DESIGN OF A MEDIUM SCALED AIR VEHICLE: FLAPPING TYPE

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FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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Field of Study: Flapping Wing Air Vehicle

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ABSTRACT

Flapping wing air vehicle is an ongoing research to master the natural flyers by many different means. Both birds and insects have different methods of producing lift and thrust for hovering and forward flight. Most birds however cannot hover. FWAV is based on avian flight is called 'ornithopter' and that is based on insect flight is 'Entomopter'. Insects have great maneuverability, hovering capabilities and their performance.

The purpose of this project is to develop and test the capabilities of flapping wing mechanism that can later be adapter to a biomimetic micro air vehicle (BMAV). In this project ornithopter is used. A mechanical based mechanism is designed for the flapping motion. Preliminary analysis has been done on the wings. The aerodynamic performance characteristics is done based on the numerical analysis.

The model was designed in solid works. The mechanism uses gear and carbon fiber rods and to drive the flapping wing and the tail. The complete wing span is used in building the project is about 300 mm. Analysis is done based on ANSYS analysis.

Keywords: Flapping wing micro air vehicle, Micro Air Vehicle, Insect Flight,

ABSTRAK

Kenderaan udara sayap mengapung adalah penyelidikan yang berterusan untuk menguasai risalah semulajadi dengan banyak cara yang berbeza. Kedua-dua burung dan serangga mempunyai kaedah yang berbeza untuk menghasilkan angkat dan tujah untuk penerbangan terbang dan ke hadapan. Kebanyakan burung bagaimanapun tidak boleh bergerak. FWAV berdasarkan penerbangan burung dipanggil 'ornithopter' dan yang berdasarkan penerbangan serangga adalah 'Entomopter'. Serangga mempunyai pergerakan yang hebat, keupayaan melayang dan prestasi mereka.

Tujuan projek ini adalah untuk membangun dan menguji keupayaan mekanisme sayap mengetuk yang kemudiannya boleh menjadi penyesuai kepada kenderaan udara mikro biomimetik (BMAV). Dalam ornithopter projek ini digunakan. Mekanisme berasaskan mekanikal direka untuk gerakan mengepak. Analisis awal telah dilakukan pada sayap. Ciri-ciri prestasi aerodinamik dilakukan berdasarkan analisis berangka.

Model ini direka bentuk dalam kerja pepejal. Mekanisme itu menggunakan rod gear dan serat karbon dan memacu sayap mengepak dan ekor. Jangkauan sayap lengkap digunakan dalam membina projek itu adalah kira-kira 300 mm. Analisis dilakukan berdasarkan analisis ANSYS.

Kata kunci: Memindahkan kenderaan udara mikro sayap, Kenderaan Udara Mikro, Penerbangan Serangga,

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LIST OF SYMBOLS AND ABBREVIATIONS

MPa	:	Mega Pascal
GPa	:	Giga Pascal
g	:	Grams
cm	:	Centimeters
m	:	Meters
J	:	Joules
Kg	:	Kilograms
K	:	Kelvin
W	:	Watts
C_t	:	Coefficient of thrust
T	:	Thrust
n, f	:	Flapping Frequency
D	:	Strouhal Number
ρ	:	Density of air
PLA	:	Polylactic acid
ABS	:	Acrylonitrile Butadiene Styrene
HIPS	:	High Impact Polystyrene
AR	:	Aspect Ratio
Hz	:	Hertz

LIST OF APPENDICES

CHAPTER 1 INTRODUCTION

Micro Air Vehicles (MAVs) are in the boon of research for the past few years. In which various designs were proposed in addition for the field of unmanned air vehicles (UAVs). With the help of these UAVs human can reach to the places where even other big devices cannot reach. Search and rescue, reconnaissance and surveillance can be performed using UAV which will be an added asset to the commercial and for military use. MAVs should be light weight and small with great maneuverability in complex environments. Carrying payload is an added advantage for the MAV. “Types of MAVs are fixed- which have fixed rotation axis, rotary- which have rotations along the axis or flapping wings to hover and achieve forward flight” (Park, Yang, Zhang, & Agrawal, 2012). The below figure 1.1 shown is an example of a micro air vehicle.

Figure 1.1 Micro Fixed Wing Rotary Copter

This study is based on the flapping wing Micro air vehicles (FWMAVs). These FWMAVs resemble agile flying and can maneuver with great agility which cannot be achieved when we used other flying methods (Park et al., 2012). We are inspired from the nature itself to create these agile robotic flyers. One such example of maneuverable and instant speed catching insect is the dragon fly. Other such flyers for inspiration are bats, humming birds, and fruit flies (Bunget & Seelecke, 2008; Z. A. Khan & Agrawal, 2011; Lentink, Jongerius, & Bradshaw, 2010) Flapping Wing Micro Air Vehicles (FWMAVs) are recently getting developed class of aerial vehicles that are being be used for various applications which include searching for victim in burning buildings and other collapsed buildings. FWMAV's show great aerial maneuverability (Z. Khan, Steelman, & Agrawal, 2009). Flapping mechanisms can be developed that can recue the dimensions of FWMAV (Zhang, Zhou, Wang, & Zhang, 2011). The below figure 1.2 shown is the example of an ornithopter.

Figure 1.2 Ornithopter

A large amount of energy is needed to move wings in return pushes air and creates thrust (Chapman, 1998; C. P. Ellington, 1984)

To produce lift and to overcome drag there should be aerodynamic power produced. Furthermore, to accelerate the wing from rest to flapping the wing, the inertial power is required (C. P. Ellington, 1984; Norberg, Kunz, Steffensen, Winter, & von Helversen, 1993). Increasing the frequency can increase the inertial power which in return increases the total flight power up to 53%.

For developing these flapping micro air vehicles, engineers have designed a flapping wing mechanism for generating a flapping motion which mimics the insect. This generally means that there is optimization of the parameters is done on the mechanism which aims in reducing the error between motion and the insect like wing motion (Banala & Agrawal, 2005; Żbikowski, Galiński, & Pedersen, 2005). However, the main challenge is to implement the design a small scale FWMAV. which can withstand the impact loads at each stroke when the beating at high flapping frequency. Energy is wasted during flapping due to generation of noise and which in turn affects the strength of the mechanism. The model may be incapable of flying due to this wastage of useful energy. Also, exactly mimicking the insect wing motion does not necessarily mean it will peak aerial performance (Altshuler, Dickson, Vance, Roberts, & Dickinson, 2005).

These flapping flight counterparts such as insects, birds, bats like devices are known as ornithopters or entomopters. The flight is hard to achieve with this ornithopters because they have relatively low Reynolds numbers at which most of them operate. They typically have relatively low aspect ratio of their wings which shows strong tip vortices and rolling instabilities (Weis-Fogh, 1972). There has been no such FWMAV that mimics the storing of this elastic energy. Due to difficulty in storing the elastic energy most FWMAV have limited flight endurance. Also, with the increase in wing reciprocation the inertial power increases in addition to aerodynamic power.

Z. Hu, McCauley, Schaeffer, and Deng (2009) performed force measurements, their approaches permitted accurate force measurements to be conducted with complex wing kinematics. Wings should generate two to three times more lift to support the weight of the body which can be accounted in the computational aerodynamics. (Charles P. Ellington, van den Berg, Willmott, & Thomas, 1996).

1.1 Problem statement

There are many flapping prototypes which works when given initial velocity. A normal flapping mechanism does not consider lifting off from its initial position with zero initial velocity. There is no working model of a MAV based on Flapping Type which lifts off from its initial position. The additional challenges include calibrating the mechanism to work symmetrically. Reducing the frictional parts. Calibrating the center of gravity and assembly of the completed parts.

1.2 Objective

The main objectives of the project are:

1. Design a model of medium sized air vehicle based on flapping type.

2. Investigating a suitable material for the model.

1.3 Thesis Outline

There are six chapters in this report. Chapter 1 deals with the introduction of the flapping wing micro air vehicle. Chapter 2 is the literature review of the project. The methodology of the FMWAV including the fabrication of the object, materials used, and the structural properties is discussed in chapter 3. Chapter 4 is the result and discussion on the methodology used for the product development. Chapter 5 concludes the project report on the flapping wing micro air vehicle.

CHAPTER 2 LITERATURE REVIEW

Micro air vehicles have the potential to revolutionize the information gathering and sensing capabilities in various areas such as Homeland security and environmental monitoring. There is a rapidly increasing demand on the smaller unmanned aerial vehicles (UAV). This interest is being conducted by many universities, commercial industries such Festo, governments across the globe. RAND Corporation were the first one to conduct the feasibility studies on the Micro-Air Vehicle in 1994. They thought MAV would be a great asset to the military applications. Then the US defense Advanced Research Products Agency (DARPA) funded the research in 1996. There was use of biological studies on insects and birds which were suggested to design futuristic bio-inspired aircrafts. According to DARPA, MAV should be less than 15 cm in any dimension. Also, there was an initiation on the Nano micro air vehicles abbreviated as (NAVs). These should be less than 7.5cm in any dimension and maximum weight is 10g (Hundley, 1994).

These MAVs are useful when it comes to forming a wide range of military duration in mission and for civilians. Their small, physical size makes them easy mode of transport to launch site and can be controlled by a single operator remotely. Which makes it very agile and an ideal flight for investigating hazardous sites (such as, chemical spills, gas leaks etc.) and small places that humans cannot fit in. In military application their size is added as an advantage as it is barely visible. There are mainly three types of MAVs (Thomas A Ward, 2017). They are

1. Fixed wing micro air vehicle (FMAV)
2. Rotary Wing micro air vehicle (RMAV)
3. Biomimetic micro air vehicle or flapping micro air vehicle (BMAV)

Our focus is on the biomimetic micro air vehicle. These are bio inspired like the flapping of wings from insect's birds or bats. Flapping the wings generates a greater force per wing surface area. Flapping wing generates lift and thrust. Hence the BMAV has a potential to be much smaller than the FMAV and RMAV. If the surface area of the wing is more, then increase in flapping frequency generates more lift and thrust. The flapping frequency and the surface area of the wing are related. For example, Bees have smaller wing to body ratio, therefore they need a higher flapping frequency of about 200 to 250 Hz. Whereas, Dragonflies have lower higher wing to body ratio. Hence, they need less frequency of about 30 Hz.

Reducing the size of the UAV will create new set of challenges. Creating enough lift thrust and lift with a single flapping cycle. Small UAVs are termed as micro aerial vehicles (MAVs). Initial research was to develop a 2D flapping air foils with the help of experimental and numerical approaches. The need for the 3D flapping wings modeling and simulation grew for a more accurate performance-based predictions despite the cost factors.

Both numerical and experimental approaches are equally important.

There are several degrees of freedom for a flapping wing (Chung & Dorothy, 2010). Distinguishing between dynamics and stability study of insects and flapping wing micro air vehicles is usually impossible. The dynamics and stability are bonded together in the flying system in addition to this, biomimetic analysis, the control analysis of insects or the flapping wing micro air vehicles cannot be conducted without the inclusion of a flight dynamics model. Most of the works are in control and stability, but dynamics should be addressed first.

2.1 Stability Studies

The analysis of the flight dynamics of specific insect species were the initial studies of dynamics and stability of insect flight. (G. K. Taylor & Thomas, 2003) were the first one to do the analysis. The dynamics of desert locust schistocera gregoria were studied by (G. K. Taylor & Thomas, 2003). The mass of the wings were not taken into account because it is assumed that the wing beat is not fast enough to excite the rigid body.

2.2 Dynamic studies

The central body has the inertial and mass effects of the wings. and by extension, the entire system. Different types of models do not consider the effects of inertia of the mass of the wing. A small perturbation theory can be extensively developed which includes the linearized model. This is used in the standard aircraft equations of motion. (Reid, 1996). The FWMAV in hover condition are used to simulate the wing dimension from the mathematical; model and a robotic flapper. Control research conducts the standard aircraft flapping wing flight dynamics. For example, (Duan & Li, 2009) developed the flight dynamics model for altitude control to incorporate in an ornithopter.

In (Sun & Xiong, 2005), also used the approximation method on the same rigid body for bumblebee hovering flight stability. The required data was obtained using the computational fluid dynamics. The moments and aerodynamic forces are cycle-averaged. Thus, determining the equilibrium condition of flight near the hover condition, the resultant forces for one flapping cycle is used.in loop setting the destabilization of longitudinal axis performed with the help of the aerodynamic pitching moment. The longitudinal axis in loop setting destabilizes the aerodynamic pitching moment. The phasing between the flapping motion and pitching should be exact otherwise the pitching moments of the wings will be enhanced to destabilizing effects.

2.3 Natural Fliers

Insects, birds and fist use a mode of locomotion for the flapping motion. The interaction between the flapping wings or tails in their surroundings generates lift and thrust. Leonardo da Vinci designed many types of ornithopters based on the bird flight which was inspired by the mist in the 1500s. The flapping wing is the most unsteady nature of flows, due to which the subject was difficult to achieve (Wang & Jane, 2000). Strouhal number is a non-dimensional quantity that is maintained by the natural flyer's in a range of 0.2 to 0.4. 'The propulsive efficiency which is defines as the ratio of the power produced by the wing to the power required to flap.' The Strouhal number range is maximized when the value of the thrust is also considered (Schouveiler, Hover, & Triantafyllou, 2005; Taylor, Nudds, & Thomas, 2003)

2.4 Insect Flight

Completely understanding the flapping mechanism, we must know the flapping motions of insects and birds. This will help us understand better in designing a better flapping mechanism. In general, flapping flight are of two types, they are: insect flight and bird flight (Shyy, Lian, Tang, Viieru, & H.Liu., 2008). The main difference between the insect flight and bird flight is that:

Flight of bird has two degrees of freedom, where the wings rotate in passive rotation. The slight deviation and the flapping motion from the plane of stroke defines the mean motion of the wing. Bird flight is also known as ornithopter flight.

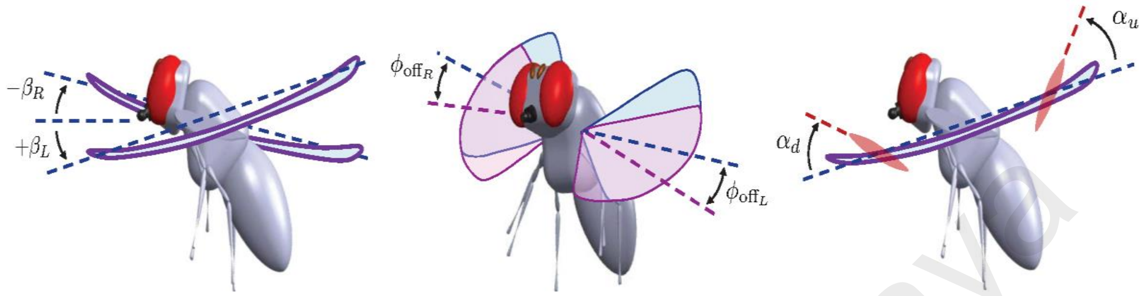

Figure 2.1 Degree of freedom for an insect

For each wing the insect flight has three degrees of freedom as shown in the figure 2.1 above. The pitch angle of the wing has it about the wing root which deviates from the stroke plane. The degrees of freedom are shown in the above figure for a wing:

The wing strokes are divided into two parts: downstroke and upstroke. Normal rotation is the wing rotation is occurring at the end of each half-stroke. Similarly, the rotation is known to be advanced if the wing rotates at the end of half stroke and after the mid stroke. Rotation is delayed if the wing rotates before the mid stroke and after the end of each half stroke. kinematics is always based on normal rotation.

