DEVELOPMENT OF THE ADJUSTABLE ENGINE MOUNT FOR THE ULTRA-LIGHT HELICOPTER

by

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ABSTRACT

The purpose of this thesis is to design, analyze and fabricate an adjustable engine mount for an ultra-light helicopter. The engine mount must be able to support the load of ROTAX 582 UL DCDI engine and the engine gearbox system which in total is about 70 kg. The engine mount is designed so that it is capable of being shifted longitudinally and rotated circumferentially around the center post. The circumferential rotation indirectly have the effect of lateral displacements. This project uses the concept of Weight Shift Control (WSC) that is commonly use for a hang glider. However, instead of controlling the weight of the pilot, this WSC project is controlled by shifting the position of the engine. The analysis is done using the SOLIDWORK® software. The analysis is performed to observe whether the structure of the engine mount can support the applied load or fail to perform as required. The analytical method are also calculated in this thesis to compare and verify the structure manually with the analysis result. When comparing the analytical and the analysis method, the stress of the engine mount have a percentage difference of 2.19%. In fabrication process, all the material and equipment in fabricating the model are available in the Aerospace workshop. This thesis provides detail method in developing the engine mount of an ultra-light helicopter starting from the conceptual design to the final fabrication of the engine mount structure.

PEMBINAAN PEMEGANG ENJIN HELIKOPTER MUATAN RINGAN YANG BOLEH DILARAS

ABSTRAK

Tujuan tesis ini adalah untuk mereka bentuk, menganalisis dan membina pemegang enjin yang boleh dilaraskan untuk helikopter muatan ringan. Pelaras enjin ini mesti berupaya untuk menyokong beban enjin ROTAX 582 UL DCDI dan sistem kotak gear enjin yang secara keseluruhan adalah kira-kira 70 kg. Pelaras enjin ini direka bentuk supaya ia mampu bergerak pada paksi sisi dan membujur. Projek ini menggunakan konsep Pengalihan Berat (WSC) yang biasanya digunakan untuk pesawat ringan. Walau bagaimanapun, daripada mengawal berat juruterbang untuk mengawal pesawat, pelaras enjin ini dikawal dengan mengalihkan kedudukan enjin. Simulasi analisis dilaksanakan menggunakan perisian SOLIDWORK®. Analisis ini dijalankan untuk melihat sama ada struktur pelaras enjin boleh menyokong beban yang dikenakan atau gagal melaksanakan kawalan seperti yang dimahukan. Kaedah analisis pengiran juga diaplikasikan dalam tesis ini untuk membandingkan dan mengesahkan struktur secara manual dengan keputusan analisis dari simulasi. Apabila membandingkan analisis dan kaedah analisis simulasi, tekanan pelaras enjin mempunyai perbezaan peratusan sebanyak 2.19%. Dalam proses pembinaan pelaras enjin, semua bahan dan peralatan dalam reka model boleh diperoleh di bengkel Aeroangkasa. Tesis ini menyediakan kaedah terperinci dalam membina pelaras enjin bagi helikopter muatan ringan bermula dari konsep reka bentuk hingga ke pembuatan struktur pelaras enjin.

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First and foremost, I would like to thank to my supervisor, PE. Dr. A Halim Bin Kadarman whose expertise, generous guidance and support that made it possible for me to work and complete the whole project within the period of time. Every step and improvement in design and fabricating this project had been done with the presence of Dr Halim.

Special gratitude to the staff member of School of Aerospace Engineering, Mr Hafizan, Mr Sahar, Mr Hisham, Mr Mahmud for their help in fabricating the model of the project. I would definitely not be able to do it on my own. Sincere thanks to Sharmendran A/L Kumarasamy and Mohammad Shair bin Mohd Zain who rendered their help during the period of the project.

Finally, greatest appreciation to all relatives, friends, seniors and others who in one way or another shared their encouragement and support, either morally, financially and physically.

Above all, to the Great Almighty, the author of knowledge and wisdom.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATIONS

CG	Centre Gravity
FEA	Finite element analysis
IR	Inner ring
IROD	inner diameter of the outer ring
OD	Outside diameter
OR	Outside ring
ORID	outer diameter of the inner ring
W	Width
WSC	Weight Shift Control
FS	Safety factor

NOMENCLATURE

U_d	:	Energy density
A	:	Cross sectional area
E	:	Young Modulus
b	:	Width
k	:	Buckling coefficient
m	:	Mass
t	:	Thickness
v	:	Poisson's ratio
F	:	Force
M	:	Moment
W	:	Weight
σ	:	Stress
S_{al}	:	Allowable strength

CHAPTER 1

INTRODUCTION

1.1 Project Background

An ultra-light helicopter have a pair of counter-rotating rotor which rotates at equal speed from a single motor which drives both of the rotor. Ultra-light helicopter are similar to a regular helicopter but are much lighter which usually consist of one or two seats. The construction of an ultra-light helicopter are simple compared to a regular helicopter as there are no cockpit presence at the structure. However, the design of an ultra-light helicopter are not the same as a regular helicopter. It might not be able to fly faster than a regular helicopter, with a limited range, endurance and load capacity. Still, it is perfectly operational helicopter that functioning well. Figure below is an homebuilt ultra-light helicopter plan named Furia helicopter by Osvaldo Durana.[1]

