DECLARATION

I declare that this thesis entitled "title of the thesis" is the results of my own research except as cited in the references.

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Bismillahhirrahmahnirrahim…

In the name of ALLAH, the Most Gracious, the Most Merciful. First and foremost, all praises be to ALLAH SWT, I can finish this thesis successfully with His Grace and Guidance.

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Finite Element Analysis of Impact Test for Fiber Metal Laminate Fuselage Using SolidWorks ® Simulation

ABSTRACT

Fuselage is the central body of an airplane that is designed to accommodate the crew and passengers. In a simple word, fuselage is a body which is mean the external structure of vehicle. Different types of aircraft have different types of fuselages, depending on how quickly they are required to travel and what they are carrying, but a fuselage is always hollow and always has a front cockpit. The main objective is to design a new fuselage with a new material that have the specific strength that may help to enhance the properties of fuselage. The fuselage model is created using the Finite Element Analysis via SolidWorks® software. The dynamic analysis is made to the test the maximum stress and maximum displacement of material. The materials used for the test are aluminium alloy Al 2042-T3, titanium alloy Ti-6Al-4V (SS) and GLARE. The three type of material were compared between each other by impact test. The results are shown in terms of stress and terms of displacement. It has been found that GLARE is the best material in terms of displacement while in terms of stress, aluminium alloy is the best material in this study.

Keywords: Fuselage, Impact Test, GLARE, FEA

Analisis Unsur Hingga Ujian Hentaman untuk Kerangka Fiber Badan Pesawat Menggunakan Simulasi SolidWorks®

ABSTRAK

Fuslaj adalah badan pusat pesawat yang direka untuk menampung kru dan penumpang. Dalam kata yang mudah, pesawat adalah badan yang bermaksud struktur luaran kenderaan. Jenis pesawat yang berlainan mempunyai jenis fius fius yang berlainan, bergantung pada seberapa cepat mereka diperlukan untuk melakukan perjalanan dan apa yang mereka bawa, tetapi fiuslinya sentiasa berongga dan selalu mempunyai kokpit depan. Objektif utama adalah untuk mereka bentuk pesawat baharu dengan bahan baru yang mempunyai kekuatan khusus yang dapat membantu meningkatkan sifat-sifat fiuslaj. Model fuselage dibuat menggunakan Analisis Elemen Hingga melalui perisian SolidWorks®. Analisis dinamik dibuat untuk menguji tekanan maksimum dan anjakan maksimum bahan. Bahan-bahan yang digunakan untuk ujian adalah aloi aluminium Al 2042-T3, aloi titanium Ti-6Al-4V (SS) dan GLARE. Ketiga jenis bahan tersebut dibandingkan antara satu sama lain dengan ujian impak. Hasilnya ditunjukkan dari segi tekanan dan terma perpindahan. Telah didapati bahawa GLARE adalah bahan terbaik dari segi anjakan sementara dari segi tekanan, aloi aluminium merupakan bahan terbaik dalam kajian ini.

Kata kunci: Badan Pesawat, Ujian Impak, GLARE, FEA

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Over the past decades, composite materials have been the subject of ongoing interest by various specialists. First, after the Second World War, military applications in the aerospace industry triggered the commercial use of composites. Composite area innovations have enabled major weight reduction in structural design. Composites offer many advantages compared to metal alloys, especially when it comes to high strength and weight ratio (Sinmazçelik, Avcu, Bora & Çoban, 2011). In addition, they provide excellent fatigue properties and resistance to corrosion in applications (Botelho, Silva, Pardini & Rezende, 2006). With all these benefits, composite structures have been widely used in the aerospace industry in recent decades (Bernhardt, Ramulu & Kobayashi, 2007).

A historical perspective creates an awareness of the evolution of the current state of practice in the manufacture of composite fuselage. It also provides insight into the future state of the manufacture of composite fuselages. Figure 1.1 shows the increase in composites usage in military and commercial aircraft over time. Initial applications of carbon fibre reinforced composites (CFRP) in commercial and military aircraft were mostly limited to non-structural applications such as fairings and surfaces for flight control. As the industry proceeded to grow up, material and processes became easily understood and cost effectiveness improved to the level that the technology has been incorporated by commercial aircraft manufacturers into the latest generation of wide body and other new aircraft (Hiken, 2017).

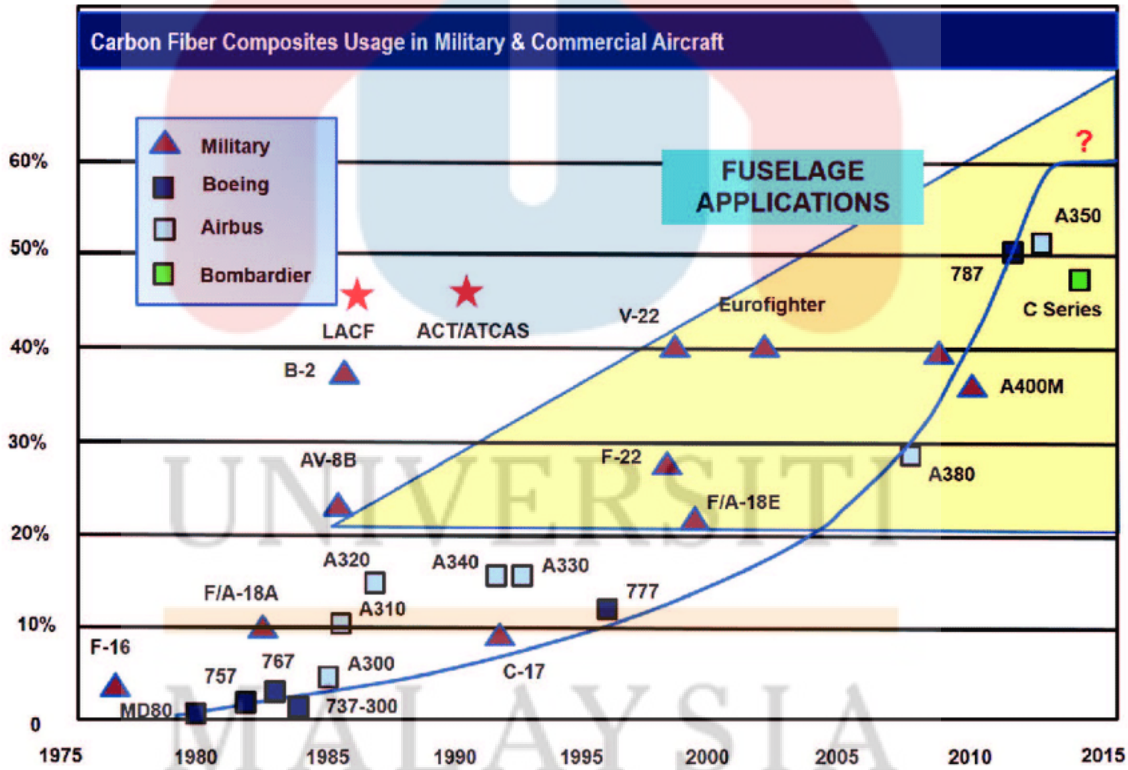


Figure 1.1: Composite Usage

(Source: Hiken,2015)

The number of flights across continents, countries, and cities are growing rapidly year by year, driven by the growing demand for air travel from customers. At the same time, environmentalist and governments are calling for a reduction in fuel emissions. Few measures have been taken to meet the demands of environmentalists and governments, including research, development and manufacture of high-performance lightweight aircraft such as Boeing 787 Dreamliner and Airbus A380. Airbus A380 manage to reduce production and operating costs by incorporating Glass Laminate Aluminium Reinforced Epoxy (GLARE) and other composite laminate into a large proportion of the skin of the aircraft. Moreover, it can significantly, increases the aircraft's safety level. However, the aircraft manufactures cannot compromise the occupant's safety as well as the structure' integrity in designing the new lightweight aircraft structure. Next, in designing the future lightweight aircraft, the crashworthiness of an aircraft is thus an important issue (Vlot et al, 1999).

An aircraft's crashworthiness can be examined using experimental method and numerical method. Assessing an aircraft's crashworthiness using experimental method or crash testing is expensive and can only be performed at the end of the design stage. Adam & Lankarani (2010) carried out aircraft crashworthiness assessments using experimental methods. On the other hand, numerical analysis and analysis of finite elements analysis are more cost-effective compared to crash testing. In the current state of crashworthiness analysis, most of the finite element model of crashworthiness assessment is verified by experimenting with the same model as introduced in several published papers by Adam & Lankarani, 2010 and Jackson & Fasanella, 2005.

The fuselage is the core element of any airplane. The fuselage must be rigid to support weight and stress and securely link all the components together. In addition, the impact of a crash must be resisted and softened to safeguard the occupants. Furthermore, to optimize fuel economy and performance, it must be as light as possible.

In this study, the crashworthiness of aircraft using fiber metal laminate (FML) as the skin of the fuselage is the main problem. The idea of fiber metal laminates is to stack metal and fiber reinforced composite layers to obtain the superiority of fatigue and fracture characteristic of fiber-reinforced composite materials and to combine the metal plastic behaviour and durability (Rans, 2011). Figure 1.2 shows a typical fiber metal laminate configuration.

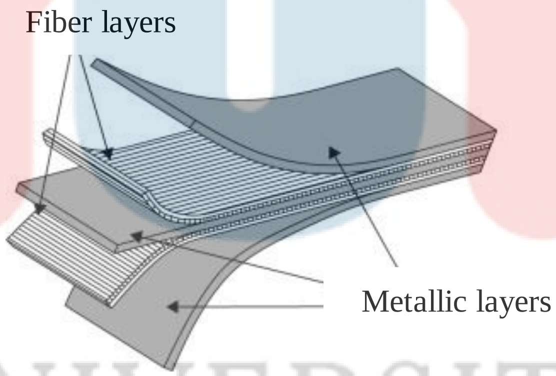


Figure 1.2: A typical FML

(Source: Rans, 2011)

1.2 Problem Statement

Aircraft weight effect on fuels and various energy sources utilization and design choices. It is therefore necessary to make innovation in the automotive industry with weight reduction, cost reduction of raw materials, short cycle time, fuel efficiency and composite emission reduction (Asensi, 2015). Most of today's aircraft are made of aluminium, a powerful yet lightweight metal. The first passenger aircraft from 1928, the Ford Tri-Motor, was made of aluminium. The modern Boeing 747 is also an aluminium aircraft. Other metals are sometimes used in the construction of aircraft, such as steel, aluminium and titanium. However, steel is heavy, so it's not used too much. Titanium is nearly as strong as steel, medium weight, heat-resistant, and resistant to corrosion. The Lockheed SR-71 Blackbird is made of titanium, the fastest jet-powered aircraft in the world.

With the development of GLARE and improvements in manufacturing technology, (Hooijmeijer, 2003) the first large-scale application of FML material in a civil aircraft, the Airbus A380, was realised. Manufacture of these larger panels was made possible by the introduction of splices in the panel to overcome the limitations of thin-sheet width dimensions. The high-strength glass fibre-reinforced adhesive layer is continuous in the splice area, whereas the thin metal sheets are joined by overlaps (Kwakernaak, Hofstede, Poulis, & Benedictus, 2012).

1.3 Objectives

1. To evaluate the impact strength on fuselage using SolidWorks® software.
2. To compare the simulation, result by using three different materials.
3. To determine the best material for better fuselage.

1.4 Scope of Study

This study was designed to under observe the benefits of FML in fuselage structure. Different type of material has their own benefits and weaknesses. A study had been carried out the impact response depends on their properties and specification. The most lightweight and high specific stiffness and strength is a great material to make fuselage. The method that will be employed is by using Finite Element Analysis via SolidWorks® software. The study also designs the 3D modelling of fuselage using SolidWorks® software.

