STRESS AND STRENGTH ANALYSES ON THE SINGLE PILOT MOVEABLE SEAT FOR THE ULTRA-LIGHT HELICOPTER

By

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ENDORSEMENT

I, Mohamad Afiq Syarafuddin Bin Rosli hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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(Signature of Examiner)

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Date:

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date:

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STRESS AND STRENGTH ANALYSIS ON THE SINGLE PILOT MOVEABLE SEAT FOR THE ULTRA-LIGHT HELICOPTER

ABSTRACT

The purpose of this thesis is to analyze the stress and strength, to design and to fabricate a moveable single pilot seat for an ultra-light helicopter (ULH). This thesis provides a detailed method in analyzing the stress and strength the single pilot moveable seat of an ultra-light helicopter and also the detail design of the moveable seat. The single moveable seat is designed so that it is capable of being shifted longitudinally (forward and backward) and able to rotated circumferentially around the centre post within a range of angles. The single moveable seat must be able to support a load of the pilot and other additional weight from a basic cockpit system which is implemented on this ultra-light helicopter where the total estimated is about 100 kg. This project uses the concept of Weight Shift Control (WSC) that is commonly used for a hang glider where the weight of the pilot itself controls the attitude of ULH. The selection of material used to complete this project is needed to ensure the strength of the selected material able to withstand to load applied to this moveable seat. The simulation analysis is done by using one of the computer-aided design (CAD) which is SOLIDWORKS 2016 X64 Edition software. The investigation is performed to observe whether the structure of the moveable single pilot seat can support the applied load or fail to deliver as required based on the several types of simulation testing. Instead of performing the analysis using a SOLIDWORKS software, the analytical approach are also calculated in this thesis to compare and verify the moveable seat structure manually. The two-dimensional equation of motion formula was used to calculate the stress of the structure. Both methods need to be performed to

compare the simulation result with the analytical method and also to calculate the percentage difference between this two approaches. By comparing both of these approaches, the percentage difference is 0.084%. To complete this project, most of the material and equipment needs in fabricating this moveable seat model are available in the Aerospace workshop.

ANALISIS TEKANAN DAN KEKUATAN ATAS KERUSI TUNGGAL BOLEH LARAS BAGI HELIKOPTER ULTRA RINGAN

ABSTRAK

Tujuan tesis ini adalah untuk menganalisis tekanan dan kekuatan, untuk merekabentuk dan membuat tempat duduk tunggal untuk sebuah helikopter ultra ringan (ULH). Tesis ini menyediakan kaedah terperinci dalam menganalisis tekanan dan kekuatan kerusi tunggal boleh laras bagi helikopter ultra ringan dan juga reka bentuk terperinci kerusi boleh laras. Kerusi tunggal boleh laras ini direka supaya mampu bergerak secara longitudinal (ke hadapan dan ke belakang) dan mampu berputar mengelilingi pos tengah dalam pelbagai sudut. Kerusi tunggal boleh laras mestilah dapat menyokong beban juruterbang dan berat tambahan lain dari sistem asas kokpit yang melaksanakan helikopter ultra ringan ini dengan jumlah yang dianggarkan sekitar 100 kg. Projek ini menggunakan konsep Pengalihan Berat (WSC) yang biasanya digunakan untuk peluncur gantung di mana berat juruterbang itu sendiri mengawal imbangan ULH. Pemilihan bahan yang digunakan untuk menyiapkan projek ini diperlukan untuk memastikan tekanan dan kekuatan bahan yang dipilih dapat menahan beban yang dikenakan pada tempat duduk boleh laras ini. Analisis simulasi dilakukan dengan menggunakan salah satu reka bentuk dibantu komputer (CAD) iaitu perisian SOLIDWORKS 2016 X64 Edition. Penyiasatan dilakukan untuk memerhati sama ada struktur kerusi juruterbang tunggal boleh laras dapat menyokong beban yang diterapkan atau gagal untuk melaksanakan sebagaimana perlu berdasarkan beberapa jenis ujian simulasi. Selain melakukan analisis menggunakan perisian SOLIDWORKS, pendekatan analisis pengiraan juga dikira dalam tesis ini untuk membandingkan dan mengesahkan struktur

tempat duduk boleh laras secara manual. Persamaan gerakan dua dimensi formula digunakan untuk mengira tekanan struktur. Kedua-dua kaedah perlu dilakukan untuk membandingkan hasil simulasi dengan kaedah pengiraan manual dan juga untuk mengira perbezaan peratusan antara pendekatan dua kaedah ini. Dengan membandingkan kedua-dua kaedah ini, perbezaan peratus ialah 0.084%. Untuk melengkapkan projek ini, kebanyakan keperluan bahan dan peralatan dalam membuat model kerusi boleh laras ini boleh didapati di bengkel Aeroangkasa.

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LIST OF ABBREVIATONS

ULH	Ultra-light helicopter
CG	Centre of gravity
VTOL	Vertical take-off and landing
FEA	Finite element analysis
FEM	Finite element method
SF	Safety factor
MIG	Metal inert gas

LIST OF SYMBOLS

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
S_y	Tension elastic limit
σ_v	Von Mises stress
a	acceleration
σ_{CR}	Compressive buckling stress
τ_{CR}	Shear buckling stress

CHAPTER 1

INTRODUCTION

1.1 Research Background

An ultra-light helicopter (ULH) is one of the types of transportation that is similar to a conventional helicopter but lighter or simplified version which usually only consist of one or two seats. However, the design of an ultra-light helicopter is not identically similar to a conventional helicopter. The construction of an ultra-light helicopter is more straightforward compared to a traditional helicopter as typically there is no cockpit presence in the structure. It might not be able to fly faster than a regular helicopter, with a limited range, endurance, and load capacity. Based on the limited performance of this type of transportation, the usage of ultra-light helicopter become more practical for a flying vehicle which people could use it to take a panorama image or video from the sky as it is light and easy to control by one person. This kind of invention is suitable for travelers or journal photographers for their purpose of travelling and taking pictures from above the ground (Bucci, 1994).

