DEVELOPMENT OF A CONTROL FLAP FOR THE ULTRALIGHT HELICOPTER

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ABSTRACT

The purpose of this project is to develop control flap for ultralight helicopter based on the concept of changing the airflow. The structure of the control flap was analyzed based on the extreme condition. The control flap consists of two materials which are Aluminum (2014-T4) and PF. The maximum Von Mises stresses obtained from the simulation was 38.75MPa. The results obtained from FEA do not exceed safety factor of 1.5 based on airworthiness requirement. Thus the structure of control flap is assumed to be safe and will not fail. For verification of the FEA software, a simple case of deflection of beam and plate were conducted and compared with the theoretical calculation. The results from both of theoretical and FEA were compared and the differences are 3.72% and 1.48% for beam and plate respectively. The results are acceptable since the differences are lower than 5%.

PEMBANGUNAN FLAP KAWALAN UNTUK HELIKOPTER ULTRARINGAN

ABSTRAK

Tujuan projek ini adalah untuk membangunkan kawalan flap untuk helikopter ultraringan berdasarkan konsep menukar aliran udara. Struktur flap kawalan dianalisis berdasarkan kepada keadaan yang melampau. Kawalan flap terdiri daripada dua bahan-bahan iaitu Aluminum (2014-T4) dan PF. Maksimum tegasan Von Mises diperolehi daripada simulasi adalah 38.75MPa. Keputusan yang diperolehi daripada Analisis Unsur Terhingga (AUT) tidak melebihi faktor keselamatan 1.5 berdasarkan keperluan kelayakan terbang. Oleh itu struktur kawalan flap dianggap selamat dan tidak akan gagal. Untuk pengesahan perisian AUT, kes yang mudah untuk pesongan rasuk dan plat telah dijalankan dan dibandingkan dengan pengiraan teori. Keputusan daripada kedua-dua teori dan AUT dibandingkan dan perbezaan adalah 3.72% dan 1.48% bagi rasuk dan plat. Keputusan yang boleh diterima, kerana perbezaan adalah lebih rendah daripada 5%.

ACKNOWLEDGEMENTS

Alhamdulillah and praise to Allah the al-Mighty because with His blessings, I have completed my final year project and thesis writing. Without His guidance, I will not be able to complete this thesis on time and again I am truly grateful that I managed to finish it on time.

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DECLARATION

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

MOHAMMAD SHAIR BIN MOHD ZAIN
Date:

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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STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organizations.

MOHAMMAD SHAIR BIN MOHD ZAIN
Date:

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NOMENCLATURE

u_d	:	Distortion energy of actual case [Joule]
$u_{d,sim}$	:	Distortion energy of simple tension case [Joule]
σ_v	:	Von Mises stress [N/m^2]
σ_y	:	Yield stress of material [N/m^2]
$Max\ y$	:	Maximum deflection in Y-axis [mm]
ω_a	:	Unit load (force per unit length) [lb/in]
l	:	Length of the beam [in]
E	:	Modulus of elasticity of Aluminum [Psi]
c	:	Moment of inertia [in^4]
b_o	:	Outside base diameter [in]
h_o	:	Outside height diameter [in]
b_i	:	Inside base diameter [in]
h_i	:	Inside height diameter [in]
a	:	Plate's length [in]
b	:	Plate's width [in]
r_m	:	Median radius [in]
r_i	:	Inner radius [in]
r	:	Radius [in]
q	:	Load per unit area [lb/in^2]

t	:	Thickness of plate [in]
y_b	:	Maximum deflection [mm]
A	:	Area of plate [in^2]

CHAPTER 1

INTRODUCTION

1.1 General overview

Generally, ultralight helicopters look very similar to the regular helicopters, except they are built lighter with much simpler construction. Besides the cost of manufacturing also much lower than normal helicopter. This ultralight helicopter is used for recreation. In addition, it can be used to patrol farm or for photographic purpose. Ultralight helicopters usually have one or two seats and no cockpit. From dimension's aspect, the diameter top rotor blade usually in the range of 12 to 25 feet and the speed might not as fast as regular helicopter. They also have a limited range and load capacity but still fully functional.

1.2 Control System

As for normal helicopter, its control system use swashplate to transmit pilot's command from the non-rotating fuselage to the rotating rotor hub and main blades. The swashplate is use to control the movement of helicopter in pitch and roll. Its mechanism is to control the cyclic and collective pitch of the rotor blade as shown in Figure 1.1 below:

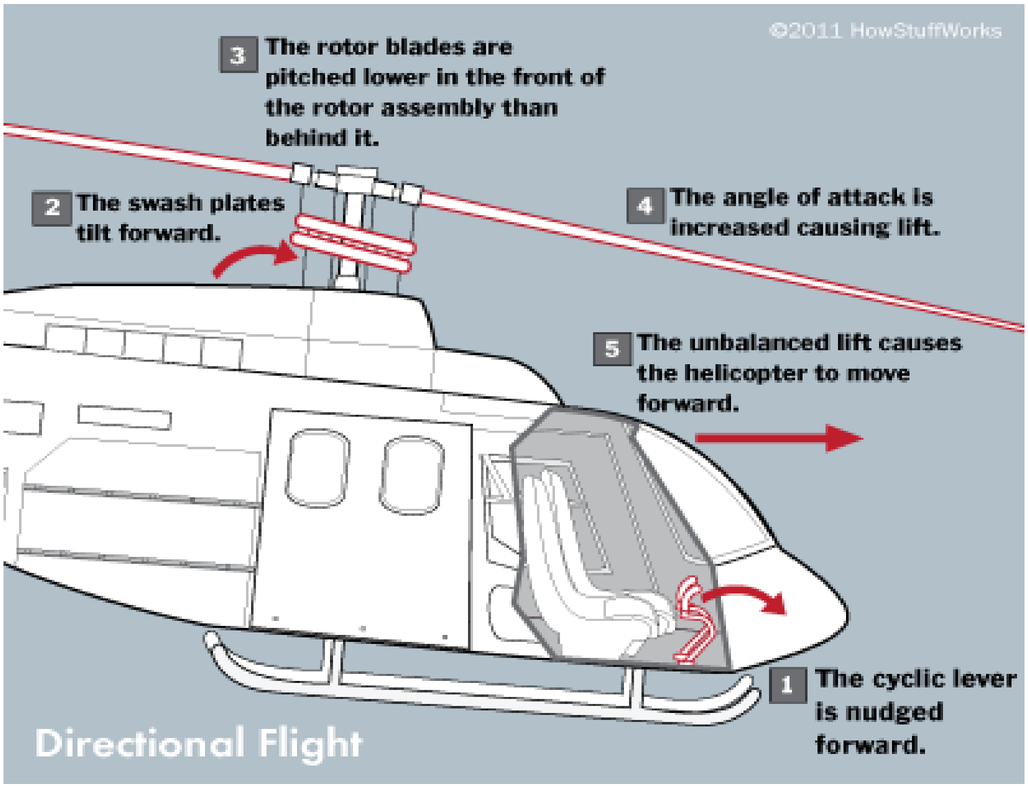

Figure 1. 1: Swash plates function **[1]**

Swashplate consists of two main parts which are the stationary and rotating swashplate. The stationary swashplate is able to move vertically and tilt in all directions while rotating swashplate is mounted on the stationary swashplate by a bearing. [2] This rotating swashplate is rotating along with the rotor mast. [1] For forward flight, the nose down moment created about the center of gravity is needed to tilt the entire aircraft. The nose down moment can be created by flapping the rotor down over the nose of aircraft. [3] Figure 1.2 and 1.3 is shown below to illustrate the part of swashplate.