1.5 Significances of Study

The finding of this study will give benefits to people and could save lives. This also can reduce death and injury from accidents. The study is important specially to avoid the increasing of airplane incident. The fibre metal laminate fuselage is current product that have their own properties which are high strength, fatigue resistance and lightweight. The properties from the FML will be compared with properties of materials that are commonly used in fuselage. The innovation of the product in aircraft industry will guarantee the safety of passengers.

CHAPTER 2

LITERATURE REVIEW

2.1 Fuselage

The aircraft's fuselage, or body, is a long hollow tube that holds all an aircraft's pieces together. As with most other aircraft parts, the fuselage shape is usually determined by the aircraft's mission. In order to reduce the drag associated with high speed flight, a supersonic fighter plane has a very slender, streamlined fuselage. An airliner has a wider fuselage to carry the maximum number of passengers. The pilots are sitting in a cockpit at the front of the fuselage on an airliner. In the rear of the fuselage, passengers and cargo are carried and the fuel is usually stored in the wings (Monetta, et al 2013).

An aircraft's weight is distributed throughout the aircraft. The fuselage contributes a significant part of an aircraft's weight together with passengers and cargo. The aircraft's centre of gravity is the average weight location and is usually located within the fuselage. In flight, due to torques generated by the elevator, rudder, and ailerons, the aircraft rotates around the centre of gravity. The fuselage must be designed to withstand these torques with enough strength (Nancy Hall, 2015). Figure 2.1 shows the structure of airplane.

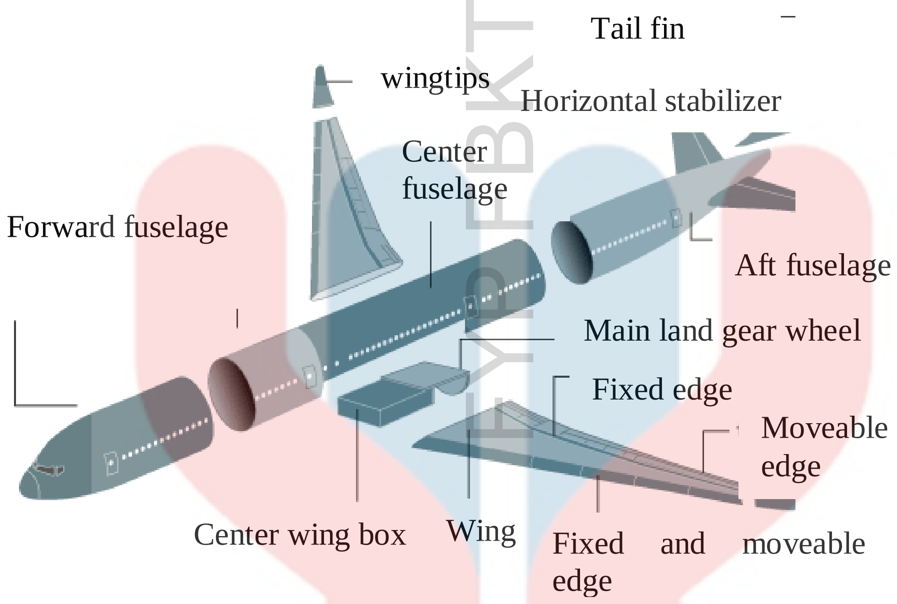


Figure 2.1: Airplane structure

(Source: Dixon, Uriel, Pisquali, & Nat. n.d.)

2.2 Materials used in Aircraft Industry.

Revolutionary light weight design led to an efficient and cost-effective aircraft new generation of fuel. The development of composites such as carbon fibre reinforced plastics and suitable production technologies played a significant role in this regard. In addition, demand for new aircraft will increase dramatically over the next twenty years. As a result, composite technologies need to be created or current manufacturing processes need to be improved to accomplish future aerospace production goals. In this context, production rates, reproducibility, automation, costs as well as ecological sustainability are important aspects (Wulfsberg, et al, 2014).

2.2.1 Aluminium

Aluminium alloys are widely used in the modern industry due to its numerous unusual combinations of properties such as light weight, high corrosion resistance, good thermal and electrical conductivity. Unfortunately, in aggressive environments, particularly those containing chloride ions, the material is susceptible to localized corrosion (Monetta et al. 2013). Because of their well-known mechanical behaviour, ease of design, mature manufacturing processes and inspection techniques, aluminium alloys have been the primary structural material for commercial and military aircraft for almost 80 years and will remain so for some time to come. Despite the above-mentioned problems, however, non-metallic materials provide a very competitive alternative due to their superior specific strength properties, so aluminium producers must continue to invest and make great efforts to improve the thermo-mechanical properties of the aluminium alloys they produce (Dursun & Soutis, 2014).

2.2.2 Titanium

Commercially pure titanium and titanium alloys for industrial use are widely used as a material with a light weight (density being 60 percent that of steel), high strength and excellent resistance to corrosion for aircraft. Recently, to improve aircraft fuel consumption, the application ratio of Carbon Fibre Reinforced Plastic (CFRP) to airframes and engine parts has increased. Similarly, demand for titanium is also increasing as it has excellent CFRP compatibility with corrosiveness and thermal expansion coefficient issues (Inagaki, Takechi, Shirai, & Ariyasu, 2014).

2.2.3 Composite material

High percentages of advanced composite materials are included in the aircraft's primary flight structures. For example, over 50% of the Boeing 787 and Airbus 350 XWB structural components are made of composite materials instead of conventional aluminium alloys. Figure 2.2 shows where composites are currently being deployed in the Boeing 787 and how, in developing new Airbus aircraft models, they have increasingly replaced other materials (Di Sante, 2015).

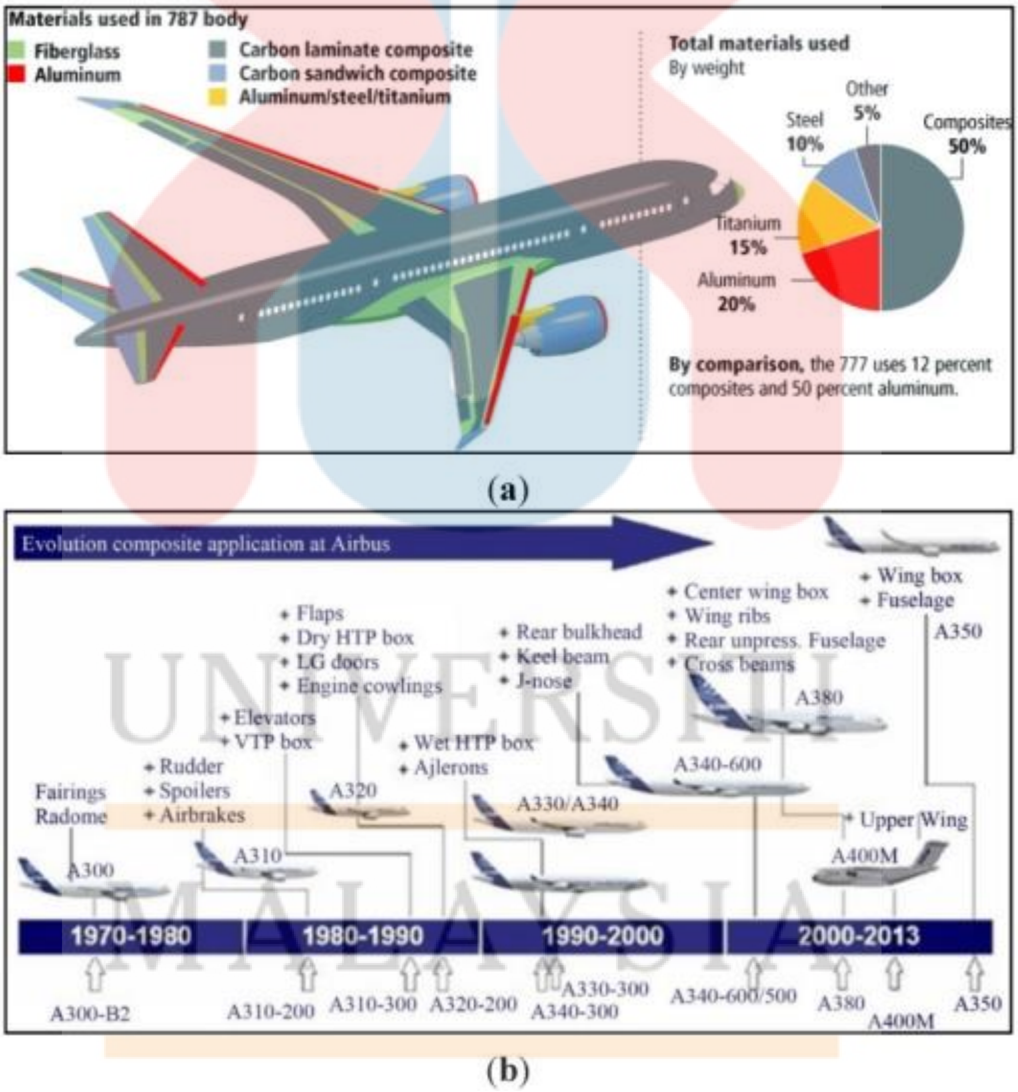


Figure 2.2: (a) Use of composite materials in the Boeing 787 and (b) evolution of the use of composites in Airbus aircraft

(Source: Di Sante, 2015)

The increased use of fibre-reinforced materials is due to their light weight and superior strength properties with respect to conventional metallic materials, which make their deployment fundamental for the reduction of weight and hence the operational costs of aircraft (Baker, Dutton & Kelly, 2004). Composite materials technology has become key to improving fuel efficiency, reducing emissions and lowering the manufacturing, operating, certification costs in current and future aircrafts (Di Sante, 2015).

2.1.2 (a) Fibre Metal Laminate

In FMLs, metal dominates the dynamic response (Mohamed, Soutis & Hodzic, 2012) and this material constituent's failure modes vary with ductility (Yungwirth et al. 2011). The stacking sequence, caused by the presence of composites in FMLs, greatly influences the damage pattern (Seyed, Liu & Liaw, 2011) and the nature of the fibers. GLARE is a member of the Fibre Metal Laminates (FML) family consisting of alternating layers of thin metal sheets of aluminium and composites of epoxy between them. GLARE materials are marketed in six standard grades. The epoxy layers are stacked between aluminium alloy sheets during the manufacture of laminates, resulting in different standard GLARE grades (Sinmazçelik, Avcu, Bora & Çoban, 2011). GLARE laminates have been applied to aircraft structures, such as fuselage and wing leading edges, due to excellent fatigue, tolerance to impact and damage and weight-saving capability (Alderliesten, 2015). GLARE is an advanced aircraft material because of its excellent fatigue crack resistance, high impact strength, high strength-to-weight ratio and high stiffness-to-weight ratio (Pawar et al. 2015).

2.2.4 Advantages and Disadvantages of Materials

Table 2.1: Discussed the advantages and disadvantages between aluminium, titanium and GLARE.

Materials	Advantages	Disadvantages	References
Aluminium	• Corrosion resistant • Lightweight • Low maintenance cost	• Lower strength than steel • Less flexibility • Limited mounting heights	
Titanium	• Chemical resistant • Rust resistant • High strength to weight	• High production cost • Hard on tooling • Reactive at high temperatures	
GLARE	• Weight saving • Fatigue resistance • Corrosion resistance • Superior lightning strike performance • Dimensional stability • Lightweight	• High cost • Size limitation • Complex fabrication	(Gardiner, 2016)

2.3 Finite Element Analysis Process via SolidWorks® Software

Finite Element Analysis (FEA) is a numerical technique for finding a partial differential equation solution approximately. Widely use in the field of mechanical system design that can explain the behaviour of the individual element with a simple equation and this set equation described the behaviour of the entire structure when combined with a large set of equations (Krishna, Subrahmanyam, & Srinivasulu, (2013). The summary of FEA process is shown in Figure 2.3.