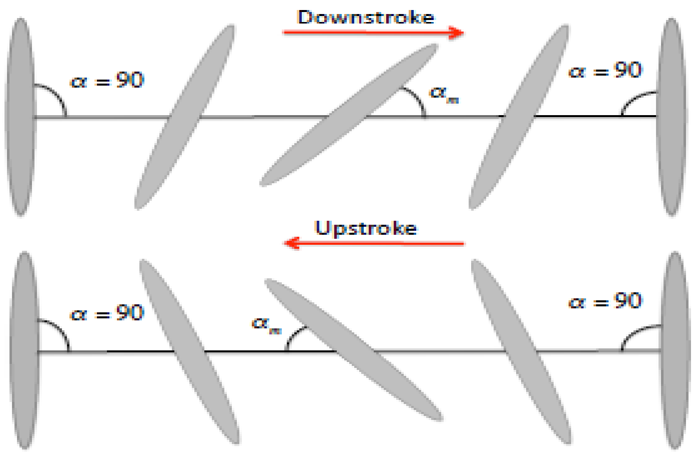

Figure 2.2 Upstroke and Downstroke of a wing, when α=90º

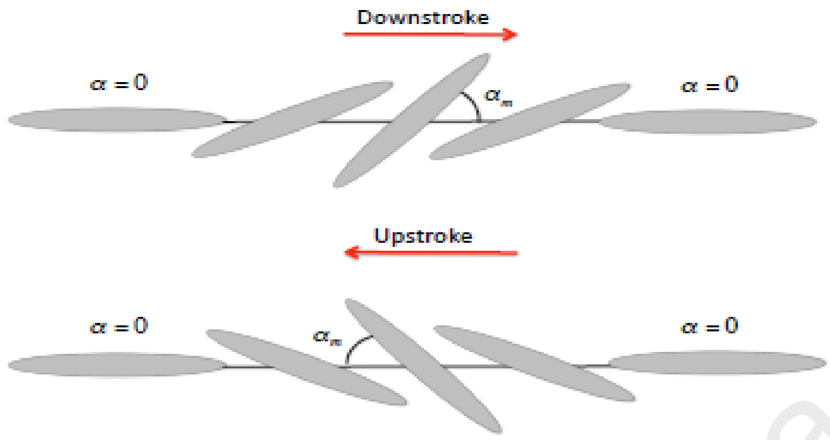

Figure 2.3 Upstroke and Downstroke of a wing, when α=0^o

The normal rotation also consists of two types: hovering normally and water treading.

Hovering normally, mid stoke will have the maximum pitch angle and angle of attack of 90^o at the end of each stroke is shown in figure 2.2.

Angle of zero at the end of each half stroke and the maximum angle of attack at the mid stroke is shown in figure 2.3. This is known as water treading (Shyy et al., 2008).

2.5 Other Authors

Hu et al. had done experiments that are necessary applications for gearless, piezoelectric flapping wings, compact stroke amplitude, and frequency of flapping within the range of the actual insect characteristics for the development of the Biomimetic micro air vehicle (BMAV). He also used a' digital particle image velocimetry (PIV) system' to achieve phase-lock and flow field measurement based on time to quantify the separation process and formation of the 'leading-edge vortex (LEV structure' on the lower and upper wing surface.

Nagai et al. had also conducted the numerical and experimental studies to understand the aerodynamic characteristics of forward flight flapping motion in a wing. Mechanical model in wing tunnel is set up using a dynamically scaled to measure the unsteady flow patterns and force measurements. The aerodynamic characteristics of the flapping motion in the forward fight has an immense effect. The results showed that aerodynamics mechanism is effective. The function of these mechanism varies depending on the up and down stroke, for different advance ratios and for different plane angles.

Singh et al. measured the thrust generation at the different pitch angles for several insect-based hover flapping wings. They created an experimental apparatus to measure that thrust. The weight of the flapping wings influences the high inertial power requirement which in turn has an effect on the maximum frequency of the mechanism. Different experiments were conducted to show that as the frequency increases the thrust decreases.

Sällström et al. used a stereoscopic particle image velocity to examine the facts generated by the two pairs of flapping Zimmerman planform wings under the hovering conditions. Although it has a lower angle of attack the wing stalls more in the beginning of each half stroke. Therefore, the less stiff of the wings sheds several vortices each half stroke.

Mahardika et al. had found that the outer wing parts can deform which resulted in lesser amount of drag generation while upstroke. Whereas the wing was still generating increased thrust and lift during downstroke.

Jadhav at al. designed a single wing mechanism. The flapping motion is motor driven crankshaft which relates to a connecting rod. The fixed pivot point is used to connect wing with the help of the connecting rod. Pitching motion is controlled by the servomotor which is connected directly below the pivot joint. There was independent pitch controlled from the servomotor for the flapping motion, which is a mechanism capable of changing the pitch while flying. This whole flapping mechanism was operated in water, due to this reason the flapping frequencies were low. There is still a room for improving the increase in flapping frequencies when flapped in air while still dynamically control the pitch in the fly.

McIntosh et al. designed a mechanism that can change the pitch angle while flapping two wings. A single actuator is used to control the flapping and pitching mechanism. This motion resembles the motion as that of an insect. This is not in use because the body was not able to lift off form its initial position. The frequencies in which they should operate are very low (about 1.2 to 1.9 Hz). Also, the profile of pitching was not easy to change.

2.6 Flapping Mechanism

The important part of the FWMAV is the flapping mechanism as they create lift and thrust. They are more complex depending on the type of flight. Small birds capable of hovering are more complicated design and the bird with flying without any hovering abilities are less complex to fly. Capturing the motion of the wing while design the biomimetic flapping mechanism is the main challenge. For example, humming bird has at least three degrees of freedom. They are:

a) The vertical motion of the wing rotation
b) The wing rotation motion, which allows the wing to change pitch within the flapping stroke.
c) The third motion involves the ability of the wing to flap in a stroke plane that is parallel to the ground.

These three motions combined make the humming bird hover as shown in the below figure 2.4.

Figure 2.4 Flapping motion of a humming bird

The flapping pattern is complex to design at small scales which also has the ability and hover. Even more complex is the functional capability of the flapping mechanism to lift and hover. (Svanberg & Craig, 2008)

2.6.1 Wing and Body Structure

The aerodynamics of the flapping wing is characterized by the unsteady aerodynamics. Small birds and insects are less unsteady when compared to the large birds with slow flapping rate. The unsteady effect is created by the bound and trailing vortices, as the viscous flow regime increases it gets harder to produce vortices and thus a hard work for birds. Lift like clap and fling mechanism, rapid pitch up, wake capture and delayed stall are unsteady mechanisms used by the insects and other small birds to enhance their lift.

2.6.2 Wing Kinematics

There are mainly three distinct motion with respect to three axes as shown in the below figure 2.5. They are:

- *Flapping*, motion of the wing while plunging up and down stroke. The flapping of wings produces most of the bird's power and has the largest degree of freedom.
- *Feathering*, the pitching of the wing can vary along the span
- *Lead-lag* is in-plane lateral movement of the wing.

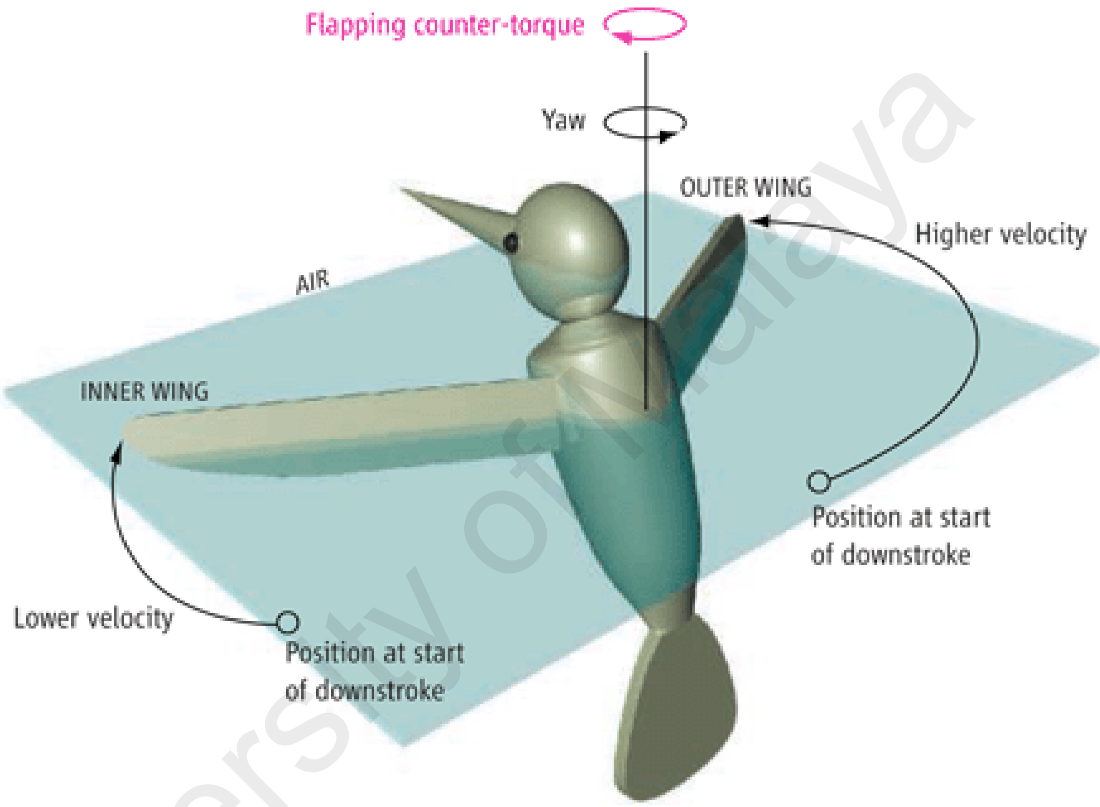

Figure 2.5 Wing Kinematics of a humming bird

2.6.3 Force Generation by Flapping Wings

Flapping consists of two strokes, 1) Down Stroke and 2) Up Stroke as shown in the figure 2.6. Vertical induced flow is maximum at the wing tips. and the magnitude decreases to the root when flapping. The angle of attack (AOA) decreases from tip towards for a constant forward speed. Wing must pitch in the flapping direction to maintain low AOA. This will help maintain the direction of flapping to maintain the attacked flow. This is the types of pressure and air flow of a bird as shown in figure 2.7.

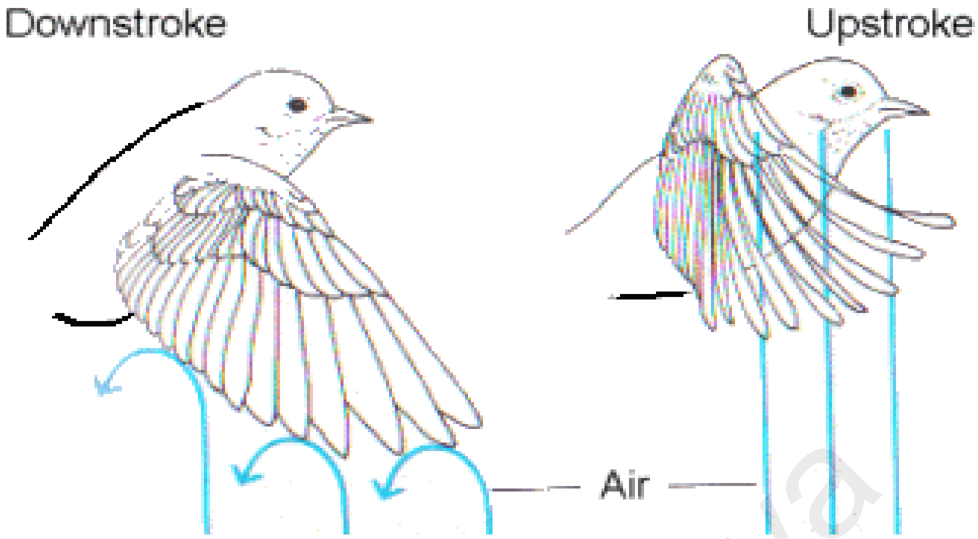

Figure 2.6 Two different strokes of a bird

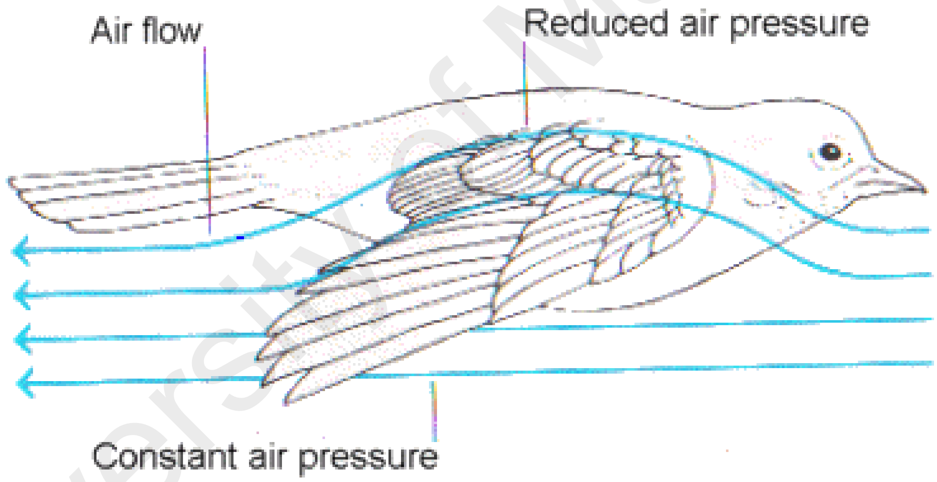

Figure 2.7 Types of pressure and air flow of a bird when in flight

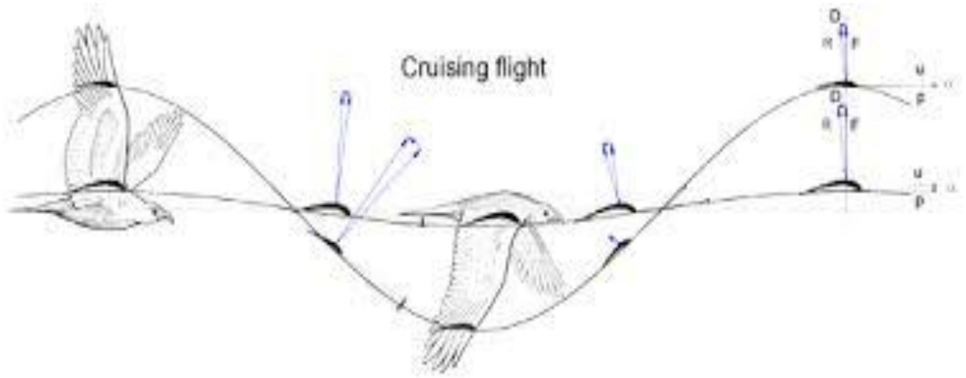

Figure 2.8 Cruising flight of a bird

The complete aerodynamic force is titled forward and has two components during the down stroke. The two components are lift and thrust, which is the cruising flight of the bird as shown in figure 2.8. The positive angle of attack during up-stroke but depending on the amount of pitching up of the wing the tip can be either positive or negative. In reverse direction to produce lift and thrust the wing must be tilted backwards and when the inner part of the wing is tilted upward there is a lot of generation of aerodynamic forces. Also, there is positive lift and drag generated at the outer part of the wing if the angle of attack is positive. If Angle of attack is negative, then the wing produces negative lift ant but positive thrust (Lynn Harmon, Masters, & Hubbard Jr, 2018).