Several companies and small workshops started producing their ultra-light helicopters worldwide. For example, Innovator Technologies provides the Mosquito XE which is able to reach up to 60 miles with 5 gallons of fuel and XEL helicopters where it can reach up to 150 miles with a maximum fuel capacity of 12 gallons, powered by Compact Radial Engines MZ202. Plus, in Europe, the Ranabot Ch 77 projet R seems to be pretty popular among the others. Ranabot has a cabin with side by side seats and is comfortable and practical for the pilot. The figure below is a homebuilt ultra-light helicopter plan named Furia helicopter by (Durana, 2001).

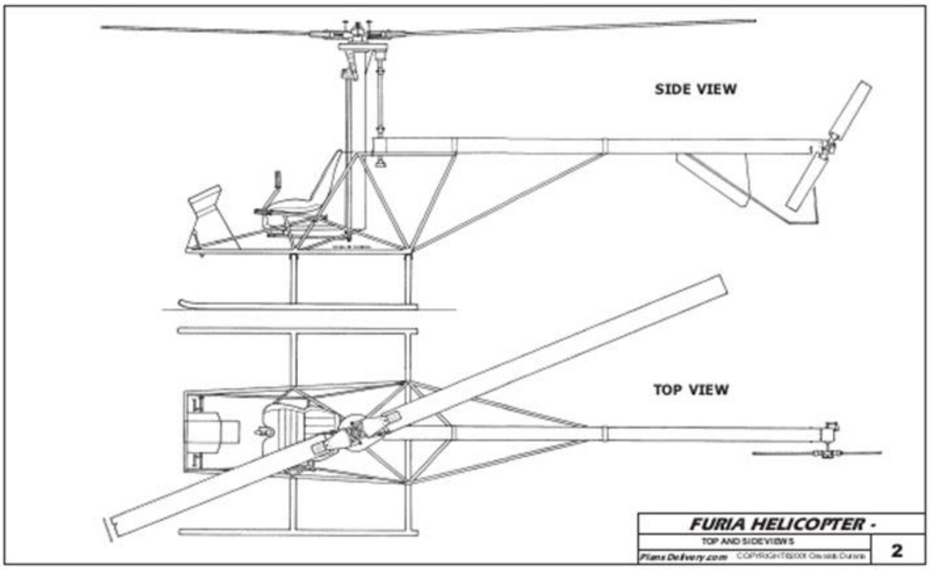

Figure 1. 1: Furia helicopter plan (Durana, 2001).

1.2 Problem Statement

Several years ago, Dr A. Halim Kadarman from the School of Aerospace Engineering, Universiti Sains Malaysia started to design and develop an ultra-light helicopter. This ultra-light helicopter project is still under development phase which generally this project is the combination of final year project students under supervision of Dr A. Halim Kadarman. In developing the ultra-light helicopter, the flight control system is the one that can be considered as a central issue for the ultra-light helicopter to become fully functional. Throughout the research, it is found that the conventional attitude control of an ultra-light helicopter is very complex to be controlled. Therefore, this project will be involving in the development of a single pilot moveable seat to shift the centre of gravity that simplifies the attitude control system of the ultra-light helicopter.

1.3 Objectives of Project

The goals of this project are as follow:

1. To design a single pilot moveable seat for an ultra-light helicopter.
2. To perform the stress and strength analyses of the single pilot moveable seat structure using simulation and analytical approach.
3. To fabricate a complete actual structure of a single pilot moveable seat for an ultra-light helicopter.

1.4 Scope of Works

The development of a new product such as the single pilot moveable seat for ultra-light helicopter can be considered as a big project which required a lot of processes to be done. Therefore, the project scope for this project are as follow:

1. Study the concept of a moveable seat that is commonly used in other transportations such as cars.
2. Study the design requirement to develop the single pilot moveable seat for a home build an ultra-light helicopter.
3. Design, perform stress and strength analyses and fabricate the single pilot moveable seat.

1.5 Thesis Layout

In this thesis, five main chapters describe full details from the introduction until the conclusion of this project. Chapter one is the introduction of this project. It describes the 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 problem statement, project objectives and project scope are also have been defined in this chapter.

Chapter two represents the literature review and theoretical background related to this thesis. This section involves research in a journal that had been formerly made by others which are connected directly to the project that will be developed. The purpose of this chapter is to attain the right knowledge and information corresponding to the project field. In this section, the theory of components used in this project is discussed and explained for the fundamental understanding of the project.

Chapter three, generally is about the details explanation about the method and process used in this project. This chapter starts by explaining the overall project flow involves before explaining in detail. All the systematic design, effective operation, simulation, and theoretical analysis are described in the methodology.

Chapter four provides the results and the discussion based on the analysis done in this project. This chapter presents the finding and outcomes of the research and reasons for a particular result obtained through simulation and analytical analysis justified in the methodology. The comparison between both simulation and analytical results also been discussed in this chapter.

Chapter five is the conclusion of this project. The comprehensive summary about the project is included which generally states the overall process in developing this project. Some recommendations are included for the future development of this project.

CHAPTER 2

LITERATURE REVIEW

The helicopter is one of the first aircraft which able to perform specific performance such as vertical takeoff and landing (VTOL), hover on the air and also played in low-speed maneuver flight. Unfortunately, the helicopter is one of the aircraft that face a lot of difficulties to fly due to unstable and heavy coupling characteristics and the problem will become more severe during maneuver flight. Over a decades before the first flying quality specification for rotorcraft appeared in 1961, maneuverability is one of the things that not crucial in helicopter design compared with the performance of the helicopter. After this quality specification was introduced, various flying quality criteria were proposed where some of that influences on helicopter maneuverability (Wu, 2017).