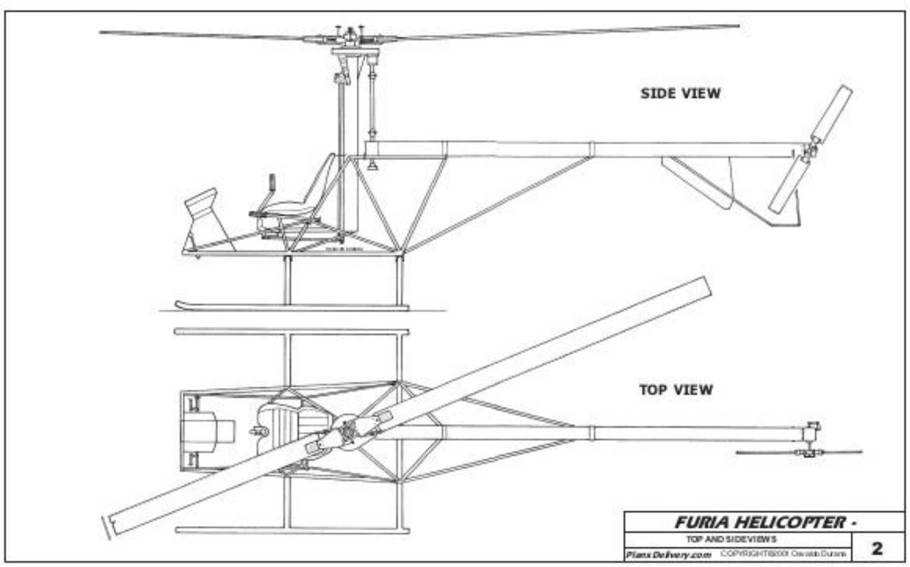

Figure 1. 1: Furia helicopter plan [1]

1.2 Problem Statement

An ultra-light helicopter had been well designed and developed by Dr. A. Halim Kadarman with several final year project student for the past several year. Through research, it is found that when the load is placed to the helicopter, the centre gravity of the helicopter will changed its position. The centre gravity of a helicopter are important as it provide stability for the helicopter to lift and fly safely. If the weight of the helicopter is too far forward, the helicopter will move forward and if the weight is too far behind, the helicopter will move backward. Same happen when the weight is more to the left or right, the helicopter will tend to move to the left or right respectively. This motion is also called a weight shift method in controlling the movement of the aircraft. It may be one of the control system which can control the action of the ultra-light helicopter. Therefore, this project will be involving the development of an adjustable engine mount for the ultra-light helicopter so that it can be one of the control system which can control the action of the ultra-light helicopter.

1.3 Objective of project

The objectives of this project are as follow.

1. To design an adjustable engine mount for ultra-light helicopter
2. To perform analysis for the structure of the adjustable engine mount for ultra-light helicopter
3. To fabricate a complete model of the adjustable engine mount for ultra-light helicopter

1.4 Thesis Layout

This thesis consist 5 chapters. Chapter 1 gives a project background related to the ultra-light helicopter. The design of the actual helicopter with an ultra-light helicopter is discussed in this section. Then, the general concept about a weight shifting method is also introduced in this chapter where it will be the main idea in developing this project. Finally, the objectives of the project are defined.

Chapter 2 reviews all literatures related to this work. This section involve research in journal that had been formerly made by other which are related directly to the project that will be developed. The purpose of this chapter is to attain genuine knowledge and information corresponding to the project field. In this section, the literature in designing the ultra-light helicopter and any structure related to it had been analyze and interpreted.

In Chapter 3, the method and process used in this project had been explained in detailed. All systematic, theoretical analysis and practical process are described in the methodology. This chapter consist 4 parts which related in developing this project from its first design to a complete fabrication process.

Chapter 4 is concerning about the result and the discussion of the project. This chapter present the finding and outcomes of research and reasons for a particular result obtain through practical and analytical analysis justified in the methodology. In this section, there are comparison between the development project with the theoretical and some result had been verified in order to have a valid result.

Finally, Chapter 5 is involving the conclusion and recommendation where logical deduction based on result obtain in the chapter 4. The comprehensive summary about the project are included which generally state the overall process in developing this project. At the end of the thesis, there will be some recommendation and future work stated to improve the project development.

CHAPTER 2

LITERATURE REVIEW

2.1 Ultra-light Helicopter

An ultra-light helicopter has a pair of counter-rotating rotor assemblies which in combination yield zero net angular momentum when rotating at equal speeds. A single motor drives both rotors through a counter-rotating bevel gear set coupled to a pair of concentrically nested output shafts. In an alternative embodiment, the motor is coupled to the rotors through a hydraulic drive system which includes a hydraulic pump and at least one hydraulic motor driving each of the rotor assemblies.[2]

2.2 Stability

An aircraft is designed to have stability that allows it to be trimmed to maintain straight-and-level flight with hands off the controls. In reference [3], the aspects of stability are divided into static stability and dynamic stability. Static stability refers to whether the initial tendency of the vehicle response to a perturbation is toward a restoration of equilibrium. Whereas, Dynamic stability refers to whether the vehicle ultimately returns to the initial equilibrium state after some infinitesimal perturbation. Dynamic stability only make sense for vehicles that are statically stable. Meanwhile in static dynamic, if the response infinitesimal increase in angle of attack of the vehicle generates a pitching moment that reduces the angle of attack (statically stable). However, if the initial tendency to return toward equilibrium leads to an overshoot, it is possible to have an oscillatory divergence of continuously increasing amplitude, thus the vehicle can be statically stable and dynamically unstable. [3]

2.2.1 Centre of Gravity

For any type of aircraft, one of the most important process is determining the centre gravity of the aircraft where it will affect the stability of an aircraft. A journal by Marian Bobe and Doru Luculescu stated that, an important stage in designing aircraft is determining the weight of the components and the position of the centre of gravity, in other words the centrage calculation. The accuracy of centrage execution influence the results subsequently obtained in calculating the static and dynamic stability as well as the results of the performance calculation. A significant error in determining the position of the centre of gravity leads to significant errors in the results previously mentioned.[4]

Hence, it is vital to comply with weight and balance limits established for helicopters. Operating above the maximum weight limitation compromises the structural integrity of the helicopter and adversely affects performance. Balance is also critical because, on some fully loaded helicopters, centre of gravity (CG) deviations as small as three inches can dramatically change a helicopter's handling characteristics.[5]

For previous history in ultra-light helicopter, the centre gravity of the helicopter will be controlled by the pilot itself. The design of the ultra-light helicopter back then are much more different and in such a dangerous way. The pilot is advantageously suspended in a "hang-glider" type harness from a single hang point positioned proximate the centre of lift of the helicopter. A control bar is fixedly mounted to the frame and is grasped by the pilot suspended in the harness. The pilot manoeuvres the helicopter in both the pitch and roll directions by manipulating the control bar. The pilot shifts his own centre of gravity relative to the centre of gravity of the helicopter while grasping the control bar to thereby manoeuvre the helicopter.[2] This mode of controlling the helicopter are not safe and might endangered the pilot life.