2.7 Materials

There are wide variety of materials that is been used in this project. They are:

1. Carbon Fibre shafts.
2. High Impact Polystyrene (HIPS)
3. Acrylonitrile Butadiene Styrene (ABS)
4. Polylactic Acid (PLA)
5. Plastic sheet for wings

2.7.1 Carbon Fibre Shafts

These are also known as carbon Fibre rods (solids). They are used in many cases. For example, RC airplane matte pole, applied stunt kites, mechanical equipment, robotics Etc. These carbon Fibre rods have high strength when compared to that of steel. They are almost 8-10 stronger and but weight only 1/5 of steel. It has good electrical conductivity. No current can pass through that, so it is safe to work with them in electrical environments.

Tensile strength of this carbon Fibre rods is very high. These can be used in environments where there is danger of corrosion as they are corrosion resistant. Also flexible to some extent before their yield strength. Overall, they give stable performance with the intent they are used for (Plate, 2018).

These are manufactured to engineering tolerances from pultruded unidirectional carbon fibres which means that all the strength of the rods runs laterally along their length. They come in various diameters and lengths as shown in the figure 2.9 below.

If the rod weighs approximately 1.2 grams per meter

Figure 2.9 Carbon Fibre Shaft

The below table shows the typical empirical values for easy composites carbon fiber pultruded tubes, strips and box sections:

Table 2.1 Properties of the Carbon fiber shaft

Property	Direction	Value
Tensile Strength	Length-ways	400 – 500 MPa
	Width-ways	18 - 30 MPa
Tensile Modulus	Length-ways	28 – 40 GPa
	Width-ways	8 – 12 GPa
Flexural Strength	Length-ways	250 – 400 MPa
	Width-ways	80 – 150 MPa
Flexural Modulus	Length-ways	20 – 30 GPa
	Width-ways	10 – 15 GPa
Compressive strength	Length-ways	200 – 320 MPa
	Width-ways	60 – 100 MPa
Compressive Modulus	Length-ways	10 – 20 GPa
	Width-ways	8 – 20 GPa
Short beam shearing strength	Length-ways	30 – 40 MPa
Barcol Hardness		25 – 45
Relative Density		1.30 - 1.50 g/cm^3

2.7.1.1 Barcol Hardness

Barcol hardness is used to determine the hardness of both reinforced and non-reinforced rigid plastics (Intertek, 2018). This is an indentation type of hardness, where pressure is uniformly applied on the surface of a specimen to the dial indicator maximum reading. The depth of penetration or indentation is then converted into an absolute barcol number. The barcol number is automatically generated by the measuring equipment. The testers are available in a range of model depending on the nature of materials to be tested.

The indenter point is placed perpendicular to the surface being tested. Light pressures are exerted in the measuring instrument, driving the spring-loaded indenter point into the surface. The spring effect leads to the indication of the hardness on the dial. The data is directly obtained, hence making Barcol hardness an easy-to-measure property of materials (Corrosionpedia, 2018).

Barcol impresser scale determines the degree of hardness of the material. This quantity can be measure the hardness of materials like (Corrosionpedia, 2018):

1. Plastic and polymers (duro-plastics and thermo-plastics)
2. Soft metals and alloys (aluminum)
3. Composites
4. Rubber
5. Fiberglass
6. Leather
7. Finished and semi-finished products.

2.7.2 High Impact Polystyrene (HIPS) Filament

HIPS is a dissolvable filament that is frequently used as support material. It acts as a great support material because it is easily removed with Limonene solution, leaving the clean high-quality print that you want behind. HIPS require no scraping, cutting, or any other method of removal that may cause damage to your prints (Flynt, 2018, March 24).

Features of HIPS Filament (Technologies, 2016):

- Great impact strength

- Good dimensional stability
- Excellent machinability
- Low shrinkage value
- Low cost
- Light weight

Table 2.2 Properties of the High Impact Polystyrene filament

Property	Value
Ultimate tensile strength	32 MPa
Young's modulus	1.9 GPa
Poisons Ratio	0.41
Specific heat capacity	1400 J/Kg-K
Thermal expansion	80 μm/m-K
Thermal conductivity	0.22 W/m-K
Density	1.0 g/cm^3
Tensile strength	21.5 MPa
Compressive strength	27.57 MPa
Flexural modulus	2137.37 MPa

2.7.3 Acrylonitrile Butadiene Styrene (ABS)

ABS is a petroleum-based printing material which belongs to the thermoplastic category. ABS is extensively used in the 3D printing industry. There are many different types of ABS. so choosing the proper material according to usage and design is crucial. Experienced user may use ABS for many designs because it is affordable, strong and also it is easily modifiable for 3D printing. But the user who is a novice in dealing with ABS will find it tricky to use. It is because the flow rate from the print head is slow and it constricts as it cools down. Therefore, printing high precision products is not possible (3DINSIDER, 2018).

Benefits of using ABS materials:

- Very hard and sturdy
- Heat resistant
- Soluble in acetone
- Sanding and gluing is easy
- Smooth finish
- Good plastic properties
- Difficult to break

Table 2.3 Properties of Acrylonitrile butadiene styrene filament

Property	Values
Young’s modulus	2.5 GPa
Flexural modulus	7.6 GPa
Ultimate tensile strength	110 MPa
Density	1.4 g/cm^3
Thermal expansion	95 µm/m-k
Poisson Ratio	0.35
Coefficient of thermal conductivity	90 µm/m-^oC

2.7.4 Polylactic Acid (PLA)

They are very different from most the other thermoplastic polymers. PLA are made from renewable sources of energy like sugar cane and corn starch. Other thermoplastics are made from nonrenewable reserves of petroleum. PLA is also known as a bioplastic as it is made from renewable sources.

PLA is biodegradable which has characteristics as polypropylene (PP), polyethylene (PE) or polystyrene (PS). They don't have to be made from the industrial manufacturing techniques as other nonrenewable sources. Hence, they are cost effective and are cheap to manufacture. Production volume of PLA is second largest in the bioplastic category and is typically cited as the thermoplastic starch.

The most common PLA application is the use in plastic films, biodegradable medical devices such as pins, screws, rods) and bottles. Also, if there any use for the shrinking plastic, then PLA is best suitable because they constrict under heat. PLA comes in different colors for 3D printing based on the color differentiation required by the user.

The disadvantages of PLA are that it has relatively low transition temperature. Due to this it is highly inapplicable for application with high temperatures. PLA is a little more brittle than that of ABS for 3D printing (Rogers, 2015, October 7).

Table 2.4 Properties of Polylactic Acid filament

Property	Value
Youngs modulus	3.5 GPa
Ultimate Tensile Strength	53 MPa
Density	1.3 g/cm^3
Thermal conductivity	0.13 W/m-K
Specific heat capacity	1800 J/Kg-K
Coefficient of thermal expansion	68 μm/m-^oC
Melting point	150 – 160 ^oC

2.8 Research Gap

The research on Flapping wing micro air vehicle has been going on for a lot of years. But producing a fully functioning model has been achieved on the recent years. There are different modes of flight achieved by different researchers. There are many Mechanism that came in place but there are only a few functional mechanisms. There are different types of mechanism such as piezoelectric, fully mechanical, mechanical and electronics combined.

2.9 Introduction to solid works

Solid Works is a Solid modeling computer aided design (CAD) and Computer aided engineering (CAE) computer program which runs in Microsoft windows. Dassault systems published solid works. Solid works was founded in December 1993 by Massachusetts Institute of Technology graduate Jon Hirschtick. To set up the company he used $1 million which he earned when he was a member of MIT Blackjack Team.

Solid works 95 was first released in November 1995 when the company was operating from concord, Massachusetts. Two years later Dassault, acquired $310 million in stock. We all know that Dassault is known best for Catia (Wikipedia, 2018, JUNE 15).

2.9.1 Modeling Technology

Solid works is a solid modeler which utilizes a parametric feature-based approach which was firstly developed by PTC (Creo/Pro-Engineer) to create assemblies and models. Constraints defining the values determining the shape or the geometry of the model or assembly. They can be both numeric parameters such as circle diameter or line length or geometric parameters.

The creator of the specific part which responds to the changes and updates is known as the Design Intent. Solid works allows the user to specify that hole is a feature on the top surface. No matter the height of the component it honors the design intent.

Features are the building blocks of the part. They are the operations and shape that construct the part. 2D or 3D sketches are usually shape based. For example, holes, bosses, slots etc. The shape drawn is then extruded or cut depending on the requirement to add or remove the part respectively. Fillets, chamfer, shells are operation-based feature which are not sketched (Wikipedia, 2018, JUNE 15)..

2.9.2 Designing in Solid works

2D sketch is usually used to start sketching a model in solid works. There is an option to start directly to start with 3D sketches which are available for power users. The sketch consists of different geometry such as lines, arcs, points and splines. Dimensions are added after sketching the part to define the location and size of the geometry. There are relations that can be used to sketch to define the attributes such as parallelism, tangency, concentricity and perpendicularity. The dimensions and relations drive the geometry in solid works but not vice versa. Different parameter outside and inside the sketch can be controlled independently or by different relationships.

After designing the parts, assembling the parts is necessary to achieve a completed product. The analog to sketch are mates. Gear and cam follower mates are advanced mating features used in solid works. This allows the modeled gear assemblies to accurately reproduce the rotational movement of an actual gear train.

Finally, the sketches can be created from assemblies or parts. Saving the file in various formats, such as, SLDPRT (part files), SLDDRW (drawing files), SLDASM (assembly files).

CHAPTER 3 METHODOLOGY

3.1 Design of Flapping Wing Micro Air Vehicle:

There are 5 main parts created in part files. They are as shown below:

3.1.1 Wing Rod

This is the Carbon Fibre rod which is the wing frame is shown in the figure 3.1. This will help the wing to move in the desired angle. This wing because of the number of revolutions will generate lift for the complete product to lift off. This wing is directly attached to the mechanism for it to flap.

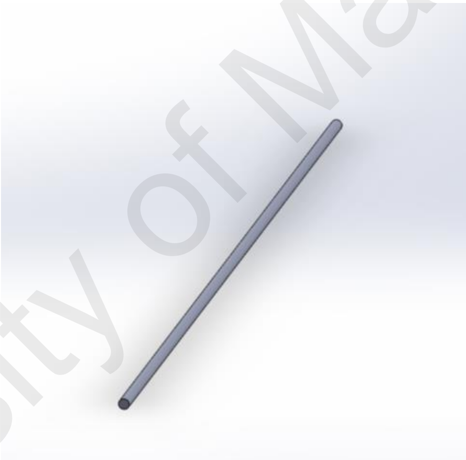

Figure 3.1 Carbon Fibre Rod

The length of rod is 150 mm whereas the circle diameter is 1.8 mm.

3.1.2 Wing connection Right

The figure 3.2 is the right-wing connection component of the final assembly. The left-wing connection was mirror image. Mirror image function helps us in creating the completed part mirror image. This mirror image feature is used to create a part which is the mirror image of the current object.

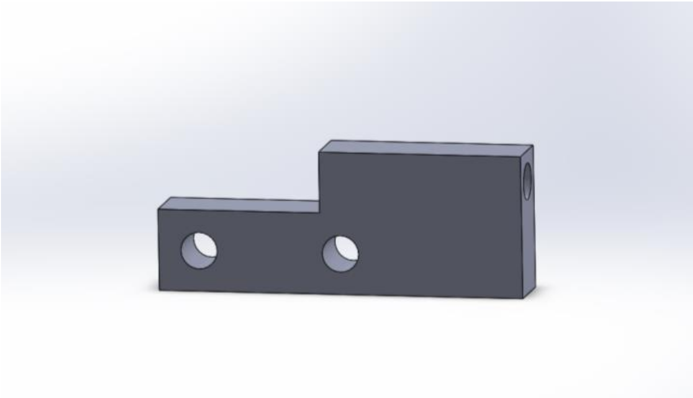

Figure 3.2 Right wing connection

In the top part the wing is connected and is mated to that inner circle. The connection is rigid and does not have any free movement. They are rigid and fixed connection.

The total length of the component is 22 mm and the height is 7 mm.

3.1.3 Body

This the main body or chassis of the complete product as shown in the figure 3.3. This will help hold many connections such as, gears are mounted to this part fixed with small carbon Fibre rods. in general, the whole mechanism is mounted to this part. Without this body the structure will not be in place.

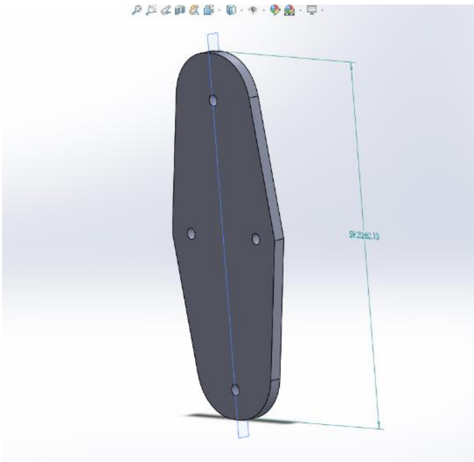

Figure 3.3 Main body

The height of the body is 59.32 mm and the width is 24 mm. Further details is as shown in the drawing section.

3.1.4 Gears

This gear as shown in the figure 3.4 is designed based on the loads and the strength needed. Made sure to eleminate the friction from the two moving gears.

