters and flapper weighs approximately 3 grams (g) [3]. The flapper is mounted to a test stand that is composed of a machined part with a ¼ inch thread and circular platform that is screwed into a metal rod with a binder clip fastened to the top – the circular platform of the part connects to the Nano17 Titanium. The test stand and flapper were mounted to a tripod stand using a tripod mount and a series of styrene and foam plates screwed together. A circular 3D printed piece was placed around the force/torque transducer to provide dampening and minimize noise.

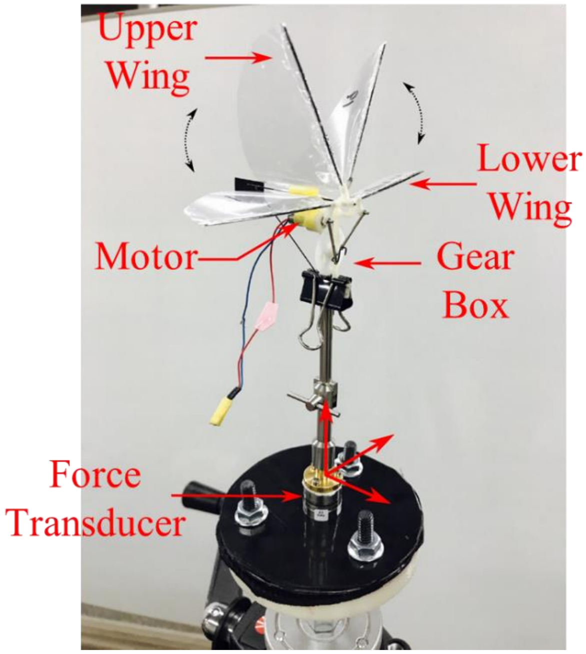

Figure 4: Experimental apparatus. Flapper is mounted on the force measurement test stand.

4.2 Experimental Method

Figure 5 shows the method used to conduct the experiments. First power is supplied to the flapper using a variable DC power supply. Simultaneously, the ATI Nano17 force/torque transducer and the USB data acquisition device (DAQ) are powered by the DAQ interface power supply (IFPS) box – power is supplied to the IFPS box using a 12 Volt (V) wall mount power supply. After power is supplied to all required equipment, a specified voltage is applied to the flapper using the DC power supply box. The ATI Nano17 measures forces and torques in the x, y, and z direction concurrently. Then the DAQ converts the transducer signals from analog voltages to data that the computer can process. Lastly, the data is output to a '.csv' file in Microsoft Excel.

The transducer measures the forces generated by using three symmetrically placed beams with strain gauges attached – the gauges act as strain sensitive resistors and changes in resistance are measured as force is applied. In order to determine the forces and torques sensed by the transducer, calculations must be performed. The strain gauge measures amplified voltages which are converted to digital data by the DAQ. The data is converted to force and torque using a calibration matrix and the provided software from ATI.