2.1 Ultra-light Helicopter

(Bucci, 1994) stated that ultra-light helicopter is one of the types of aircraft that operates with a pair of counter-rotating rotor assemblies where the net angular momentum yield zero when both of the rotors rotating at equal speeds. He also mentioned that both of the rotors been driven by a single motor using a counter-rotating bevel gear set coupled to a pair of concentrically nested output shafts. Other than the usage of bevel gear, it also possible for the rotor assemblies being controlled by a hydraulic drive system which may include hydraulic pump. The ultra-light helicopter provides simple structure, compact and reasonable, low cost to overcome deficiencies. The construction of ultra-light helicopter is to achieve light and safe flight besides to save flight cost.

2.2 Coaxial Rotor Blades

The development of designing a coaxial helicopter has been limited because of the difficulties involved in the control of the cyclic and collective pitch of rotor blades in a coaxial configuration. By providing control input linkages for a cyclic and collective pitch from both upper and lower rotor, the coaxial designs offer all of the rolling, pitching and yawing control. Coaxial rotor blades consist of two swash plates where the lower rotor functioned to transfer control inputs to the upper rotor which rotates in the opposite direction (Rock, 2005).

Based on (Feil et al., 2017), he stated that although the coaxial rotor can reduce power consumption by omitting the tail rotor, configurations of the coaxial rotor blades are still exception compared to single-main and tail rotor configurations. He also mentioned by applying coaxial settings to the helicopter, it might offer controllability benefits since a common control input needs will not consider any pedal control to maintain yawing moment compare to single main and tail rotor configurations.

Purposed by (Yuan et al., 2018), he clearly stated that coaxial compound configuration is the one of future high-performance rotorcraft. Plus, for the coaxial rotor blades configuration, the propeller itself may provide axial thrust and the anti-torque device is not required. He also mentioned that to improve the performance and the flight dynamics characteristics for the coaxial rotor blades configuration, it requires a good design control plan for the propeller. Figure 2.1 shows the configurations of coaxial rotor blades by (Yuan et al., 2018).

Figure 2.1: Configuration of coaxial rotor blade (Yuan et al., 2018).

2.3 Stability

Based on a book written by (Nelson, 1998), stability means the tendency of the aircraft to return to its equilibrium position after it has been disturbed either by a pilot's actions or atmospheric phenomena such as wind gusts and air turbulence. Stability divided into two aspects which are 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. Dynamic stability refers to whether the vehicle ultimately returns to the initial equilibrium state after some infinitesimal perturbation. Figure 2.2 and 2.3 show the illustrations for various conditions of static and dynamic stability.

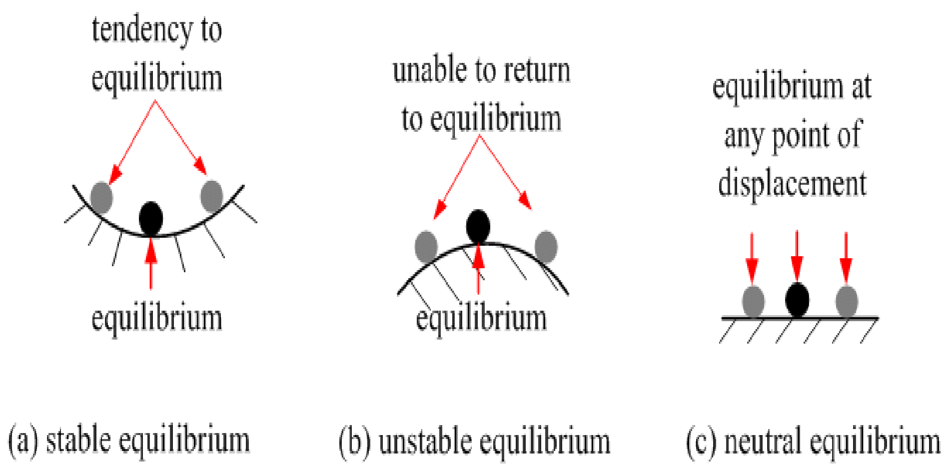

Figure 2.2: Illustrating various conditions of static stability (Nelson, 1998).

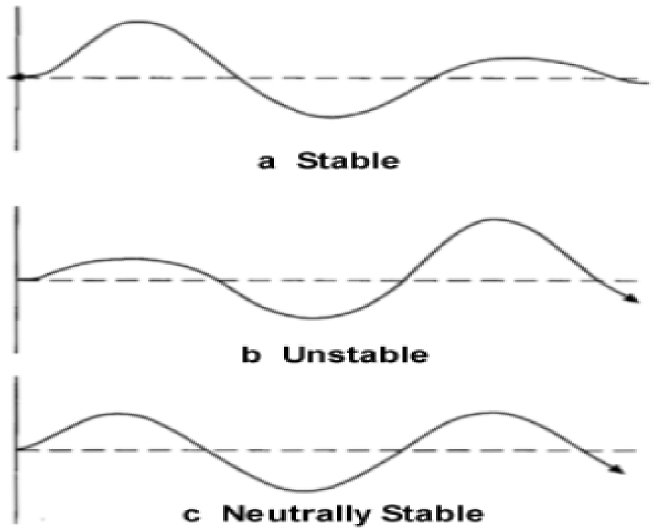

Figure 2.3: Illustrating various conditions of dynamic stability (Nelson, 1998).

According to (Caughey, 2011), dynamic stability can be considered for the aircraft that are statically stable. However, an aircraft can be statically stable and dynamically unstable if the initial tendency to return toward equilibrium leads to overshoot where it is possible to have an oscillatory divergence of continuously increasing amplitude.

2.3.1 Centre of Gravity

In designing any aircraft, to determine the weight of each component and position of the centre of gravity (CG) is one of the crucial stages. For the helicopter, balance is the other part that is considered critical because when the helicopter operates with fully loaded payload, the small deviations of the centre of gravity can dramatically influence handling characteristics for the helicopter. According to the journal written by (Marian Bobe 2012), the centre of gravity may also be known as centrage calculation. The accuracy of centrage execution is critical because it may affect the static and dynamic stability and even the overall performance of the aircraft. An error while determining the centre of gravity causes significant errors in the results previously mentioned. Based on her journal, she purposed that one of the classical methods to determine the centre of gravity was by estimate the weights of different mechanical and electrical components.