2.3 Steering System

Steering principle of helicopter with coaxial rotor configuration is that the helicopter has to be steered around four axes for full control which are horizontal (x-axis and y-axis), in heave (z-axis) and in heading. The coaxial helicopter have various possibilities in controlling the attitude and horizontal movement of the helicopter in the horizontal direction. Different concept of steering can be applied such as changing the orientation of the air flow, changing the centre of gravity (Weight Shift Control) and changing the tip path plane respective to the fixed body[6]. In this project, the concept of changing the CG by weight shift control (WSC) is used in steering the helicopter.

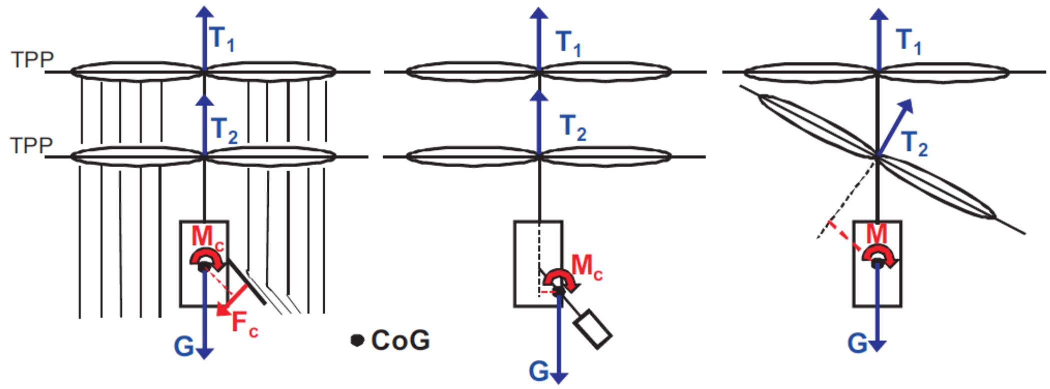

Figure 2. 1 Steering concept[6]

2.3.1 Weight Shifting

Weight-shift control is one of method used to produce changes in pitch and banks. Pilots achieve control of an aircraft by shifting the weight. Weight-shift control (WSC) is widely used in hang gliders and ultra-light trikes. Hang gliding is an aerial sport where some pilots believe that is the closest in mimicking the free flight of birds. The gliders evolved into two basic type of aircraft called flex-wings and rigid wings. A flex-wings is a hand gliding which is a practical pilot support and weight shift control method coupled with a wing whereas a rigid wings appear to be a gliders with rigid structure which is more like a private aircraft. The key design features in controlling the hang glider is based on weight shifting. Pitch control is by pilot weight shift fore and aft and roll/yaw control is by pilot weight shift side to side where it causing differential sail twist. [7]

Figure 2. 2: Hang glider. (a) Flex wing (b) Rigid Wing [7]

In the design of aircraft from a handbook by Federal Aviation Administration (FAA), the wing had been attached with the weight of the airframe and its payload at a single point in a pendulous arrangement. The pilot will controls the pendulum's arm and thereby controls the aircraft. The pilots displaces the aircraft's weight by appropriate distance and direction if there is change in flight parameter. The equilibrium between the four forces acting on the aircraft (lift, weight, thrust and drag) will be momentarily disrupts. In order to reestablish the desired relationship between these forces which happen due to inherent stability, the wing flexes and alter its shape. Thus lift is varied at different points on the wing to achieve desired flight parameters where it affect the pitch-and-roll axes. Unlike an actual airplane, the CG experienced by the WSC aircraft wing will remains constant. [8]

A lightweight helicopter control system based on the WSC are quite similar with the hang glider explained before. The only different is instead of using a wings to fly, they has a rotary wing to move through the air. A patent by Bashkar R Pal which explained about a lightweight helicopter with features of coaxial, contra-rotating rotors and weight shift control. The helicopter directional control is achieved through a weight shift principle by manipulating the control bar. It causes the contra-rotating rotors to tilt, and thereby causing a tilt to the aerodynamic thrust of the rotors to the required direction. When using this weight shift control, the main advantages is that the control mechanism of the helicopter had been simplified. In conventional helicopter, there is cyclic pitch control mechanism present where it make the control much more difficult. [9]

2.4 Structure

In structure engineering, a beam anchored at one end is called cantilever. Cantilevers need to be tough and very strong so that they do not bend or break as beam that carries the load to the support is resisted by moment and shear stress.[10]

2.4.1 Truss Structure

A truss is a simple framework structure where in theory, the truss members are subject to tension and compression forces only which does not involve bending forces. In tension, the truss member tends to stretch whereas the compression force members tend to squeeze the member. Tension forces on truss member are more economical and can be made thinner while compressive forces have shorter members which can carry higher compressive loads. There are numerous type of trusses available that had been made in construction of a structure.

