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Composite Material Usage in Aircraft Structure

Thesis Submitted inPartial Fulfillment of the Requirements for the Degree of Bachelor of Science. (BSc Honor)

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الآية

" آتُونِي زُبَرَ الْحَدِيدِ ۖ حَتَّىٰ إِذَا سَاوَىٰ بَيْنَ الصَّدَفَيْنِ قَالَ انفُخُوا ۖ حَتَّىٰ إِذَا جَعَلَهُ نَارًا
قَالَ آتُونِي أُفْرِغْ عَلَيْهِ قِطْرًا "

سورة الكهف الآية (96)

Abstract

This project studies theoretically and practically the composite materials used in aircraft structure to save the weight resulting from using other materials also by designing a tapered wing span using (CATIA) drawing and then dividing it into ten equal segments to know the values of bending moments and shear loads in each segment along the wing spar after applying the loads on it by using ANSYS application to prove that the resulting deformation is very small and can be neglected and carbon fiber is suitable to fabricate tapered wing spar.

التجريد

هذا المشروع يدرس بصورة نظرية و تطبيقية المواد المركبة المستخدمة في هيكل الطائرة لحل مشاكل الوزن الثقيل الناتج من استخدام المعادن الأخرى وذلك باجراء تصميم لعارضة الجناح الرئيسية بإستخدام برنامج الرسم (CATIA)وتقيسمها الى عشرة أجزاء متساوية ومن ثم تسليط القوى على الأجزاء لمعرفة قيم عزم الانحناء و قوة القص في كل نقطة على طول العارضة و اجراء الاختبارات عليه بواسطة البرنامج الهندسي (ANSYS) لاثبات أن قيمة التشوه الناتج من تسليط القوة على طول العارضة صغيرة ويمكن اهمالها و أن نوع المادة المركبة المستخدمة مناسبة لصناعة عارضة الجناح الرئيسية.

Acknowledgement

It is a pleasure to thank those who were supporting us during this project...

First, to ALLAH who created us …

To our families who built us to face this life …

And to my great teacher Prof. AbderaheemSaad I would thank you for your patience and support.

الإهـــــــــــــــداء

الى حكمتي وعلمي الى أدبي وحلمي الى طريقي المستقيم...

الى طريق الهداية الى ينبوع الصبر والتائل والأمل...

الى كل من في الوجود بعد الله ورسوله الى أمي الغالية وأبي الغالي ...

الى من تذوقت معهم أجمل اللحظات ...

الى من سأفتقدهم الى من جعلهم الله اخوتي

الى أصدقائي الأعزاء...

الى أساتذتي الأجلاء...

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Symbols

V	Shear load
M	Bending moment
W	Weight of aircraft
N	Load factor
C_R	Root chord
C_t	Tip chord
H	Spar height
X	Spar length
B	Wing span
A	Spar width
C	Wing Chord

1. Chapter one: Introduction

1.1 Overview

Composites are materials made of two or more constituents with different physical or chemical properties. When these materials are combined, the new material has different characteristic from the individual components. But the two or more materials which combine the composite materials must not melt in each other e.g. (Glass fiber reinforced plastic (GPRP), Continuous Fiber Ceramic Composites (CFCC), Carbon Fiber Reinforced Plastic (CFRP) and Aramid Fiber Reinforced Plastic (AFRP). These materials have been used in the aerospace industry as a new material according to the following features:

Table 1Composite materials features and benefits

Feature	Benefits
Light weight	It's lighter than steel by 5 times that means less power consumption and reduce corrosion and cost
High stiffness	It's more stiff than steel by two and half times
strength	It's stronger than steel by two and half times
Few parts	It reduces the cost and stress because the number of cables are few between parts and that means less stress

The best materials for the aircraft are those with high specific properties (mechanical property/ density).

The light metals aluminum and titanium are popular aircraft materials, as composite materials like glass or Carbon Fiber Reinforced Plastic. For example, If we make a comparison between the density of Aluminum alloy and Glass Fiber Reinforced Plastic we find that the densities are 2700 and 1700 kg/m3 respectively.[1]

1.2 Advanced Composite Material:

An advanced composite material is made of a fibrous material embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness. Fibrous materials are not new; wood is the most common fibrous structural material known to man.