By referring a handbook produced by the Federal Aviation Administration (FAA) (U. S. Department of Transportation and Administration, 2013), the helicopter must be balanced perfectly by a pilot to maintain the helicopter remains horizontal in hovering flight. For the conventional helicopter, the angle at which the helicopter hangs from the rotor is affected by the location of the centre of gravity. The helicopter will be hung horizontally if the centre of gravity is directly under rotor mast, else if the location of the centre of gravity is too far forward or aft, a helicopter might be hanging with nose tilted down or going up. Figure 2.4 illustrates the effect of the centre of gravity to the helicopter position.

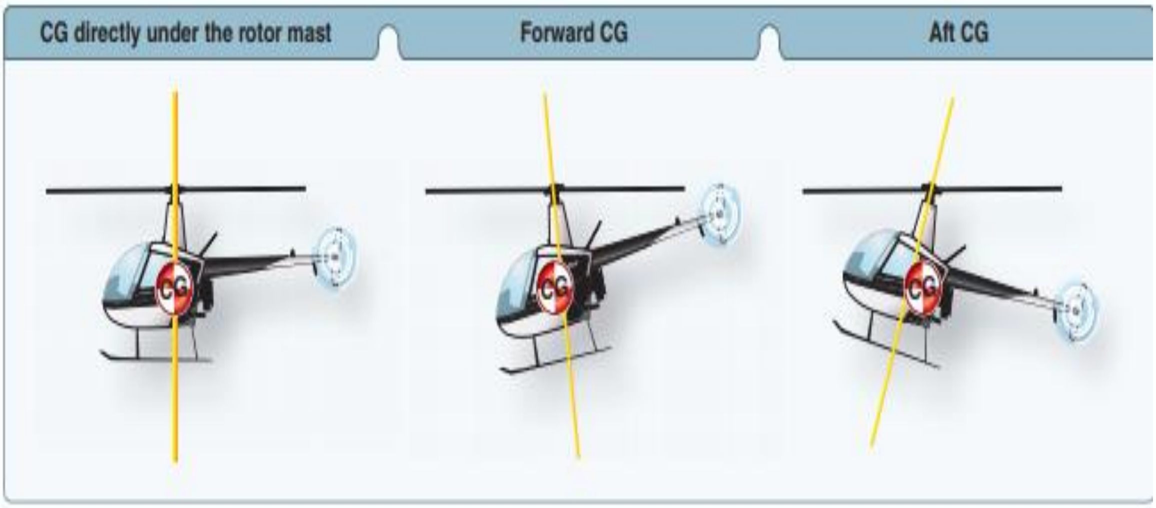

Figure 2.4: Location of CG and the effect for helicopter position (U. S. Department of Transportation and Administration, 2013).

Based on (Durana, 2001), during the past, the centre of gravity of the ultra-light helicopter been controlled by the pilot itself. In the past few decades, ultra-light helicopter been designed theoretically looks like a hang-glider. A control bar is fixedly mounted to the frame and is grasped by the pilot suspended in the harness. By manipulating the control bar, the pilot may control and maneuvers the helicopter in both roll and pitch directions. Figure 2.5 shows the position of the pilot which control the movement of the ultra-light helicopter.

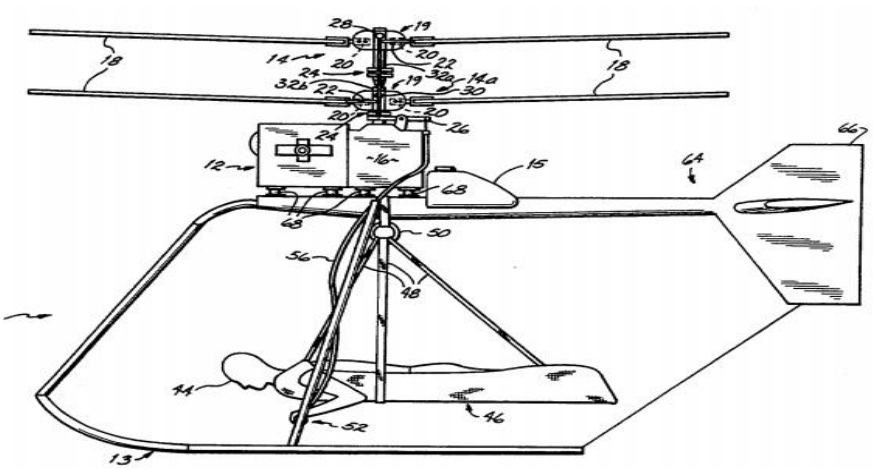

Figure 2.5: Illustration of pilot position in ultra-light helicopter according to (Durana, 2001).

2.4 Steering Principles

For the ultra-light helicopter, the steering system is the key element for control and navigation. The steering for the helicopter has to be precise, reliable, and lightweight to provide a sufficient control authority for the pilot (Schafroth et al., 2008).

According to a thesis written by (Schafroth, 2010), the helicopter has been able to be steered around the four axes which are horizontal (x- and y-axis), in heave (z-axis) and the heading (ψ). For all of model size helicopters, the steering in heave (z-axis) and in the heading (ψ) is usually done the same regardless of the size of the helicopter. The heave is controlled by changing the net thrust whereas the heading is controlled by differential speed variation of the two rotors leading to an imbalance in the net drag torque around the rotor axis and a yawing of the fuselage. To control the horizontal directions of the coaxial helicopter, there are several possibilities to control the attitude of the helicopter such as changing the orientation of air flow, changing the centre of gravity and changing the tip path respective to the fixed body frame. Figure 2.6 shows the illustrations on how the horizontal directions can be controlled regarding possibilities mentioned previously.