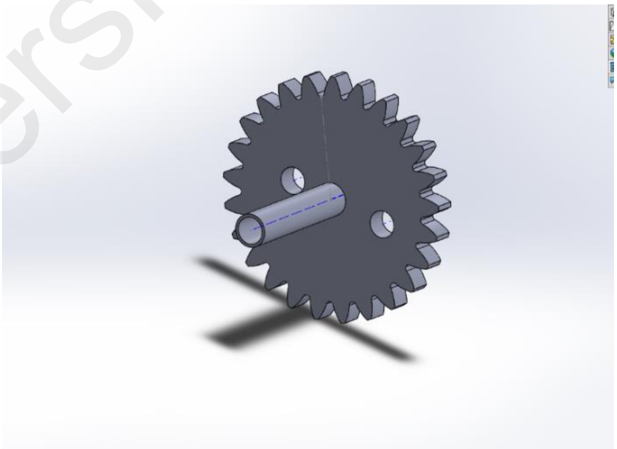

Figure 3.4 Gear

The dimensions of the gear are a shown in the drawing section below

3.1.5 Gear wing connecting shaft

The gear wing connection shaft is as shown in the figure 3.5 below. This is a crucial part because this helps the motion from the gear to the wing. Without this part the wings wouldn't even move. This changes the rotational motion to translation motion with the right amount of designed degree to move.

Figure 3.5 connection between gear and wing

For dimensions refer the drawings section at the end of the document.

3.1.6 Complete Assembly

The complete assembly of the individual parts is as shown in the figure 3.6 below.

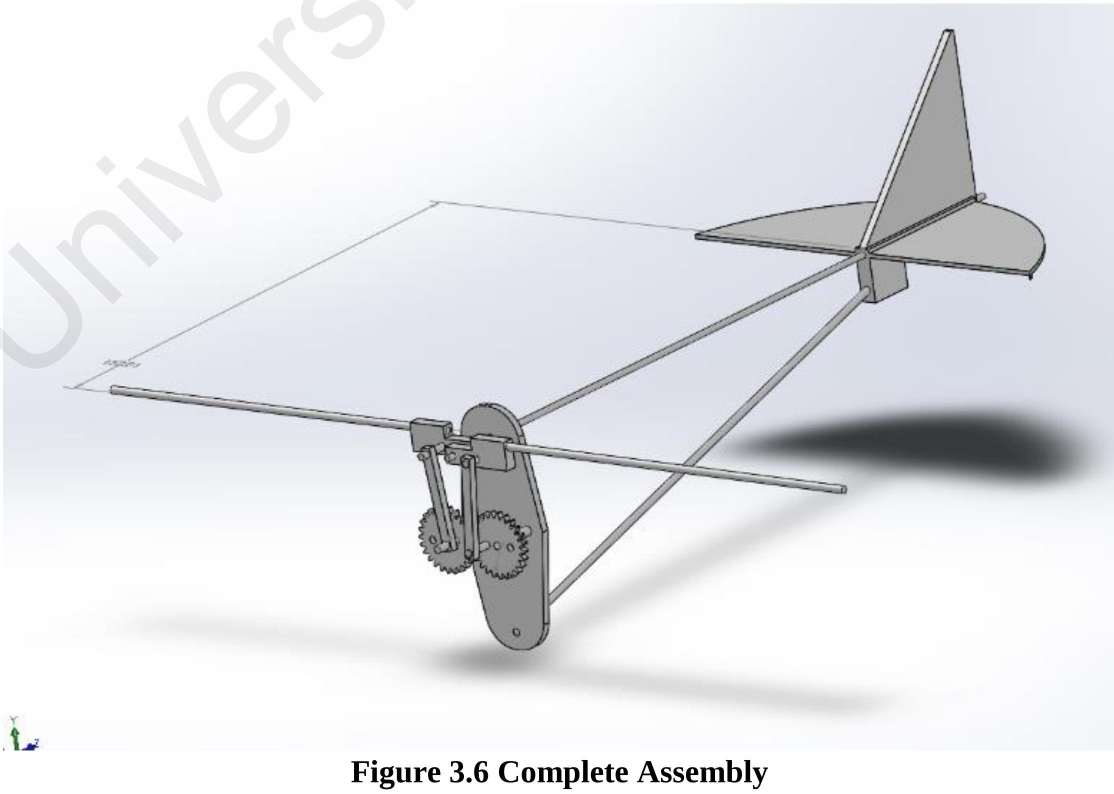

Figure 3.6 Complete Assembly

Motion analysis has also been done with the help of solid works. Fixing to gear with the contact parameter. The motor parameter with 5 RPM is given to the center of the left gear in clockwise direction.

3.2 Aspect Ratio:

Aspect Ratio is usually termed with respect to the wing. It is the ratio of the wing span to its mean chord. Wing area can be divided by the square of the wingspan. Narrow and long wing will have high aspect ratio whereas the short and wide wing will have low aspect ratio (Wikipedia, 2018, JUNE 6)(3).

To predict the aerodynamic efficiency of the wing aspect ratio and other features are used because the lift to drag ratio increases with the aspect ratio. Having this aspect reduces the amount of work done or in other words energy needed to fly.

It is numerically defined as

$$AR = (\text{Wing Length})^2 / (\text{Wing area})$$

Bending stresses are high in long wing than the short one for a given load. Hence a long wing needs a strong wing to withstand that stress. They also might have torsion, which is undesirable in some applications.

Higher roll angular acceleration is there for the short wing than the one with high aspect ratio. High moment of inertia must be overcome by the high aspect ratio wing. Fighter aircrafts unsulky use lower aspect ratio wings for great maneuverability. They have good roll rates.

The maximum thickness is greater and greater internal volumes for low aspect ratio wings which can be used to house the retractable landing gear and fuel tanks. This the application for practicality.

3.3 Analytical Calculation

3.3.1 Weight of individual components.

The weight of each component is weighed using a digital scale measuring device. It has a precision of up to 0.01 grams. The weight of each component is as shown below:

- Gear = 0.27 grams

  There are two gears so the total weight of two gears is 0.27*2= 0.54 grams

- Gear wing connecting shaft = 0.12 grams

  There are two components of this type. So, the total weight is 0.12*2 = 0.24 grams

- Rod pins = 0.06 grams

  There are total six rod pins for holding the gears and the connecting shaft in position.

  The total weight is 0.06*6 = 0.36 grams

- Wing connections made = 0.28 grams.

  This is the part where the wing rod is inserted. This is the rotational part for flapping. There are two parts as there are two wing connections.

  The total weight is 0.28*2 = 0.56 grams

- Tail body Connection = 0.90 grams

  This is the part which connects the tail to the main body and holds down the parts together.

- Tail rudder = 1.78 grams

  The tail rudder is used to give good aerodynamic capabilities while maintaining the center of gravity. This part is connected to the tail wing.

- Tail wing = 3.62 grams

  This also helps the ornithopter to fly in a more streamlined way while keeping the balance. This also helps to keep the center of gravity of the total body.

- Body = 2.31 grams

  The body holds all the parts in place. This acts as the chassis of the complete product.

- Wing = 0.02 grams
- Wing skeleton = 1.19 grams

  There are two skeletons holding down the wing. Each connected to the wing connection to move with the designed angle.

  The total weight of the wing skeleton is 1.19*2 = 2.38 grams

- Rod connecting the body and the tail = 0.83 grams

  This rod holds down the two parts far away from each other.

- The weight of the Dc motor used = 6.39 grams

  The weight of the three materials is the same as the properties are almost same.

Adding the total weight of all the component we get 19.93 grams. We can write this in terms of kgs. The total weight is then 0.01993 kg. it will be 0.196 N.

3.3.2 Calculating for the angle

The angle for flapping depends on the connection between the gear and the wing. The designed gear is of diameter 16.20 mm. the distance between the center of the gear and the shaft center of the gear is 3mm. The length of the shaft is 25 mm. We know the required angle to be around 60^o. We must convert the rotational to translational motion. We have the formula.

$$\textbf{Length of arc AB} = (< \mathbf{AB} \div \mathbf{360}) * \mathbf{2} * \mathbf{r} * \boldsymbol{\pi} \qquad \textbf{(3.1)}$$

Putting in the angle of 58°. we have the length of the arc AB to be 16.96 mm. This is the travel of the wing from top to bottom.

3.3.3 Wing Calculation:

The length of the designed wing is 300 mm in length. The chord is 50mm in length. The thickness is based on the material we are using for the wing and is assumed to be 0.001 mm. based on these constraints the area of the wing area is 0. mm^2. The wing is as shown below in the figure 3.7:

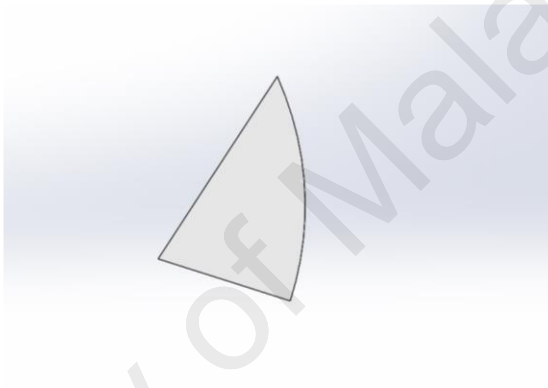

Figure 3.7 Wing Design

3.3.4 Aspect Ratio:

As we know the formula of the aspect ratio, that is:

$$\mathbf{AR} = (\mathbf{wing\ length})\mathbf{2} \div (\mathbf{wing\ area}) \quad \textbf{(3.2)}$$

The wing length as mentioned is 300 mm and the area is 29971.06 mm^2. With these parameters the Aspect Ratio is 3.003.

3.3.5 Flapping Frequency:

Azuma gave the below relation for different sizes of birds (Sai & Bharadwaj, 2016)

$$\boldsymbol{f}(\mathbf{Large\ Birds}) = \mathbf{116.3}\ \boldsymbol{m}^{-(\frac{1}{6})} \quad \textbf{(3.3)}$$

$$f(\textbf{Small Birds}) = \mathbf{28.7}\, m^{-\left(\frac{1}{3}\right)} \quad \textbf{(3.4)}$$

Where, f is the flapping frequency and m is the mass of the flapping bird.

Based on this equation, the ornithopter we designed comes under the small bird category.

3.3.6 Lift Force Calculation:

The lift should be more than that of the weight of the body for it to move. That is to overcome the force to move forward or lift off from its initial position. The Force equation is as shown below:

$$\mathbf{F} = \rho \mathbf{A} v^2 \quad \textbf{(3.5)}$$

The value for density of air is 1.1839 kg/m^3

The Velocity of air is the speed of that aircraft is going relative to all that is going happening around it. The velocity of the flapping model is assumed to be 10 m/s.

The area of the wing span as calculated above is 29971.06 mm^2 or 0.029971 m^2.

This force is a lot when compared to the weight of the complete body. This has enough force to lift the body up. But it also depends on the frequency of the flapping.

When we compare it to the lift equation give in (Sai & Bharadwaj, 2016). The lift equation is given as: w

$$\mathbf{Lift} = (1/2) * K_L * S_W * \beta * \rho * V^2 \quad \textbf{(3.6)}$$

Now in (Sai & Bharadwaj, 2016) assumed that the aspect ratio coefficient is 4 for a weight of 20 grams. And the positive angle of attack of the wing is 2^o.

By taking this equation and formulating the lift, we have

The total weight of the component to be 19.93 grams. So, if the aspect ratio coefficient is 4 and the positive angle of attack is 2^o in radians. Which shows that the lift force is not enough for the model to lift off. By increasing the wing span. We can create more lift.

The current wing span is 200 mm. by increasing the wing span to 300 mm. and the chord length 150 mm. we have the area of the wing as. 30000 mm^2. Now again calculating the lift with the present wing span and the area we have,

This is enough force to lift the model in the air. Hence proving its purpose.

3.3.7 Thrust measurement:

By taking the on-flexible properties of the wing flapping motion to be designed, the mean lift force calculation is as follows (Sai & Bharadwaj, 2016):

$$\mathbf{Trust} = (\mathbf{1/3}) * \mathbf{KL} * \boldsymbol{SW} * \rho * \boldsymbol{\sigma 2} * \mathbf{V2} \qquad \textbf{(3.7)}$$

Now taking the equation of coefficient of thrust equation from (Svanberg & Craig, 2008), we have:

$$\boldsymbol{C_t} = (\boldsymbol{T}/(\boldsymbol{\rho n^2 D^4})) \qquad \textbf{(3.8)}$$

CHAPTER 4 RESULTS AND DISCUSSIONS

The main purpose of this research is to show that different fabrication methods can be used, and different materials can be used for the flapping wing micro air vehicle. Fabrications methods such as solid works and 3D printing techniques have been used for designing the flapping wing micro air vehicles. We used three different types of materials when 3D printing a few parts.

Numerical methods have been used to establish the lift force that is needed to lift the body from ground. There are two formulae used to determine the lift. In the first equation we assumed coefficient of drift to be 1. Then calculated for the force generated with the designed wing span.

This force is compared to the lift force equation to the other author's equation. We can find the difference below.

4.1 Product Development

4.1.1 Flapping Mechanism:

The designed parts are assembled to make a complete flapping mechanism. This flapping mechanism is used to verify all the testing methods. To achieve the main aim of the project we need to make sure that the flapping mechanism works as desired.

It was decided that the wings will be connected to two gears individually with the help of the connecting shaft. When the gear rotates with the help of the DC Motor. The connecting shaft translates the rotary motion to translation motion. The distance between the center of the gear to the connecting shaft difference with the angle of flapping. We can also increase and reduce the length of the shaft to reduce or increase the angle of flapping of the wing respectively. The flapping model was made to rotate in different modes in Solid works. To make sure that there was not obstruction in the movement of the wing.