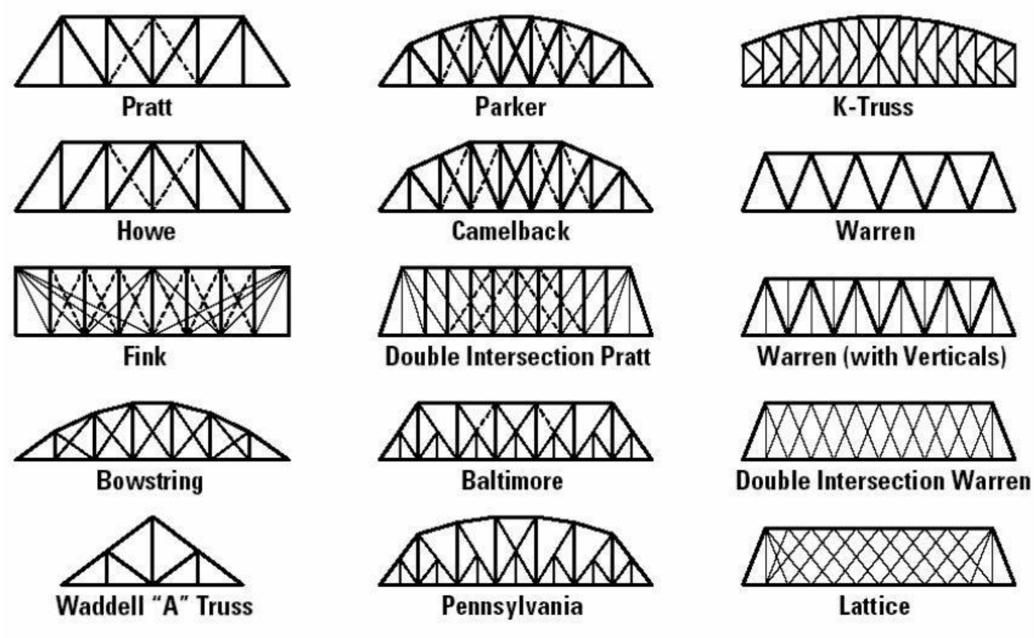

Figure 2. 3: Type of trusses in construction

Based on Tetsuya A and Hitoshi H on their paper on Mechanical advantages of truss-structure-based fracture fixation system, truss is a structure consist of triangular units that is composed by straight members and joints. This structure are refers as nodes which connect members to each other. All nodes are treated as hinges and in manners of exclude moments which result in compressive or tensile forces in the members. Compared to other ways of arranging materials, trusses structure is physically stronger.[10]

In using truss structure, there are several advantages and disadvantage found when using these system in construction. The main advantages of using this truss system is when load are applied on a structure, the elements of truss contribute to the load bearing capacity. Other than that, this system reduces the costs of supporting structure as the load are all distributed equally to the support. To be compared to a plane structures which have equivalent span and loading, using truss structure may reduced the deflection. If failure happen in one of the element or some of elements, it does not affect the entire structure to collapse. However, there are also a few disadvantage can be observed when using this truss structure. Due to their very small tolerance, the cost in constructing the structure is high compared to alternative structural system. Truss structure can be dense where the number and complexity of joint can lead to erection time on site. [11]

2.4.2 Bearing

Bearing are available in many different size and shapes. To support a rotating shaft in mechanical equipment, ball bearing are used. Ball bearing are used as they can support loads over a wide speed range and it is virtually friction free. The structure of a ball bearing consist of inner ring (IR), outer ring (OR) complements of balls and a separator in which it contains the balls. A pathway (groove) between the outer diameter of the inner ring (IROD) and the inner diameter of the outer ring (ORID) is where the balls roll on. The basic diameter of a bearing are the bore (B), outside diameter (OD) and width (W). [12] Various type of bearing are illustrated in figure below.

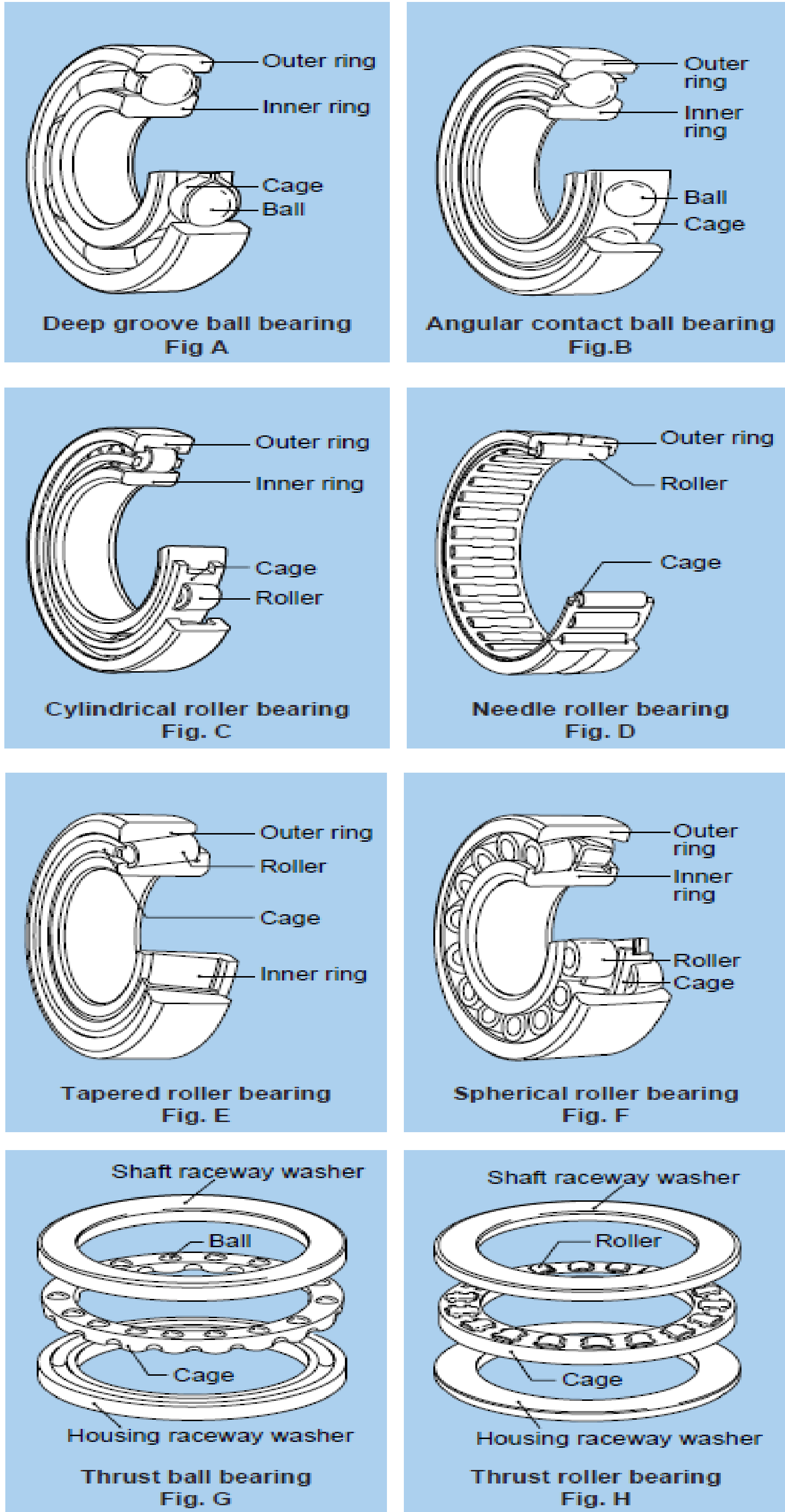

Figure 2. 4: Type of bearing [13]

CHAPTER 3

METHODOLOGY

This chapter presents all the method in developing the engine mount for the ultra-light helicopter. The following methods are illustrate in the flow chart below.