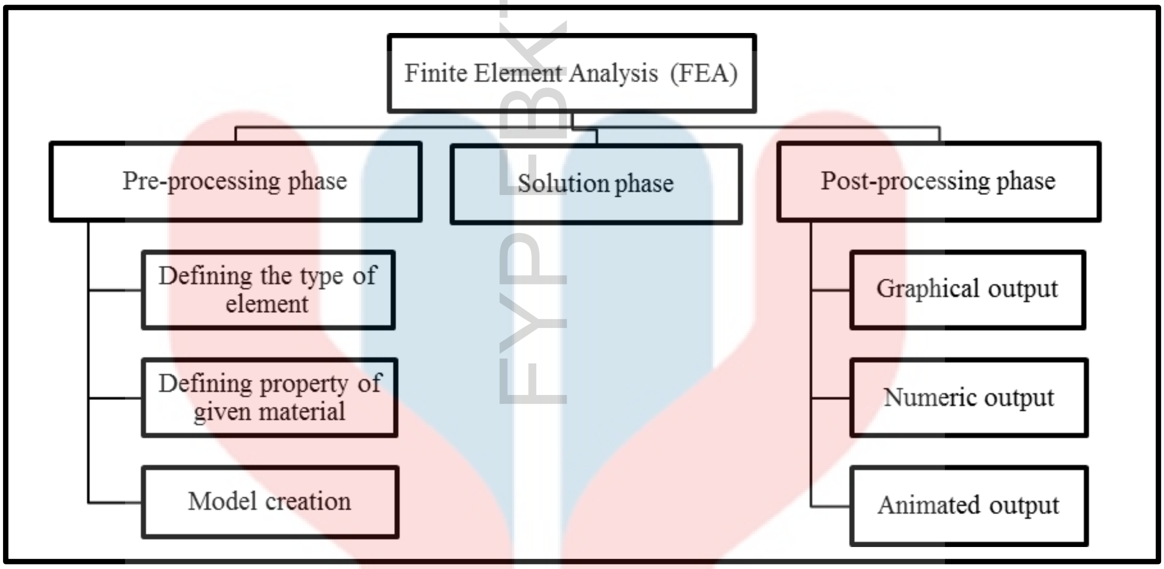


Figure 2.3: The summary of process of FEA

(Source: Mohammed & Desai, 2014)

FEA's process has separated into three stages. The first step is the pre-processing phase involving the definition of the type of element directly proportional to the model of accuracy and the property of materials in terms of physical properties. Next, create the model for living structure in 3-D CT scan and then define the mesh density in 3D laser scan for non-living structure. Second stage is solution phase that described boundary condition when forced to apply it and form free floating rigid body without any deformation occurring. The final stage is post-processing where the results are obtained in three different ways through the processing phase. The graphical output interprets the colour - coded maps, the numerical output shows the value of the main stress and strain of the materials, and the last way is the animated output showing animation (Mohammad & Desai, 2014).

2.4 Impact test

Sinmazçelik, Avcu, Bora & Çoban, (2011) reviewed on test methos on FML categorized impact test on FML into three: low velocity, high velocity and blast loading impact tests. Recently, Chai & Manikandan (2014) reviewed low velocity impact test of FML and he classified various parameters that influence impact test of FML into two main groups: material-based parameters and geometry-based parameters. Materials based parameters include types of metals, types of fibre-reinforced composite, lay-up configuration and constituent's volume fraction. Impact test is not the only methodology in investigating impact response of FML. A few researchers developed finite element modelling of dynamic impact and damage for FML due to several advantages including capability to analyse barely visible impact damage (BVID) in composite, capability to quantify the degradation of the materials, inexpensive and quicker method compare to experiment. Thus, impact test and damage analysis of FML that carried by numerical studies are also reviewed and discussed in this section. Morinière, Alderliesten & Benedictus, (2013) discussed the failure mechanisms of GLARE that make it a superior impact resistance. When subjected to lateral impact loading, the composite laminate core that has higher bending stiffness than aluminium modifies the flexural deformation profile of the aluminium alloy.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

The material that been used in this research are aluminium, titanium and glass laminated aluminium reinforced fiber (GLARE). The lamination of this material needs to be test before applying to automobile industry to know either the properties is good enough for the fuselage production. In real conditions, the lamination of fibre metal gave excellent strength and stiffness to the fuselage. Figure 3.1 shows the built-up of GLARE and that is a typical layer of FML.

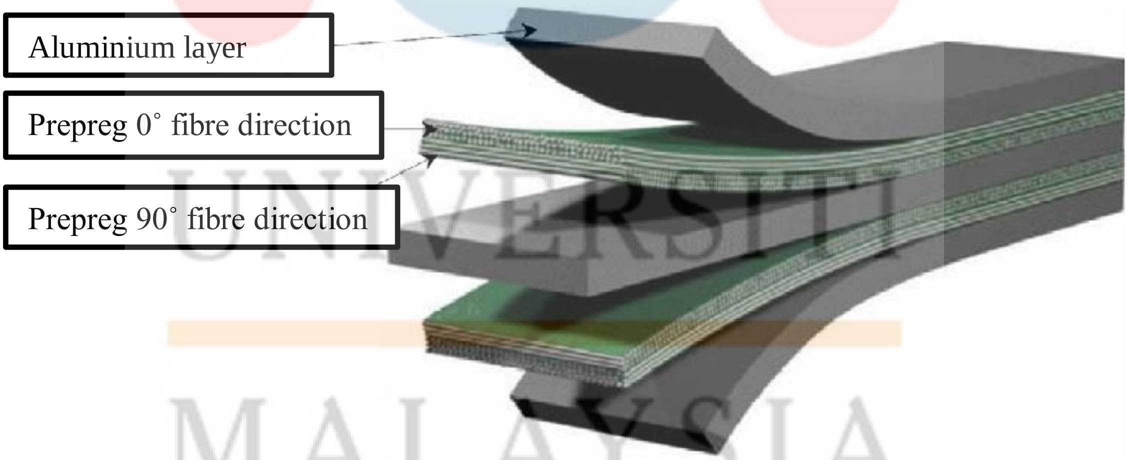


Figure 3.1: Built-up of GLARE Fibre Metal Laminate

(Source: Emberey et al. 2007)

3.2 Methods

Firstly, the fuselage had been created using SolidWorks® software and proceeded the process of lamination of fibre metal (GLARE). To obtain the appropriate thickness of the safety requirement, this lamination followed the standard measurement according to the standard of the aircraft. Then, this lamination of fuselage has been compared with widely used materials of aircraft.

Titanium and aluminium were the materials that have been compared. These materials have their own properties which also have been compared between them. This simulation is an analysis of a fuselage impact test. The figure shows research flow of using solidwork software and the test, is shown in Figure 3.2.

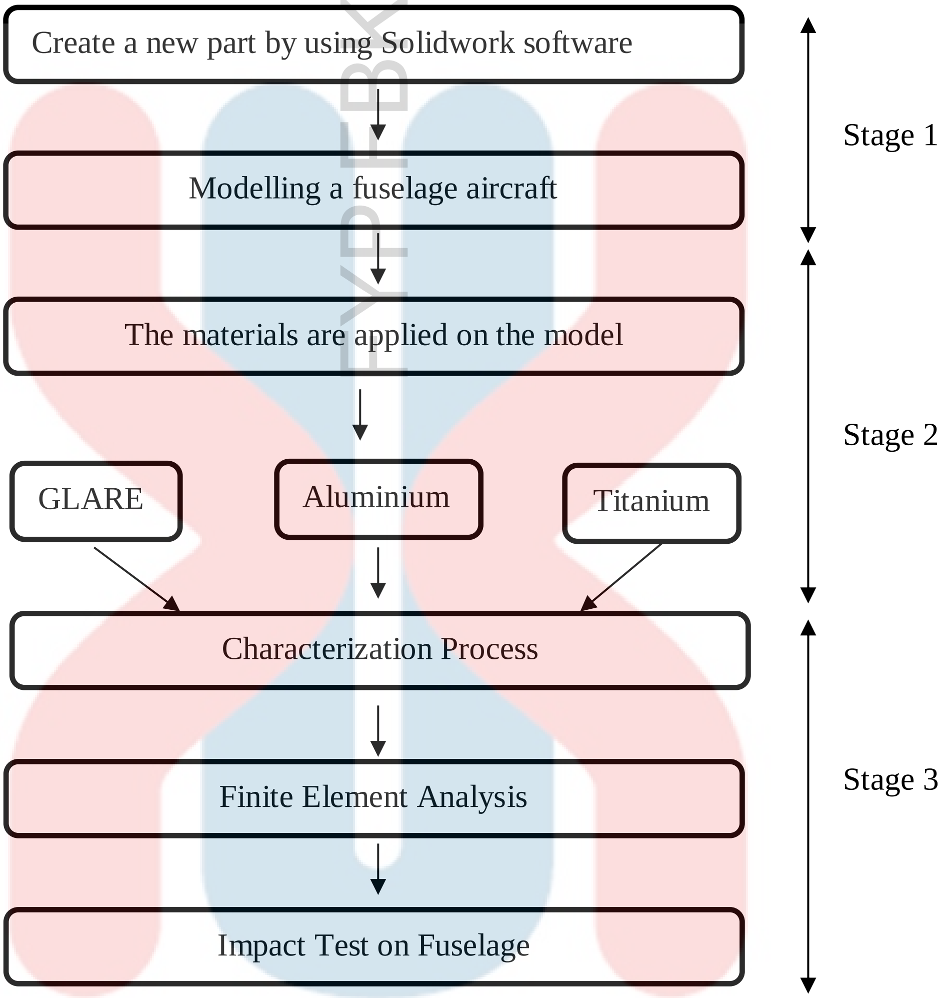


Figure 3.3: Flowchart of the thesis

3.2.1 Modelling a Fuselage using SolidWorks®

The fuselage was designed using Solidworks® 2013 version as shown in Figure 3.3 to Figure 3.13. This prototype was inserted its materials which had been explained in materials section and will be running impact test by using Finite Element Analysis (FEA).

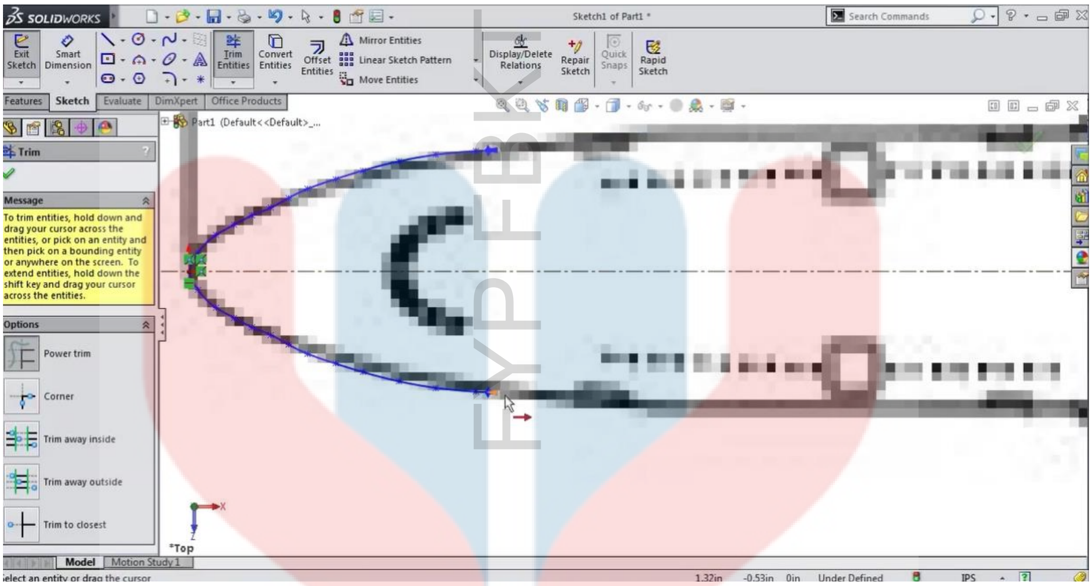


Figure 3.3: Sketch and draw profile on the top plane with suitable smart dimensions.