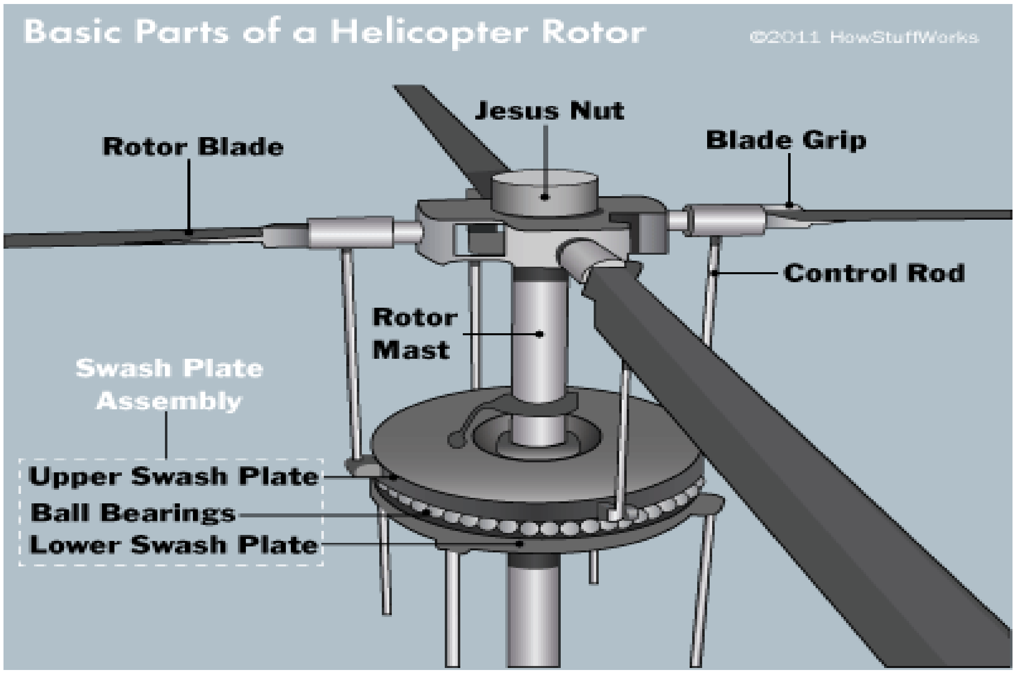

Figure 1. 2: Swashplate’s part **[1]**

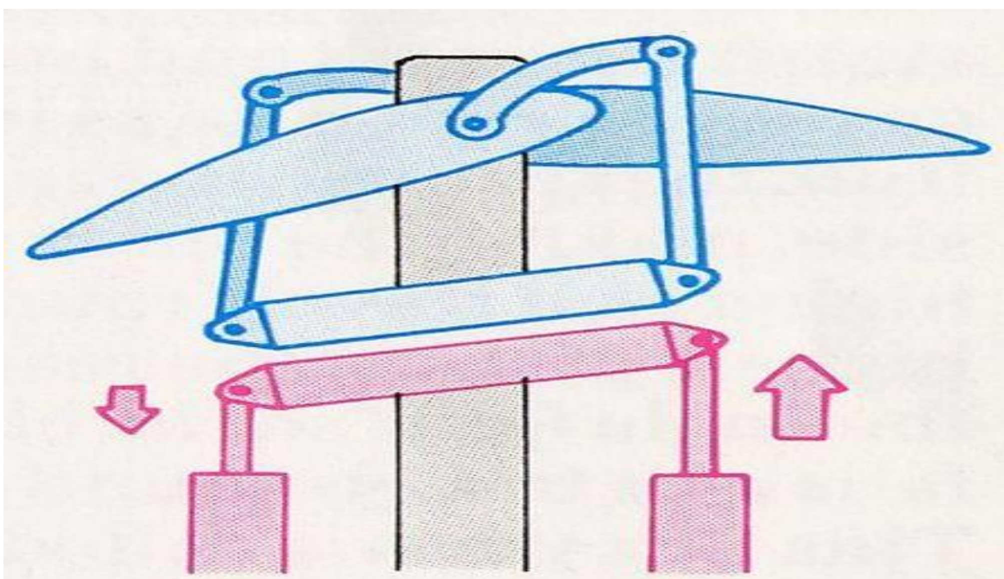

Figure 1. 3: Stationary and Rotating swashplate **[2]**

However, this swashplate causes high manufacturing cost beside its complicated mechanism for simple ultralight helicopters, another research is conducted for a simpler control system with the same mechanism as the swashplate.

1.3 Problem Statements

Through many research, it is found that the ultralight helicopter need the control flap in order to perform maneuver very well and to make it stable for flying safely. Hence, the model of the control flaps need to be designed properly as it should be fully functional during flight time. The analysis of the model also will be computed to ensure the structure will not fail and safe for flying. In this thesis, the requirement for modelling the control flap for ultralight helicopter including the analysis and fabrication is considered.

1.4 Objectives of Research

The research work described in this thesis is performed based on the following objectives:

(i) To design control flap for ultralight helicopter.

(ii) To carry out structure analysis of control flap component of the ultralight helicopter.

(iii) To fabricate the complete model of control flap for ultralight helicopter.

1.5 Thesis Layout

This thesis consists of 6 chapters where Chapter 1 will give a general overview of the ultralight helicopter, objectives and problem statement of this research and study. Chapter 2 consist of literature review that will explain about the research of ultralight helicopter through the reading of journal, books, websites, and other sources. Next, Chapter 3 will give a brief steps and procedures that has been done throughout this research while Chapter 4 will give the explanation of the results obtained. Besides, the discussion also takes place in Chapter 4. Lastly, Chapter 5 will focus on conclusion about this study and research. Recommendation and future work also inserted together in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 General Overview of Ultralight Helicopter

Ultralight helicopters are just the same as regular helicopters, except they are built lighter with much simpler construction. The helicopter by default are much more complicated vehicles than airplanes. However, ultralight helicopter anyways created by homebuilt industry are basically simplified models and perfect for building in personal workshop. The price of homebuilt ultralight helicopters ranging from $20,000 to $25,000 but if compared to regular helicopter, it is nothing. [4] Ultralight helicopters usually have one or two seats and no cockpit. From dimension's aspect, the diameter top rotor blade usually in the range of 12 to 25 feet and the speed might not fast as regular helicopter. They also have a limited range and load capacity but still fully functional.