The flapping model is as shown below in the figure 4.4.1:

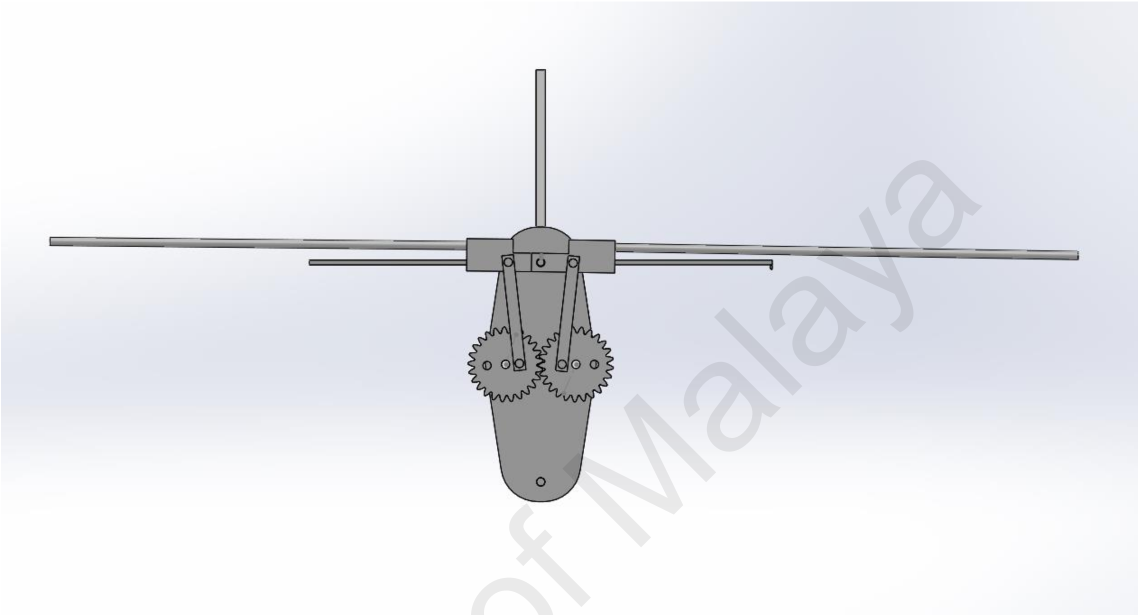

Figure 4.4.1 Front view of the assembly

This mechanism offers great symmetricity. The DC motor is connected to one of the gear. When the gear connection of the shaft is on top side of the gear. That position is the highest flap of the model. As shown in the figure 4.4.2 below:

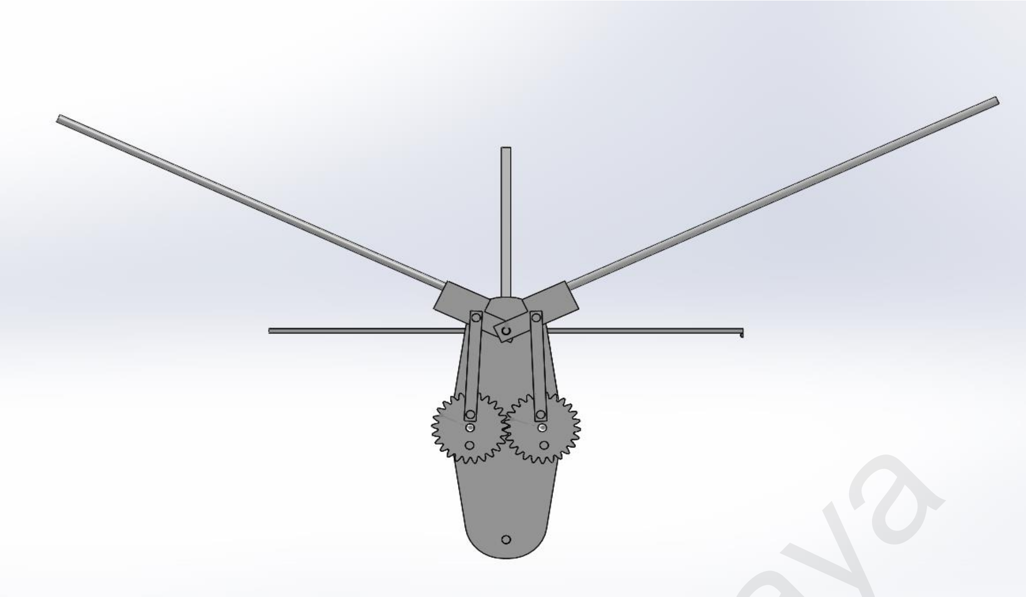

Figure 4.4.2 Position of the highest flap

When the gear is the lowest point in the gear the wing is also at its lowest. It is as shown in the figure 4.4.3 below.

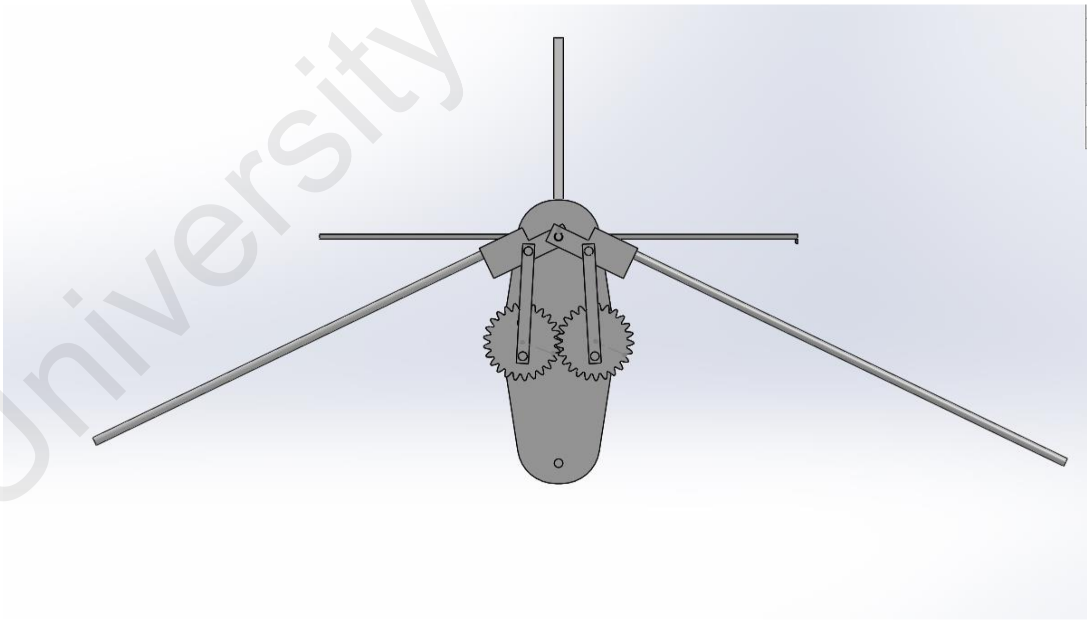

Figure 4.4.3 Position of the lowest flap angle

This the different angle considered by the motion study in solid works software.

The complete model is made with accuracy and stability and resistance to break. Usually there are a lot of vibrations in the model. To reduce these vibrations the body is made to be rigid and fixed positions. The tail portion is present to balance the flapping flight. As a change for direction we can make use of servo motor. Attached to a chip.

4.2 Numerical Calculation

The weight of all the components combined is 19.93 grams or 0.196 N. The wing span is 300 mm and the chord length is 150 mm. The wing area is 29971.06 mm^2 or 0.029971 m^2.

Aspect Ratio is based on the wing span and the wing are is 3.003. Also, calculating the flapping frequency from the give formula. Then the flapping frequency will be 12.07 Hz.

According to all these parameters the lift force calculation according to the equation 3.5:

$$\mathbf{F} = \rho \mathbf{A} v^2 \qquad \textbf{(4.1)}$$

By substituting the appropriate values into the equation, the value for force is 3.55N. Which can also be written as 0.36kg for force.

Also, by using the equation (3.6):

$$\mathbf{Lift} = (1/2) * K_L * S_W * \beta * \rho * V^2 \qquad \textbf{(4.2)}$$

The lift is measured to be 0.248 N or 0.0253 kg. In both the cases the lift forces calculated are good to generate lift.

Now from equation (3.7) we have the equation:

$$\mathbf{Trust} = (\mathbf{1/3}) * \mathbf{KL} * \mathbf{SW} * \boldsymbol{\rho} * \boldsymbol{\sigma}\mathbf{2} * \mathbf{V2} \qquad \textbf{(4.3)}$$

The thrust is 0.425 N or 0.0433 kg when substituted the appropriate values into the equation.

The formula for coefficient of thrust is as given in equation (3.8),

$$\boldsymbol{C_t} = (\boldsymbol{T}/(\boldsymbol{\rho n^2 D^4})) \qquad \textbf{(4.4)}$$

For the frequency of 12.07 Hz the coefficient of thrust as 0.304.

No taking the values for different coefficient of thrust with 1 Hz intervals as shown in the table 4.1.

Table 4.1 Frequency vs coefficient of thrust

S. No	Frequency (Hz)	Coefficient of Thrust
1.	5	1.773
2.	6	1.231
3.	7	0.904
4.	8	0.693
5.	9	0.547
6.	10	0.443
7.	11	0.366
8.	12	0.308

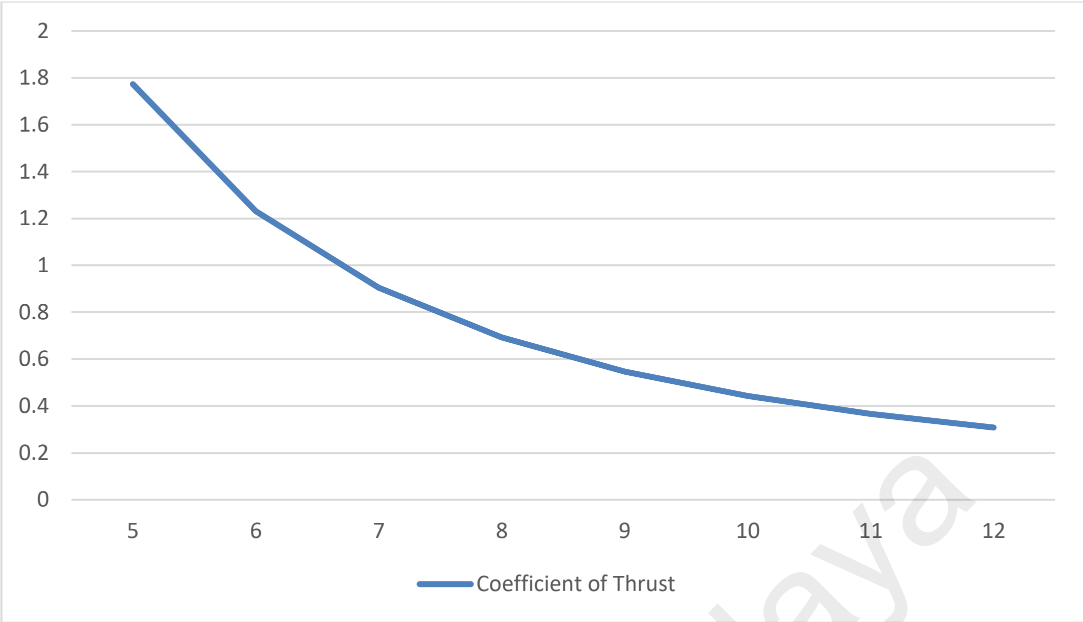

Figure 4.4 Coefficient of thrust vs Frequency

There is increase in frequency in x-axis, the coefficient of thrust decreases along y-axis.

4.3 Ansys Analysis Results:

I have mainly three results based on the Ansys software analysis. The results are for each component used. They are HIPS Filament, ABS Filament and PLA Filament.

The analysis is done mainly for the total deformation, equivalent elastic strain, equivalent stress and the Elemental Euler XY angle. This analysis is done for all the material used for the project. Based on the values we got from the analysis the graphs has been plotted to show the best suitable material for the model. The order for the section is:

