ENDORSEMENT

I, Zularieff Redzwan Bin Sulaiman 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 Student)

Date:

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(Signature of Supervisor)

Name: P.E DR A. HALIM KADARMAN
Date:

____

(Signature of Examiner)

Name: DR ASLINA ANJANG AB RAHMAN
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.

____

ZULARIEFF REDZWAN SULAIMAN

Date:

ACKNOWLEDGEMENTS

In performing this project, many help and guidance had been received from some respected person, who deserve greatest gratitude. Without the participation and assistance of these people, the project could not have been possible.

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

STRENGTH AND STRESS ANALYSIS ON HELICOPTER ROTOR BLADE GRIP

ABSTRACT

The purpose of this thesis is to design, analyze and apply a spacer with a different materials to the unfilled gap of rotor blade grip for an ultra-light helicopter. The unfilled gap of the blade grip has to be occupied by the spacer in order to obtain the highest grip effectiveness towards the rotor blade. The absence of the spacer might be fine for certain length of rotor blade but it would be wasted if the efficiency of the rotor blade grip ability is not fully utilized. Therefore, these empty spaces of the blade grip are better to be filled in by some sort of materials as the fewer the empty space of the blade grip, the better the grip blade towards the rotor blade it will be. For this project, the chosen materials to fill the empty spaces are epoxy, car body filler and aluminium. The objective for these materials to be filled into the non occupied blade grip area are to act as a spacer (support) and making the blade position more rigid and compact. However, different materials has different strength thus producing different amount of blade grip effectiveness. In order to analyze and monitor each of the different materials behavior, a reliable test can be done. Software such as SOLIDWORKS is used because it offers a simulation test. From the simulation test, strength and stress can be analyzed by setting up a specific constraints and pre-conditions. Besides, it is important to verify the simulation analysis which can be obtained by taking the rotor blade tip deflection from the lab experiment and compared together with the simulation displacement results. As a reference, to have a better insight towards the simulation situation, the model has been setup according to cantilever support situation where it is free of external load except for gravitational force. In a nutshell, from the simulation results, it can be

observed that aluminium spacer is the best material to enhance the blade grip effectiveness where all of the results are discussed in this thesis.

ANALISIS KEKUATAN DAN TEKANAN PADA GENGGAMAN PEMUTAR BILAH HELIKOPTER

ABSTRAK

Tujuan tesis ini adalah untuk mereka bentuk, menganalisis dan menggunakan penjarak dengan bahan-bahan yang berbeza untuk mengisi ruang kekosongan pada genggaman pemutar bilah untuk helikopter ringan. Ruang kekosongan yang ada pada genggaman bilah harus dipenuhkan dengan penjarak untuk mencapai kerberkesanan genggaman yang paling tinggi pada pemutar bilah. Ketiadaan penjarak mungkin berkesan untuk panjang pemutar bilah yang tertentu tetapi ia akan menjadi kekurangan sekiranya keberkesanan pada kebolehan genggaman pemutar bilah tidak digunakan sepenuhnya. Oleh itu, ruang kekosongan pada genggaman bilah sebaiknya dipenuhkan dengan menggunakan bahan-bahan yang tertentu dimana lebih kurang kekosongan pada genggaman bilah, lebih kuat genggaman bilah terhadap pemutar bilah. Untuk projek ini, bahan-bahan yang telah dipilih untuk mengisi ruang kekosongan adalah epoksi, pengisi badan kereta dan aluminium. Tujuan bahan-bahan ini diletakkan pada ruang kekosongan genggaman bilah adalah bertujuan untuk dijadikan sebagai penjarak (sokongan) dan membuat posisi bilah lebih kukuh dan mampat. Walaubagaimanapun, bahan-bahan yang berbeza mempunyai kekuatan yang berbeza justeru menghasilkan jumlah keberkesanan genggaman bilah yang juga berbeza. Untuk menganalisis dan memantau pada setiap tingkah laku bahan-bahan, ujian yang boleh dipercayai boleh dijalankan. Perisian seperti SOLIDWORKS telah digunakan kerana ia mempunyai ujian simulasi. Daripada ujian simulasi, kekuatan dan tekanan dapat dianalisis dengan menetapkan kekangan dan prasyarat yang tertentu. Selain itu, adalah

penting untuk mengesahkan analisis simulasi yang boleh diperolehi dengan mengambil pesongan hujung pemutar bilah daripada makmal eksperimen dan dibandingkan bersama dengan keputusan anjakan simulasi. Sebagai rujukan, untuk pemahaman yang lebih baik kepada situasi simulasi, model tersebut telah direka mengikut situasi sokongan penyangga di mana ia bebas daripada tekanan luaran kecuali tekanan graviti. Secara keseluruhan, daripada ujian simulasi, ia dapat dilihat bahawa penjarak aluminium adalah bahan yang terbaik untuk meningkatkan keberkesanan genggaman bilah dimana semua ujian telah dibincangkan dalam tesis ini.

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LIST OF ABBREVIATONS

ULH	Ultra-light helicopter
FE	Finite element
FEM	Finite element method
FOS	Safety factor
FAR	Federal Aviation Regulation

LIST OF SYMBOLS

A	Cross sectional area
m	Mass
F	Force
L	Lift force
C_L	Lift coefficient
ρ	Air density
F_C	Centrifugal force
ω	Angular velocity
x	Radial position
a	Angular acceleration

CHAPTER 1

INTRODUCTION

1.1 General Overview

The rotor system is the rotating part of a helicopter which generates force that is necessary to lift up the helicopter. The rotor consists of 3 significant major parts such as mast, rotor blades and hub that includes blade grip. For every helicopter, it is important for a blade grip to able to hold and grip the rotor blade perfectly since it is the main component that drives the movement of the helicopter by creating lift and thrust. If the rotor blade slip away or break from the blade grip, air crash might occur since the ability to control the movement of the helicopter is now lost.