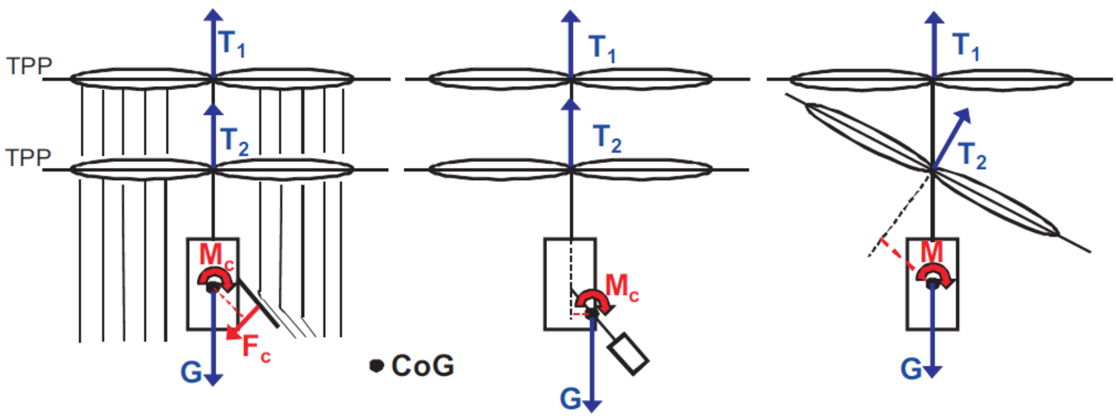

Figure 2.6: Illustrations of different steering concepts (Schafroth, 2010).

2.5 Weight Shifting

Weight-shift control is one 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 types of aircraft called flex-wings and rigid wings. A flex-wings is a hand gliding which is practical pilot support and weight shift control method coupled with a wing whereas rigid wings appear to be gliders with the rigid structure which is more like a private aircraft. The key design features in controlling the hang glider are 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 (Dees, 2010). Figure 2.7 shows an image of two essential hang glider which is flex wing and rigid wing.

Figure 2.7: Flex wing (left) and Rigid Wing (right) hang glider (Dees, 2010).

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 (U. S. Department of Transportation and Administration, 2013).

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. 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 (Abhishek and Rawal, 2015).

2.6 Structure

Based on the book published by (J. Connor and Faraji, 2013), the structure is several parts that are assembled which are designed to withstand the action of loads applied to it. These loads may be due to gravity, wind, ground shaking, impact, temperature, or other environmental sources. Thus, it is critical that the nature and magnitude of the loads they may experience be accurately defined. By identifying the maximum loads that a structure may experience, selecting a proper material and dimensions and determining the suitable arrangement of structure members will ensure that the structure can achieve desired performance and will not collapse when subjected to its design loading.

2.6.1 Truss Structure

The truss is a structure composed of slender members joined together at the endpoints. Metal bars or wooden struts usually used in the construction of trusses. The truss members are subjected to tension and compression forces only which does not involve bending forces (Hibbeler, 2014). In tension, the truss member tends to stretch whereas the compression force members tend to squeeze the member. Tension forces on truss members are more economical and can be made thinner while compressive forces have shorter members who can carry higher compressive loads.

Based on the Journal paper written by (Arai et al., 2013), a truss is a structure consisting of triangular units that are composed of straight members and joints. This structure is referred to as nodes that connect members to each other. All nodes are treated as hinges and in manners of excluding moments that result in compressive or tensile forces in the members. Compared to different ways of arranging materials, trusses structure is physically stronger.

(Ana-Maria TOMA, 2015) In her journal paper described that there are two types of trusses which is planar truss and spatial truss. A planar truss is one where all the members and within a two-dimensional plane, spatial truss has members and nodes extending into three dimensions. By applying the truss element on the structure, deflections are reduced, compared to plane structures of equivalent span and loading. Plus, if an adequate alternative load path exists in the structure design, failure of one or a limited number of elements does not lead to the overall collapse of the structure. Figure 2.8 shows an example of various type of trusses that widely used to stiffen the structure.

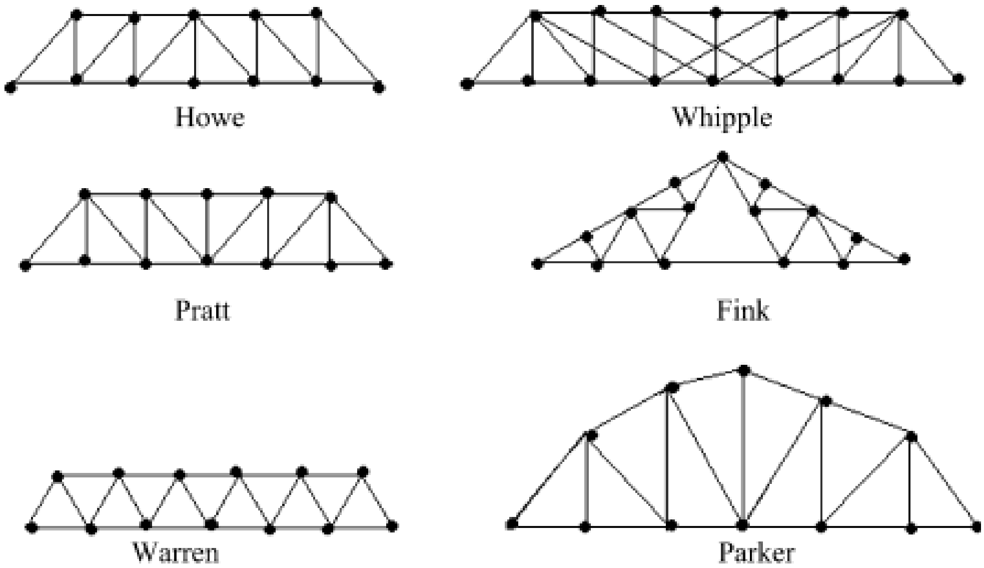

Figure 2.8: Examples of named trusses (J. Connor and Faraji, 2013).