One of the ultralight helicopter is mosquito AIR helicopter. Its airframe is made up of Aircraft Grade 6061-T6 aluminum and utilizes a simple triangulated structure with straight tubing throughout to maximize strength, reduce weight and simplify construction. The tripod legs are equipped with small skid pads to help reduce lateral movement during engine run-up to lift off stage. The airframe also consists of handling wheels for easy ground movement. [5] Mosquito AIR figure is shown in Figure 2.1 below:

Figure 2. 1: Mosquito AIR

From another perspective of view, ultralight helicopter is to be said that the ultimate form of ultralight flight which is fast, nimble and able to go almost anywhere. In addition, ultralight helicopters way more economical than normal helicopter. [6] Plans and kits are usually available for purchase on the internet. However, it will cost more than building one from scratch. Another ultralight helicopter is MINI-1 which is low-cost and simple design of flying machine. It can take off and land vertically with its 13-foot rotor and capable of reaching top speed of 60 mph. It is the most compact personal helicopter in the world and the simplest to build and fly. Besides, its control system also highly simplified by eliminating swashplate and other complex mechanism. Its Aluminum tubing frame is designed for the highest strength per weight ratio. [7] MINI-1 ultralight helicopter is illustrated as Figure 2.2 below:

Figure 2. 2: MINI-1 Ultralight Helicopter

2.2 Helicopter Aeromechanics

Rotor modelling should be designed by the combination of fundamental of mechanics and aerodynamics. Besides, the function of main rotor is to be able to support the aircraft's weight with the force generated. The main rotor blade also provide control for helicopter mainly in pitching up and down and also for turning. It transfers the aerodynamic forces and moments generated from the rotating blade to the non-rotating blade. The blade's speed is kept uniform by a shaft torque from the engine. The hinges are used on blade roots to allow free motion of the blade. Basically, these hinges are used to makes the blades act like flap. This flap will induce different lift that mostly will be used in climbing up and descending. In order to climb up, the blades will tilt into positive angle of attack and hence create more lift force to ascend while to descend, the blades will tilt to a negative angle of attack. [8] The mechanics of flap hinges is shown in Figure 2.3 below:

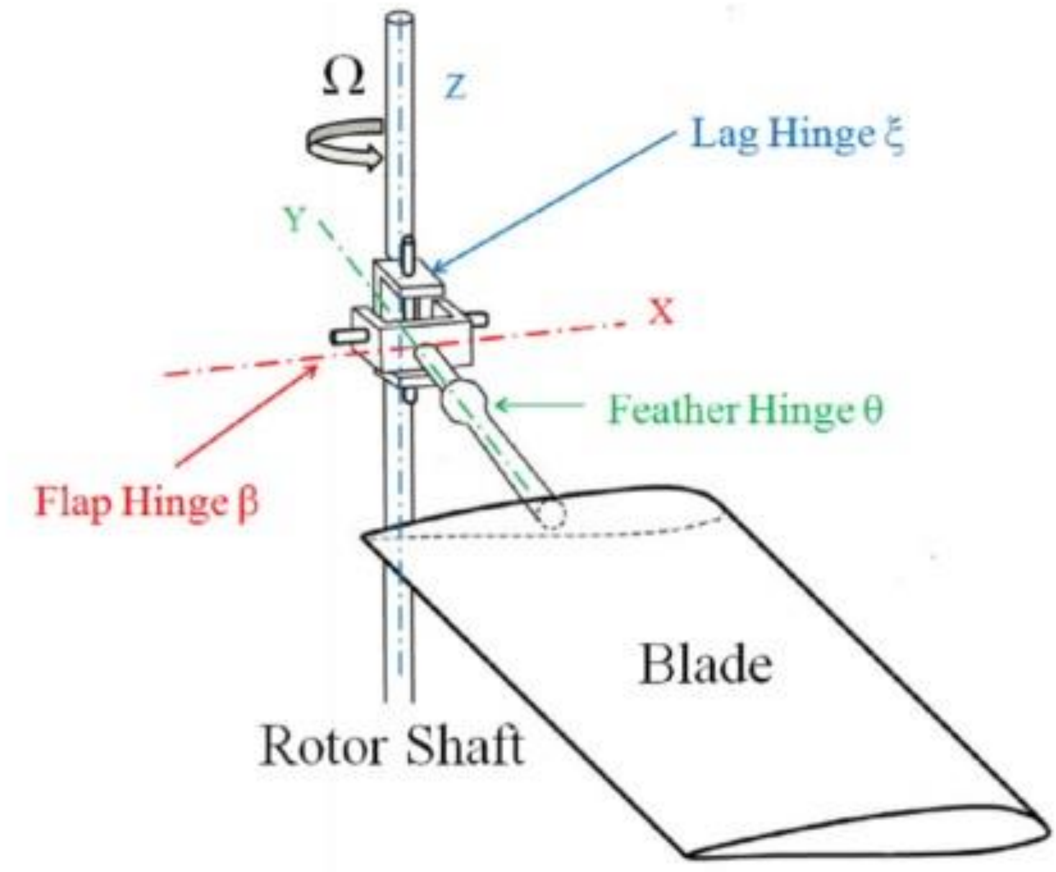

Figure 2. 3: Flap hinge

Hinges that being mounted by the blades allow the three angular degrees of freedom. Figure 2.4 below is shown to illustrate clearly the arrangement of hinges. The flapping motion contain of blades and shaft that rotates in up and down direction in a plane. The flapping angles is known as positive when the blade moves upward. Besides, high speeds rotation of flapping blade will induce large Coriolis moments in the plane of rotation, so the lag hinge is produced to lessen the moments. [9]