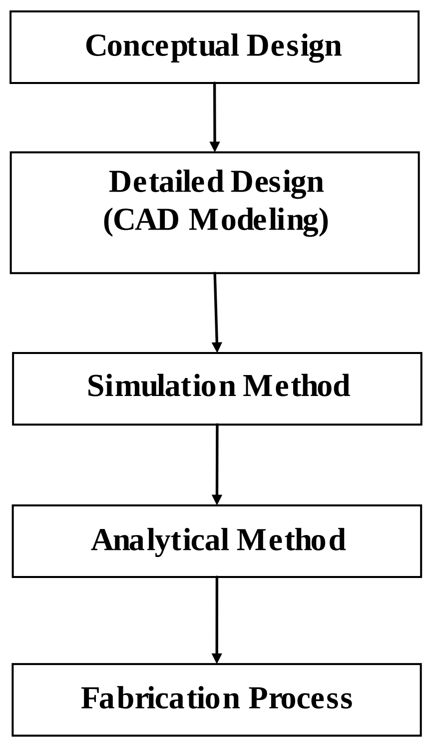

Figure 3. 1: Overall flowchart

3.1 Conceptual Design

The first phase involve in developing the structure of the engine mount is designing. Conceptual design is the primary phase where the design is at the concept level. In this phase, all the requirement in developing an engine mount must be stated. The detailed description of the engine is identified before proceed in designing the engine mount.

The engine specification are as follow:

Table 3. 1: ROTAX 582 UL DCDI Engine specification

Description	Value	Units
Weights		
Weight	27.4	kg
Exhaust system	5.1	kg
Gearbox “B”	4.5	kg
Electric starter	3.5	kg
Dimensions		
Bore	76	mm
Stroke	64	mm
Displacement	580.7	mm
Compression ratio (theoretical)	11.5 : 1	
Compression ratio (effective)	5.75 : 1	
Performance		
Maximum power	48	kW
Torque	75	Nm
Rotation	6 500	RPM

Conceptual design begin with a rough sketch of an engine mount that need to be designed based on the specification known. The engine mount need to withstand the weight of the engine and must also be able to move the position to meet the requirement of an adjustable engine mount. The position of the engine mount to its holder at the helicopter are analyze so that it can be positioned properly. Based on requirement, the engine mount must be able to adjust to lateral and longitudinal axis. This adjusting will lead in imbalance to the helicopter and the helicopter will tend to move to the right or left and forward or backward based on the weight shift position. The position of the engine mount will be adjust by the control stick and the movement of the helicopter is based on the weight shifting.

3.1.1 Preliminary Design

Preliminary design of the engine mount and the movement of the ultra-light helicopter.