Applications of composites on aircraft include

- Fairings
- Flight control surfaces
- Landing gear doors
- Leading and trailing edge panels on the wing and stabilizer
- Interior components
- Floor beams and floor boards
- Vertical and horizontal stabilizer primary structure on large aircraft
- Primary wing and fuselage structure on new generation large aircraft
- Turbine engine fan blades
- Propellers

1.3 Drivers for Improved Airframe Materials

Weight saving through increased specific strength or stiffness is a major driver for the development of materials for airframes. there are many other incentives for the introduction of a new material.

A crucial issue in changing to a new material, even when there are clear performance benefits such as weight saving to be gained, is affordability. This includes procurement (up front) cost (currently the main criterion) and through life support cost (i.e., cost of ownership, including maintenance and repair). Thus the benefits of weight savings must be balanced against the cost. Approximate valuesthat may be placed on saving 1 kilogram of weight on a range of aircraft types.

In choosing new materials for airframe applications, it is essential to ensure that there are no compromises in the levels of safety achievable with conventional alloys. Retention of high levels of residual strength in the presence of typical damage for the particular material (damage tolerance) is a critical issue.

Durability, the resistance to cyclic stress or environmental degradation and damage, through the service life is also a major factor in determining through-life support costs. The rate of damage growth and tolerance to damage determine the frequency and cost of inspections and the need for repairs throughout the life of the structure.

1.4 Aim and Objectives

This research aims to study the composite materials as well as designing a wing spar model made out of composite material (carbon Fiber)

1.5 Problem statement

This project is about composite materials to solve the problem of high weight from the metal alloys used in aircraft structure.

1.6 Proposed solution

By applying the use of composite material in aircraft structure.

1.7 Methodology

This research has been done after the study of the prosperities and features of the composite material and compare them with other materials, we found that they are suitable to be used in the aircraft structure. After returning to different references and scientific papers the data has been collected and analyzed and then the structural application model has been designed and tested and we approved that carbon fiber is suitable to be used in wing spar structure.

1.8 Methods and Tools

Computerized system:

- CATIA
- ANSYS
- Excel

1.9 Thesis Outlines

This research which is about composite materials used in aircraft structure consists of five chapters

Chapter one is about the introduction to composite materials, their specifications, the difference between them and other materials and it has an answer to the question why they preferred the composite material in aircraft industry

Chapter two is about the history of composite materials in general, the history of them in aircraft industry, types of fiber, the usage of composite materials in the UAVs design, design for manufacturing of composite structures for commercial aircrafts, detect the defect by using non-destructive-testing (NDT), composite material repair and joining.

Chapter three is about the calculations of designing the wing spar including the equations, drawings of spar meshing and structure analysis.

Chapter four is about the results, discussion of calculations of the wing spar and graph shows the forces applied on it,

Chapter five is about the conclusion, recommendation and the future work.

2 Chapter Two: Literature Review

2.1 History of Composites

Throughout history, humans have used composite type materials. One of the earliest uses of composite material was by the ancient Mesopotamians around 3400 B.C., when they glued wood strips at different angles to create plywood.[2]

Egyptians used of Cartonnage, layers of linen or papyrus soaked in plaster, for death masks dates to the 2181-2055 BC. Archeologists have found that natural composite building materials were in used in Egypt and Mesopotamia, since ancient builders and artisans used straw to reinforce mud bricks, pottery, and boats around 1500 BC.[2]

Around 25 BC, The Ten Books on Architecture described concrete and distinguished various types of lime and mortars. Researchers have demonstrated that the cement described in the books is similar, and in some ways superior to the Portand cement used today.[2]

In about 1200 AD, the Mongols invented the first composite bows made from a combination of wood, bamboo, bone, cattle tendons, horns and silk bonded with natural pine resin. Thebows were small, very powerful, and extremely accurate. Composite Mongolian bows were the most feared weapons on earth until the invention effective firearms in the 14th century.