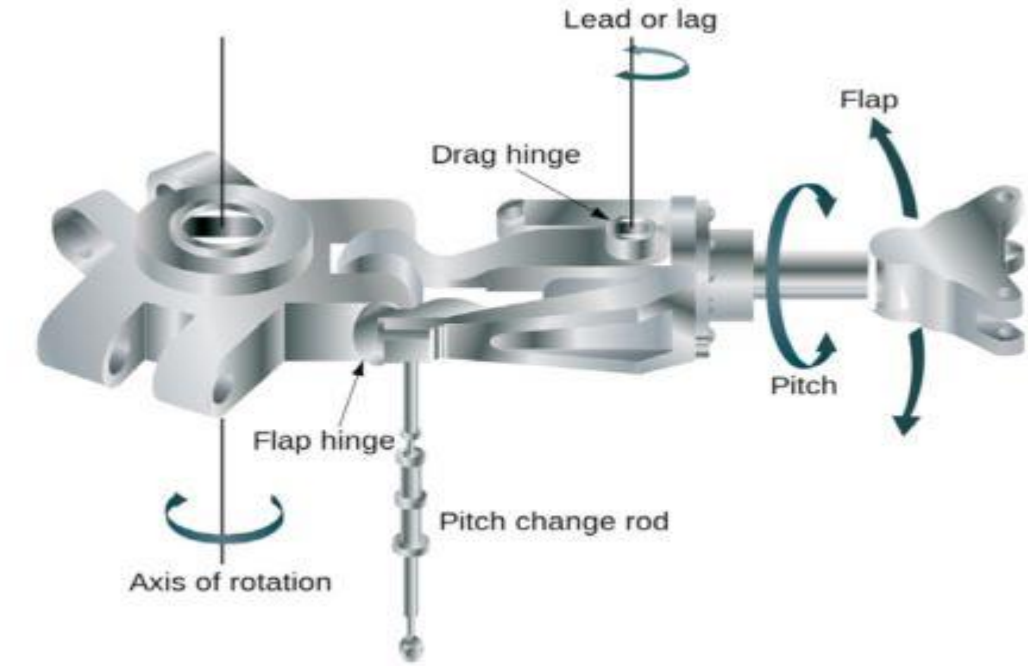

Figure 2. 4: Arrangement of hinges

2.3 Control Flap Concept

The main idea of control flap come from the imbalance pressure. The rotation of rotor blade will generate downwash force which mean the airflow moves in downward direction as shown below in Figure 2.5:

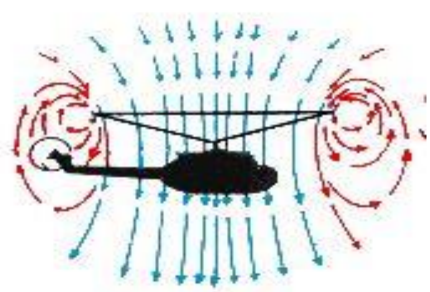

Figure 2. 5: Downwash of helicopter **[10]**

The plates of control flap are used to create the imbalance pressure by lessening the downwash force at one side as shown in Figure 2.6. Therefore, the imbalance pressure of downwash forces will make the aircraft tilt according to the desired direction. The number of plates used mostly are four for tilting in forward, backward, to the right and to the left. Apart from using control flaps alone, the weight shifting principal also is combined to make the helicopter's directional moves work successfully. The advantage of this control flap design is the control mechanism is simplified as no cyclic pitch as in the conventional helicopters and easier for pilot to control the ultralight helicopter. [11]

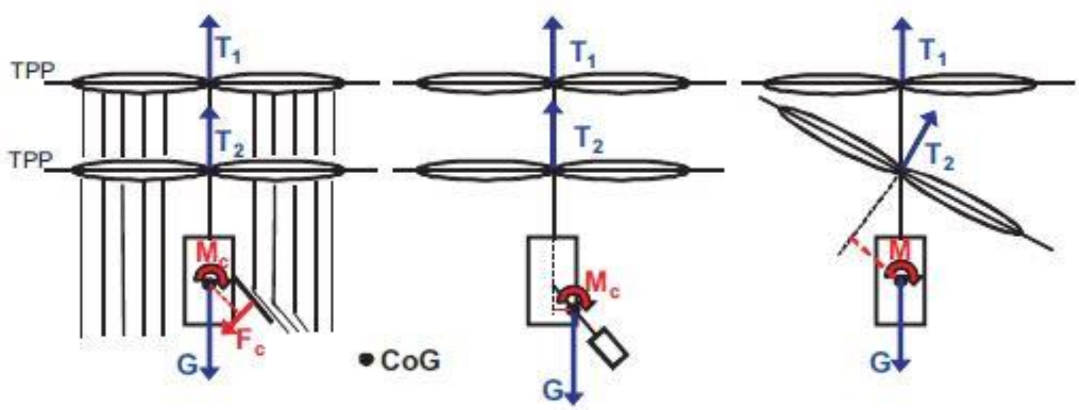

Figure 2. 6: Airflow change **[12]**

Another concept of control mechanism used is with respect to gravitational force direction which mean is by tilting the vertical shaft backward and forward and to either side and in other word by tilting the blade tips. [13] From different of invention also found the control mechanism used was by mounted the control bar to the frame and grasped by the pilot which positioned in hanging glider. In this position, the pilot be able to control pitch and roll directions of the ultralight helicopter by manipulating the control bar. In order to control the helicopter, the pilot needs to use weight shifting principal by shifting his center of the gravity relative to the aircraft's center of gravity while grasping the control bar to control the helicopter. [14] Another research regarding the control mechanism also focus on weight shifting method. With this method, the usage of swashplate can be eliminated such as for small helicopter. This method is focusing on shifting the center of gravity of an active structure to tilt the complete rotor support including motor. [15] [16]

2.4 Von Mises Stress

Von Mises stress is used to define the yielding of materials under any loading condition. In other word, to determine whether the structure undergoes plastic deformation or permanent deform. A design will fail if the Von Mises stress values of material greater than its strength of material. The concept of Von Mises stress is from the comparison between two kinds of energies [17] which are distortion energy in the actual case and distortion energy in a simple tension case. If the distortion energy from the actual case higher than the simple case, the design or structure will fail. [18] Only shape of materials change during pure distortion instead of volume.

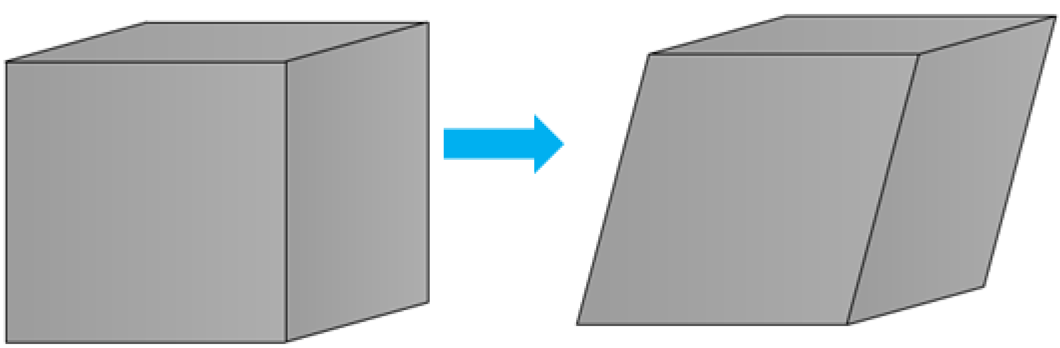

Figure 2. 7: Pure distortion

For three-dimensional case, the distortion energy required u_d is given as the Equation 2.1 below:

$$u_d = \frac{1+v}{3E}\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right] \tag{2.1}$$