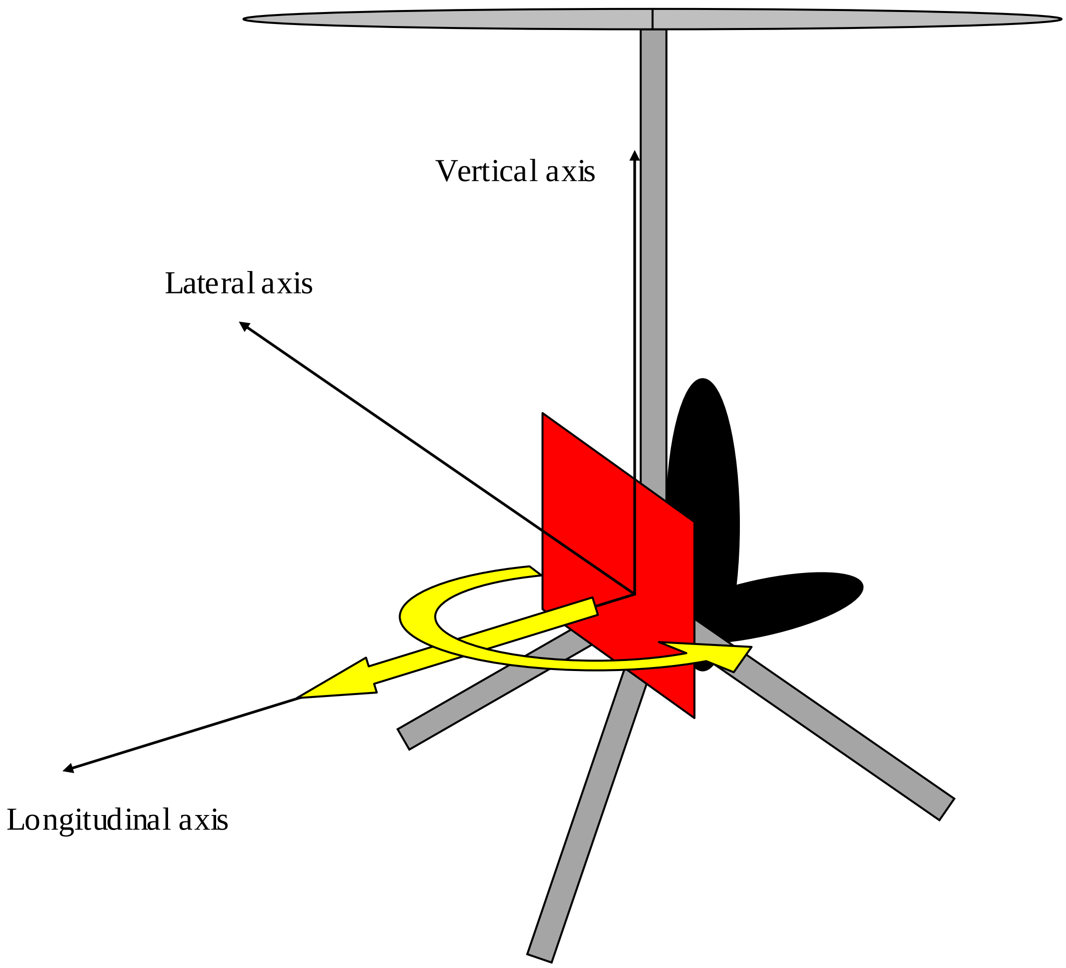

Figure 3. 2: Preliminary design of engine mount

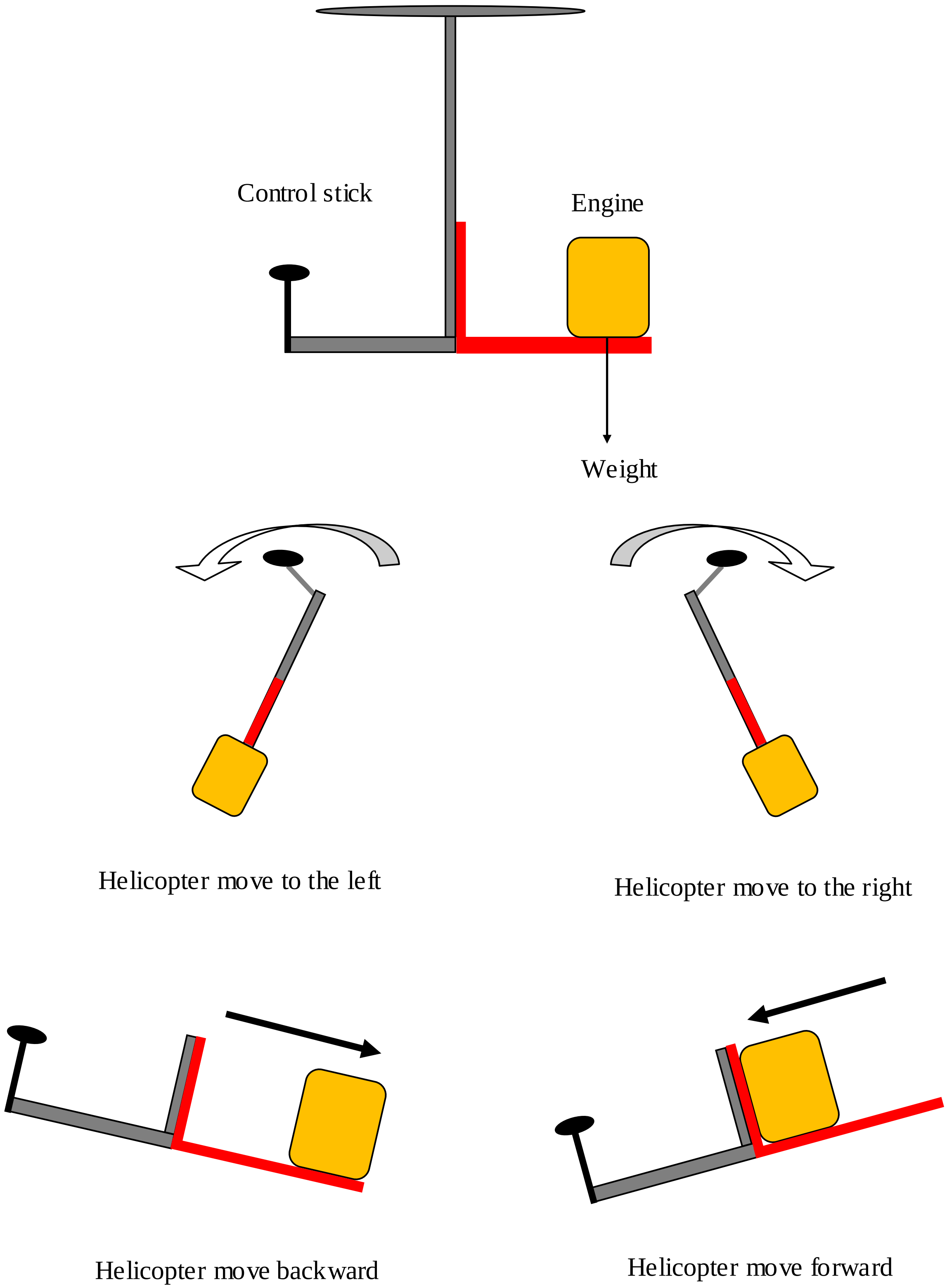

Figure 3. 3: Weight shift control of engine mount

3.2 Detailed Design (CAD Modeling)

After conceptual design, the actual designing of the adjustable engine mount is designed using a computer-aided design (CAD) software. SOLIDWORK software is used to design the structure of the engine mount. 3D drawing will be produced and more improvement can be made to the design as the view can be observe more detailed. Analysis will be done to the structure of the engine whether it can perform well at the required position especially at its critical position.