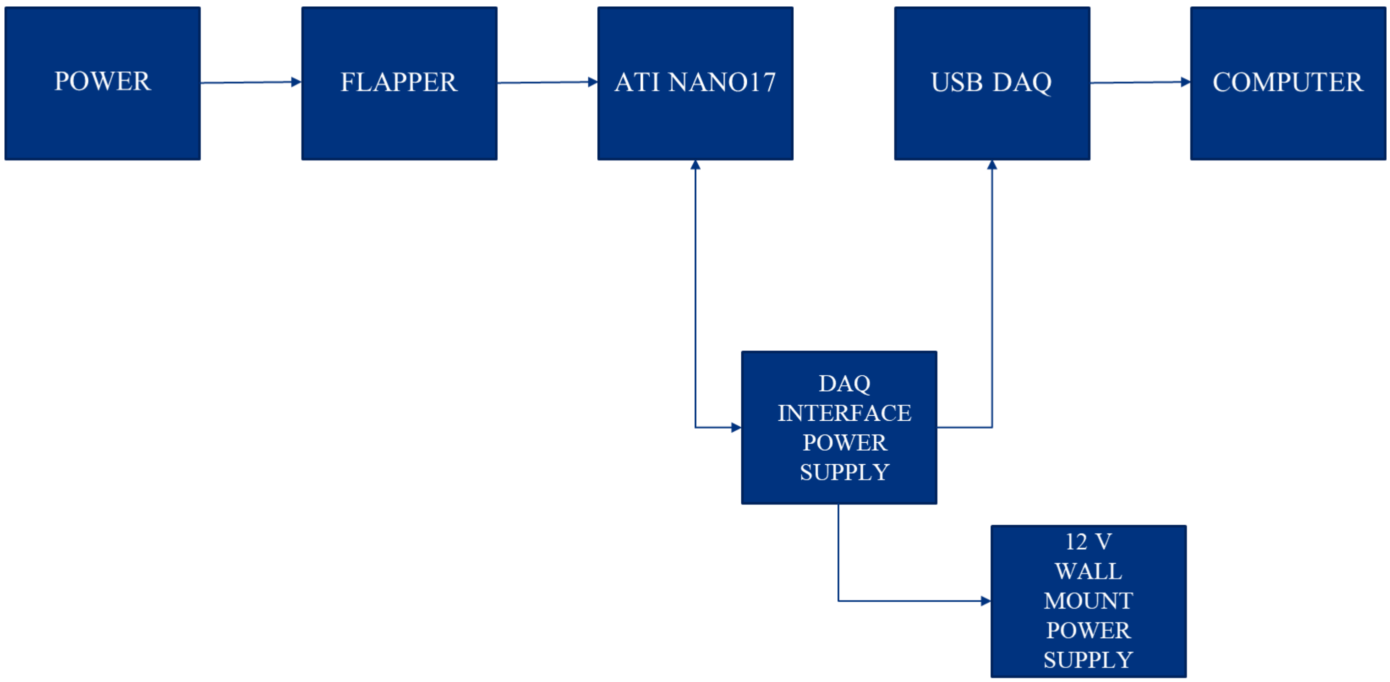

Figure 5: Experimental method flow chart.

4.3 Data Collection & Processing

Data was sampled at 5000 Hertz (Hz) for voltages of 1.0 V to 2.4 V in increments of 0.2 V – at each voltage three trials were taken. Before each trial biasing occurred tare current load readings to zero. The duration of each trial was approximately 5 seconds; however, only the samples from the last 2 seconds for each trial were processed. The idea behind this method was that the first 3 seconds were dedicated to attaining the correct voltage. Once data was obtained, MATLAB and Microsoft Excel were used for processing. The files was converted from ".csv" files to ". mat" files to process the data in MATLAB. The flapping frequency was determined first using a Fast Fourier Transform – the function FFT in MATLAB was applied to each trial to obtain signal amplitudes. Next, the frequency domain was determined by approximating a frequency and multiplying that frequency by the length of the signal minus one divided by the length of the signal. The approximate frequency used was determined by correlating voltage to frequency – for example, 1.0 V is approximately 10 Hz. After calculating both amplitude and frequency, a plot of amplitude versus frequency was generated – the highest peak shown on the plot represented the flapping frequency for that trial. Following the calculation of the flapping frequency was the analysis of the force data. A low pass Butterworth filter was used to attenuate the noise present in the data – this was an eighth order digital filter with a cutoff frequency of 0.35. The 'butter' function in MATLAB was used to determine the coefficients of a transfer function which were then used as inputs for the 'filter' function. After the data was filtered, the functions 'mean' and 'max' were used to determine the average value and maximum value at that specific flapping frequency. This process for analysis was used for each voltage and the trials per voltage were averaged together after filtering for force summaries.