While for simple tension case at the time of failure is given as:

$$u_{d,sim} = \frac{1+v}{3E}\ \sigma_y^2 \tag{2.2}$$

The equation of Von Mises stress is denoted as:

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} = \sigma_v \tag{2.3}$$

Therefore, the distortion energy failure theory equation is denoted as:

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} \geq \sigma_y \tag{2.4}$$

Thus, the failure condition can be simplified as:

$$\sigma_v \geq \sigma_y \tag{2.5}$$

CHAPTER 3

METHODOLOGY

This chapter will present all of the design and analysis used for the control flap including the steps done in fabrication process. The methodology started by gathering all the relevant data that related to the scope of study which is ultralight helicopter. The data are achieved from journals, websites, books or any other open sources. Next, the objectives and problem statements are defined. For the next phase, the design created is selected to be modelled and analyzed. If the result obtained is positive, which mean success, the process is continue to fabrication process but if the analysis's result is negatives, the fabrication process cannot be done. The model is designed again in SolidWorks and checked for the error to be analyzed again. The overview of methodology that has been briefly told is shown in the flowchart below:

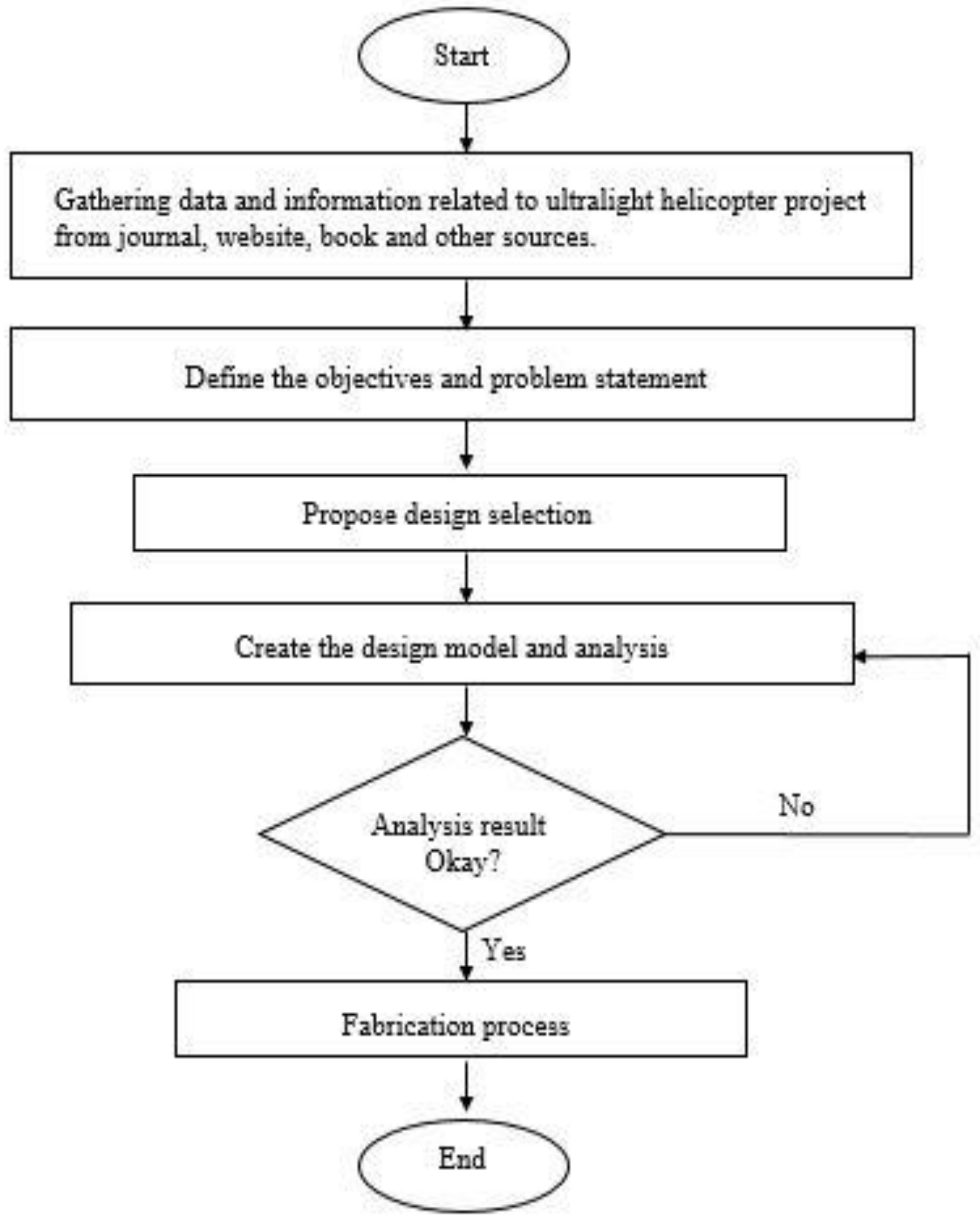

Figure 3. 1: Overall flowchart process

3.1 Conceptual Design

The research began with gathering all the data by doing literature review about ultralight helicopter. All the data is collected from many sources such as journals, books, articles and also from the websites. After the field of study is determined and the job scope is known, the objectives and problem statements has been issued as described in Chapter 1. Essentially, the conceptual design regarding control flap is identified. The main idea for control flap is illustrated as shown in Figure 3.1 below. The control flap consist of four pieces of plates which will be hold at the near end of two cross beams. [19] The plates will be hold by a cable that connected to the controller and hence also contributed in trigger the plates to be effective and ineffective.