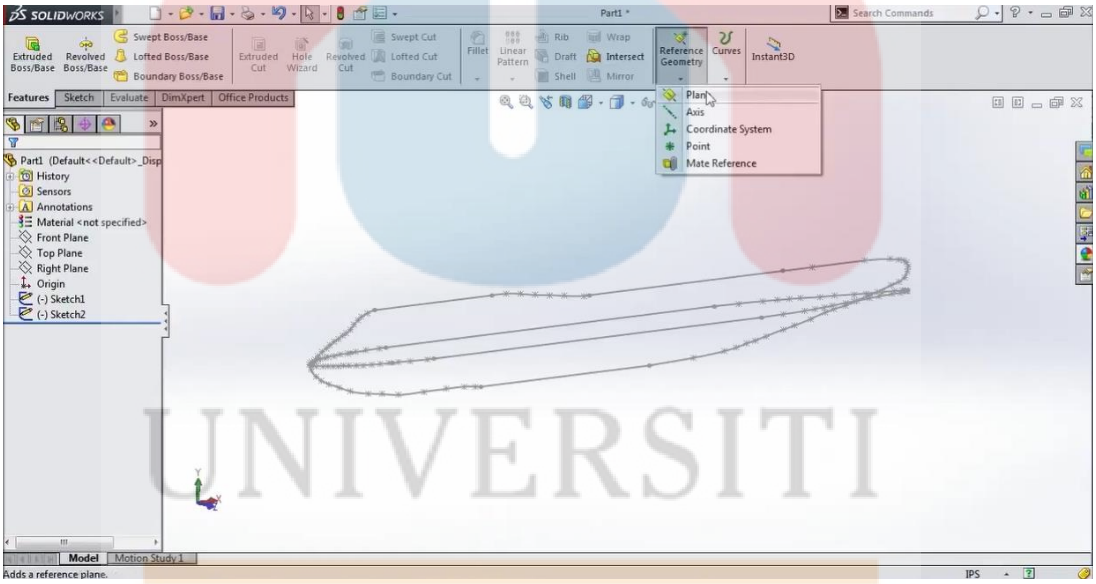


Figure 3.4: finish sketch fuselage framework

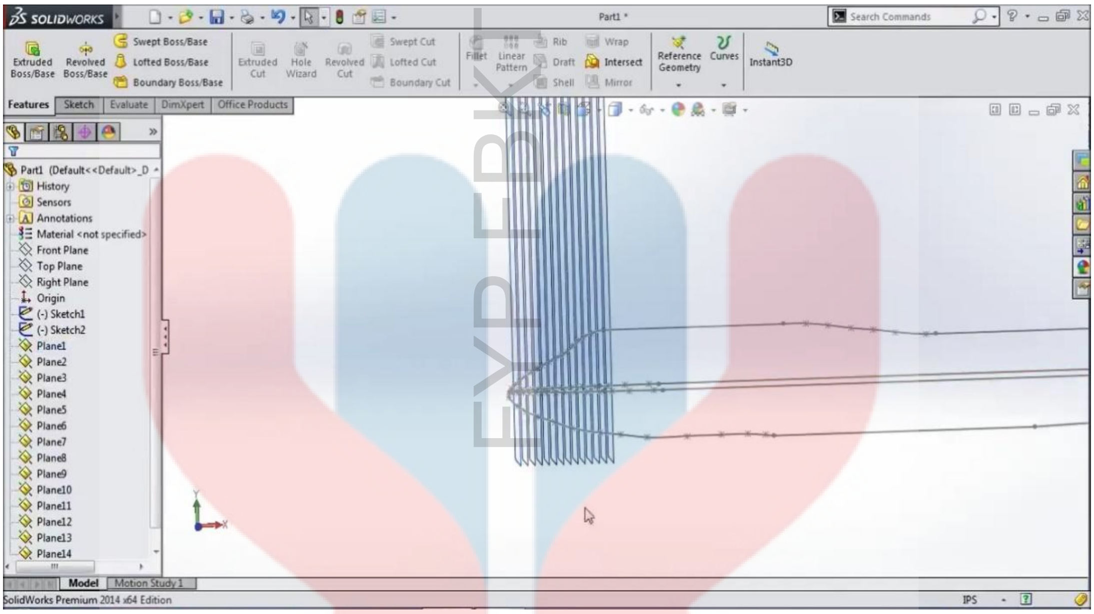


Figure 3.5: Adding plane at right plane

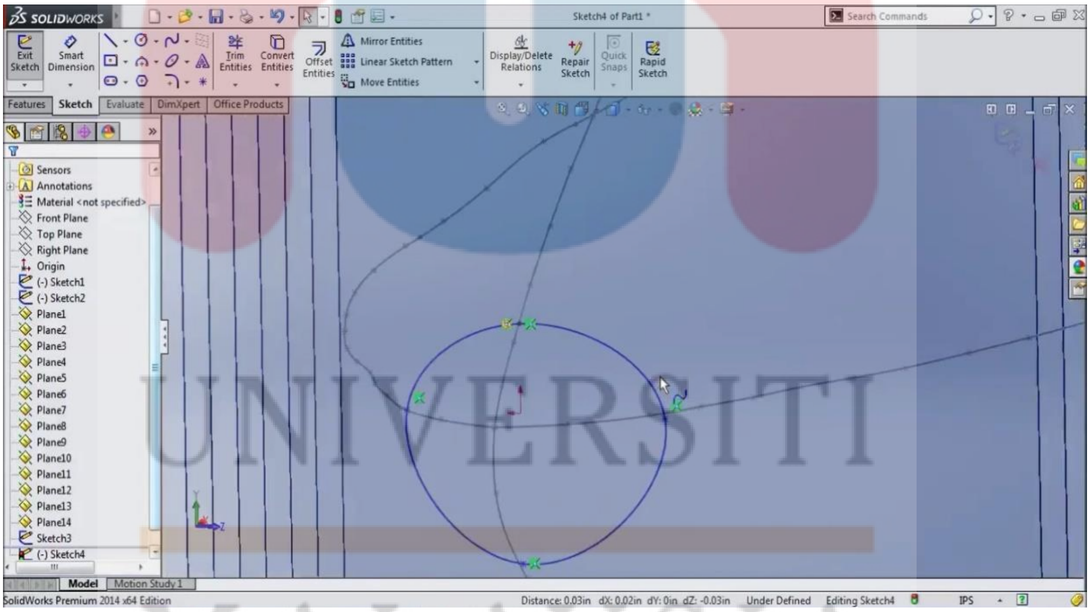


Figure 3.6: Sketch a circular spine and pierce with fuselage framework.

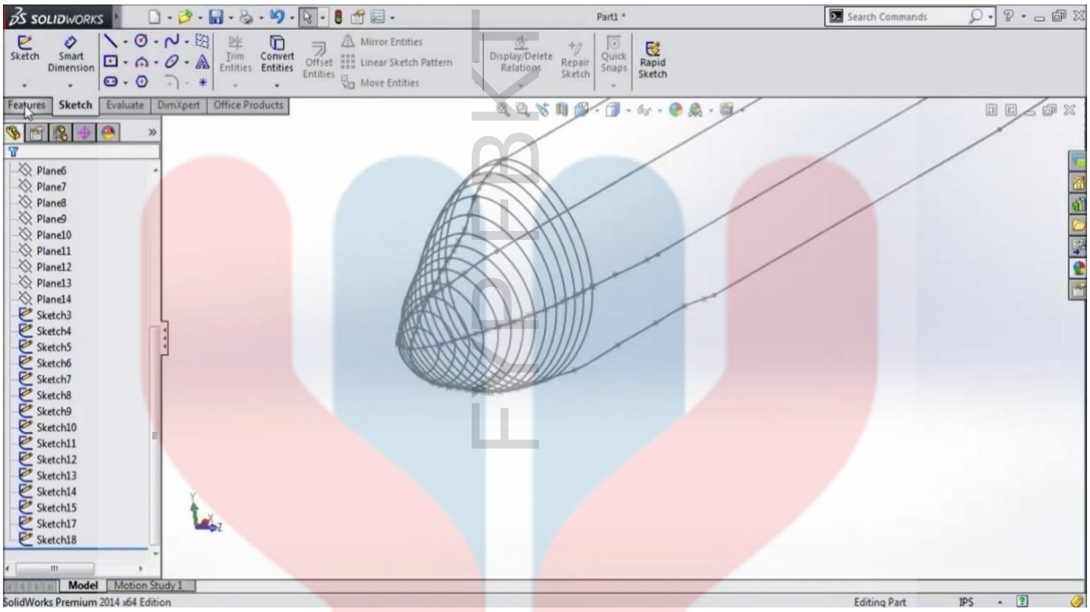


Figure 3.7: Repeated circular spine at right plane

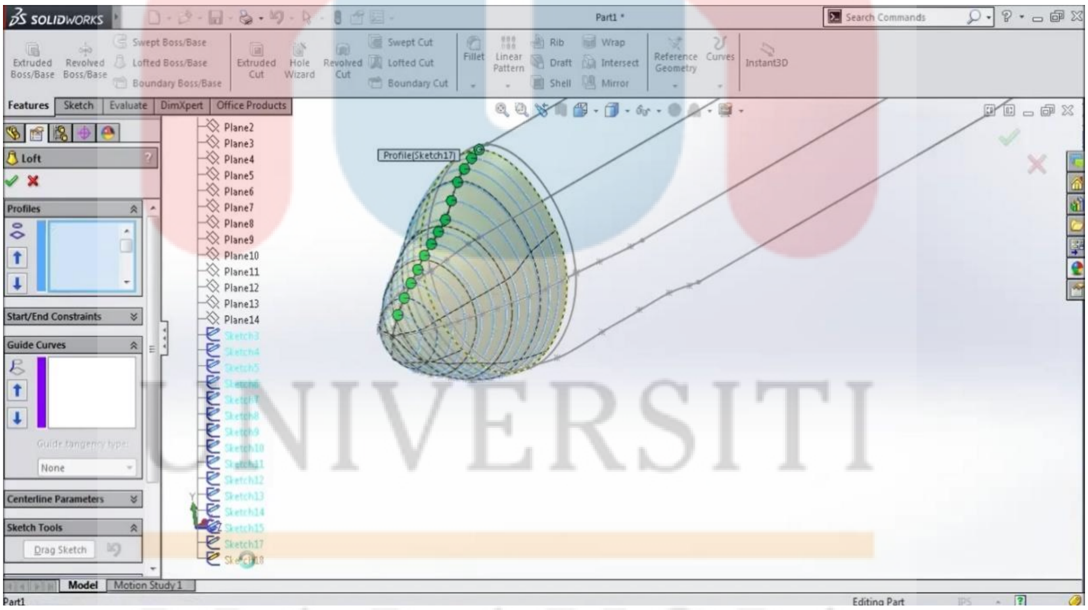


Figure 3.8: Making loft at the right plane Finish loft the right plane.