- 4000 B.C. – laminated writing material from the papyrus plant
- 1300 B.C. – Egyptians and Mesopotamian used straw bricks
- 1200 A.D. - Mongols invented the first composite bow

Figure 1History of composite materials

From the 1870's through the 1890's, a revolution was occurring in chemistry. Polymerization allowed new synthetic resins to be transformed from a liquid to solid state in a cross-linked molecular structure. Early synthetic resins included celluloid, melamine and Bakelite.

In the early 1900's, plastics such as vinyl, polystyrene, phenolic and polyester were developed. As important as these innovations were, reinforcement was needed to provide the strength and rigidity.

Bakelite, or polyoxybenzylmethylenglycolanhydride, is an early innovative plastic. It is a thermosetting phenol formaldehyde resin, formed from an elimination reaction of phenol with formaldehyde. It was developed by Belgian-born chemist Leo Baekeland in New York in 1907.

One of the first plastics made from synthetic components, Bakelite was used for its electrical non-conductivity and heat-resistant properties in electrical insulators, radio and telephone casings, and such diverse products as kitchenware, jewelry, pipe stems, and children's toys. Bakelite was designated a National Historic Chemical Landmark in 1993 by the American Chemical Society in recognition of its significance as the world's first synthetic plastic. The "retro" appeal of old Bakelite products has made them collectible.

The thirties were perhaps the most important decade for the composites industry. In 1935, Owens Corning launched the fiber reinforce polymer (FRP) industry by introducing the first glass fiber. In 1936, unsaturated polyester resins were patented. Because of their curing properties, they would become the dominant choice for resins in manufacturing today. In 1938, other higher performance resin systems like epoxies also became available.

World War II brought the FRP industry from research into actual production. In addition to high strength to weight properties, fiberglass composites were found to be transparent to radio frequencies and were adopted for radar domes and used with other electronic equipment. In addition, the war effort developed first commercial grade boat hulls. While they were not deployed in the war effort, the technology was rapidly commercialized after the war.

By 1947 a fully composite body automobile had been made and tested. This car was reasonably successful and led to the development of the 1953 Corvette, which was made using fiberglass preforms impregnated with resin and molded in matched metal dies. During this period, several methods for molding were developed. Eventually two methods, compression molding of sheet molding compound (SMC) and bulk molding compound (BMC), would emerge as the dominant forms of molding for the automotive and other industries.

In early 1950's, manufacturing methods such included pultrusion, vacuum bag molding, and large-scale filament winding were developed. Filament winding became the basis for the large-scale rocket motors that propelled exploration of space in the 1960's and beyond. Pultrusion is used today in the manufacture of linear components such as ladders and moldings.

In 1961, first carbon fiber was patented, but it was several years before carbon fiber composites were commercially available. Carbon fibers improved thermoset part stiffness to weight ratios, thereby opening even more applications in aerospace, automotive, sporting goods, and consumer goods. The marine market was the largest consumer of composite materials in the 1960's.

Fiber development in the late 1960's led to fibers made from ultra-high molecular weight polyethylene in the early 1970's. Progress in advanced fibers led to breakthroughs in aerospace components, structural and personal armor, sporting equipment, medical devices, and many other applications. New and improved resins continued to expand composites market, especially into higher temperature ranges and corrosive applications. In the 1970's, the automotive market surpassed marine as the number one market – a position it retains today.

Mar-Bal, Inc. was formed in 1970 and began their journey of becoming the most integrated Thermoset Composites Solution Provider of today. Mar-Bal began small and custom molded components for the Electrical (e.g. breakers), Motor Assembly (e.g. housings) and Small Appliance (e.g. waffle makers) industries.

By the mid 1990’s, composites hit mainstream manufacturing and construction. As a cost effective replacement to traditional materials like metal and engineered thermoplastics, Industrial Designers and Engineers began specifying thermoset composites for various components within the Appliance, Construction, Electrical and Transportation industries.