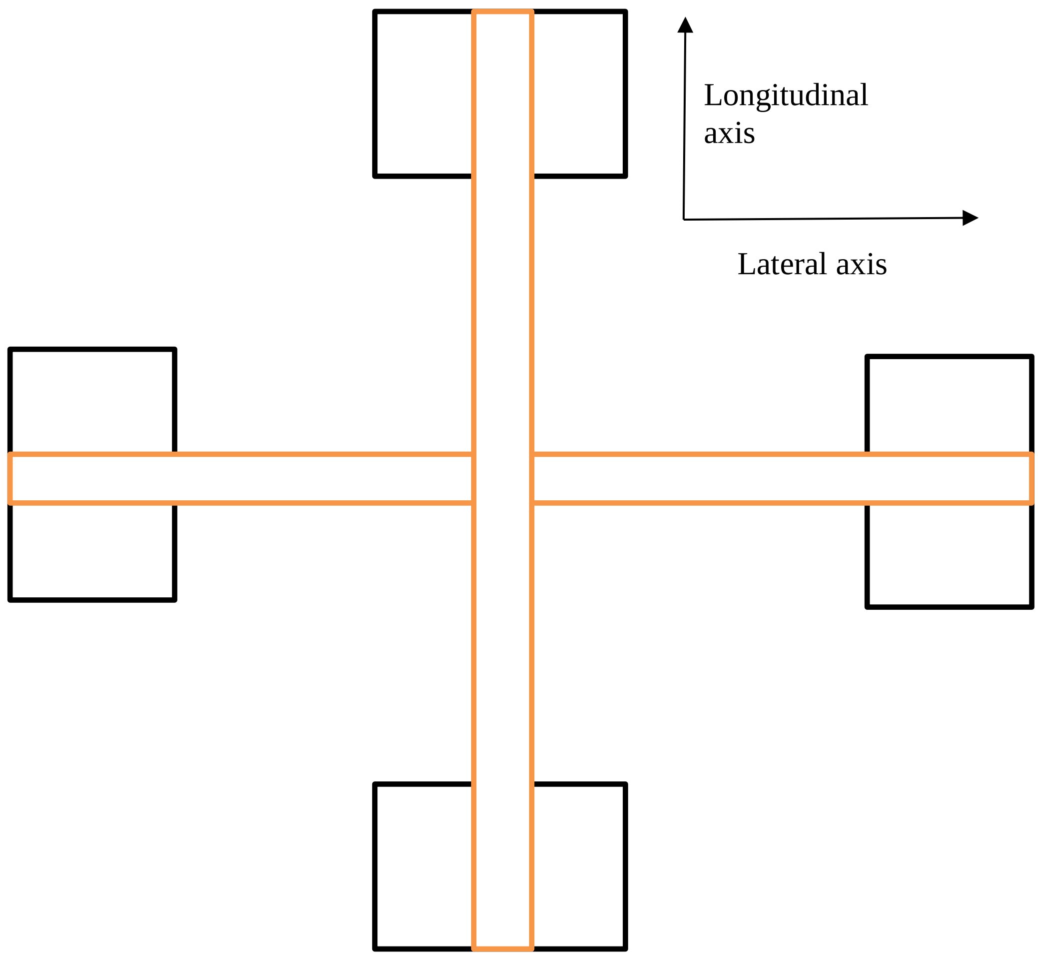

Figure 3. 2: Top view of conceptual design

Figure 3. 3: Front view during effective

Figure 3. 4: Front view during ineffective

From the front view of the control flap shown in Figure 3.3 and Figure 3.4 above, the effective takes effect during the plates condition was in closed condition while for ineffective effect was during open condition. The mechanisms of the control flap basically based on imbalance pressure that acts on the plates. During flying, downwash forces created by the rotor blade of ultralight helicopter. In order to tilt the ultralight helicopter, the plates will be closed which means the effective conditions will takes place. As the downwash forces become imbalance between the right and left, the ultralight helicopter will tilt towards the effective conditions which having less downwash forces.

Before the model was designed in SolidWorks software, the overview flow from the modelling to analysis was created. The parameters of the plates of control flap was gathered. The dimension for all parts that needed for drawing was taken properly. Then, all of the parts was drawn in the SolidWorks as parts. After that, all of the parts then were assembled together. The collision need to be checked whether it occur or not. Next, before the analysis takes place, the materials were applied for every part. The force was applied to the surface and the fixed support was determined. After that, the analysis was run. If the result obtained positive, compare the results from the simulation with the tensile strength of the materials and if the result obtained negative, the model should be repaired, reassembled and checked for the collision. After comparing the result has been done and the results satisfied the requirement, the analysis is done as the control flap be able to support the systems. The flowchart of the analysis process is shown in Figure3.5.