CHAPTER 3

METHODOLOGY

The previous chapter discussed theoretical background and empirical literatures of ultra-light helicopter models on the relationship between different factors of influence the efficiency and overall performance and the proposed model basis, which are considered as useful information for the research study. In this chapter, the detailed methodology explains how the proposed research will be achieved. The outline of this chapter is illustrated in the flow chart in Figure 3.1.

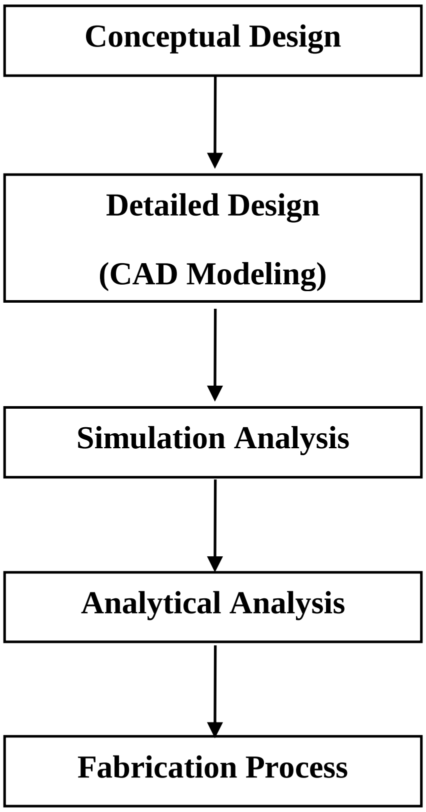

Figure 3.1: Flow chart for the outline methodology.

3.1 Conceptual Design

The first step which involves in developing the structure of the moveable seat is designing. Conceptual design is the solution outline for a design problem and an early or a primary phase of the design process. At this phase, the general information related to an overview of the overall single pilot moveable seat design should be presented. The main objective of this conceptual design phase is to come out with all the possibilities that look reliable for a final product. In this stage, all the parameters and requirements in developing a single pilot moveable seat such as weight, development cost, detail dimensions, and time consumption must be estimated. The identification of a detailed description of the moveable seat must be finished before it can proceed in designing the seat. The research related to the degrees of freedom for the adjustable pilot seat between 1-dimensional axis (lateral direction) and 2-dimensional axis (lateral and longitudinal direction) and how these different degrees of freedom influence the attitude control of the ultra-light helicopter must be finished.

In this stage, the first sketch of a moveable helicopter seat needs to be designed after all the specification parameters are known. The design of the seat needs to withstand the weight of the pilot and also be able to move to the position to meet the requirement of a moveable seat without any problems. Based on the specification, the pilot seat must have the flexibility to be able to adjust in 2- dimensional axis which is in the lateral and longitudinal axis. This adjustment will lead to imbalance to the ultra-light helicopter and the helicopter will tend to move to the right or left and forward or backwards based on the weight shift positions. The control stick will adjust the location of the pilot seat and resulting movement of the helicopter based on the weight shifting.

Table 3.1: General specifications related to the moveable seat.

Description	Value	Units
Weight of the moveable pilot seat structure	7.5	kg
Maximum load of the pilot	100	kg
Minimum height of the pilot	155	cm
The overall dimension of the moveable pilot seat (width x height x length)	42.5 x 93.5 x 156	cm
Angle of rotation	± 30	degree
Lateral travel distance	30	cm

3.2 Detailed Design (CAD Modeling)

Detailed design is the phase where the design is refined and drawn, specifications of the pilot seat and the estimates are created. After all the detail about the key parameters and requirements related to the moveable pilot seat was finalized and approved at the conceptual design phase, the actual designing of the moveable single pilot seat is designed using computer-aided design (CAD) software. To achieve the objectives of this thesis, the SOLIDWORKS 2016 x64 Edition CAD software has been chosen to be used to develop the entire structure of the moveable single pilot seat. Compare to other CAD software, SOLIDWORKS enables a user to easily edit and modify the design concept at any stage in the design process. In SOLIDWORKS software, users can see the accurate mass properties and check for any interference for each part design. In the other hand, SOLIDWORKS software is also one of the productive 3D software tool that helps to simulate physical behavior which suits to all design types. The analysis will be done on the structure of the pilot seat whether it can perform well at the required position especially at its critical location. Figure 3.2 and 3.3 show the complete design of the seat mount base and the seat holder with a footrest by using SOLIDWORKS 2016 x64

Edition. The details dimensions about these two different design are shown in Appendix F and Appendix G. It is noted that all the moveable seat dimension is in unit millimetre, mm.

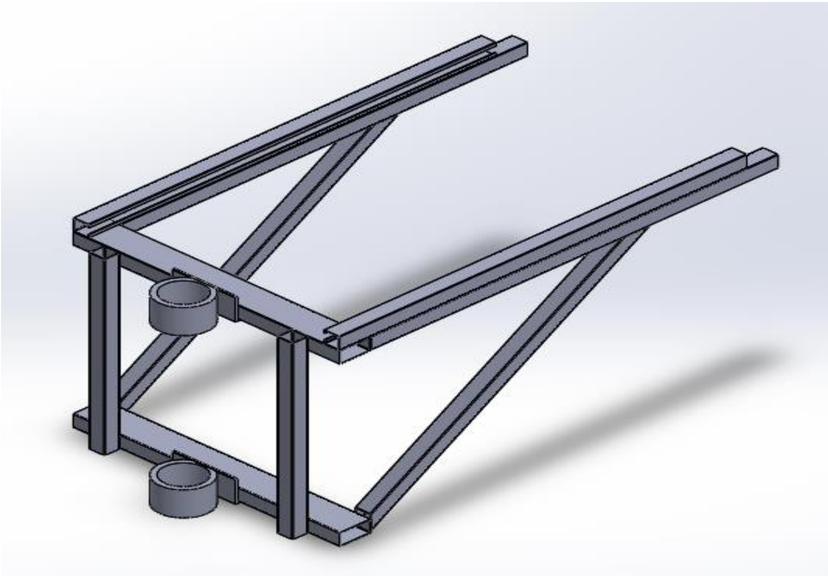

Figure 3.2: Design of seat mount base.