Consumers came into contact with composite materials every day from Handles and Knobs on their gas driven ranges to beautifully stained entry doors of their homes and utilized within electrical infrastructure for the safe and effective delivery of electricity.

Composites began to impact the electrical transmission market with products such as pole line hardware, cross-arms and insulators.

In the mid-2000s, the development of the 787 Dreamliner validated composites for high-strength and rigid applications.

Continued development of finish technology, like PVD and THERMTIAL™, grew the number of applications in automotive, appliances and consumer products industries. Composites were just beginning to find their way into nanotechnologies.[2]

2.1.1 History of composite material in aircraft industry:

Composite materials are not a stranger to the aerospace industry and as early as 1940s, Glass Fibre Reinforced Polymers (GFRP) began to find their way into the maritime industry. In 1944 the first aircraft with composites in its fuselage was flown in the USA, an experimentally modified Vultee BT-15.[25]

In the early 1960, composites were used in the form of ‘pre-pegs’ which consist of a series of Fibre Reinforced Plastics (FRP) pre-impregnated with an epoxy resin. Examples can be seen in the wings and forward fuselage of the AV-8B Harrier and the tail of the A320, as well as other military aircraft such as the Eurofighters2000.[18]

Recently, Airbus increased its use of composites from 25% in the iconic A380 to 53% in the new A350 XWB. Boeing did the same : 12% of the structure of the 777 is made of composites and now their newest aircraft the 787 is comprised in 50% of composites. This produced a reduction in weight of 20% in the 787 and reduced scheduled and non-routine maintenance due to a reduced risk of corrosion and fatigue.