5 Results

The results of the analysis conducted on the measured data is shown in the following graphs. Figure 6 shows the average forces produced by the flapper in the x, y, and z directions. There is a positive correlation between voltage and flapping frequency – frequency increases with voltage. Furthermore, there is a direct correlation between average force generated and flapping frequency – average force increases with flapping frequency. The highest average force produced occurs in the z-direction which peaks at approximately 0.14 Newtons (N) . Lift production of the flapper corresponds to force production in the z-direction – the flapper can lift approximately 14 grams. Comparatively, modern MAVs such as the Dally Micro (~3 g), the RoboBee (~1/10th g), and the Golden Snitch (~8 g) are lighter than 14g. Drag production approximately corresponds to the force production in the x-direction which peaks at approximately 0.1 N – it decreases at approximately 16 Hertz (Hz) and 18 Hz.

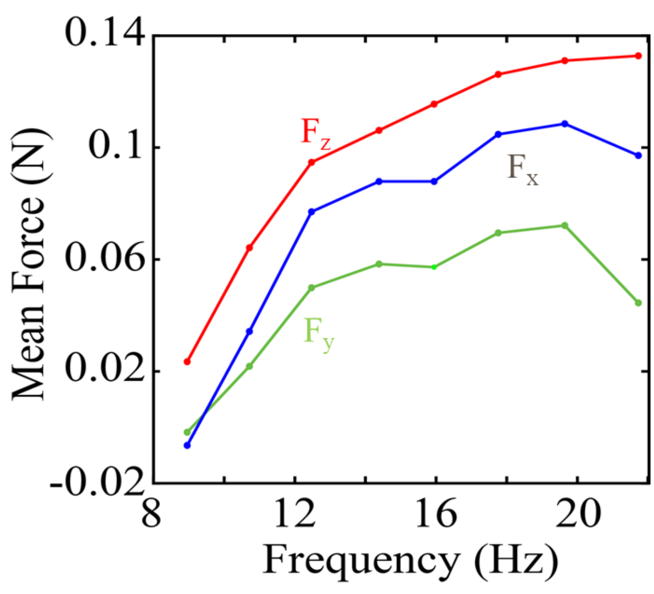

Figure 6: Mean force in the XYZ direction.

Figure 7 shows a summary of the maximum forces generated by the flapper in the x, y, and z directions. The highest maximum force produced by the flapper occurs in the y-direction which peaks at approximately 0.39 N. Although, the highest average force was generated in the z-direction, the lowest maximum force generated occurs in the z-direction and the lowest mean force is produced in the y-direction. The reversal in the dominating direction for maximum and average force production reflects the fact that the forces in the x-direction and y-direction oscillate around zero resulting in high peaks contributing to the observed maximum forces but low average forces due to the contribution of high and low peaks. Lastly, as flapping frequency increases the maximum forces generated in each direction decrease and then increase again. The frequencies in which the decline in maximum force production occurs varies – the decrease occurs at roughly 16Hz and 20 Hz in the z and y directions respectively.

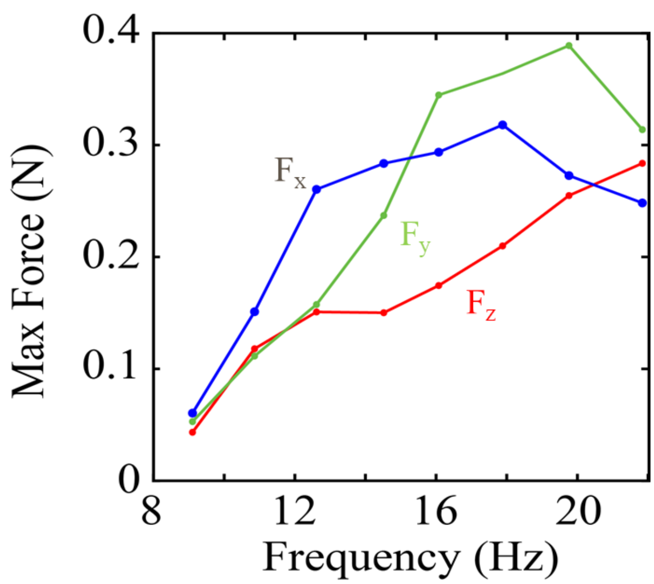

Figure 7: Max force in the XYZ direction.