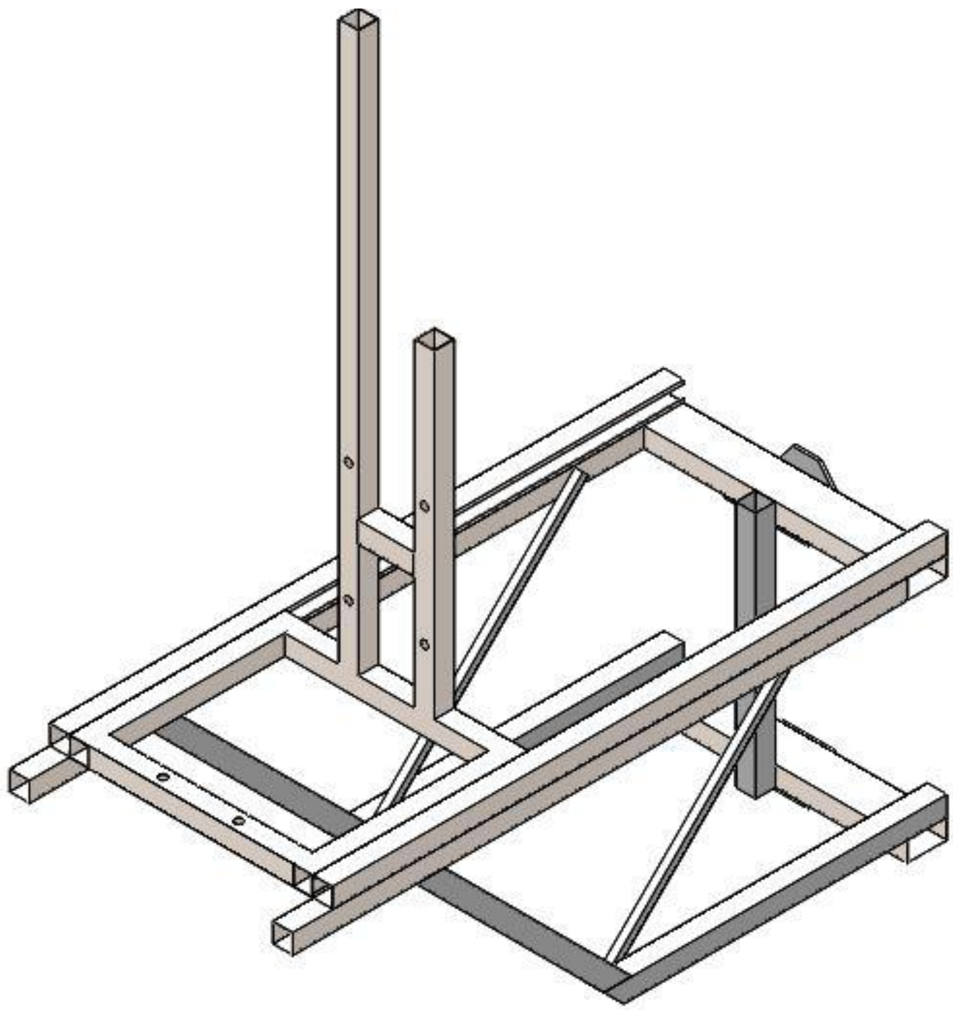

Figure 3. 4: Detailed design Simulation Method

Simulations is performed on the engine mount of the ultra-light helicopter that had been designed in the previous chapter. The simulations are implement using the SOLIDWORK® software. The simulated of these engine mount is discussed in details in this chapter.

3.2.1 Finite Element Analysis

Finite element analysis or finite element method is a numerical method for solving problems in engineering and mathematical physics. FEA are very useful for problems with complicated geometries, loadings and material properties where analytical solutions cannot be obtained. The finite element analysis can be applied in structure analysis, solid mechanics, dynamics, thermal analysis, electrical analysis and biomaterials. In finite element analysis, there are three general procedure which are preprocessing, solution and post processing[13]. In preprocessing, all the geometric domain, element, material properties, geometric properties, element connectivity and physical constraints are define. Next, the unknown values such as reaction forces, element stresses and heat flow are compute in solution and finally, the results from a finite element solution can be obtain[14]. The engine mount analysis process are shown in flowchart below.