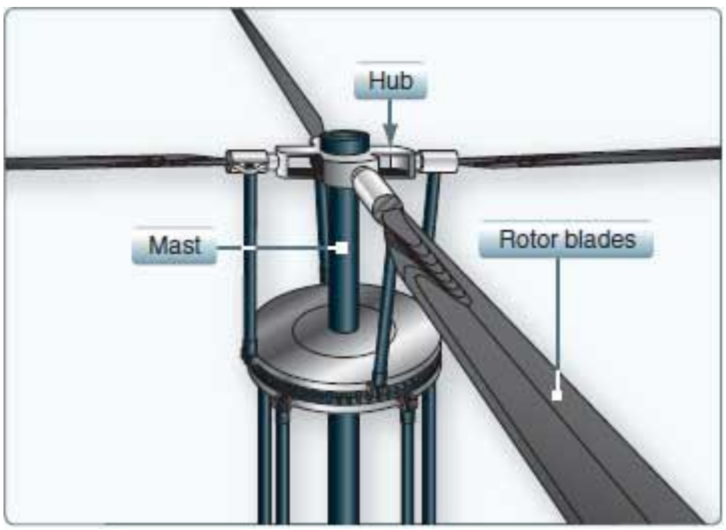


Figure 1.1: Helicopter rotor system

When rotor blade is rotating, a lot of forces will acting along the rotor blade. Disturbances such as vibration and twist will likely to happen during the motion. These disturbances are impossible to be avoided because it is a natural behavior when something is rotating, a vibration and twist will be present. However, it depends on how the rotor blade grip is able to withstand these disturbances and also as long it does not exceeds the limit of the blade grip ability, therefore it should be fine.

1.2 The Design of the Rotor Blade

The shape of the rotor blade will obviously be like an airfoil shape which can be divided into 2 types (Symmetrical and Asymmetrical). For this particular reason, an airfoil shape is vital for an aircraft because its unique shape is able to generate a lift due to movement of fluid (air) that creates pressure difference. Due to the blade grip having flat surfaces and rotor blade of having an airfoil shape, these two components will not completely fits to each other. During the initial era of flying technology, most of them were symmetrical. However, a higher L/D (Lift to Drag) ratio is possible with non-symmetrical versions.

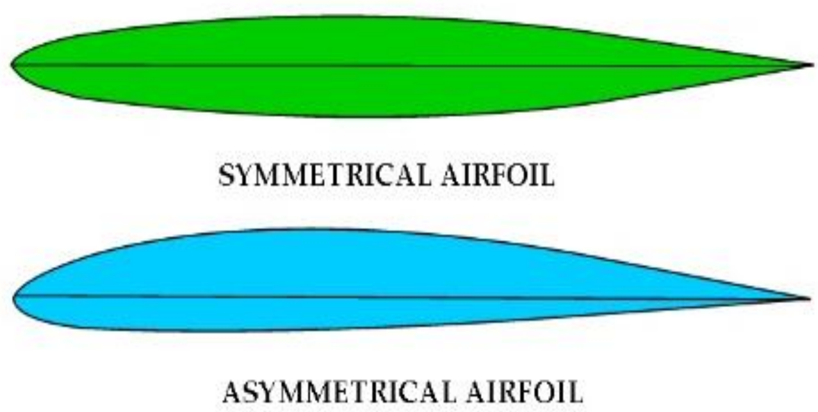


Figure 1.2: The shapes of airfoil

1.3 Problem Statement

An ultra-light helicopter had been well designed and developed by Dr. A. Halim Kadarman with several final year project students for the past several years. Through research, it is found that the shape of the rotor blade airfoil design does not match with the shape of the blade grip section. These non occupied spaces of the blade grip will affects the grip ability towards the rotor blade as the effectiveness of the grip is not be fully utilized. Therefore, these empty spaces of the blade are better to be filled in by some sort of materials as the fewer the empty space of the blade grip, the better the grip blade towards the rotor blade it will be. The few empty spaces of the blade grip has to be fully occupied so that the stress are reduced and well distributed along the rotor blade. A materials that can easily fit into these empty spaces such as epoxy and car body filler would make the rotor blade position more rigid and compact since these materials are acting as a spacer. Each of materials has different stiffness and strength thus producing different amount of blade grip effectiveness. In order to visualize the stress distributions, a simulation of the rotor blade and blade grip can be build with the aid of SOLIDWORKS software.

1.4 Objectives

- To study the effect of different materials that act as a spacer on stress distribution
- To identify the limit load of the rotor blade grip that can withstand the forces acting along the rotor blade
- To investigate how does a blade grip effectiveness with fully occupied blade grip area varies with non-fully occupied blade grip area

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Rotor Blade System

For every helicopter, in order to maintain and hold the position of the rotor blade, the rotor blade grip part must be present. This is because the blade grip is acting as a connecting part whereas the rotational power that required for the rotor blade to spin is transmitted from the engine into the rotor mast. The numbers of rotor blade grip required for a helicopter is dependant to the numbers of the rotor blade that will be used. The minimum numbers for a helicopter to operate is two and can be added. Usually, the minimum and maximum for teetering motor are two while the minimum for articulated and hingeless rotor systems are three (Yang, 2015).

There are different types of rotor that helicopters are designed with for instance, the common types are teetering rotor, articulated rotor, and semirigid rotor. The selection of number of rotor blades is chosen by careful study on how much power one can be obtained by having what kind of rotor blades. Besides, solidity ratio is necessary to be identified in order to know how much of the rotor disc area is actually one that creates lift. Moreover, the weight and complexity of having many blades is important to ease the assembly of the rotor blade to the helicopter. Typically, a less number of blades a rotorcraft has, the cheaper and simpler it is to maintain and manufacture (Yang, 2015).