Figure 8 shows the forces generated in the z-direction for three separate voltages: 1.2 V, 2.2 V, and 2.4 V. As the voltage applied increases, the forces produced by the flapper in the z-direction also increase. At 2.4 V, the flapper produces the highest force in the z-direction which is approximately 0.27 N. The solid red, blue, and green lines indicate an average of the forces generated at 1.2 V, 2.2 V, and 2.4 V respectively. The shaded regions around the lines indicate the uncertainty of the measurements collected – as voltage increases, uncertainty decreases.

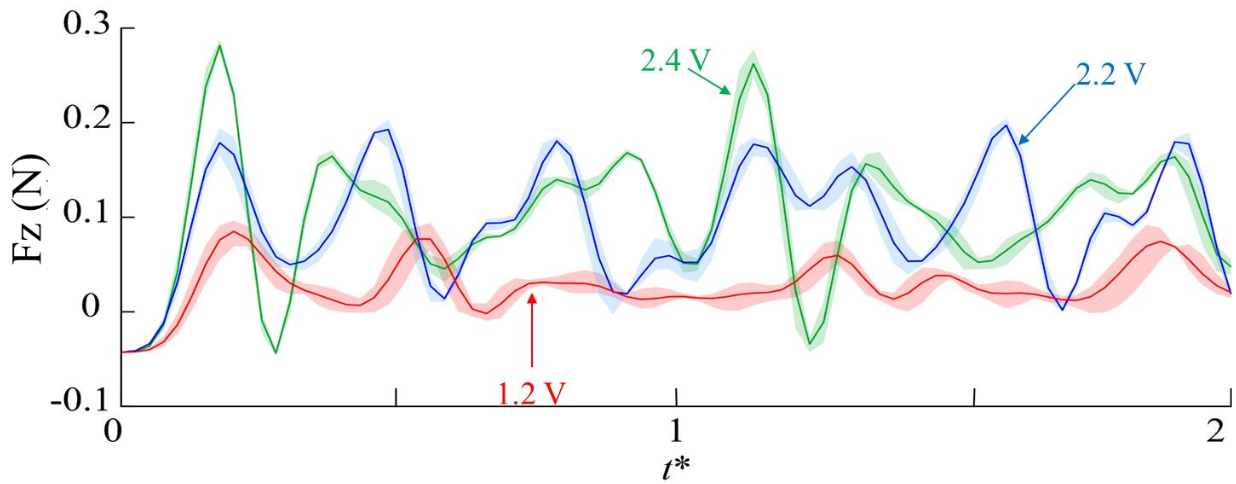

Figure 8: Time history of force production in z-direction for two flapping periods.

Figure 9 shows the forces generated in the x-direction for three separate voltages: 1.2 V, 2.2 V, and 2.4 V. The forces produced in the x-direction follow similar trends to the forces produced in the z-direction. As the voltage applied increases, the forces produced by the flapper in the x-direction also increase. At 2.4 V, the flapper produces the highest force in the y-direction which is approximately 0.29 N. Also, as the voltage applied increases, the measurement uncertainties decrease.