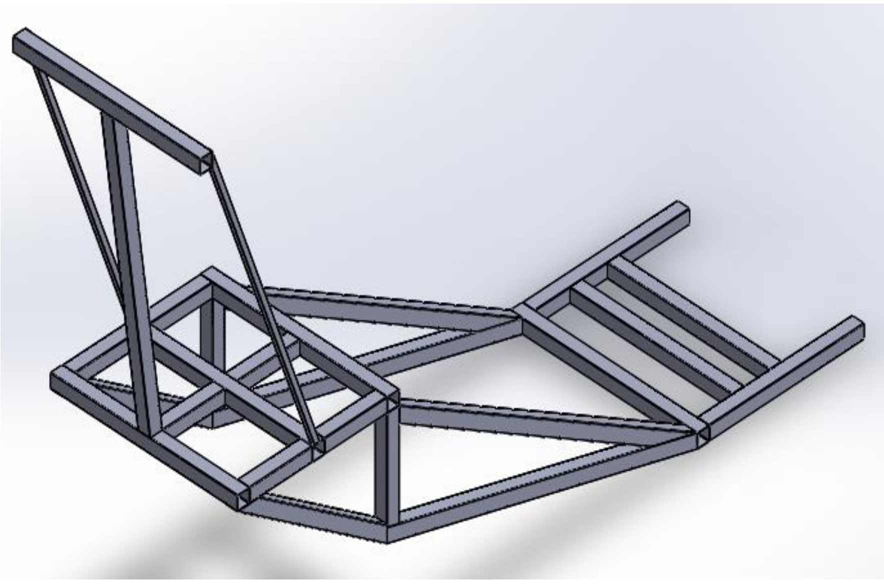

Figure 3.3: Design of seat holder.

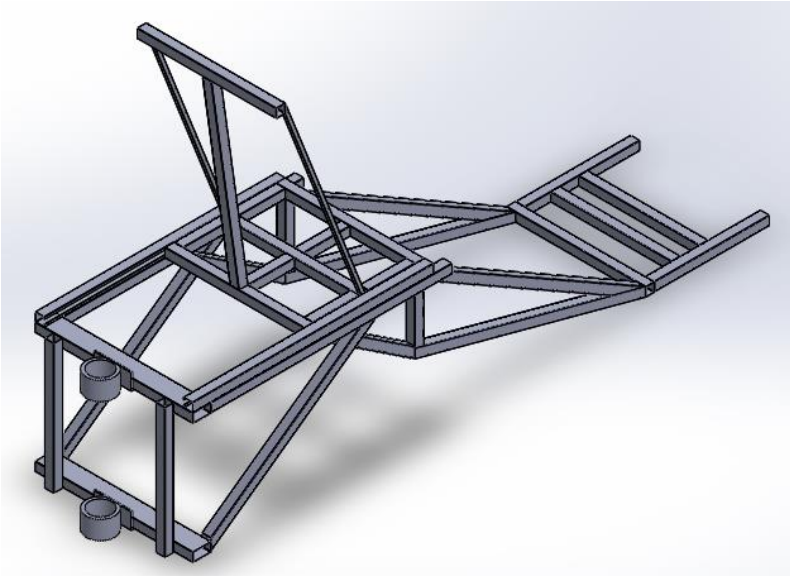

Figure 3.4: Overview of entire moveable seat design.

3.3 Simulation Analysis

In this phase, the stress and strength of the structure relative to the loads applied were analyzed. The result of this structural analysis will be discussed in the next chapter.

3.3.1 Finite Element Analysis

The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called Finite Element Method (FEM). FEM is the first technique to perform stress and strength analyses. FEA is 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 structural analysis, solid mechanics, dynamics, thermal analysis, electrical analysis, and biomaterials (Pravin Pawar et al., 2016).

3.3.1.1 Basic Finite Element Concepts

In solving any structural problem regardless of the type of the structure, type of loading applied, static or dynamic and the nature of structural material, there are only three types of argument that can be deployed. These arguments are equilibrium, compatibility and stress-strain law. For the equilibrium, the discussions relate between the stress and the applied forces, or often to other stresses whether the applied forces are present or not. Compatibility relates the strains to displacements and is purely geometrical arguments which depend on the definition of strain and the type of deformation and geometry of the particular structure. The stress-strain law is empirical and depend on the experimental evidence which for most problems it will have a linear-elastic behavior.

3.3.1.2 Basic Finite Element Analysis Procedure

For the finite element analysis, the basic procedure can be broken down into three simple steps which are preprocessing, solution and postprocessing. In preprocessing, all the geometric domain, element, material properties, geometric properties, element connectivity, and physical constraints are defined. The analysis type, meshing type, the meshing element size, boundary conditions and the loads are the critical parameters that need to be set in the solution (Bathe, 2016). The postprocessing is the step where the results from a finite element solution can be obtained. Figure 3.5 shows the flowchart of how the analysis of a moveable pilot seat can be done.