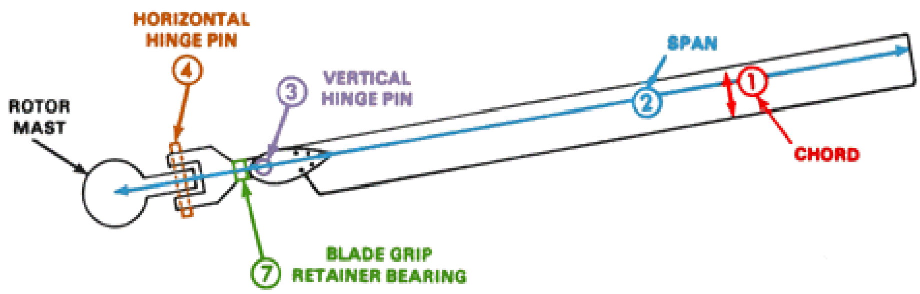


Figure 2.1: Fully Articulated Rotor System

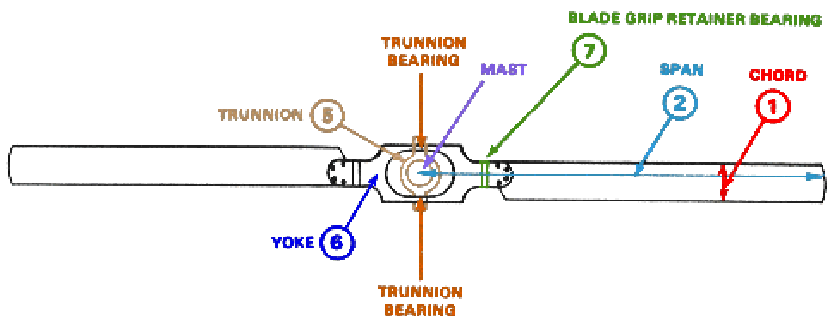


Figure 2.2: Semirigid Rotor System

2.2 Behaviour of Rotor Blade

Main rotor blades are slender, flexible beams. The rotating blades deform structurally and interact with unsteady air flow and control systems. Having a different blades connection to the rotor creates a different vibrational modes. That is to say, different creation of mode shapes are made by possessing a different degrees of freedom on the attached blades. Since a rotor blade is fixed on one end, it behaves a lot like a cantilever beam which the same thing goes to the propeller blade as stated by (Taylor, 1910).

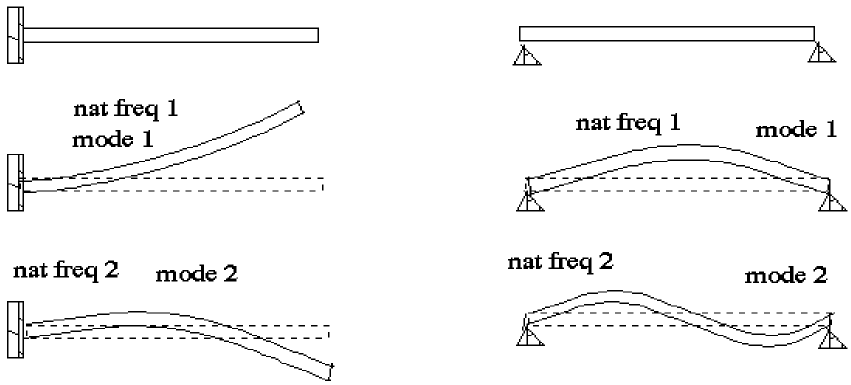


Figure 2.3: Cantilever beam (left) and simply supported beam (right) (Yang, 2015)

However, it would be a different story if the hinge can flap on where the mode shape will change. This is due to the fully articulated rotor consist lead-lag hinge and flapping hinge which enables it to flap to four directions (up, down, back and forth) that differs from the hingeless rotors. Not to be mentioned that due to the high rotational speed of the rotor blade, disturbances such as vibration will most likely to be happens. Since the blade is assumed as a beam, it can vibrates on multiple mode shapes simultaneously (Yang, 2015). The behavior of the rotor blade can be best illustrated on the figure 2.4 below.

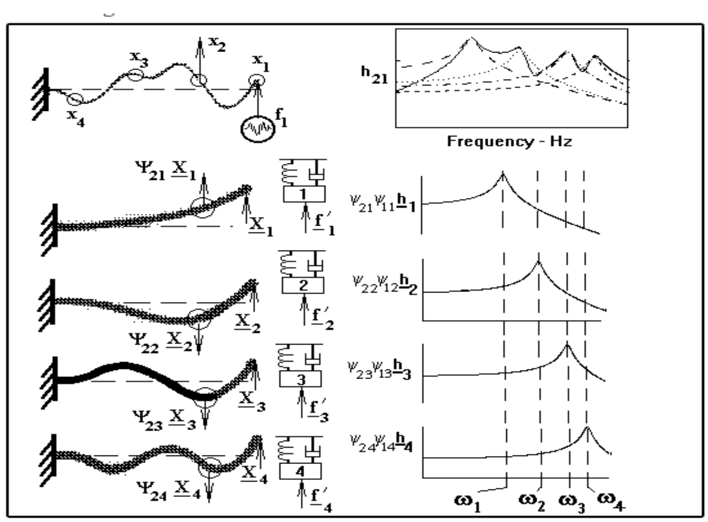


Figure 2.4: Frequency vs amplitude graph towards blade vibration (Yang, 2015)

2.3 Design Optimization

Since a vibration is not preventable, a rotor system needs to be designed and created around its rotor speed and harmonics. An excessive vibration generated by a certain harmonics that resonates may causes a serious damage to the structure and system which potentially put the whole operation into unsafe situation. To prevent that, engineers has come with a solution by analyzing the rotor system using multiple methods to generate a fan plot. From the fan plot, the rotor's in-plane and out-of-plane oscillations can be observed which from this plot, the critical frequencies vibrations that is able to damage the rotor system and ultimately lead to failure can be identified (Yang, 2015). Therefore, different types of rotor system will have a different types of fan plot as shown in figure 2.5 and figure 2.6.