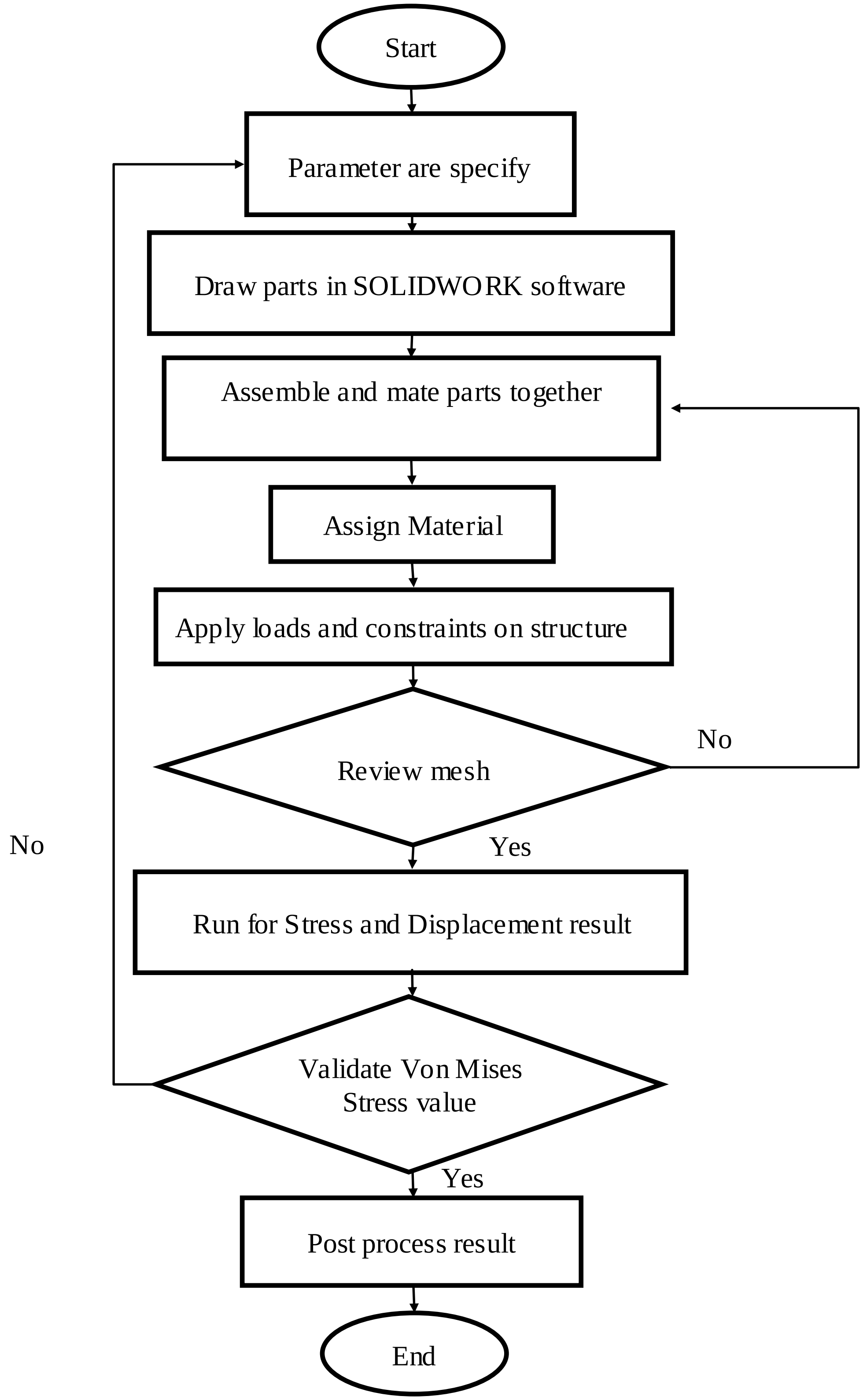

Figure 3. 5: Finite element analysis flowchart

3.2.2 Von Mises Stress

Designing a structure require validation in term of stress. In order to validate whether the structure fail or not, Von Mises Stress can be used. A design can be deduce as fail if the maximum value of Von Mises stress induced in the material is more than strength of the material. Von Mises stress concept are from the distortion energy failure theory where it is the comparison between two kind of energies which are the distortion energy in the actual case and the distortion energy in a simple tension case at the time of failure. According to the energy failure theory, when the distortion energy in actual case is more than the distortion energy in a simple tension case, failure occurs. [15]

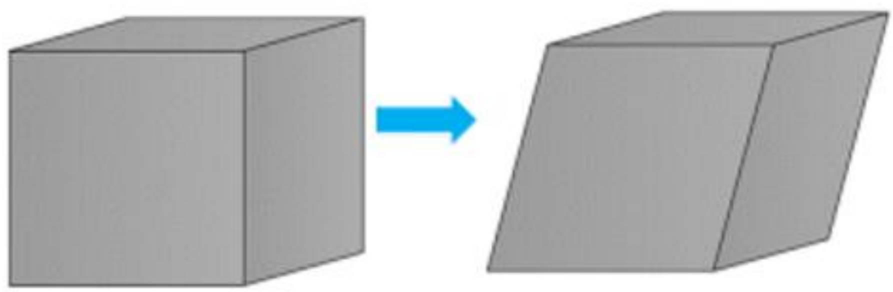

Figure 3. 6: Von Mises stress concept [15]

According to the Von Mises's theory, a ductile solid will yield when the distortion energy density reaches a critical value for that material. The derivation of distortion energy can be obtain in the Fracture Mechanics - Fundamentals and Application by T. L. Anderson [16]. The distortion part of energy in terms of principle stress value is:

$$U_d = \frac{1+v}{3E} \; \frac{\sigma_1 - \sigma_2{}^2 + \sigma_2 - \sigma_3{}^2 + \sigma_3 - \sigma_1{}^2}{2} \qquad 4.1$$

$$U_d = \frac{1+v}{3E} \; \sigma^2{}_{VM} \qquad 4.2$$

$$U_d = \sqrt{\frac{\sigma_1 - \sigma_2{}^2 + \sigma_2 - \sigma_3{}^2 + \sigma_3 - \sigma_1{}^2}{2}} \qquad 4.3$$

Where,

σ = Stress

E =Young modulus

v = Poisson’s ratio

U_d = Energy density

3.3 Analytical Method

3.3.1 Truss Element

A truss is commonly used to stiffen the structure. In construction, trusses are extremely strong and able to maximize the efficiency of the structure. There are various type of trusses design that are well used in as describe in Figure 2.3 in Chapter 2. In designing the engine mount for the ultra-light helicopter, truss element had been used to make the structure which holds the engine become more steadfast and are able to sustain the load as the weight of the engine is at the critical condition. The two dimensional view of the engine mount is drawn in figure below.

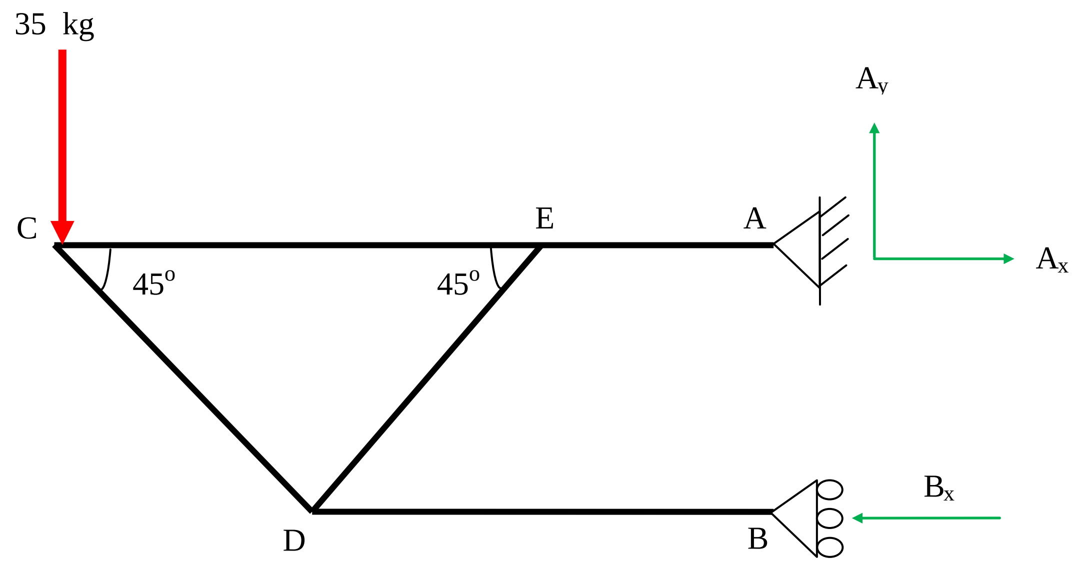

Figure 3. 7: Truss structure of engine mount

Based on Newton, a mass accelerates to the vector of sum is applied, where

$$\sum F = ma \quad 4.4$$

Where,

F = force

m = mass

a = acceleration

In analytical calculation, two dimensional are used where there are two coordinate direction which are x and y Cartesian. The force components are F_x and F_y is the structure constrain against translation motion use to solve most two unknown forces in structural problems. If the structure is constrained against rotation as well as translation, moment equation is added.[17]