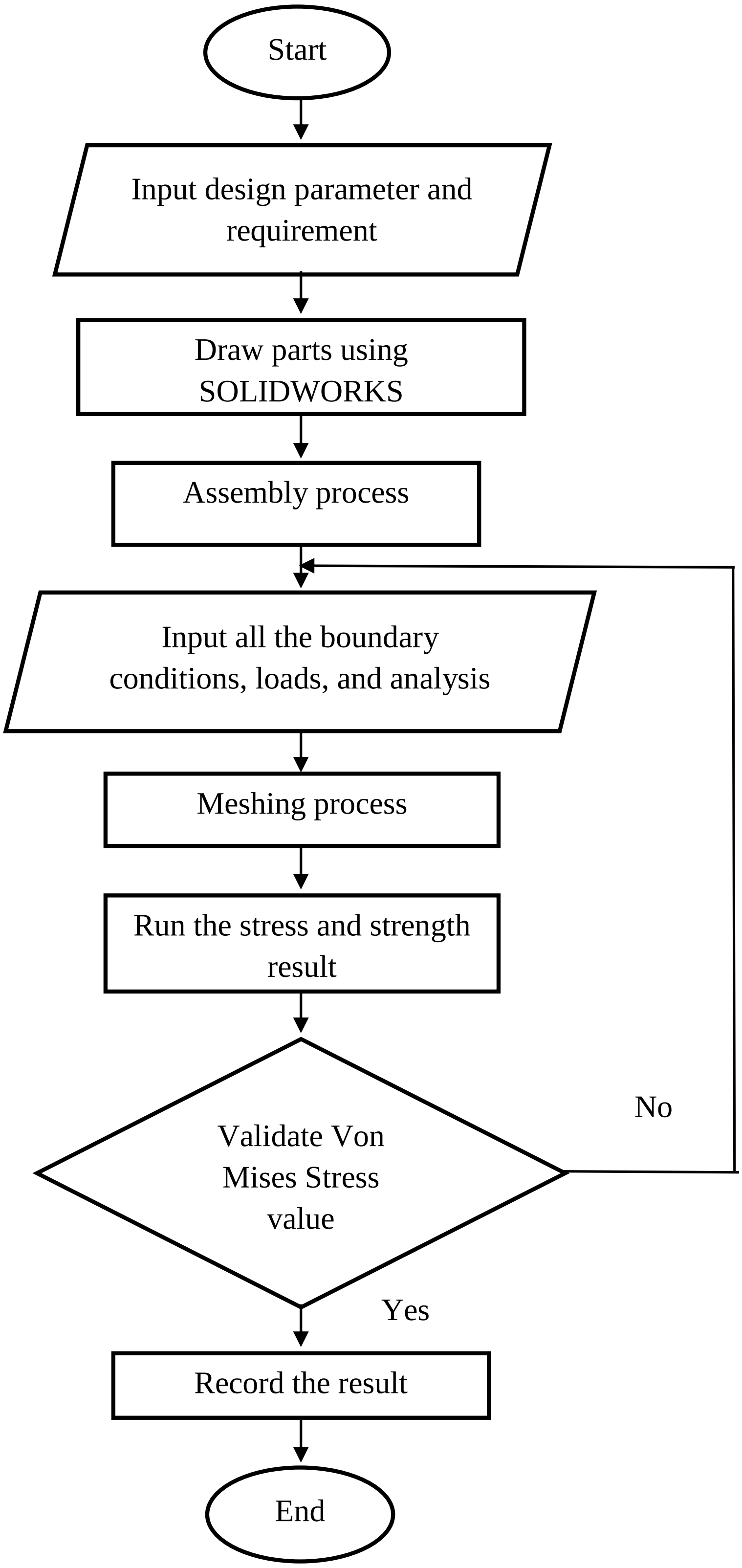

Figure 3.5: Flowchart for the simulation process.

3.3.1.3 Meshing

The meshing process is the process where the program subdivides the model into small elements which are connected at a common point. In analyzing any engineering designs, the meshing process is considered as one of the most complicated steps to be completed. An imperfect meshing process will influence the effectiveness and precision of the result analysis. The automatic mesher in the software generates a mesh based on a global element size, tolerance, and local mesh control specifications. Mesh control used to specify different quantities of elements for components, faces, edges, and vertices.

There are three types of meshing elements available in SOLIDWORKS software. This elements types consist of solid elements, shell elements and beams elements. In this project, the 3D tetrahedral solid elements will be used. The solid elements were chosen because it is naturally suitable for the engineering designs which are considered as bulky models.

There are three important aspects to qualify whether the mesh produced is a good mesh or not. These aspects are the maximum aspect ratio, percentage of elements with an aspect ratio less than 3, and the percentage of elements with an aspect ratio greater than 10 (Petrock, 2017). Figure 3.6 shows the shapes of the element with a different value of aspect ratio. Table 3.2 describes the details of these three aspects.

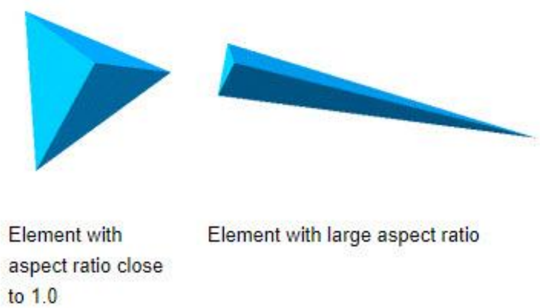

Figure 3.6: Shape of element with different aspect ratio (Petrock, 2017).

Table 3.2: Criteria to determine a good meshing.

Criteria	Details
Maximum Aspect Ratio	Should be at most low double digits (10-50 depending on complexity)
Percentage of elements with Aspect Ratio < 3	Should be in the range of 70-90 for complicated models
Percentage of elements with Aspect Ratio > 10	Should be low than 1

The comparison of element size of 10, 9, 8 and 7 has been made to determine which is the best element size that will be used in this project. The details about the mesh properties for all of these four elements size as shown in Figure 3.7 – 3.10.

Jacobian points	4 points
Max Element Size	10 mm
Min Element Size	2 mm
Mesh quality	Draft
Total nodes	353872
Total elements	1116785
Maximum Aspect Ratio	63.941
Percentage of elements with Aspect Ratio < 3	60.5
Percentage of elements with Aspect Ratio > 10	0.817

Figure 3.7: Mesh properties for element size of 10.

Jacobian points	4 points
Max Element Size	9 mm
Min Element Size	1.8 mm
Mesh quality	Draft
Total nodes	422759
Total elements	1364286
Maximum Aspect Ratio	63.786
Percentage of elements with Aspect Ratio < 3	67.7
Percentage of elements with Aspect Ratio > 10	0.579

Figure 3.8: Mesh properties for element size of 9.