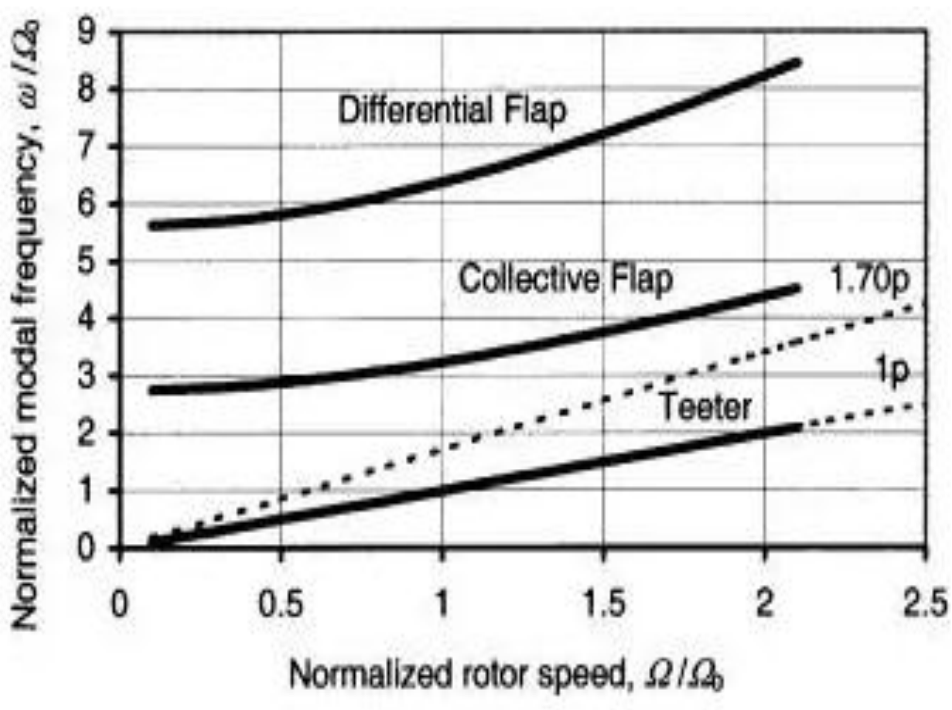


Figure 2.5: Fan plot for teetering rotor system (Yang, 2015)

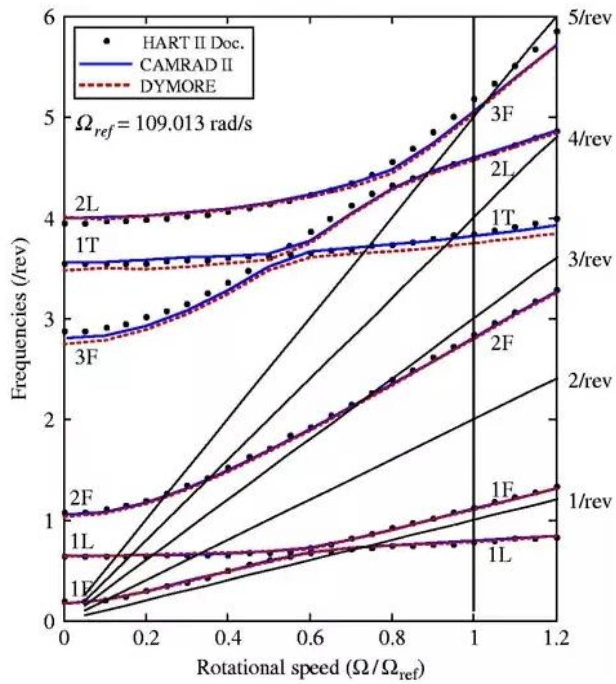


Figure 2.6: Fan plot for 4-bladed fully articulated rotor system (Yang, 2015)

Optimization methods were introduced to helicopter design from the early 1980s (MURA, 1985). Friedmann (FIEDMANN, 1991) summarized the early research of vibration reduction on helicopters using structural optimization. Celi (CELI, 1999) and Ganguli (GANGULI, 2004) provided further reviews rotorcraft design optimization(Ganguli and Chopra, 1996). A more recent review of multidisciplinary design of rotor blades can be found in Yuan and Friedmann (A. Yuan and Friedmann, 1995) and Ganguli and Chopra (Ganguli and Chopra, 1996) focused on forward flight vibratory load reduction at the hub subject to frequency and aeroelastic stability constraints. Kim and Sarigul-Klijn (Kim and Sarigul-Klijn, 2000) & (Kim and Sarigul-Klijn, 2001) developed a multi disciplinary optimization method that strived for minimum weight and vibration and maximum material strength of the blade with a constraint to avoid flutter. Soykasap (Soykasap, 1999) focused on aeroelastic optimization for composite tilt rotor blades. Ozbay (Ozbay, 2006) investigated the potential of the star cross-section to tailor extension-twist coupling for tilt-rotor blades.

The optimization model includes design objectives, constraints, assumptions, and variables. Currently, in rotor blade structural design, it is quite popular to assume a specific topology of structural components inside a given airfoil shape. This sort of assumption reduces the problem to a sizing optimization in which one varies dimensions, orientations, and locations of structural components to achieve the desired sectional properties.Some researchers did not assume any specific connectivity and designed the cross-section layout from scratch. This design concept is called “topology optimization.” (Lewiński et al., 2013). Using this concept, Fanjoy and Crossley, (Fanjoy and Crossley, 2001) minimized the distance between the shear center and point of load application for a given airfoil; but, as the authors pointed out, the computational load was significant. Arora and Wang (Arora and Wang, 2005) reviewed alternative formulations for optimization of structural and mechanical systems, including configuration and topology design, and discussed features of various formulations. Compared to sizing optimization, topology optimization provides innovative cross-sectional layouts that can meet requirements for sectional properties. However, the resulting layouts from topology optimization need to be refined by sizing or shape optimization (Lewiński et al., 2013). As computing capability increases continuously, topology optimization is attracting more attention.

2.4 Fatigue Failure Analysis

Robert C. Juvinall states that fatigue failure results from repeated plastic deformation and without repeated plastic yielding, fatigue failures cannot occur (Ku, 2007). Fatigue also most likely can occur at stepped shaft or fillet. Structural damage can occurs when a structure experience cyclic loading continuously. Bruce Boardman, Deere and Company, Technical Center in their research paper state that fatigue damage is caused by the simultaneous action of cyclic stress, tensile stress and plastic strain. The term of factor of safety is usually use in fatigue failure analysis and always use to design the fatigue of a mechanical part. Factor of safety (FOS) is the ratio of the allowable working unit stress to allowable stress or working stress (Ganguli and Chopra, 1996).

2.5 Airfoil Selection

Strivers and Rice (Stivers and Rice, 1946) investigate on aerodynamic characteristics of four NACA airfoil sections designed for helicopter rotor blades. The characteristics of airfoil that are suitable for use as rotor blade sections are pitching moment is nearly zero, low drag throughout the range of low and moderate lift, and moderate drags at high lifts. However, there are some undesirable characteristic such as, lift-curve slope, sensitivity to roughness and abrupt adverse changes in drag, and pitching moment in the vicinity of the high-lift end of the range of low drags. Strivers and Rice conclude that NACA 8-H-12 and 9-H-12 airfoil sections seem to be more promising for use as rotor blade than any other airfoil that have been tested at the NACA laboratory whereas figure 2.7 illustrates the shape of the NACA 8-H-12 airfoil.