4.3.1 HIPS Filament

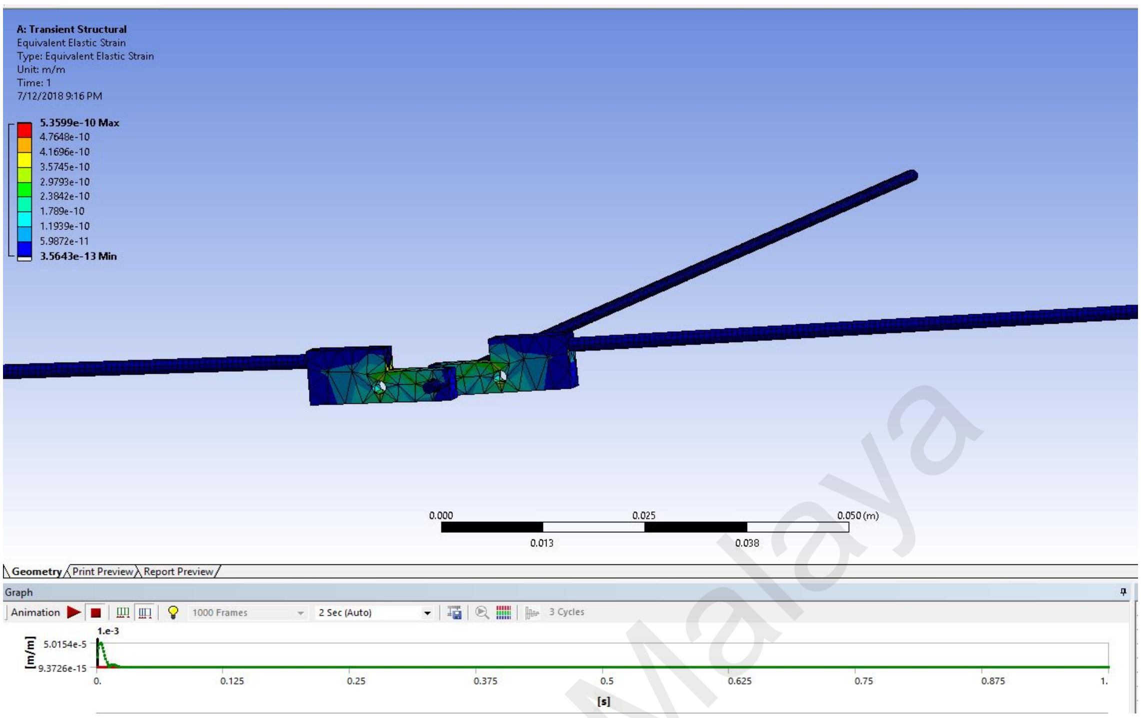

Figure 4.5 Total Deformation

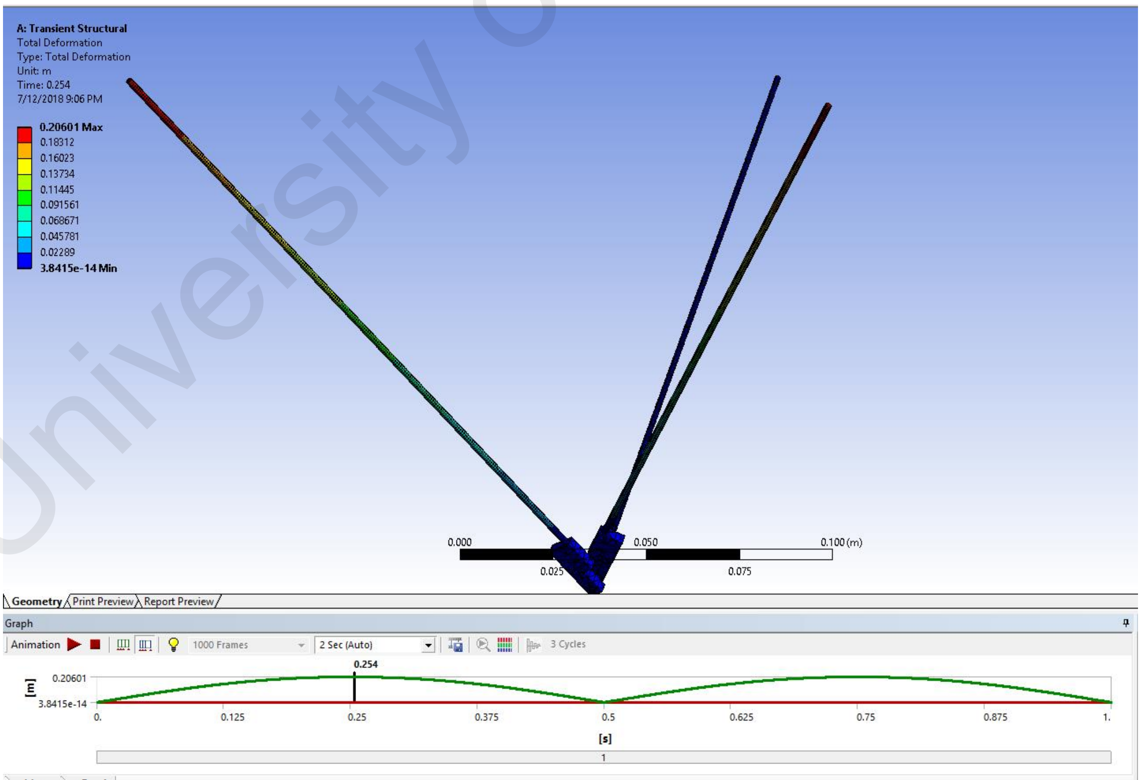

Figure 4.6 Equivalent Elastic Strain

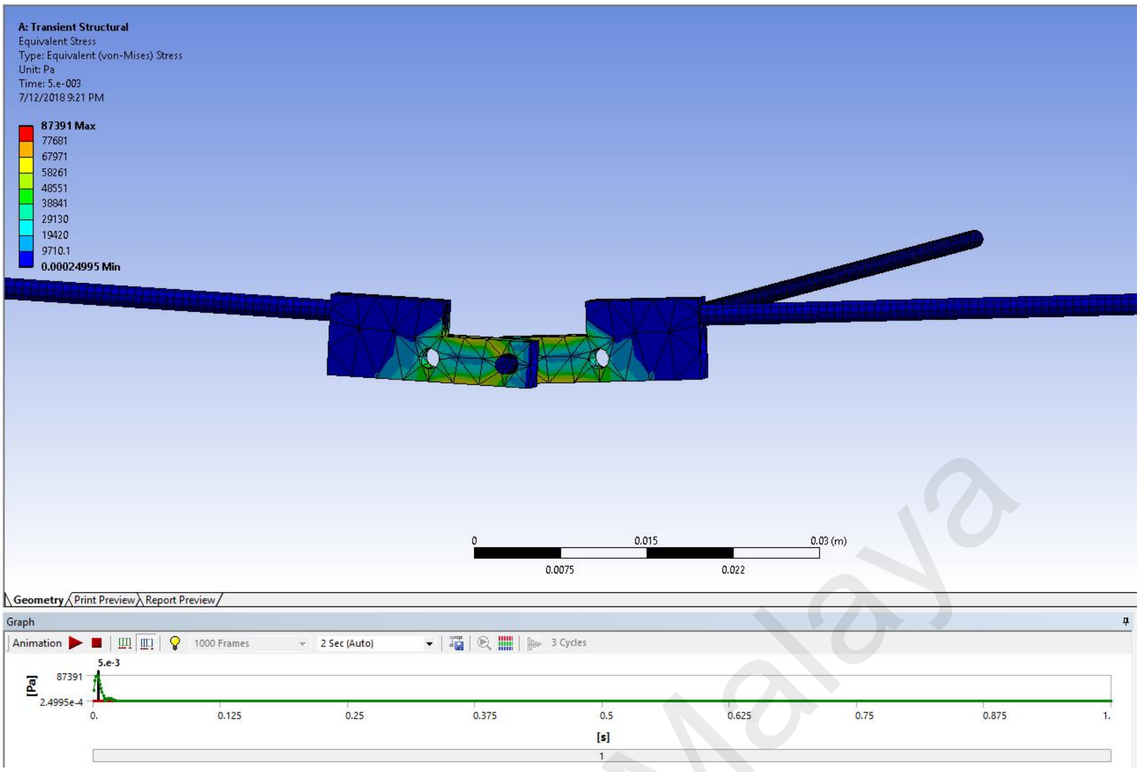

Figure 4.7 Equivalent Stress

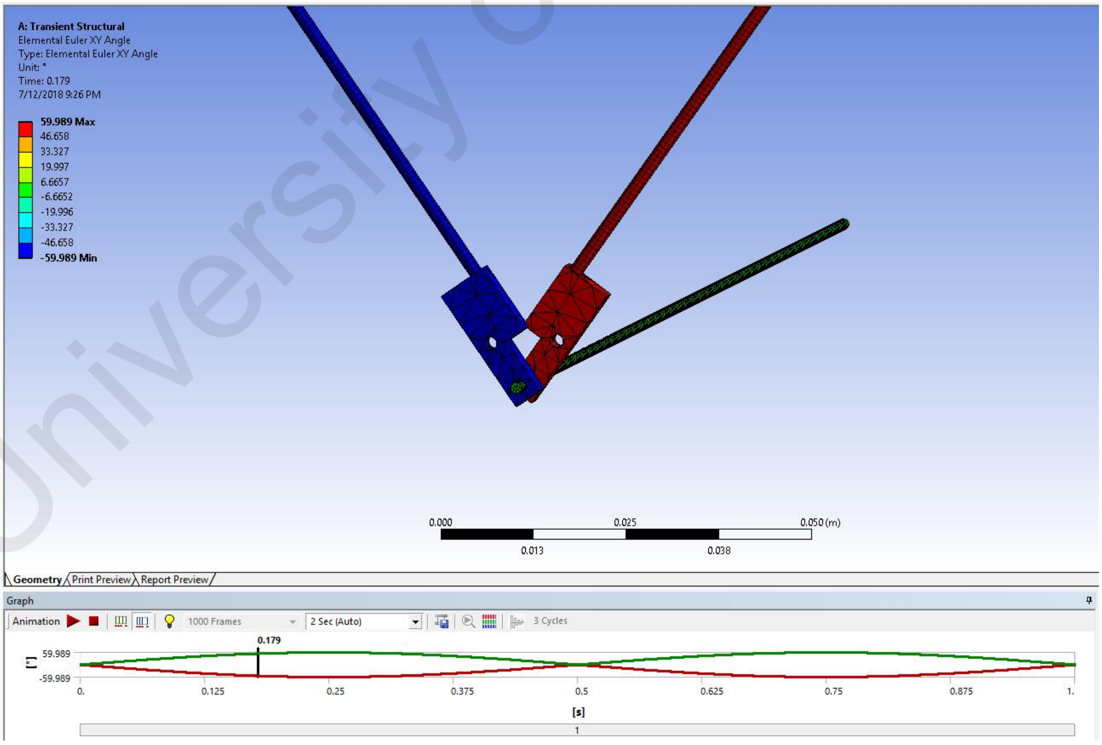

Figure 4.8 Elemental Euler XY Angle when it is max angle

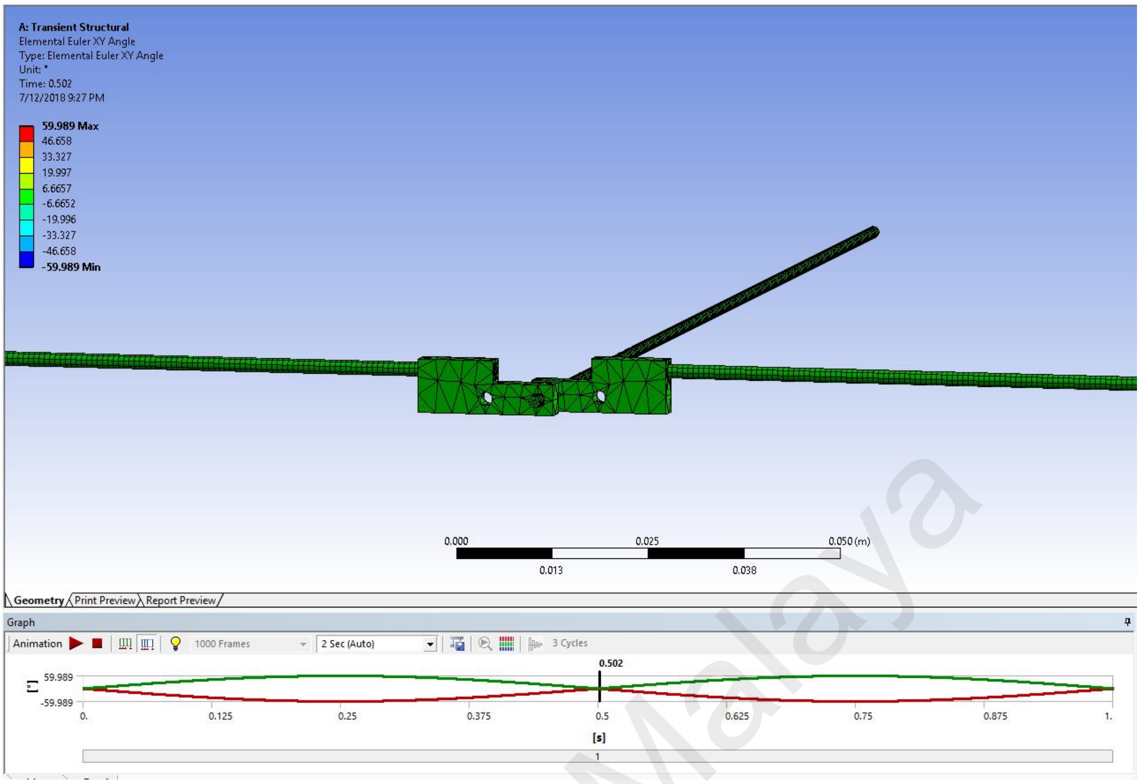

Figure 4.9 Elemental Euler XY Angle in the middle.