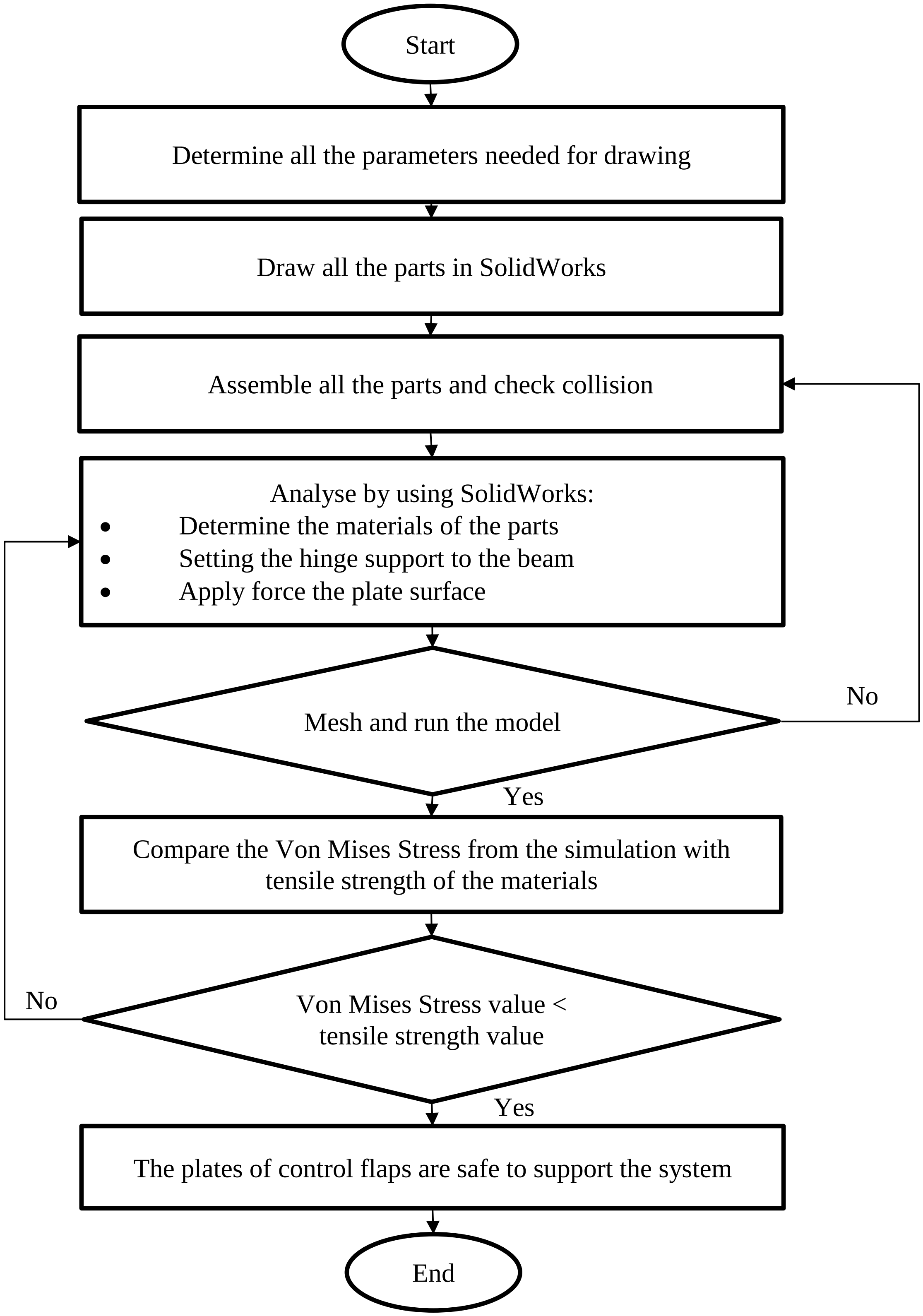

Figure 3. 5: Flowchart of the analysis

3.2 Control Flap

3.2.1 Designing in SolidWorks

All the parts of the plates are sketched in the SolidWorks software. [20] Each part is drawn with real scale. Basically, a plate of control flap consists of four parts which are three beams as the frame and one PF for the surface. Each part is designed and checked to ensure there is no collision occur during assembly. The assembly began by inserting each component to be mate together. Besides, all of the values and dimensions are taken properly as it will be used in fabrication. However, the first draft was failed during analysis. As shown in Figure 3.6, one of the beam was quite long as it will bring imbalance to the structure itself due to the miscalculation the dimension. However, the major cause of failure was by the gap between the beams and the PF and is shown in Figure 3.7. There were three layers of beams, the end of the beams was untouched to the Pelexyglass and the analysis produced error.

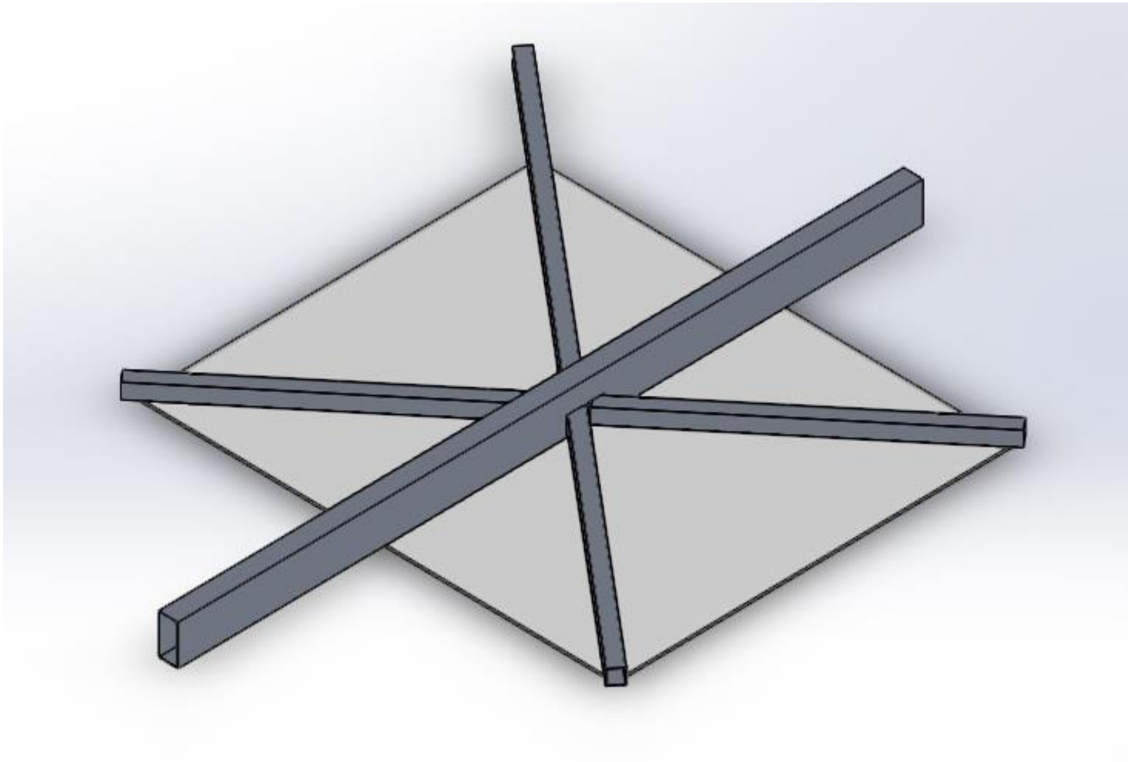

Figure 3. 6: First draft

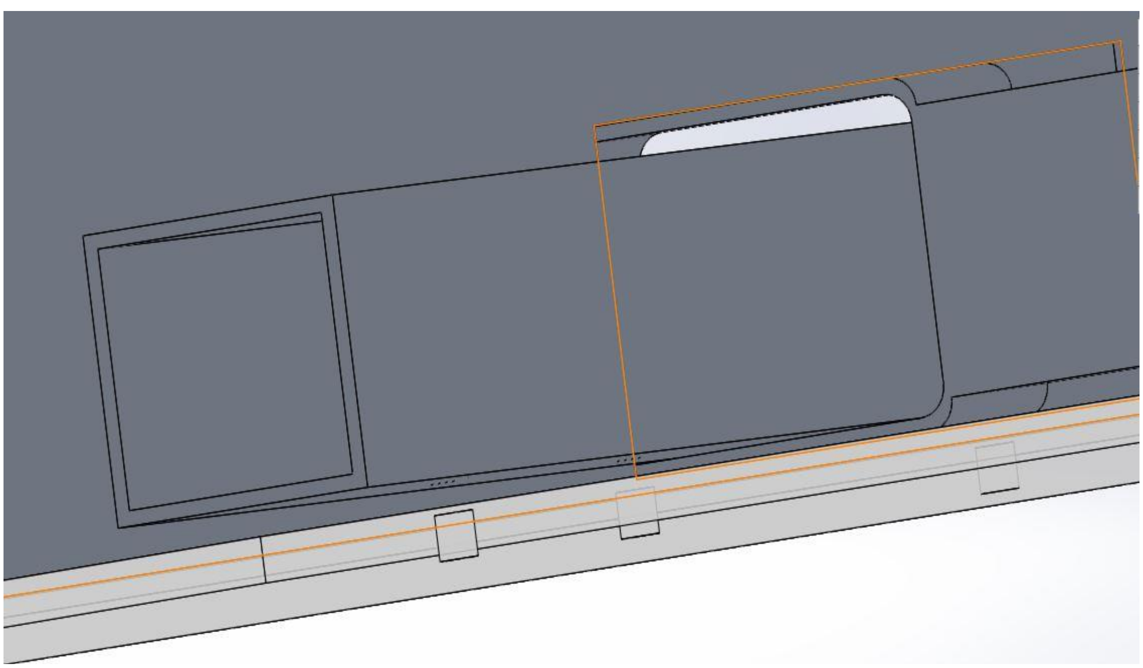

Figure 3. 7: Cause of failure

After the errors were identified, the model then undergoes repair process and checked again to ensure the errors would not occur. The result of the final draft is shown in Figure3.8. The final draft has been repaired until the gap between the beams and PF gone so that the analysis can be done. The final draft's correction is shown in Figure 3.9. The two-dimensional drawing of the design can be referred in Appendix A.