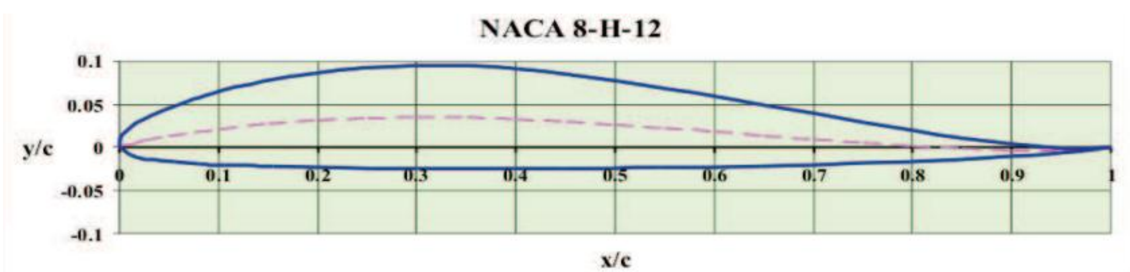


Figure 2.7: NACA 8-H-12 airfoil (Kostic, 2004)

Nowadays, the common shape for an aircraft wing and blade have to be an airfoil shape. The shape could be rectangular or even oval but it will not provide a greater lift as airfoil shape did. Different shapes of the object will be affecting the amount of lift that will be generated out as the amount of flow that is turned would varies too. It can be stated that the lift is a very complicated function of the shape. Throughout the years, wind tunnel testing is used to determine the lift coefficient corresponding to the shape model by aerodynamicists. It is still possible to create some simple shapes as mathematical equations to determine the lift coefficient can be developed by referring to two dimensional Kutta-Joukowski airfoil as guidance. The analysis has been done by a researchers and it can be concluded that the higher the flow turning, the greater the lift generated by an airfoil. The yellow lines indicate the streamlines of flow from left to right. A large amount of lift can be observed since a bigger amount of turning is making by the (NASA, 2008). The previous explanation can be best illustrated on the figure 2.8 below where the fluid flow is moving towards the asymmetrical airfoil.

Figure 2.8: Flow towards asymmetrical airfoil (NASA, 2008)

CHAPTER 3

METHODOLOGY

The process for this project must follows the flow chart that has been stated in figure 3.1. This is to prevent any missing methods that might occurs during the process and the main objective for a flow chart is as guidance to every students.

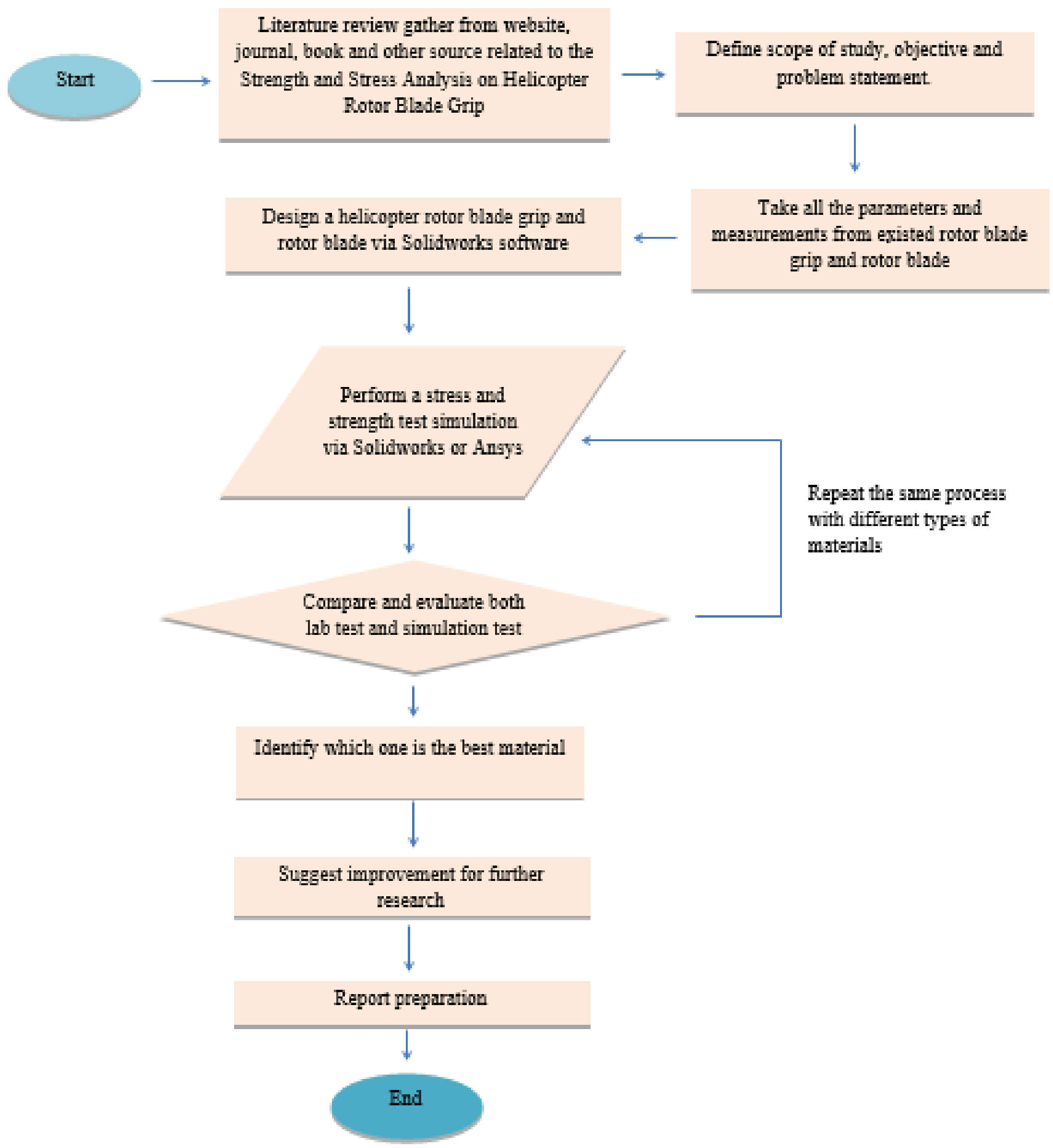


Figure 3.1: Flow Chart of the project

3.1 Rotor Blade Performance Study

Since a rotor blade is connected to the blade grip, therefore it is important for a rotor blade to be studied first. Besides, the ability to grip the rotor blade is dependent on how extreme the rotor blade will be acting due to high rpm power. The helicopter can obtain its lift by making the rotor blades turning to create a relative wind that is opposite the direction of rotor system rotation. Besides, the centrifugal force can also be created by the rotation of the rotor system, pulling the blades straight outward from the main rotor hub whereby the faster the rotation, the greater the centrifugal force, the faster the rotation. The significance from this force is it grants the rotor blades their rigidity and the strength to support the weight of the helicopter. The process can be referred to the figure 3.2