4.3.2 ABS Material

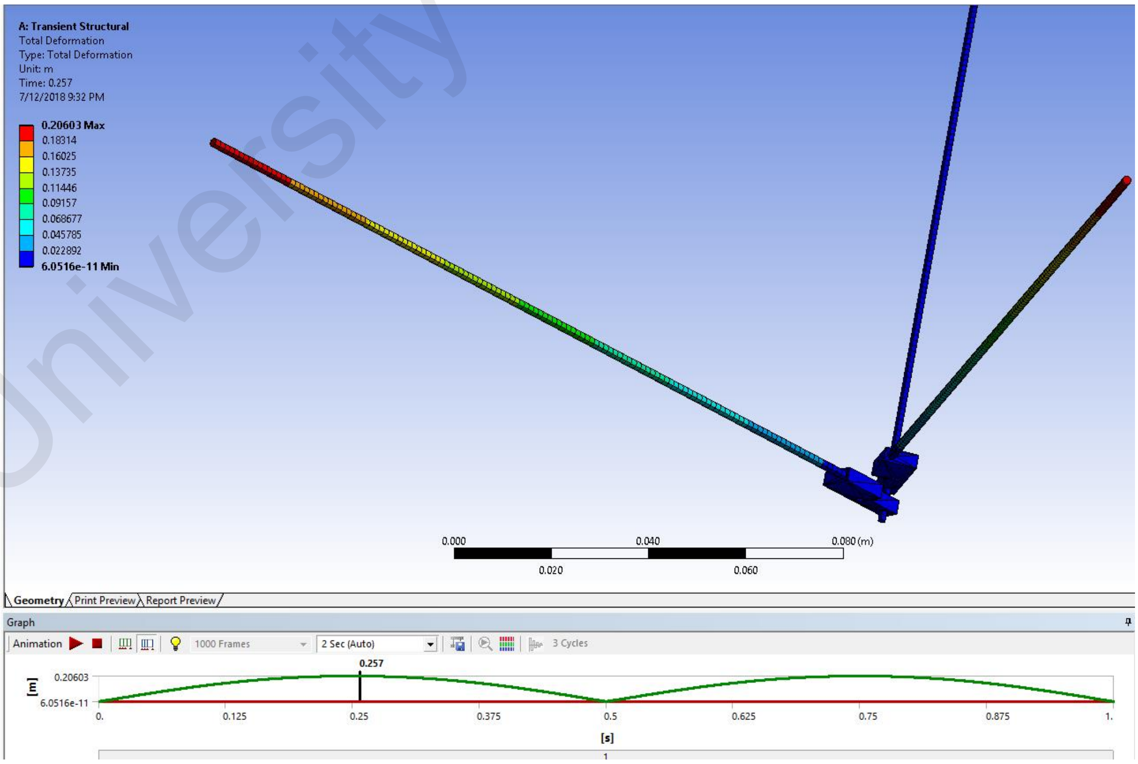

Figure 4.10 Total Deformation

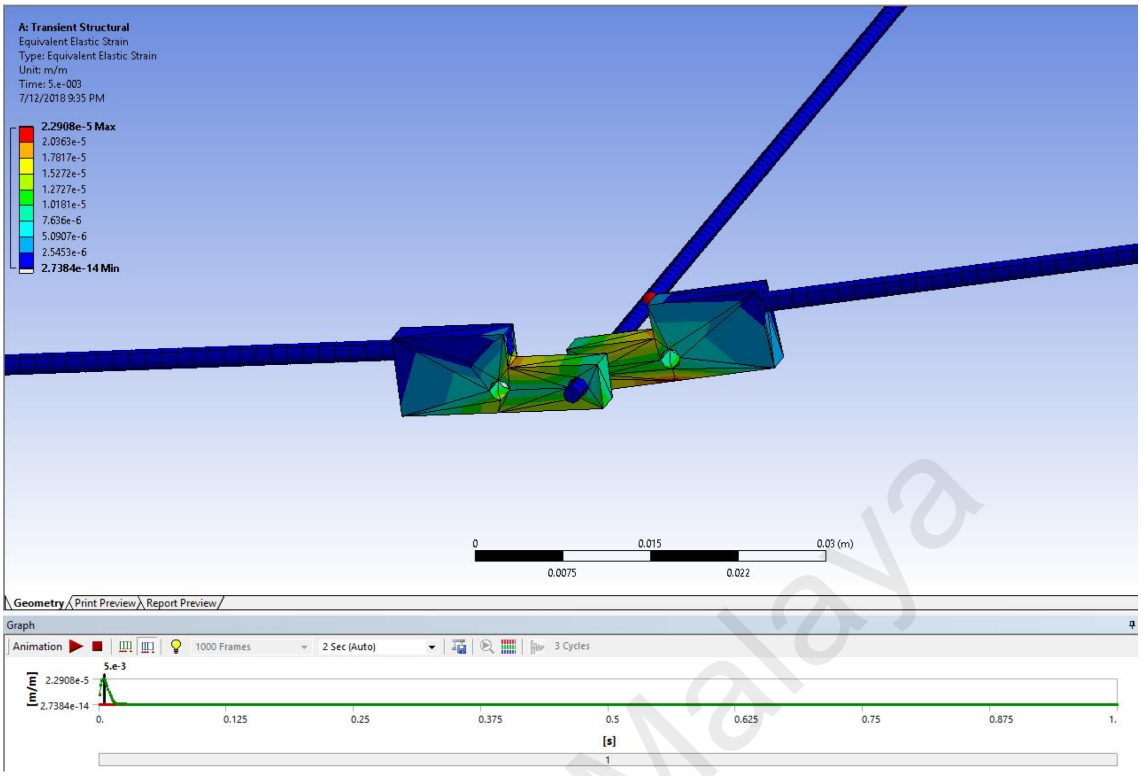

Figure 4.11 Equivalent Elastic Strain

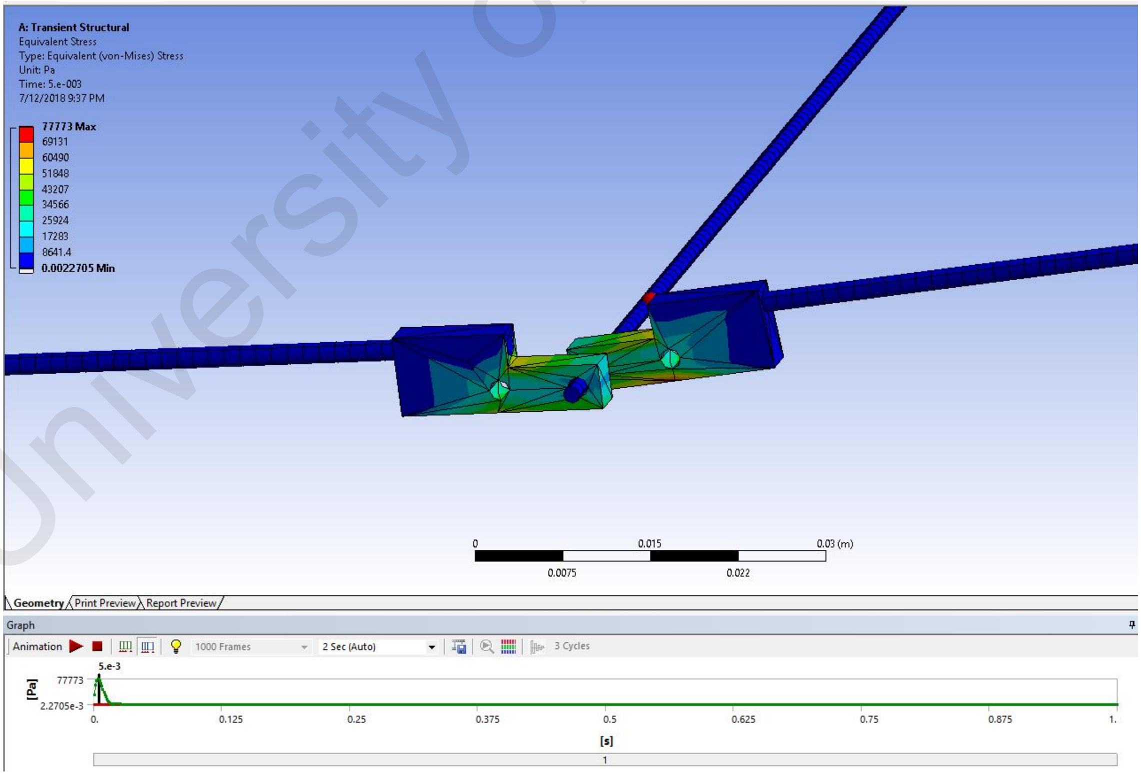

Figure 4.12 Equivalent Stress

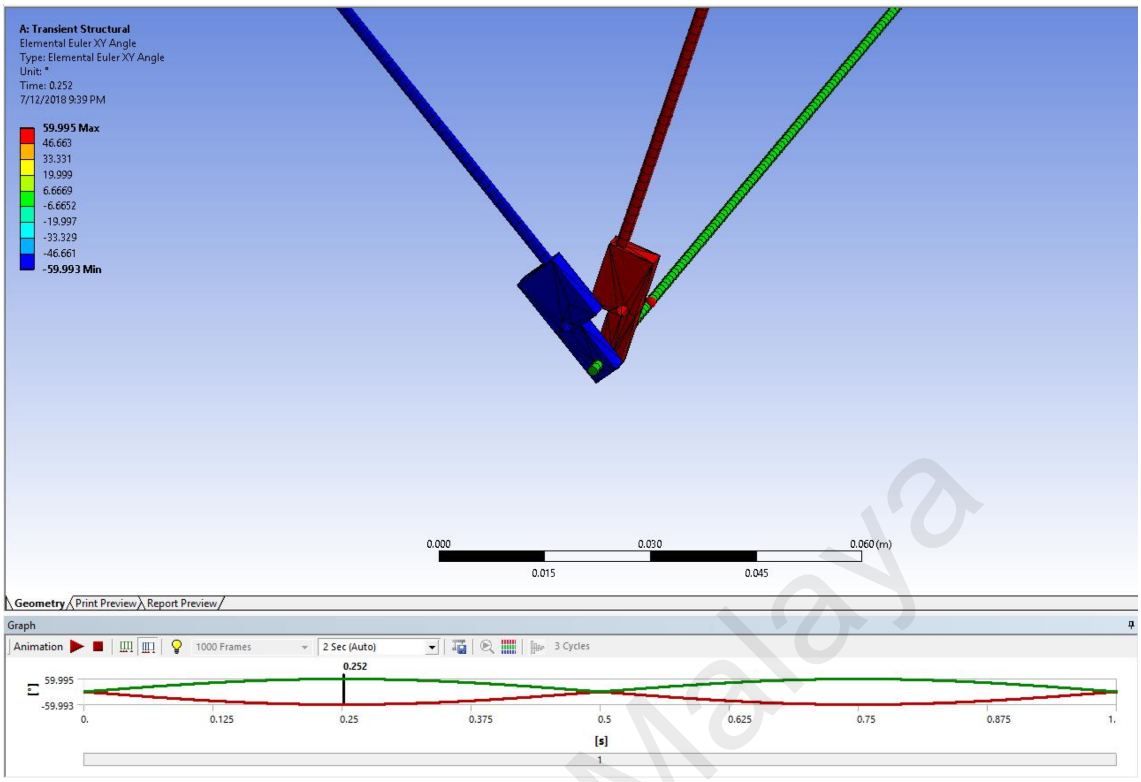

Figure 4.13 Elemental Euler XY Angle when it is max angle

4.3.3 PLA Filament

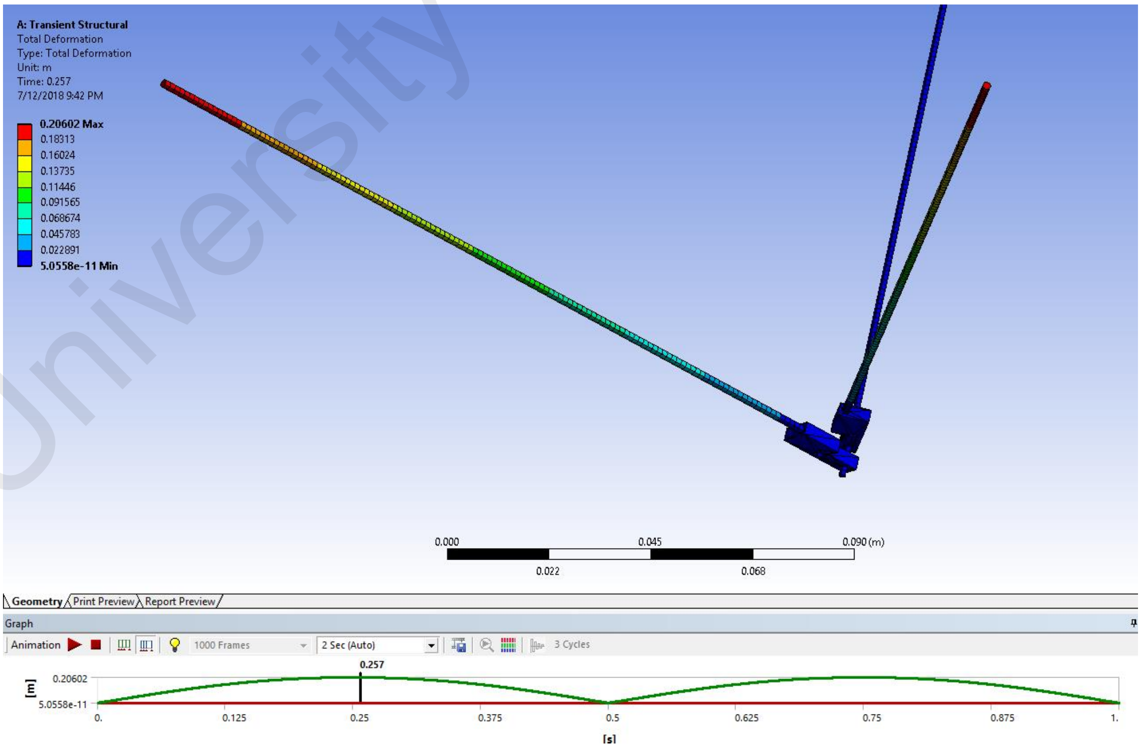

Figure 4.14 Total Deformation

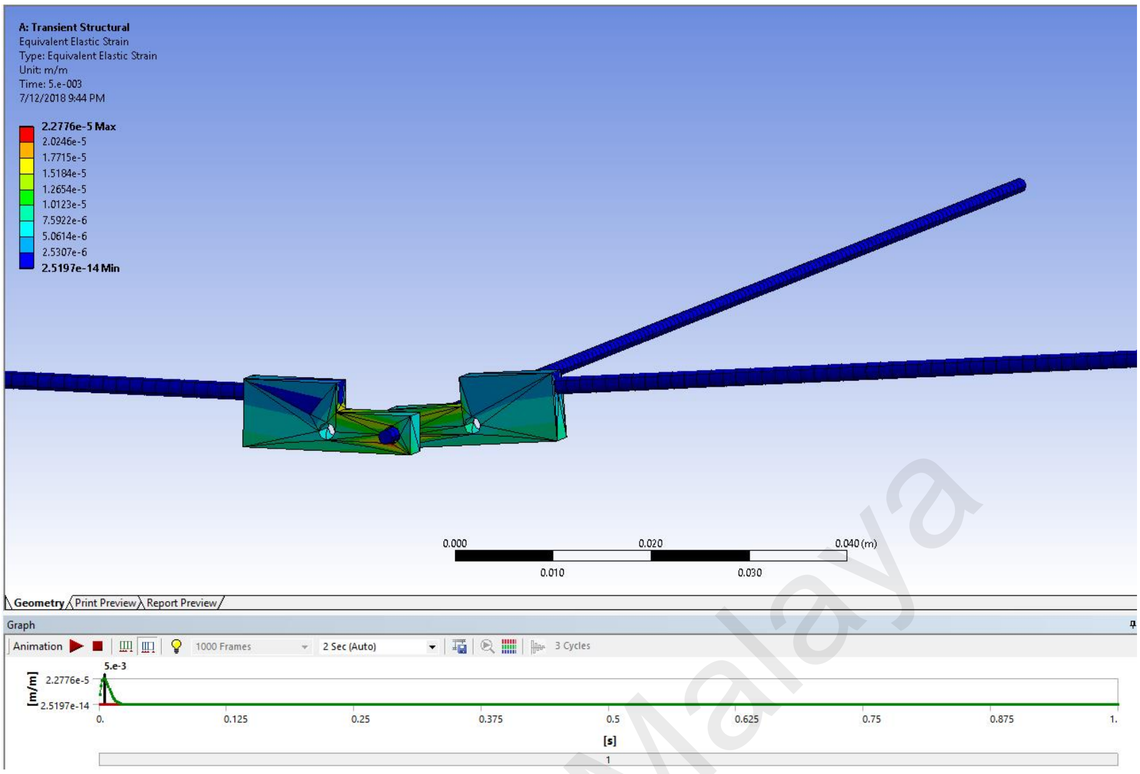

Figure 4.15 Equivalent Elastic Strain

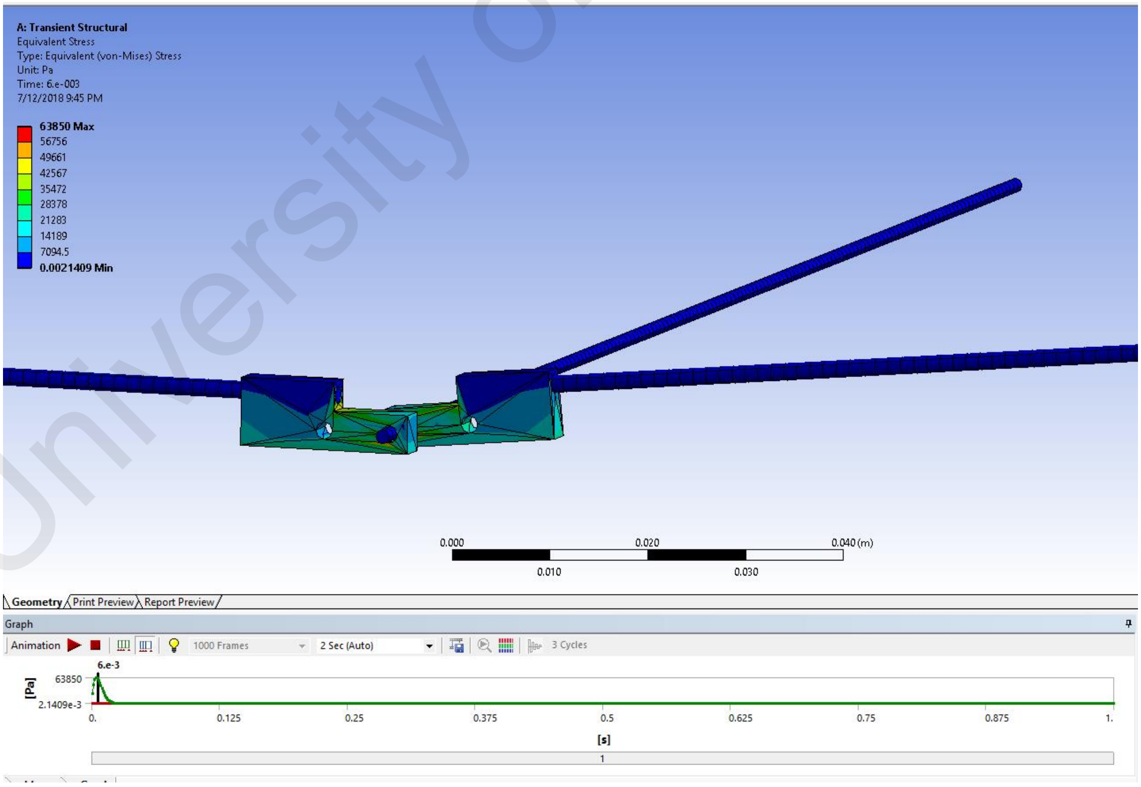

Figure 4.16 Equivalent Stress

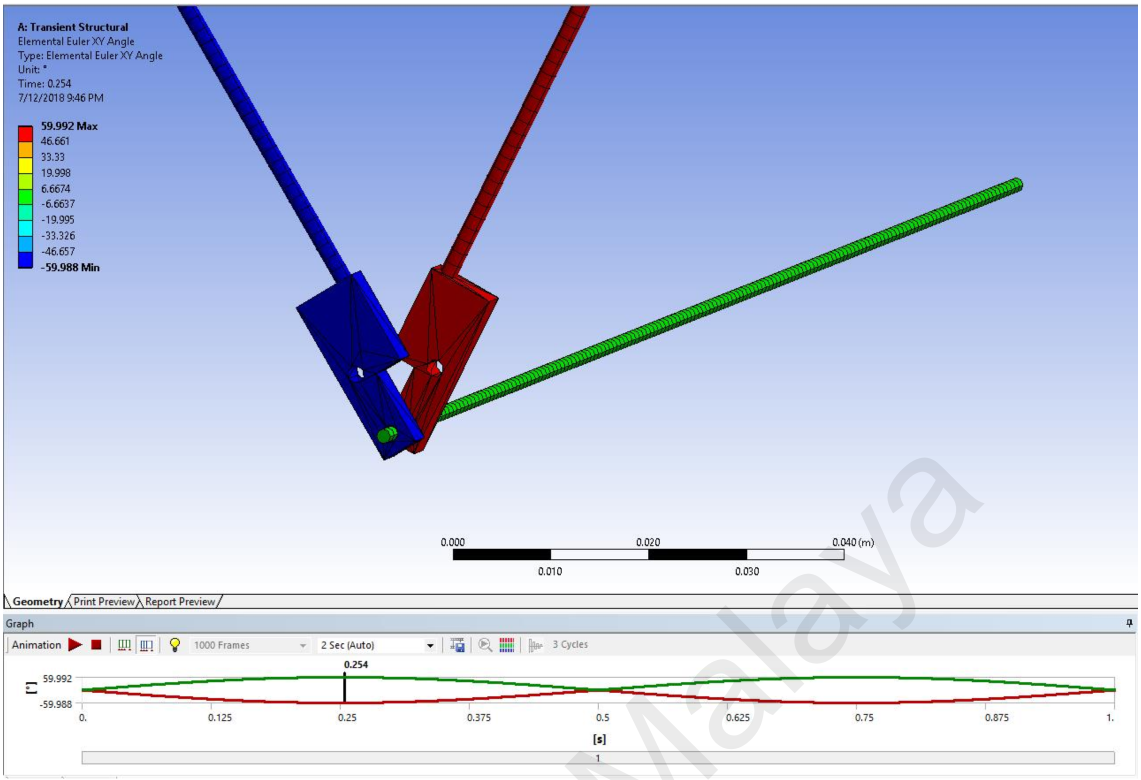

Figure 4.17 Elemental Euler XY Angle when it is max

These are the values for three different types of materials. All the required Ansys analysis is done.

4.4 Preliminary Report

There are mainly three results based on the Ansys software analysis. The results are for each component used. They are HIPS Filament, ABS Filament and PLA Filament. The total deformation of all the materials chosen is shown in table 4.2

Table 4.2 Total Deformation of the Materials

		Total Deformation (m)	
S. No	Material	Min Value	Max Value
1	HIPS	3.56E-13	5.36E-10
2	ABS	6.05E-11	0.20306
3	PLA	5.06E-11	0.20602

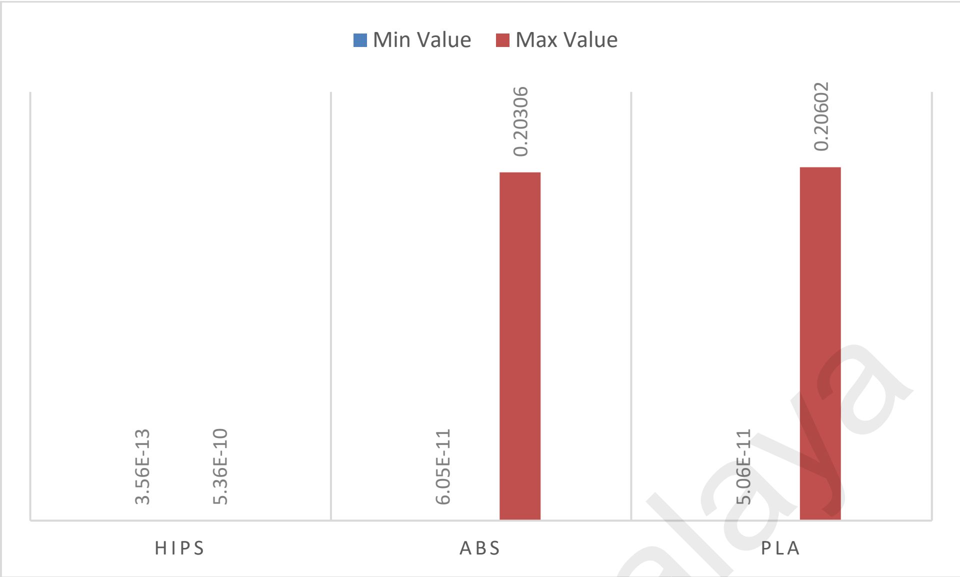

Figure 4.18 Maximum and Minimum values of different materials for Total Deformation

It can be observed that the HIPS filament has no deformation when compared to the other filaments.

Table 4.3 Equivalent Elastic Strain of all materials

		Equivalent Elastic strain (m/m)	
S. No	Material	Min Value	Max Value
1	HIPS	3.84E-14	0.20601
2	ABS	2.74E-14	2.29E-5
3	PLA	2.52E-14	2.28E-5

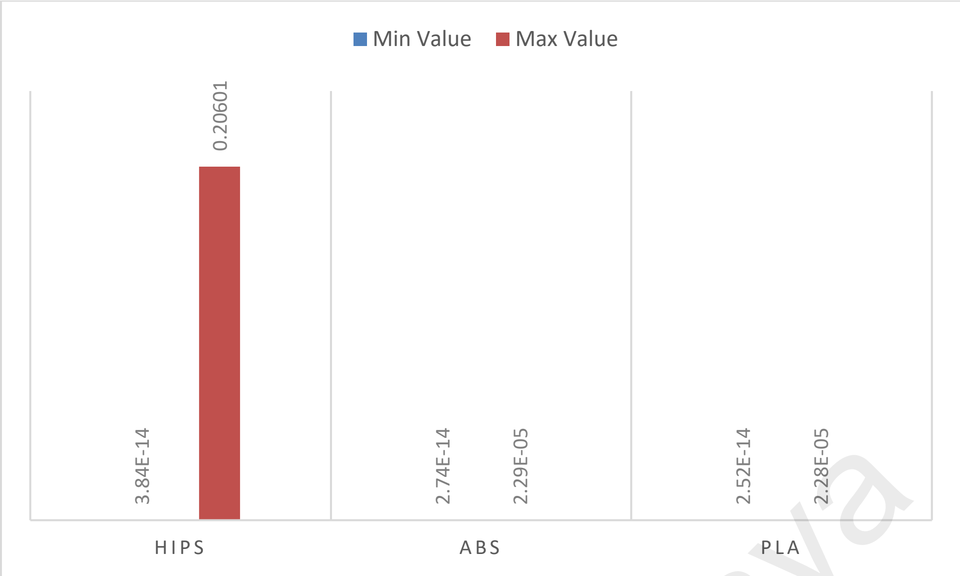

Figure 4.19 Maximum and Minimum values of different materials for Equivalent Elastic Strain

It can be observed that the presence of strain in HIPS filament.

Table 4.4 Equivalent Stress of all Materials

		Equivalent Stress (MPa)	
S. No	Material	Min Value	Max Value
1	HIPS	0.04	0.087391
2	ABS	2.27e-9	0.077773
3	PLA	2.14e-9	0.06385

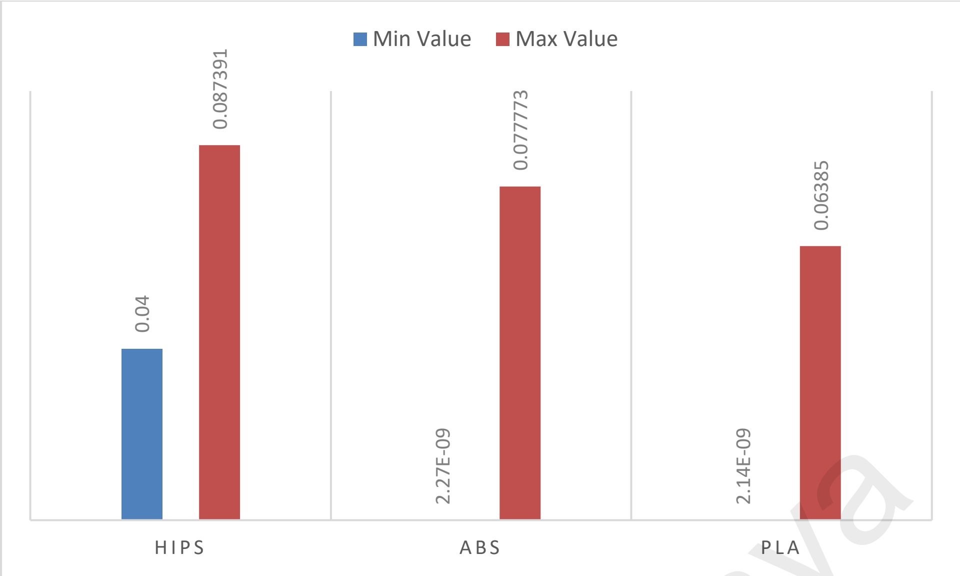

Figure 4.20 Maximum and Minimum values of different materials for Equivalent Stress

PLA has the least amount of stress induced.

Table 4.5 Elemental Euler XY Angle

		Elemental Euler XY Angle (°)	
S. No	Materials	Min Value	Max Value
1	HIPS	-29.794	29.797
2	ABS	-29.795	29.795
3	PLA	-29.794	29.794

As we can see the Values from the table they are almost the same. This is the complete flap angle of the body. This is used to determine the angle of rotation of the wing. These values are needed to calculate the force required.

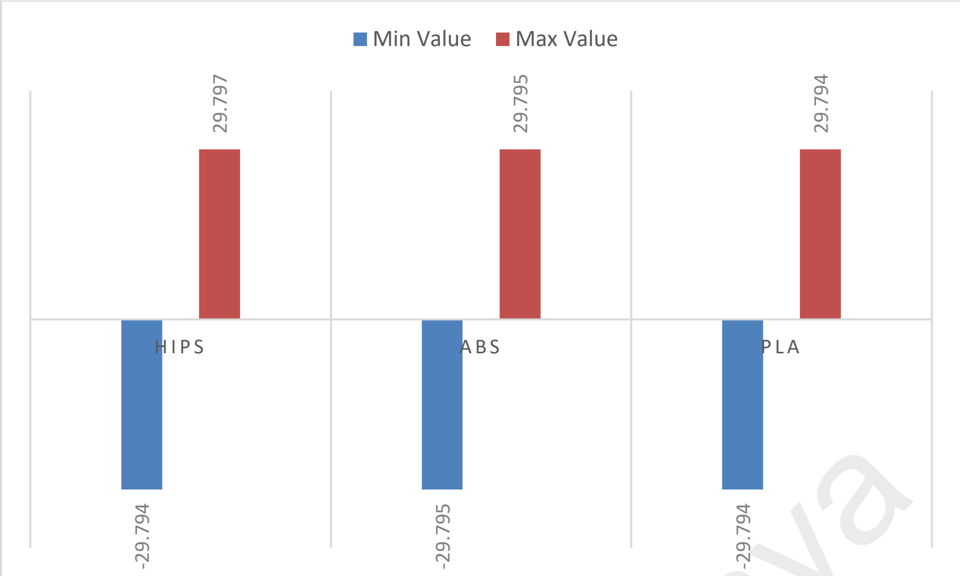

Figure 4.21 Maximum and Minimum values of different materials for Elemental Euler XY Angle

Based on this preliminary report we can see that as the material properties changes there is always a change in the stress, strain and the deformation. But very deflection in the Euler XY angle. This preliminary report is based on a single frequency. Also, we can say that theoretically that as the frequency increases the load on the wing increases. Thus, increasing the stresses, strains and the deformations in the parts.

The percentage error of 2% is considered while solving numerically and the for the preliminary report. While performing Ansys we have considered the wing parts connections and not the entire body.

4.5 Discussions