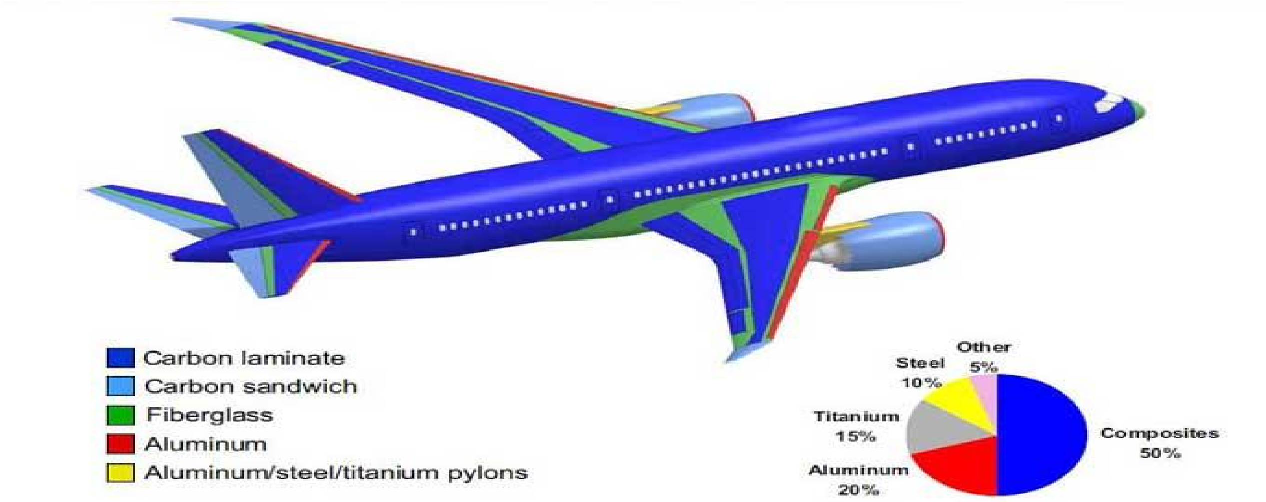

Figure 2 Use of composite material in B 787

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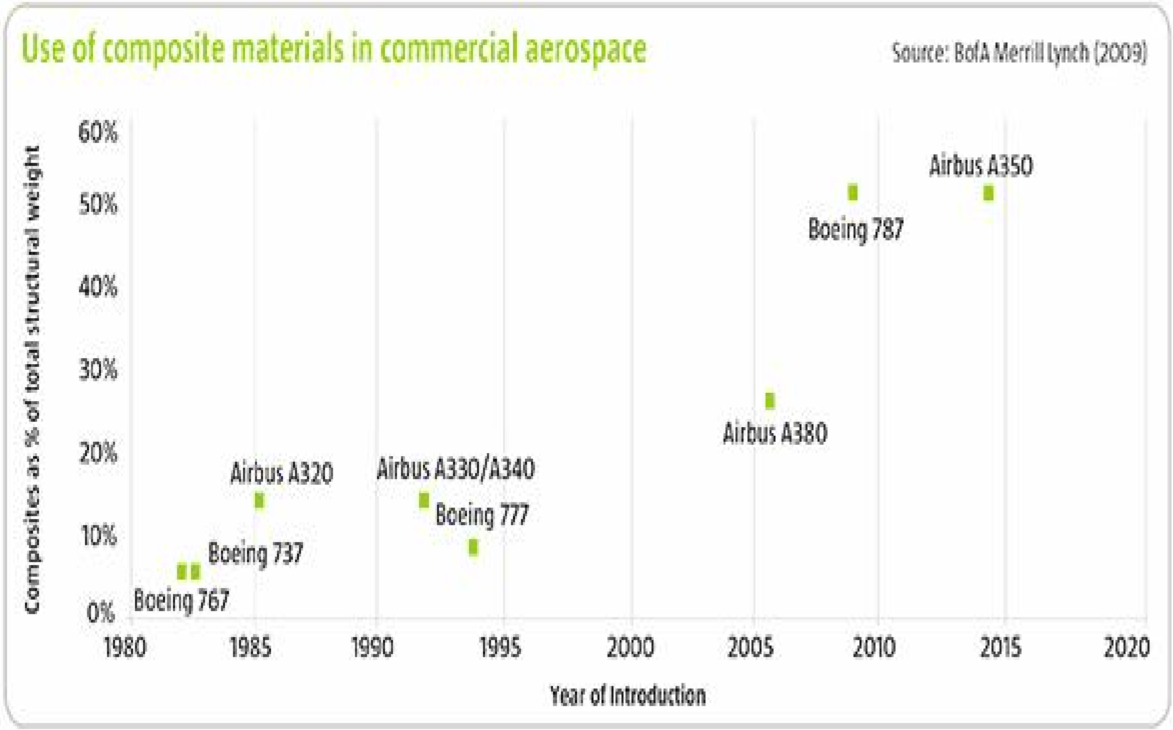


Figure 3Use of composite materials in commercial aerospace

Although these composites have many features such as light weight, Hight stiffness…etc, but it also has many disadvantages such as:” it can be old under yhe effect of high temperature and humidity, medium resistance to shocks, difficulties in repairing and difficulties in series production.[3]

They are using composite materials instead of aluminum in a wide range of the aircraft industry because of high specific solidity, light weight and high specific stiffness.

Composites have also been used in the designing of the UAVs industry. In 2009, a survey of 200 models by composite world found that all of the models have composite component and number of cases reported the use of carbon fiber for the construction of the airframes.[8]

However, the increase demand for payload capacity and drone performance made the industry switch to another composite for the construction of the drone construction: carbon fiber reinforced polymers (CFRP) which is now the primary material used in the construction of the UAV airframes.[4]

According to composite world, in 2007 and 2008, 231 and 247 metric tons of composites were produced to support UAVs and the market is expected to produce 738 metric tons of airframe structure by the year 2018.

As the market share of drones increases in civil and military applications, the demand for more maneuverable, pay-load effective UAVs is going to increase with composite materials playing a vital role in the development of these new aircraft.[7]

The use of additive manufacturing techniques such as Fused Deposition Modeling (FDM) and Laser Sintering (LS) in conjunction with composite materials is going to permit the development of more effective drones for security and military purposes.