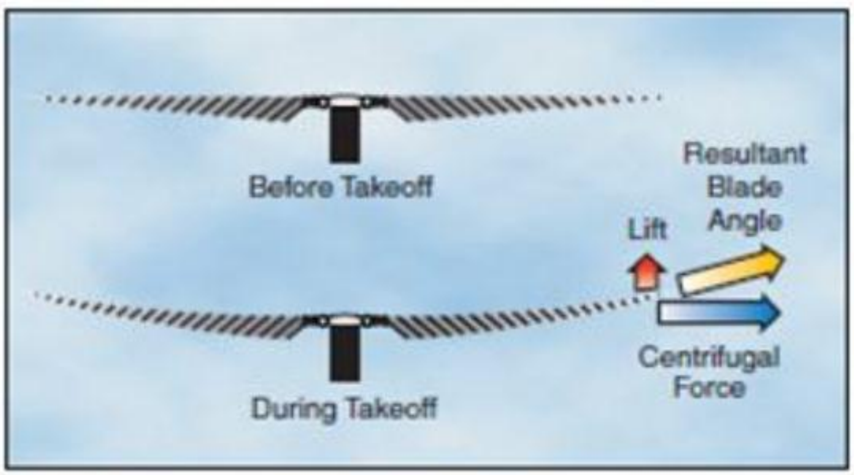


Figure 3.2: Rotor blade coning occurs as the rotor blades begin to develop lift (Guide, 2012)

During vertical takeoff, two main forces are acting at the same time which is the centrifugal forces are acting outward and perpendicular to the rotor mast and the lift which is acting upward and parallel to the mast. Due to different axis of forces, a resultant force is created towards the resultant blade angle direction that creates a conical path instead of remaining in the plane perpendicular to the mast.

The calculation of the stresses in a blade is extremely complicated, due to the fluctuating load, its distribution over the blade surface is difficult to calculate, and the geometry of the blade is rather complex. Therefore, simplified method was used to calculate the stresses in the blade and applied parameter for maximum case scenario. The simple method is based on following assumptions:

I. The blade is assumed to be a cantilever fixed (clamped joint) at the root.
II. The maximum rotational speed applied which would be 500 rpm (taken from previous research student project).
III. The lift force, L and centrifugal force, F_C on the blade is assumed to act through the surface of each section (as stated below).
IV. The value of lift coefficient, C_L mass air density, ρ and blade sectional mass, m would be applied are 0.85 (taken from previous research student project), 1.225 kg/m^3 and 0.273kg respectively
V. Sectional length and chord length would be 0.287m and 0.132m respectively.

Let x be the radial position of each sections, and the blade rotates at a ω (500 rpm) when developing lift forces, L.

The related formulas used are shown as follow.

$$L = C_L \frac{\rho}{2} v^2 A \quad (1)$$

$$F_c = ma \quad (2)$$

$$v = x\,\omega \quad (3)$$

$$\text{A} = \text{sectional length x chord length} \quad (4)$$

$$a = x\,\omega^2 \quad (5)$$

Figure 3.3 shows plot of the lift forces acting at corresponding radial positions from the blade root to the tip while figure 3.4 shows the plot of section centrifugal force also acting from the blade root to the tip. These force values were input into the FE model for the analyses.