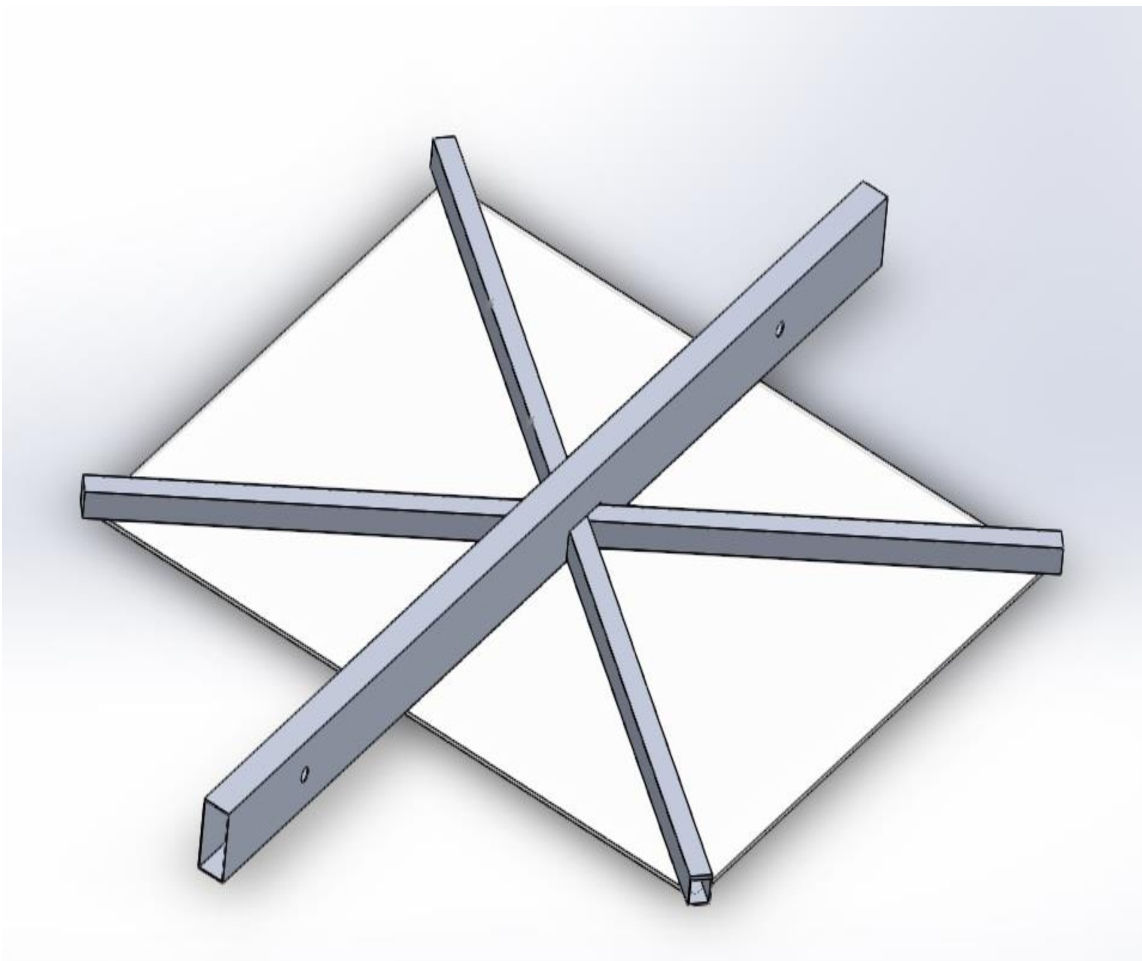

Figure 3. 8: Final draft

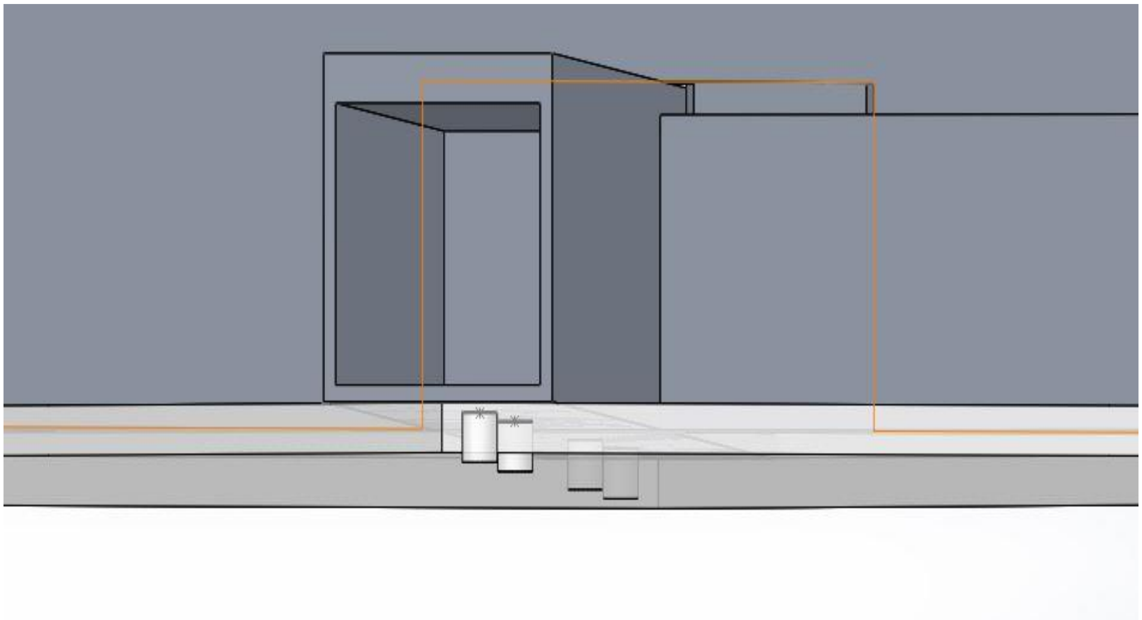

Figure 3. 9: Correction done

Before the analysis was carried out, all of the parts were applied material. For beams, Aluminum 2014-T4 (Figure 3.10) was used while for Plexy glass, PF (Figure 3.11) was used. This material selection will be told in fabrication process.