The results shown were consistent with the analytical solution but the not similar. It is because the in analysis there is no consideration of the environmental effects acting on the body. External forces were not considered when designing the model. Therefore, two to three percent of error percentage has been considered. In most of the designs using gears there is a motion transfer of rotational to translational motion.

As shown in the table 4.1 the coefficient of thrust decreases with the increase in frequency. Which means that the force is more when the coefficient of thrust is less. Also, we must consider the stresses that will be acted when the frequency increases. High frequency means high stress in the wing connection.

The total deformation depends on the load given on the wings and the force acting on it. As the number of links increases in the flight mechanism and the body has more friction. This also increases the vibrations in body. Also, it should be functional at the same time. Choosing the right material is crucial for the successful functionality of the model. The graphs from the result chapter show the right material to choose from.

From the graph 4.2 we can see the total deformation is minimum when using HIPS Filament with the other body parts. From graph 4.3 PLA filament is the lowest strain material. From graph 4.4 the minimum stress is PLA. The elemental Euler angle is almost 60^o for all elements.

Changing the wing surface area will increase the force which also means that the mechanism should be able to take the weight of the wing and perform smoothly. All the constraints should be properly calculated in all aspects.

CHAPTER 5 CONCLUSIONS

The goal of this research was to design a model of a medium sized flapping air vehicle and to show is functional characteristics. Flapping mechanism was designed which runs smoothly. Solid works was used to create a model and to assemble each part. To see the motion of the assembled components, motion analysis in solid works was used to judge the functional capability of the mechanism.

The angle of the flap is calculated analytically and by the help of Ansys analysis. Ansys was also used to show the stresses, strains and deformations occurred.

Overall weight of the body is found to be around 19.93 grams which is almost 0.197 N. This meant that the force should be more that 0.197 N to lift the body up in the air. Also using two equations showed that the lift forces are 3.55N and 0.248N respectively.

The thrust is 0.425N when using the equation 3.7. Which is enough to make the model fly in air without any external forces of air acting on it. The coefficient of thrust has also been calculated for different frequencies. In this model both thrust and lift are produced by the flapping wings.

From the material analysis it is determined that PLA material is more suitable for the designed model. It has more impact resistance properties and can also absorb vibrations. PLA is also more stability and it is capable of enduring high stress than the other materials.

There are many designs for a flapping wing micro air vehicle. Based on their experiments this mechanism is viable but not enough to generate force as much as it is producing in other flapping mechanism.

5.1 Recommendations for the future work

The following are the recommendations for future work:

- Actuators can be used for the movement of the wing instead of the lever and motor which has high friction.
- A more complex mechanical model can be designed to reduce the links. Reduction of links reduces the friction and connection which in turn helps in smooth movement.
- Lighter materials should also be considered for the body and wings.

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