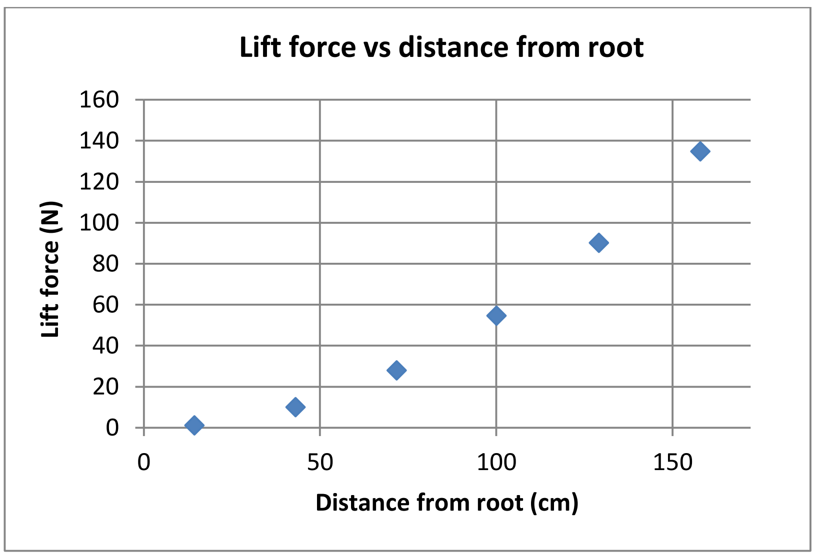


Figure 3.3: Graph of lift against distance from root

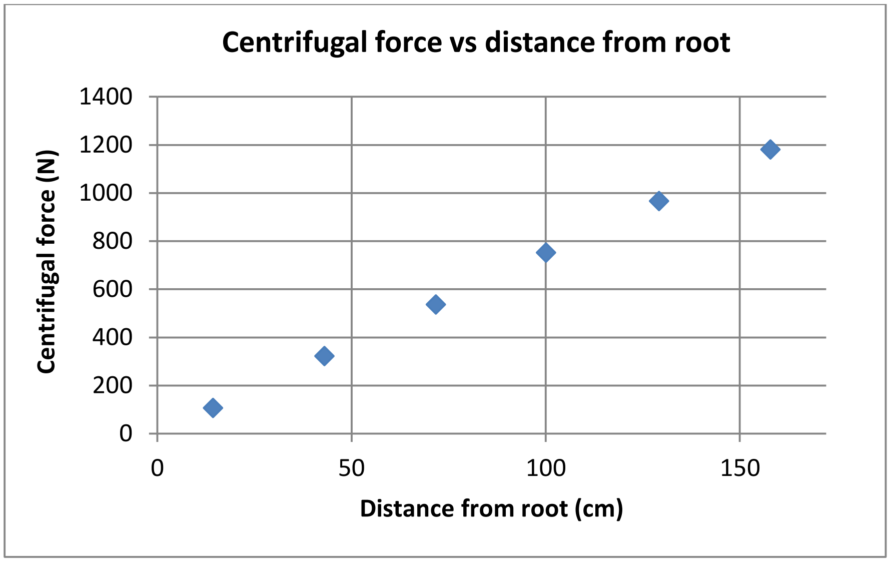


Figure 3.4: Graph of sectional centrifugal force against distance from root

3.2 Modelling and Analysis

In performing the calculations, the Finite Element (FE) Method was employed. And the software SOLIDWORKS 2018 was utilized for the FE modelling and analysis.

3.3 Configuration and Materials

Figure 3.5 shows the picture of an actual NACA 8-H-12 rotor blade with a uniform chord length of 5.25 inches which was used as reference for the 3D analyses that were designed in SOLIDWORKS 2018 software. 6063-T6 aluminum is the material of the rotor blade with aluminium rods inside of the airfoil leading cell hole; realizing the best compromise between strength, extrudability, and cost; the thin-skinned cross section of the blade precludes the use of higher strength aluminum. Besides, aluminium is commonly used among helicopter industry as it possess an ability to withstand a greater stress and the mass density for an aluminium is quite low making the rotor blade as light as possible.

Figure 3.5: Model of rotor blade and its cross section

Material properties for aluminium used.

Table 3.1: Properties of Aluminium Alloys (6063-T6)

Properties	**Value**
Density (kg/m^3)	2700
Yield Strength (MPa)	215
Ultimate Tensile Strength (MPa)	240
Elastic Modulus (GPa)	69
Shear Modulus (GPa)	25.8
Poisson's Ratio	0.33

An aluminium cylindrical blade grip is used in purpose of holding and gripping the rotor blade. This symmetrical blade grip has a multiple holes at the gripping area that allows for a bolt to make a connection between the rotor blade grip and rotor blade, preventing them from moving each other. The space on the gripping area must be sufficient or less so that the rotor blade will fits between it, hence it is important for a blade grip to be designed carefully according to the size of the rotor blade. The properties of the rotor blade grip can be referred to the table 3.2 while figure 3.6 shows the actual rotor blade grip that was used in this project.

Figure 3.6: Rotor blade grip

Table 3.2: Properties of Aluminium

Properties	**Value**
Density (kg/m^3)	2810
Yield Strength (MPa)	505
Ultimate Tensile Strength (MPa)	570
Elastic Modulus (GPa)	720
Shear Modulus (GPa)	26.9
Poisson's Ratio	0.33

A carbon steel bolt (AISI 1045) is used to assemble the parts between rotor blade and the blade grip. This carbon steel bolt is known by a good machinability, good weldability and grant a high strength to the connecting operation. A nut must be present together with a bolt since it is required to fasten multiple parts together. Without the nut, the bolt is unable to fasten parts properly as the bolt position is not been constrained enough. Moreover, the bolt thread size is crucial in determining the size of the nut since a wrong size of nut would not be able to mate into the bolt. The bolt thread size can be determined by using few equipments such as calliper, a pitch gauge and thread identification guide. The first step to determine the bolt thread size is to identify the thread category. From the figure 3.7, the thread category is divided into two which is male and female.

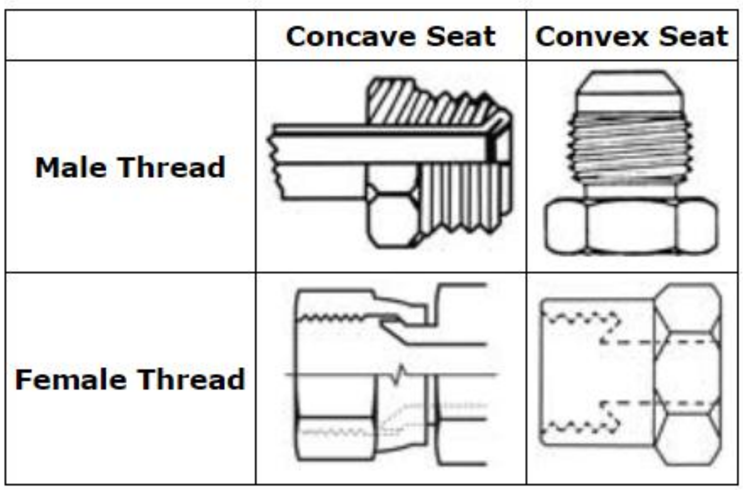


Figure 3.7: Types of thread and its partner

By using a calliper, a nominal diameter of the bolt can be obtained whereas the thread pitch can be identified by using a pitch gauge. Gathering these three information (thread gender, nominal diameter and thread pitch) leading to the last step which is referring to a thread identification guide. This identification guide will assist us in identifying the thread size based on the three previous information. There are so many thread identification guide available from the hardware stores and the internet but most of them are quite similar. The properties of the bolt can be referred to the table 3.3 while figure 3.8 shows the actual bolt that was used in this project.

Figure 3.8: Carbon Steel bolt

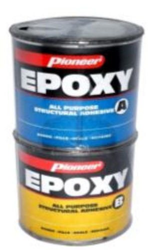
Table 3.3: Properties of AISI 1045

Properties	**Value**
Density (kg/m^3)	7850
Yield Strength (MPa)	530
Ultimate Tensile Strength (MPa)	625
Elastic Modulus (GPa)	205
Shear Modulus (GPa)	80
Poisson’s Ratio	0.29

Figure 3.9: Thread pitch gauge

There are three materials that has been used and applied to the unfilled area of the blade grip such as aluminium, epoxy and car body filler through SOLIDWORKS simulation. For now, only car body filler is used to fill the gap at the lab since we wanted to see first which material that will act as the best spacer from the simulation. The spacer materials and its properties are shown in the table 3.4 below.