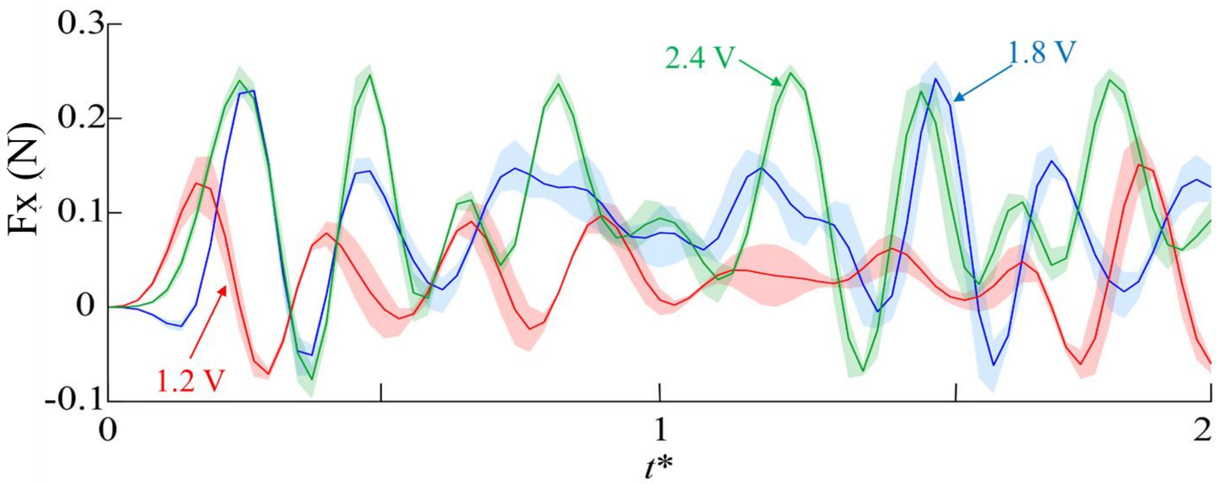

Figure 9: Time history of force production in the x-direction for two flapping periods.

6 Conclusion

Analysis of the collected data indicate several meaningful points that contribute to the understanding of the MAVs force generation. Several trends were observed over the course of the data analysis. The first trend observed revealed that an increase in the voltage supplied to the MAV would result in an increase in the MAV's flapping frequency. The next trend revealed that the average force and maximum force increase with input voltage and flapping frequency; however, there are nonlinear trends particularly in the x and y direction. In those two directions, it can be shown that the forces increase, decrease, and increase again as voltage and flapping frequency increase. The average force generated in the z-direction – the lift experienced by the MAV – has the greatest magnitude. The maximum force generated in the y-direction has the greatest instantaneous magnitude but due to the oscillations of the forces around 0 in the y-direction as well as the x-direction result in high maximum values and low mean values. Based on the forces measured in the z-direction, the flapper can lift a total weight of approximately 14 grams – this means that the flapper is lifting approximately four times its own weight and is capable of flight. Another significant insight is that in terms of lift production, the flapper seemingly outperforms some birds and insects only if a constant power source is applied. The goal of understanding the forces generated by the flapper was achieved throughout the course of this project but more work needs to be done. Future work will focus on applying the knowledge gained and the process developed throughout the course of the project to develop a flapping wing MAV similar to the one used for testing.

7 References

[1] W. Shyy, H. Aono, C.-K. Kang and H. Liu, An Introduction to Flapping ing Aerodynamics, New York: Cambridge University Press, 2013.

[2] Nature's Invitation, "Hummingbirds Ultra Slow Motion - Amazing Facts, Full HD.," 2016. [Online]. Available: https://www.youtube.com/watch?v=FPRswRWZ23Q . [Accessed 8 February 2018].

[3] T. Nakata, H. Liu, N. Tanaka, X. Wang and A. Sato, "Aerodynamics od a bio-inspired flexible flapping-wing micro air vehicle," *Bioinspiration & Biomimetics,* vol. 6, no. 4, pp. 1-11, 2011.

[4] M. H. Dickinson and S. P. Sane, "The Control of Flight Force by a Flapping Wing: Lift and Drag Production," *Journal of Experimental Biology,* vol. 204, no. 16, pp. 2607-2626, 2001.

[5] L. Zhao and S. P. Sane, "Aerodynamic effects of flexibility in flapping wings," *Journal of the Royal Society Interface,* vol. 7, no. 44, pp. 485-497, 2010.

[6] T. Weis-fogh, "Quick Estimates of Flight Fitness in Hovering Animals, Including Novel Mechanisms for Lift Production," *Journal of Experimental Biology,* vol. 59, no. 1, pp. 169-230, 1973.