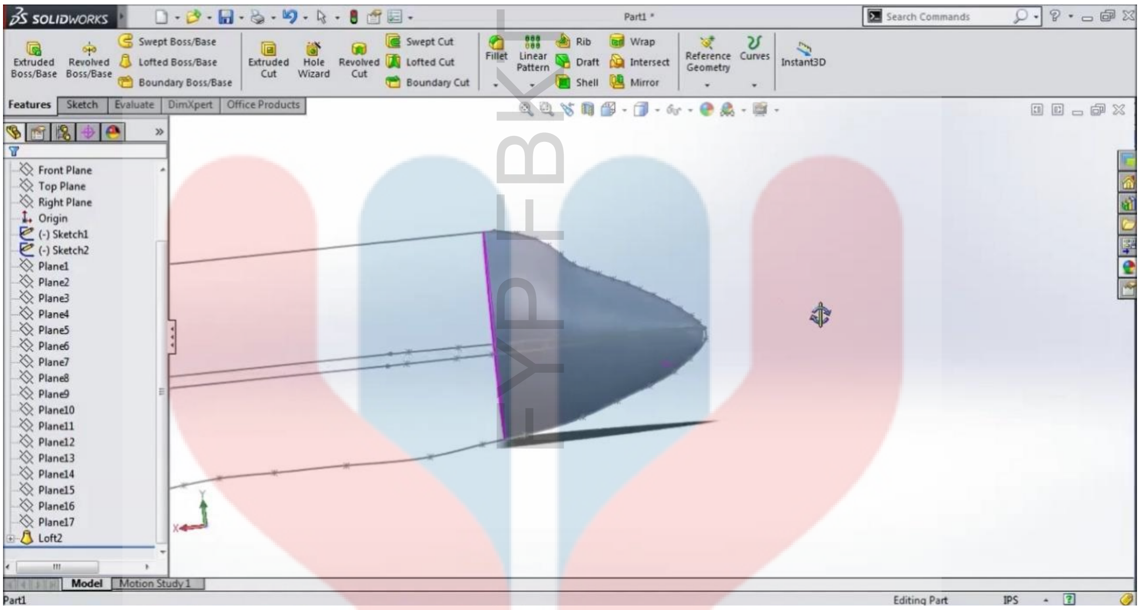


Figure 3.9: Finish loft the righ plane

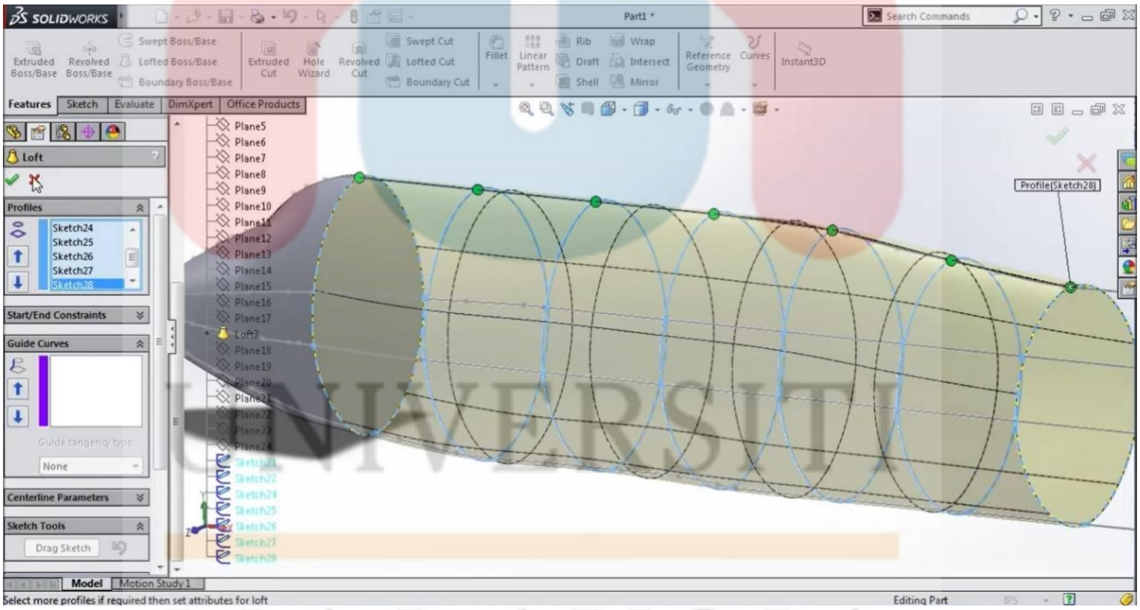


Figure 3.10: making loft at fuselage

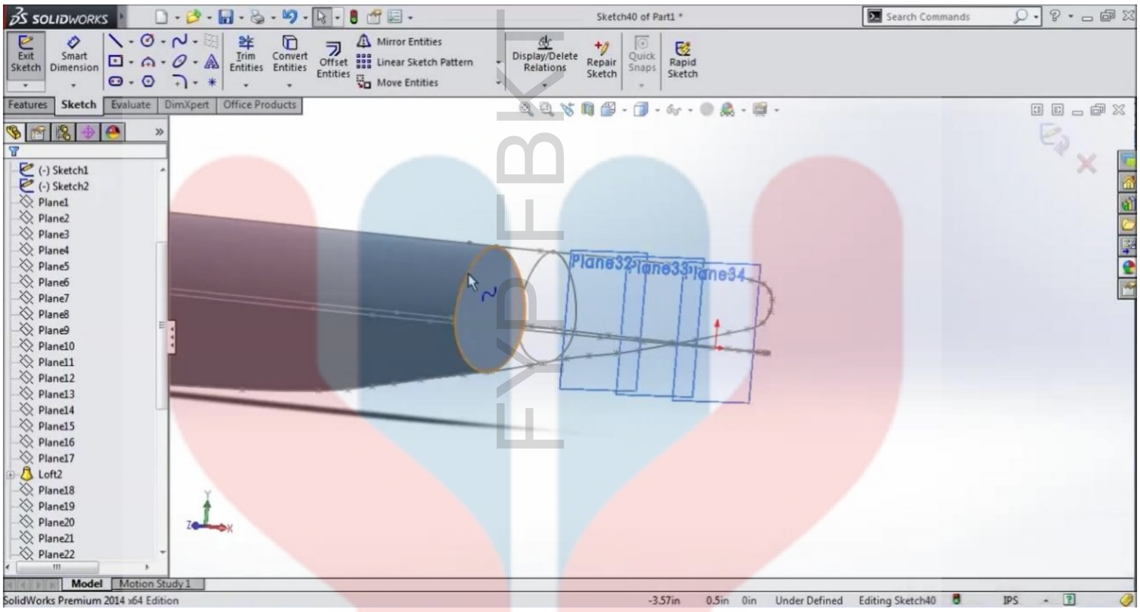


Figure 3.11: Sketch plane at tail of aircraft

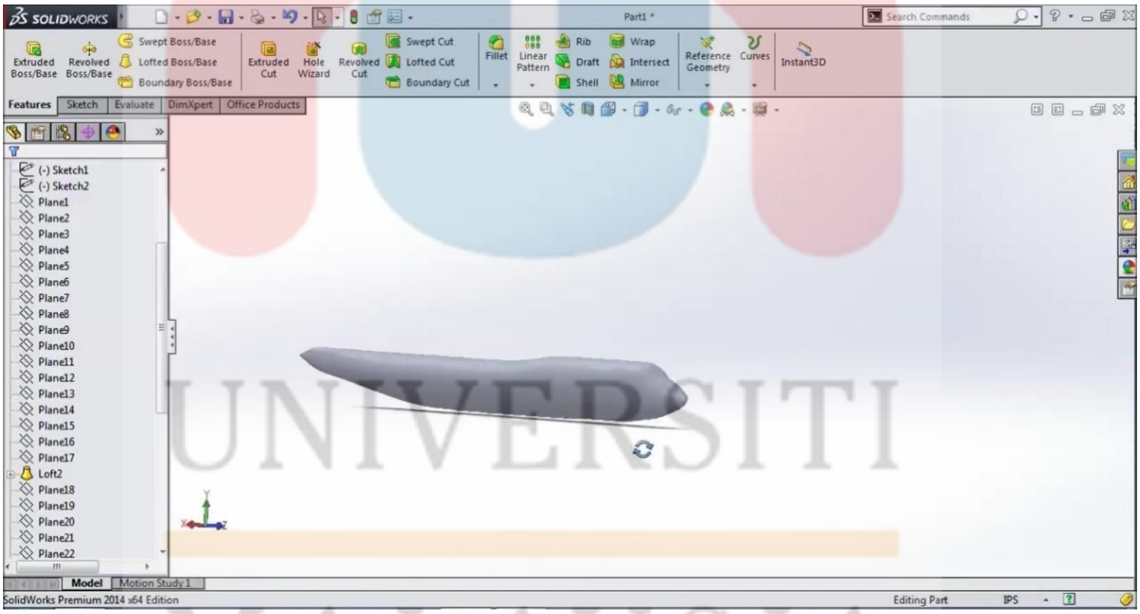


Figure 3.12: The fuselage is finish

3.2.2 Finite Element Analysis via SolidWorks® Software

SolidWorks® is one of the software that can be used to create FEA. SolidWorks® is a computer-aided (CAD) computer program that performs solid modelling and computer-aided engineering (CAE) computer program that needs to be installed and run using Microsoft Windows®. A simulation of a fuselage has been tested by using this software. As a parameter to compare and determine the best materials that can be used to make fuselage, different material and different pressure had been applied to the design. Material that have been used were GLARE and will be compared with other materials such as aluminium and titanium.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Analysis of impact test of fuselage

This chapter will discuss about all the result and analysis of the 3D-modelling of the fuselage that is inserted by different types of material to be undergo Finite Element Analysis (FEA) which is linear test. The design model of fuselage is shown in figure 4.1. The test was run with different types of material.

Figure 4.1: The fuselage model

After finished the simulation process, the result will show the value of stress (von-mises) and displacement of the fuselage on 3 different types of the materials that is being used.

4.2 Materials Choose with a Particular Pressure

Aluminium alloy (Al 2043-T3), titanium alloy (Ti-6Al-4V) and Glass laminate aluminium reinforced epoxy (GLARE) were the materials used in this SolidWorks simulation. Every material has its own properties that can be used to predict the material's strength, stress, displacement, and deformation. In this impact test analysis, the various pressure is used to measure the design's parameters. Using this method, the peak pressure used is 13 psi. The following two pressures used were 11 psi and 12 psi. The applied pressure is directly perpendicular to the fuselage's center of gravity.

4.2.1 Aluminium alloy (Al 2042-T3)

For material 1, the material that had been selected for fuselage is aluminium alloy (Al 2042-T3). The model and the properties of product 1 are as shown in the Table 4.1.

Table 4.1: Material properties of Aluminium Alloy (Al 2042-T3)

(Source: Lipski & Mroziński, 2012)

Property	Aluminium Alloy (Al 2042-T3)
Density (Kg/m^3)	2780
Poisson's ratio	0.33
Young Modulus (MPa)	73100
Yield strength (MPa)	345
UTS (MPa)	483

Table 4.1 shows the properties of aluminium alloy (Al 2042-T3) for fuselage design product. Based on Lipski & Mroziński (2012), density of the material was 2780 kg/m^3. For Poisson's ratio was 0.33, young modulus was 73100 MPa, and for yield strength was 345 MPa. Lastly for ultimate tensile strength was 483 MPa. Aluminium alloy 2524-T3 is a comparatively new fuselage layer sheet product that can provide enhanced performance when multi-site damage occurs.