Table 3.4: Materials of the spacer

Type of materials	**Properties**	
 1) Epoxy	Density (kg/m^3)	1100
	Compressive Strength (MPa)	104
	Ultimate Tensile Strength (MPa)	28
	Elastic Modulus (GPa)	2.415
	Poisson's Ratio	0.35
 2) Car body filler	Density (kg/m^3)	1120
	Compressive Strength (MPa)	30
	Ultimate Tensile Strength (MPa)	19
	Elastic Modulus (GPa)	0.79
	Poisson's Ratio	N/A

 3) Aluminium Liquid	Density (kg/m^3)	1580
	Compressive Strength (MPa)	58
	Ultimate Tensile Strength (MPa)	22.2
	Elastic Modulus (GPa)	1.78
	Poisson's Ratio	N/A

3.4 Finite Element Modelling

Modelling of the rotor blade system was done using SOLIDWORKS 2018. The first model is the rotor blade and it is necessary to sectionalize the blade at various radii as shown in figure 3.10.

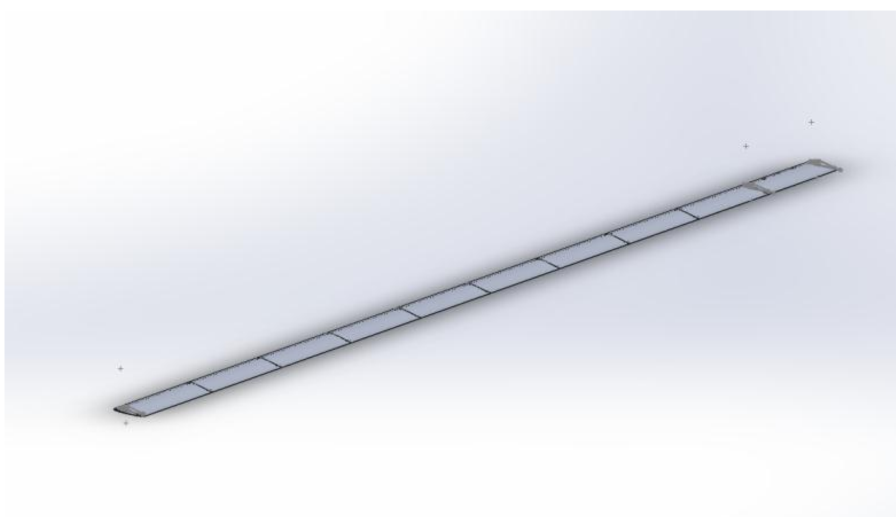


Figure 3.10: Shown sections on rotor blade

The geometry of the airfoil curve (NACA 8-H-12) can be obtained from online website (airfoilstools, 2019). The geometry of the airfoil is in a coordinate form which required us to download the selig format dat file first. Followed by that, the information from selig format dat file data has to be converted into excel so that all of these coordinates can be imported to the SOLIDWORKS. The dimensions of the blade is obtained through direct email from the supplier. The data information of the NACA 8-H-12 airfoil can be referred to figure 3.11 and the rotorblade dimensions can be obtained from figure 3.12.

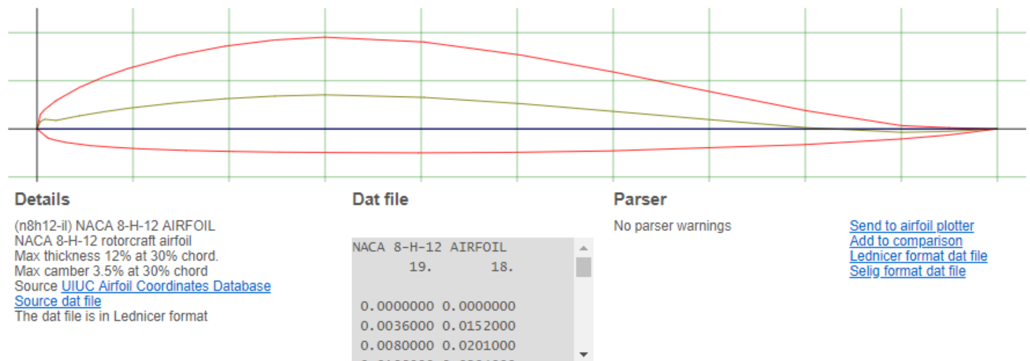


Figure 3.11: The details of the NACA 8-H-12 airfoil

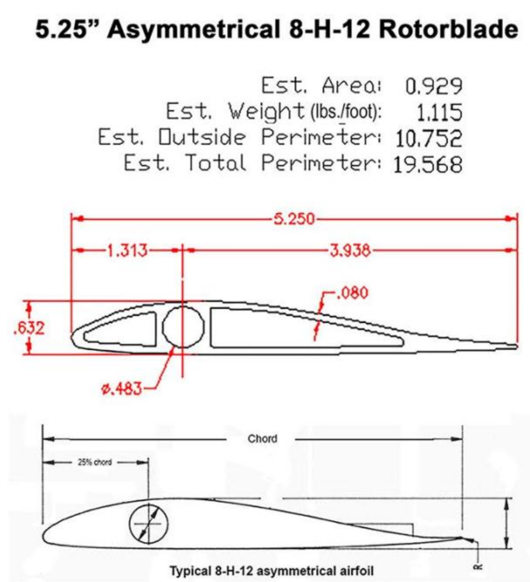


Figure 3.12: The side view dimensions of the NACA 8-H-12 airfoil

For the remaining parts, a dimensions has to be taken first from the lab before modelling them inside the SOLIDWORKS software. Equipments such as measurement tape, weighing scale, ruler and callipers are used to ease the measurements process. The figures 3.13, 3.14 and 3.15 show the 3d model of the blade grip, bolt and the whole rotor system that has been done through SOLIDWORKS software respectively. Besides, figure 3.17 shows the condition of spacer material application towards the rotor system while figure 3.18 shows the absence of spacer material application towards the rotor system.

Figure 3.13: Rotor blade grip