2.2 Types of Fiber:

Fiberglass is often used for secondary structure on aircraft, such as fairings, radomes, and wing tips. Fiberglass is also used for helicopter rotor blades. There are several types of fiberglass used in the aviation industry. Electrical glass, or E-glass, is identified as such for electrical applications. It has high resistance to current flow. E-glass is made from borosilicate glass. S-glass and S2-glass identify structural fiberglass that have a higher strength than E-glass. S-glass is produced from magnesia-alumina-silicate. Advantages of fiberglass are lower cost than other composite materials, chemical or galvanic corrosion resistance, and electrical properties (fiberglass does not conduct electricity). Fiberglass has a white color and is available as a dry fiber fabric or prepreg material.[8]

Kevlar is DuPont’s name for aramid fibers. Aramid fibers are light weight, strong, and tough. Two types of Aramid fiber are used in the aviation industry. Kevlar 49 has a high stiffness and Kevlar 29 has a low stiffness. An advantage of aramid fibers is their high resistance to impact damage, so they are often used in areas prone to impact damage. The main disadvantage of aramid fibers is their general weakness in compression and hygroscopy. Service reports have indicated that some parts made from Kevlar absorb up to 8 percent of their weight in water. Therefore, parts made from aramid fibers need to be protected from the environment. Another disadvantage is that Kevlar® is difficult to drill and cut. The fibers fuzz easily and special scissors are needed to cut the material. Kevlaris often used for military ballistic and body armor applications. It has a natural yellow color and is available as dry fabric and prepreg material. Bundles of aramid fibers are not sized by the number of fibers like carbon or fiberglass but by the weight.[8-11]

Carbon/Graphite is One of the first distinctions to be made among fibers is the difference between carbon and graphite fibers, although the terms are frequently used interchangeably. Carbon and graphite fibers are based on graphene (hexagonal) layer networks present in carbon. If the graphene layers, or planes, are stacked with three-dimensional order, the material is defined as graphite. Usually extended time and temperature processing is required to form this order, making graphite fibers more expensive. Bonding between planes is weak. Disorder frequently occurs such that only two-dimensional ordering within the layers is present. This material is defined as carbon.

Carbon fibers are very stiff and strong, 3 to 10 times stiffer than glass fibers. Carbon fiber is used for structural aircraft applications, such as floor beams, stabilizers, flight controls, and primary fuselage and wing structure. Advantages include its high strength and corrosion resistance. Disadvantages include lower conductivity than aluminum; therefore, a lightning protection mesh or coating is necessary for aircraft parts that are prone to lightning strikes. Another disadvantage of carbon fiber is its high cost. Carbon fiber is gray or black in color and is available as dry fabric and prepreg material. Carbon fibers have a high potential for causing galvanic corrosion when used with metallic fasteners and structures. [Figure4]