Table 4.2: Model and Mechanical Properties of Aluminium Alloy (Al 2042-T3)

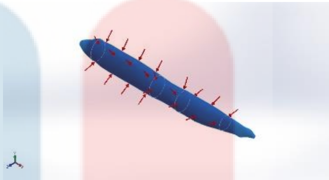
Model	
	Mass: 4.95705e + 06kg
Volumetric properties	Volume: 1783.13 m^3
	Density: 2779.97 kg/m^3
	Weight: 4.8579e +07 N
	Name: 2024-T3
Materials properties	Model type: Linear Elastic Isotropic
	Yield strength: 3.45e + 08 N/m^2
	Tensile strength: 4.85e + 08 N/m^2
	Total Nodes: 10694
	Total Element: 6632

Table 4.2 shows the results of the SolidWorks simulation report developed. In the SolidWorks program, aluminium alloy (Al 2042-T3) had already been created. For product 1 volumetric properties, the prototype weighed 4.95705e+ 06 kg. The volume was then 1783.13 m^3, the density was 2779.97 kg/m^3 and the weight was 4.8579e + 07 N. Comparison between both the paper Lipski & Mroziński (2012) and the SolidWorks program was the same based on mechanical properties. Besides that, there were 10694 and 6632 total nodes and the full element of the fuselage design that had been collected from the analysis.

Table 4.3: Results of Displacements and Stress with applied pressure

Pressure (psi)	Displacement (mm)	Stress (N/m^2)
11	3.854e+01	1.178e+05
12	4.204e+01	1.285e+05
13	4.555e+01	1.392e+05

Table 4.3 reveals the aluminium alloy (Al 2042-T3) displacement and stress with three different pressures. The first pressure that applied was 11 psi. After that, the values of pressure were followed by 12 psi and 13 psi. The value of displacement and stress was increasing as increasing pressure applied. From the Table 4.3, the different values within each pressure were 1 psi. Then, the increasing value for each displacement and stress was 0.351e+01 mm 0.107e+01 N/m^2 respectively. Displacement was recorded in millimetres and Newton per meter square was recorded as a result of stress.

4.2.2 Titanium alloy Ti-6Al-4V (SS)

For material 2, the material that had been selected for fuselage is titanium alloy Ti-6Al-4V (SS). The model and the properties of product 2 are as shown in the table 4.4.

Table 4.4: Mechanical properties of titanium alloy Ti-6Al-4V(SS)

(Source: Rafi, Starr, & Stucker, 2013)

Property	Ti-6Al-4V (SS)
Density (Kg/m^3)	4420
Poisson's ratio	0.33
Young Modulus (MPa)	114000
Yield strength (MPa)	880
UTS (MPa)	1170

Table 4.4 shows the mechanical properties of the Ti-6Al-4V(SS) titanium alloy. It is a non-magnetic alloy with two phase alloy, having crystalline structure in both alpha and beta form. It has good mechanical properties, an alloy with high strength and a high ratio of strength to weight (Rafi, Starr, & Stucker, 2013). It is one of the most common titanium alloys for general use. The material density was 4420 Kg / m3. While the ratio was 0.33 for the poisson, the young modulus was 114000 MPa, the yield strength was 880 MPa, and the ultimate tensile strength was 1170 MPa.

Table 4.5: Model and Mechanical Properties of titanium alloy Ti-6Al-4V(SS)

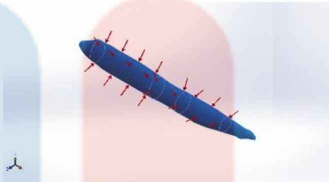
Model	
Volumetric properties	Mass: 7.89701e + 06 kg Volume: 1783.13 m^3 Density: 4428.74 kg/m^3 Weight: 7.73907e + 07 N
Materials properties	Name: Ti-6A-4V (SS) Model type: Linear Elastic Isotropic Yield strength: 8.2737e + 08 N/m^2 Tensile strength: 1.05e + 09 N/m^2 Total Nodes: 10694 Total Element: 6632

Table 4.5 shows the result for product 2 of the fuselage model's volumetric properties and material properties. The weight received was 7.89701e + 06 kg. Then the density was 4428.74 kg/m^3 for the volume was 1783.13 m^3 and the weight was 7.73907e + 07 N. In each fuselage design, the total nodes and the final component were the same.

Table 4.6: Results of Displacements and Stress with applied pressure

Pressure (psi)	Displacement (mm)	Stress (N/m^2)
11	2.419e+01	1.112e+05
12	2.639e+01	1.213e+05
13	2.859e+01	1.314e+05

Based on Table 4.6 shows the results of displacement and stress of titanium alloy Ti-6Al-4V(SS). The pressure that had been applied were same with the test on aluminium alloy (Al 2042-T3). The values of displacement and the stress also increase according to the pressure that had been applied during simulation. The average value of displacement in Table 4.6 was lowest than displacement in Table 4.3. This is because aluminium alloy (Al 2042-T3) has more ductile than titanium alloy Ti-6Al-4V(SS). Titanium alloy Ti-6Al-4V(SS) has double the strength of aluminium alloy (Al 2042-T3) (Miracle. D. B, et al 2011). While for stress in Table 4.6 was lower than stress in Table 4.3.

4.2.3 Fiber Metal Laminates (FMLs)

Fiber Metal Laminates (FMLs) are composite materials made up of overlapping metal sheet layers and composite sheets. Glare is among them are the best-known member, consisting of layers of aluminium and composite sheets reinforced with glass fibre. Glare's six standard grades are different. All of them are pre-preg oriented, consisting of unidirectional S-glass fibres embedded in an adhesive FM 94. The pre-preg can be laid out about the aluminium alloy sheet according to different orientations, resulting in different grades. Glare, as a composite, puts together some of the benefits of either aluminium alloy or composite material such as improved impact properties, damage tolerance and durability compared to composites, and stronger fatigue resistance, resistance to corrosion, lower specific weight and customizing capability compared to aluminium alloys. Delamination, voids, porosity, inclusions, disbonds, and cracks in the aluminium layers that deteriorate the mechanical properties of the structural component can be found in the cured laminates after the production process. A detailed and thorough understanding of the manufacturing process is therefore important to avoid the occurrence and progression of defects or flaws, (Nardi, Abouhamzeh, Leonard, & Sinke, 2018).

The material that had been selected for fuselage was Glass laminate aluminium reinforced epoxy (GLARE). The model and the properties of the material are as shown in Table 4.7.

Table 4.7: Mechanical properties of Glass laminate aluminium reinforced epoxy (GLARE)

Property	Glass laminate aluminium reinforced epoxy (GLARE)
Density (Kg/m^3)	2470
Poisson's ratio	0.22
Tensile strength (N/m^2)	3450
Shear Modulus (MPa)	17600
Compressive strength	267
Elastic modulus (N/m^2)	58100

The material properties of GLARE are shown in Table 4.7. The composite material is a material that in sections with many specifications and demands is still relatively new and unused in the aircraft industry. This is attributable to the materials ' nonlinear properties, as the metallic materials have. Such properties make it difficult to determine how in various load cases or impacts the material would deform or behave. But there is a great deal of knowledge about how various composite materials behave in easy cases such as tensile tests or axial and transverse compression tests. This type of composite materials has long been appealing to designers because the load carrying material can be produced for a given weight in a given application to provide an optimum combination of stiffness and strength. GLARE provides a high resistance to extreme strength and fatigue. These kinds of properties make them a better way to secure objects from damage (Karlsson, 2016).

Table 4.8: Model and Mechanical Properties of Glass laminate aluminium reinforced epoxy (GLARE)

Model	
Volumetric properties	Mass: 4.40428e + 06 kg Volume: 1783.13 m^3 Density: 2,469.98 kg/m^3 Weight: 4.3162e + 07 N
Materials properties	Name: GLARE Model type: Linear Elastic Isotropic Yield strength: 2.84e+08 N/m^2 Tensile strength: 3.45e + 09 N/m^2 Total Nodes: 10694 Total Element: 6632

Table 4.8 shows the mechanical properties of Glass laminate aluminium reinforced epoxy (GLARE) for material 3. Result obtained from the Solidwork Simulation show that the mass of the material was 4.40428e + 06 kg. Next, the volume and weight of the material were 1783.13 m^3 and 4.3162e + 07 N respectively. The yield strength of material is 2.84e +08 N/m^2 followed by tensile strength which is 3.45e + 09 N/m^2.

Table 4.9: Results of Displacements and Stress with applied pressure

Pressure (psi)	Displacement (mm)	Stress (N/m^2)
11	4.337e+01	9.106e+04
12	4.732e+01	9.934e+04
13	5.126e+01	1.076e+05

From Table 4.9 shows that, the results of displacement and stress of GLARE. The value of the displacement and stress was increasing depends on the pressure that had been applied. Compared with the material of aluminium alloy (Al 2042-T3) and titanium alloy Ti-6Al-4V(SS), the displacement of GLARE was the highest among the others material in this study. While for the stress value of GLARE was the lowest compared to other two materials.

4.3 Effect of Pressure on the Displacement of Three Types of Materials Applied.

Three types of materials which are aluminium alloy (Al 2042-T3), titanium alloy Ti-6Al-4V (SS) and GLARE were set to impact test in SolidWorks simulation. During the impact test, the materials were added with three different pressure to test their displacement. In Figure 4.1 shows the comparison of maximum displacement between the materials due to the pressure that had been added.

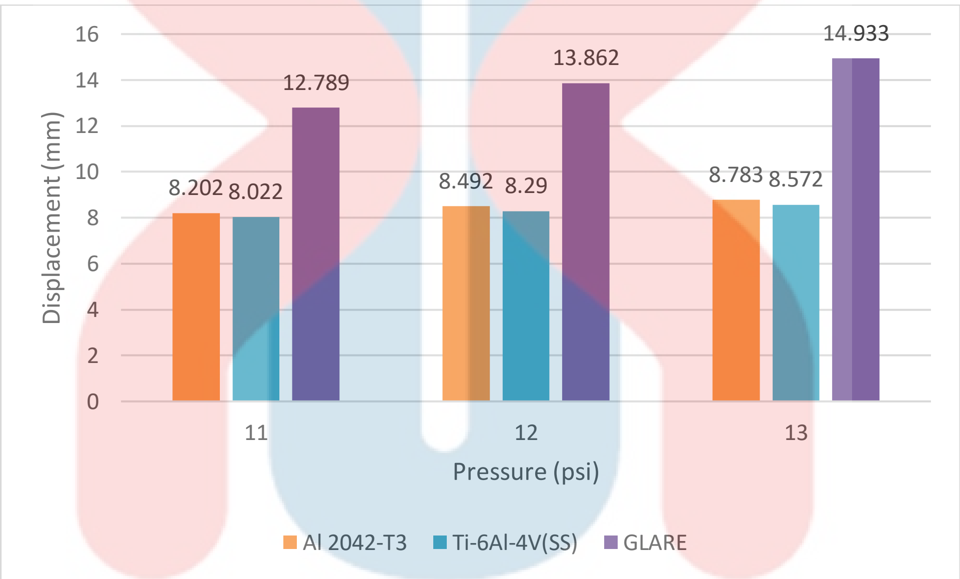


Figure 4.2: Graph of maximum displacement against pressure for different materials.

Figure 4.2 demonstrates the contrast of three different materials used in the manufacture of fuselage in one graph considering displacement and pressure. The GLARE maximum displacement is shown to be higher than the titanium alloy Ti-6Al-4V (SS) and aluminium alloy (Al 2042-T3).

Then, titanium alloy Ti-6Al-4V (SS) was the lowest maximum displacement in the graph the result shows that, compared to two other materials. Aluminium alloy has high ductility properties. Aluminium has a low hardness relative to the titanium alloy Ti-6Al-4V (SS) for the hardness properties.