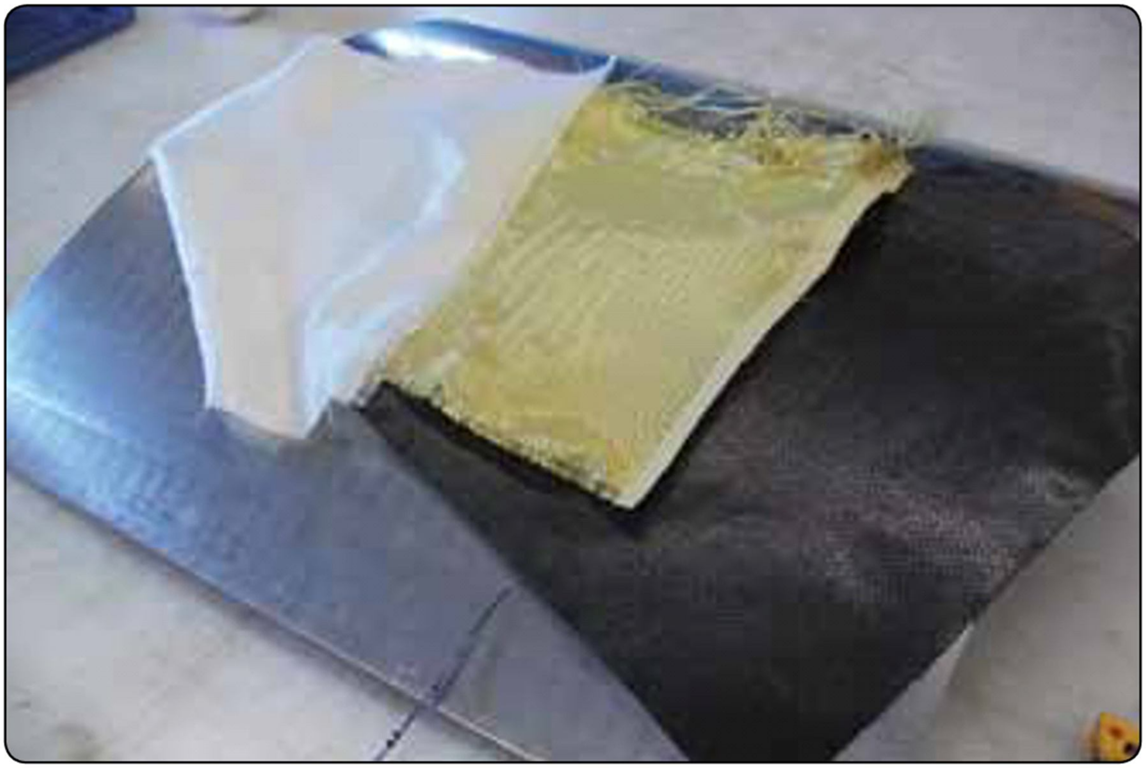


Figure 4 Fiberglass (left), Kevlar (middle), and carbon fiber

Boron fibers are very stiff and have a high tensile and compressive strength. The fibers have a relatively large diameter and do not flex well; therefore, they are available only as a prepreg tape product. An epoxy matrix is often used with the boron fiber. Boron fibers are used to repair cracked aluminum aircraft skins, because the thermal expansion of boron is close to aluminum and there is no galvanic corrosions potential. The boron fiber is difficult to use if the parent material surface has a contoured shape. The boron fibers are very expensive and can be hazardous for personnel. Boron fibers are used primarily in military aviation applications.[9]

Ceramic Fibers Ceramic fiber sare used for high-temperature applications, such as turbine blades in a gas turbine engine. The ceramic fibers can be used to temperatures up to 2,200 °F.

2.2.1 Solution of the problem of lightning strike in composite:

Lightning Protection Fibers is an aluminum airplane is quite conductive and is able to dissipate the high currents resulting from a lightning strike. Carbon fibers are 1,000 times more resistive than aluminum to current flow, and epoxy resin is 1,000,000 times more resistive (i.e., perpendicular to the skin). The surface of an external composite component often consists of a ply or layer of conductive material for lightning strike protection because composite materials are less conductive than aluminum. Many different types of conductive materials are used ranging from nickel-coated graphite cloth to metal meshes to aluminized fiberglass to conductive paints. The materials are available for wet layup and as prepreg.[8]

In addition to a normal structural repair, the technician must also recreate the electrical conductivity designed into the part. These types of repair generally require a conductivity test to be performed with an ohmmeter to verify minimum electrical resistance across the structure. When repairing these types of structures, it is extremely important to use only the approved materials from authorized vendors, including such items as potting compounds, sealants, adhesives, and so forth.[8]

2.3 Composite Manufacturing

The primary manufacturing methods used to produce composites include:

- Manual Lay-Up
- Automated Lay-Up
- Spray-Up
- Filament Winding
- Pultrusion
- Resin Transfer Molding

Manual lay-up involves cutting the reinforcement material to size using a variety of hand and power-operated devices. These cut pieces are then impregnated with wet matrix material, and laid over a mold surface that has been coated with a release agent and then typically a resin gel-coat. The impregnated reinforcement material is then hand-rolled to ensure uniform distribution and to remove trapped air. More reinforcement material is added until the required part thickness has been built-up. Manual lay-up can also be performed using preimpregnated reinforcement material, called 'prepreg'. The use of prepreg material eliminates separate handling of the reinforcement and resin, and can improve part quality by providing more consistent control of reinforcement and resin contents. Prepreg must be kept refrigerated prior to use, however, to prevent premature curing.[17]