Composite materials have a greater ability to absorb heat than aluminium plus a lower weight than aluminium. Composite material is therefore stronger than aluminium alloy because the composite displacement reading was higher compared to the displacement reading of aluminium alloy. This showed a better energy absorption capacity of composite material compared to aluminium and titanium. Composite is indeed the best material compared to aluminium and titanium that can be used based on this study to manufacture fuselage. The composite's high strength properties compared to aluminium also make it more suitable to provide passengers with enough safety compared to aluminium materials and meet the objective of this study.

Depending on the pressure displacement of the finite element analysis test, the graph's entire pattern was increasing linearly. The graph can be inferred that the greater the displacement, the higher the pressure applied to the fuselage.

4.4 Effect of Pressure on the Stress of Three Different Materials.

The comparisons are made between Al 2042-T3, Ti-6Al-4V (SS) with pressure and stress. The impact test on the fuselage had been conducted into three. First impact test was applied with 11 psi then followed 12 psi and 13 psi respectively. Then, using finite element analysis of SolidWorks, the results of maximum stress were obtained.

Stress is therefore the pressure or tension on a material object. Strength and toughness of fracture are two essential mechanical properties of each material. Yield strength is the stress factor the material can withstand before deformation. Tensile strength is a measurement of a metal's maximum stress before it begins to fracture. Figure 4.2 indicates that the comparison of the maximum stress of the various materials is based on the added forces.

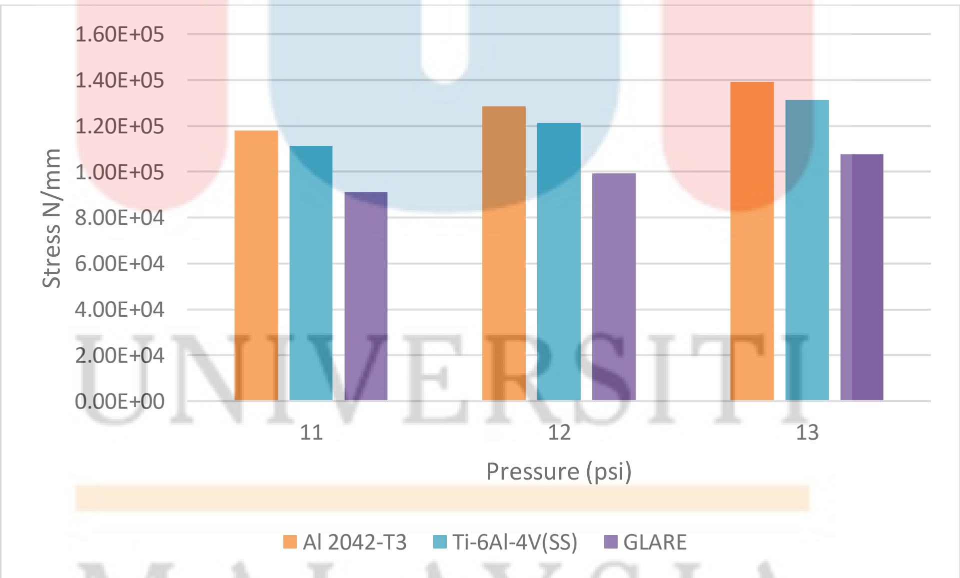


Figure 4.3: Graph of maximum stress versus pressure

Figure 4.3 shows the maximum stress for each material listed. In general, it clearly indicates that GLARE was getting the lowest value of maximum stress compared to aluminium alloy (Al 2042-T3) and titanium alloy Ti-6Al-4V (SS). The highest reading of maximum stress in the graph was aluminium alloy (Al 2042-T3). Therefore, the trend of each graph of material was increasing linearly. From the graph, the stress increases when the value pressure applied increase. This is shows that, the higher the stress on material, the higher the strength of the material. It is because, strength is the maximum stress of material can withstand.

4.5 Finite Element Analysis

The stress and displacement of the design fuselage was numerically investigated by a newly developed model of finite elements which is capable of simulating between pressure and the different materials used in the fuselage. In the aircraft industry, numerical analysis can typically be used to research the selection of materials for the aircraft component.

The advantages of simplified finite element model of fuselage were to provide the possibility of investigation of the influence of fuselage itself on cabin pressure. Materials selection of fuselage also important to reduce weight of the component that gives significant effect on the fuel efficiency. Therefore, it also can improve the overall performance of the airplane.

There have been many changes to improve the quality of the components of the aircraft while at the same time trying to preserve the environment. The strength and stiffness of the materials can be determined from the stress and displacement test. GLARE has the low displacement value based on the outcome of this analysis. This is because the structure of GLARE has been highly rigid.

Instead, compared to Al 2042-T3 and Ti-6Al-4V (SS), GLARE has the lowest value of maximum stress in all pressure as GLARE has high basic strength, strength of tensile, and resistance to fatigue. It was extremely strong and lightweight based on GLARE's material properties. In complement the complex characteristic profile, it was also excellent damping properties and high impact resistance combined with precisely adjusted thermal expansion.

4.6 Analysis result of displacement

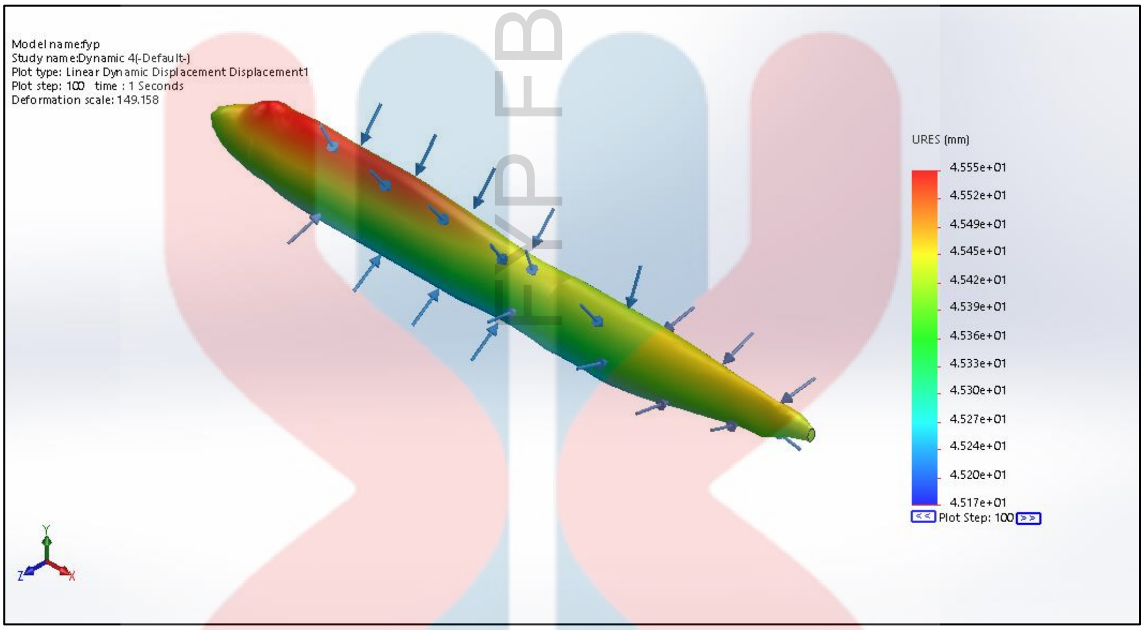


Figure 4.4: Displacement of Al 2042-T3 at 13 psi

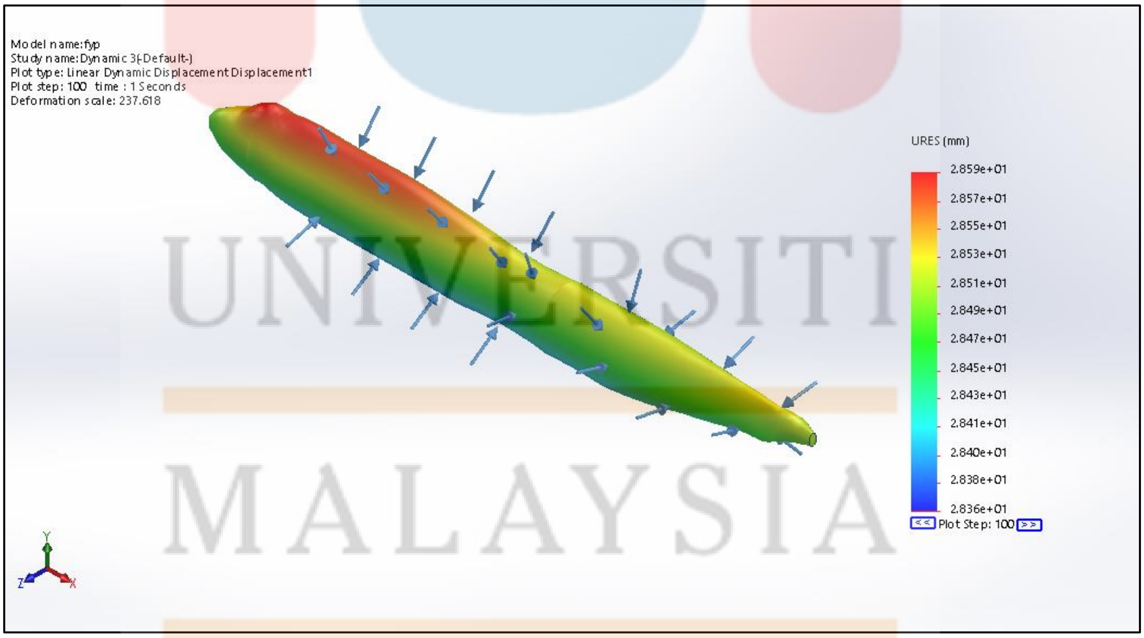


Figure 4.5: Displacement of Ti-6Al-4V (SS) at 13 psi

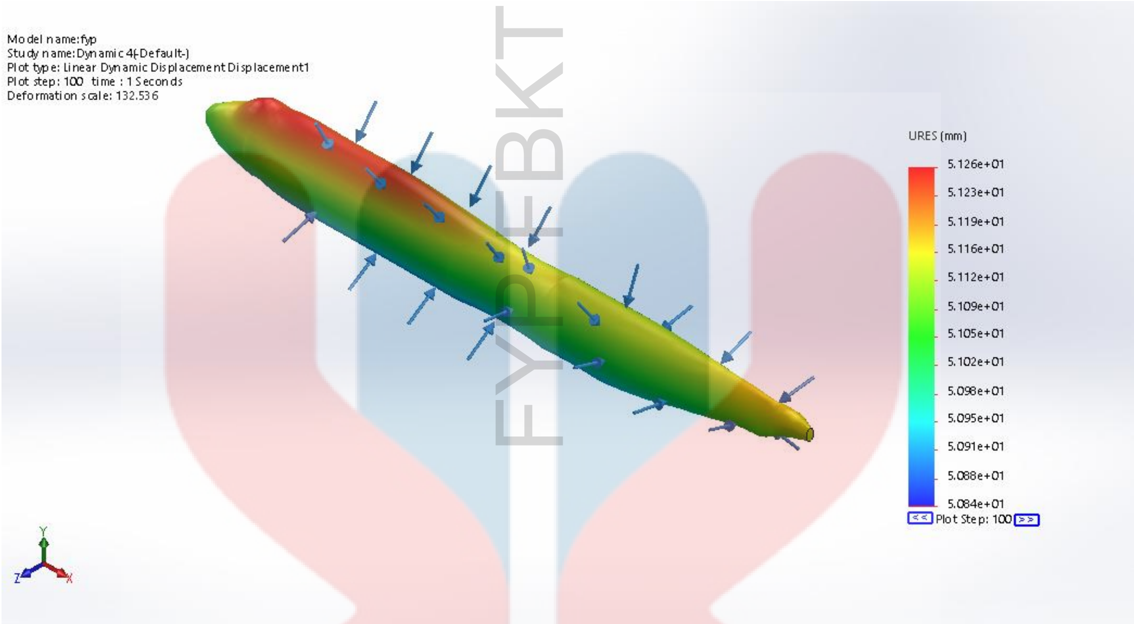


Figure 4.6: Displacement of GLARE at 13 psi

Based on Figure 4.4 to Figure 4.6, it is shown the displacement result of Al 2042-T3, Ti-6Al-4V (SS) and GLARE at 13 psi by using finite element analysis. The value of the maximum displacement was 4.555e+01 mm, 2.859e+01 mm, 1.08E+05 mm respectively. The displacement in Figure 4.4 is higher than in Figure 4.5 and Figure 4.6. The red colour in the figure shows the maximum of displacement after applied 13psi of pressure.

As GLARE is 33 percent larger than aluminium to withstand a predicted displacement, GLARE can take advantage of its component of high membrane stiffness. In addition, the energy of the membrane is proportional to the power displacement. Therefore, a thin, high-strength surface laminate that can withstand significant deformation can absorb more energy from impact than a thick plate with high bending rigidity. GLARE has a 72 percent higher structural efficiency than monolithic aluminium. Indeed, glass fibers can withstand relatively large deformation, and their high membrane stiffness attracts the impact load, enabling aluminium layers to flex with greater deflection in a safer way. An impact-resistant fiber metal laminate includes composites of high strength that can withstand large deformations (Morinière, Alderliesten, & Benedictus, 2012).

This show that the properties of GLARE was much better than aluminium. The displacement from this study and previous study show that the GLARE had the highest displacement.

4.7 Analysis result of stress

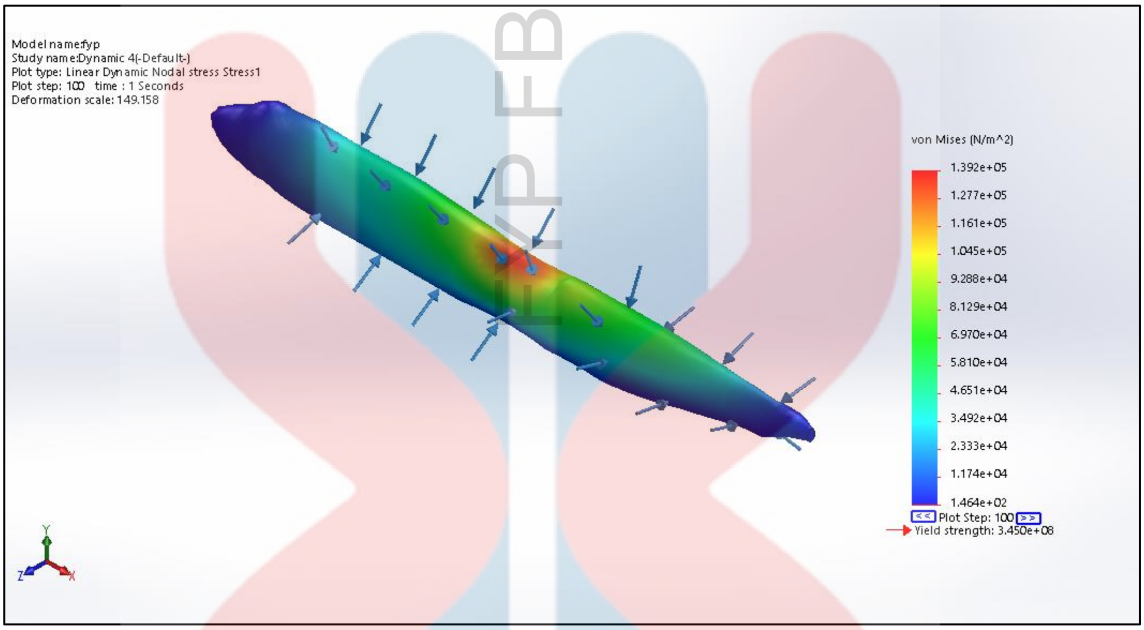


Figure 4.7: Stress of Al 2042-T3 at 13 psi

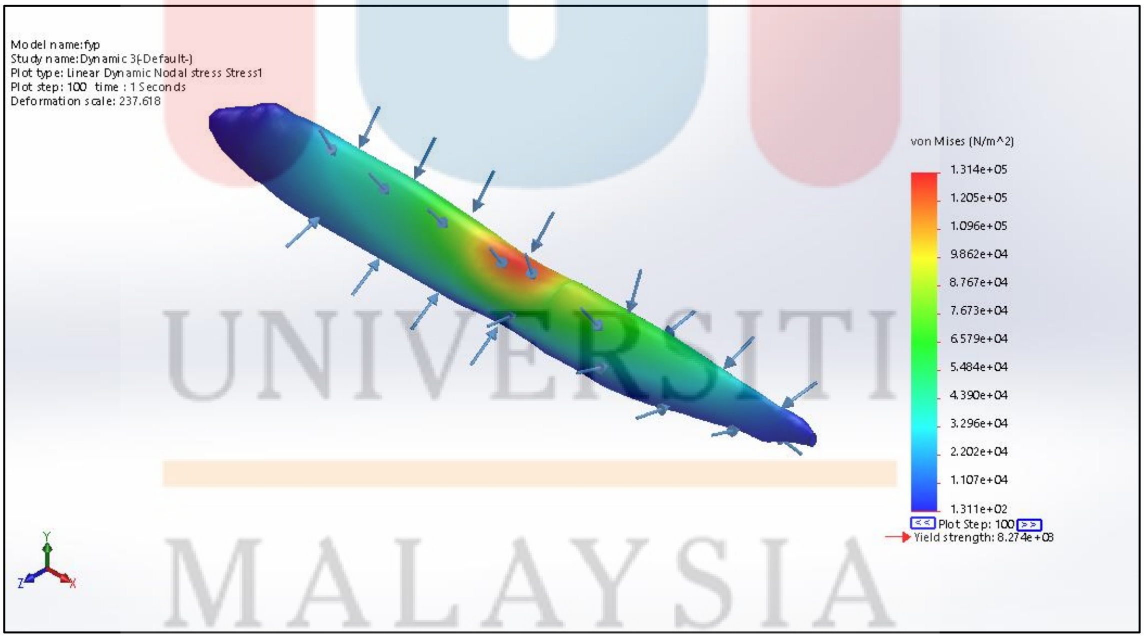


Figure 4.8: Stress of Ti-6Al-4V (SS) at 13 psi

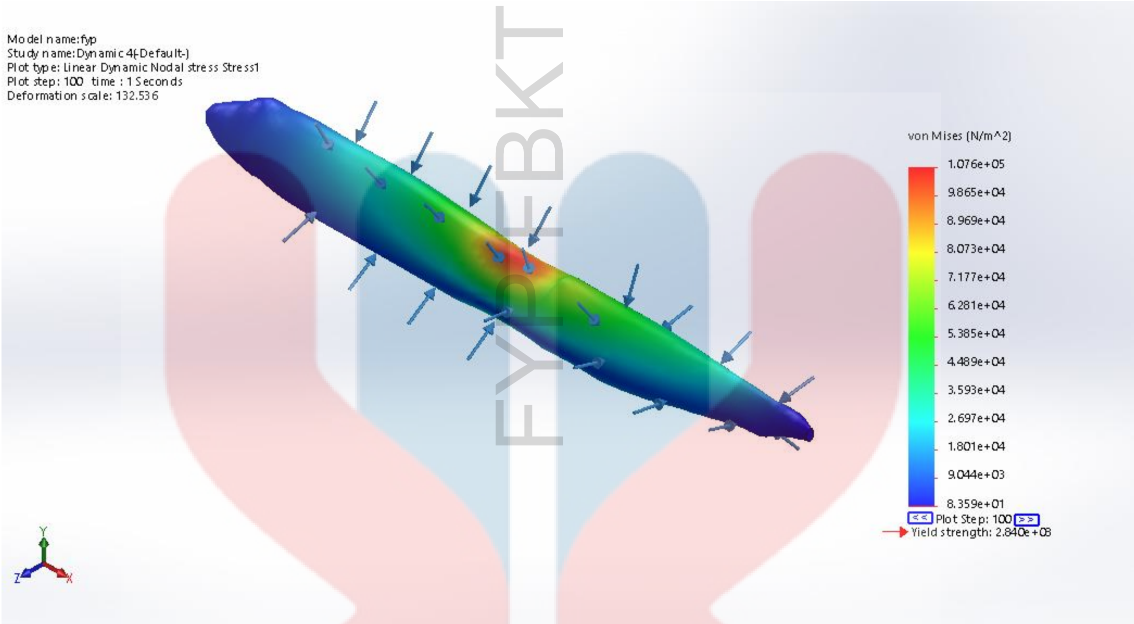


Figure 4.9: Stress of GLARE at 13 psi

Based on Figure 4.7 to Figure 4.9, it is shown the stress result of Al 2042-T3, Ti-6Al-4V (SS) and GLARE at 13 psi by using finite element analysis. The value of the maximum stress was 1.392e+05 N/m^2, 1.314e+05 N/m^2, 1.08E+05 N/m^2 respectively. The stress in Figure 4.7 is higher than in Figure 4.8 and Figure 4.9.

From this crash simulation we can see that all three materials have same pattern which the value of stress increasing upon the increasing force applied. This shows that all materials can withstand the force or the impact that is applied on them. Among three materials, composite can stand the least stress. The stress readings are the lowest compared to stress reading of aluminium alloy and titanium alloy for every pressure applied. This indicates the strength of composite materials compared to the other two materials. High strength material is good to be used in fuselage manufacturing as it can withstand pressure and stress.

We can summarize that GLARE had the lowest stress among aluminium alloy and titanium alloy. While aluminium alloy cast the highest stress value among selected materials. This might due to the materials or structure of the fuselage itself that produce the higher or lower stress (von-Mises) on the structure of fuselage during impact test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Stress and displacement analysis are numerically investigated using finite element analysis from the dynamic analysis. It was also able to simulate the fuselage impact test using simulation software from SolidWorks. The three different fuselage materials Al 2042-T3, Ti-6Al-4V (SS) and GLARE were tested by three different fuselage pressure. For the impact test 11 psi, 12 psi and 13 psi were selected as parameters. In addition, the simulation results were successfully compared using different material in terms of maximum stress and maximum displacement. From this result, it can be predicted that the material properties of GLARE are highly rigid. Consequently, GLARE has the lowest maximum pressure quality. Compared to Al 2042-T3 and Ti-6Al-4V (SS), it was shown that GLARE has high specific strength efficiency. The higher the stress the stronger the materials can create. It also has materials that are low density and lightweight. Reducing weight typically decreases power and fuel consumption because flying the airplane requires energy.

5.2 Recommendations

From this analysis, composite has been proven to be the best material that can be used as a component for fuselage due to its lightweight and high energy absorption that can minimize a lot of vehicle weight compared to aluminium alloy content. Nevertheless, due to the high cost of manufacturing, this component was not commonly used in the aircraft industry. Studying and learning more about this product as a fuselage is suggested as it gives a great deal of value to the safety of airline companies and people. Study also showed that using suitable material with suitable properties to make fuselage would help to reduce defects. For future study, it is recommended to discover more good material as a composite that is lightweight, low stiffness and high energy absorption capability to be used as a fuselage as it can reduce the aircraft's weight while at the same time giving passengers maximum protection. Finite element analysis was conducted using SolidWork ® in this research. Because finite element analysis is the tool used to perform fuselage impact testing, technology uses have been suggested to replace the manual crash test as it eliminates much of the expense, time and provides reliable and quick results to the researcher. Although there were many other applications that could be used to run FEA such as CATIA ®, GAMBIT ® and many more, SolidWorks ® software is the most preferred software because it can run both CAE and CAD compared to other software that the CAD and CAE must run using different software.

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