The productivity of the manual lay-up can be automated using CNC machines. These machines are used for both prepreg tape-laying and prepreg fiber-placement primarily in the aerospace industry. There is virtually no limit to the size of the work that can be tape-rolled, but the shape has to be relatively flat to butt each successive row without gaps, overlaps or wrinkles. Automatic, multi-axis fiber placement machines overcome this limitation by dispensing numerous, narrow individual tapes of material which are collimated as they are laid on the mold surface.[20]

In spray-up, resin is sprayed onto a prepared mold surface using a specially designed spray gun. This gun simultaneously chops continuous reinforcement into suitable lengths as it sprays the resin.[13]

After lay-up, the composite parts must be cured. Curing can take place at room temperature, often with heated air assist. Ovens, heated-platen presses, and autoclaves may also be used. Curing times may range from a single hour to one-half day or longer. Curing is also accomplished with vacuum bag molding. Here a non-adhering plastic film, usually polyester, is sealed around the lay-up material and mold plate. A vacuum is slowly created under the bag forcing it against the lay-up. This draws out entrapped air and excess resin. Vacuum bag molding is effective in producing large, complex shaped parts.[8]

Filament winding refers to wrapping a narrow fiber tow or band of tows of resin impregnated fiber around a mandrel of the shape to be produced. When the mandrel is removed, a hollow shape is the result. Uses for filament winding include pipe, tubing, pressure vessels, tanks and items of similar shape.[10] Filament winding is typically applied using either hoop or helical winding. In hoop winding, the tow is almost perpendicular to the axis of the rotating mandrel. Each mandrel rotation advances the material-delivery supporting carriage one band width, butting the edge of one band next to the previous band. In helical winding, material is deposited in a helical path in one direction, then turns around on end and returns in a helical path in the opposite direction. Filament winding mandrels may be metallic or non-metallic and designed to either collapse to facilitate part removal or may be dissolvable after curing.[5]

Pultrusion is a continuous process used primarily to produce long, straight shapes of constant cross-section.

Pultrusion is similar to extrusion except that the composite material is pulled, rather than pushed, through a die. Pultrusions are produced using continuous reinforcing fibers called 'roving' that provide longitudinal reinforcement, and transverse reinforcement in the form of mat or cloth materials.[6]These reinforcements are resin impregnated by drawing through a resin wet-out station; and generally shaped within a guiding, or preforming, system. They are then subsequently shaped and cured through a preheated die or set of dies.

Once cured, the pultrusion is saw-cut to length. Pultrusions can be hollow or solid, and applications include bar and rod, pipe, tubing, ladder rails and rungs, and supports of many kinds.

Resin transfer molding or 'RTM' produces large, complex items such as bath and shower enclosures, cabinets, aircraft parts, and automotive components.[4] In this process, a set of mold halves are loaded with reinforcement material then clamped together. Resin is then pumped or gravity fed into the mold infusing the reinforcement material. Once the mold is filled with resin, it is plugged and allowed to cure. After curing, the mold halves are separated and the part removed for final trimming and finishing.[8]

2.3.1 Composite Fabrication & Assembly

Cured composite parts may be machined, drilled, and sawed as needed to meet specifications. Tooling must be kept sharp, often being carbide or diamond tipped, as the composite material can be highly abrasive. A coolant is often used to prevent heat buildup during machining.[5]

The two principle joining methods used for assembling composite parts are adhesive bonding and mechanical fastening.[11]

Adhesive bonding produces strong, permanent joints. Proper preparation and cleanliness is critical. Typical joint configurations include lap, double lap, overlays, and scarf joints. Work pieces may be placed in a fixture and pressed together while setting and curing.[5] Elevated temperatures may be required depending on the adhesive type used.

Mechanical fastening employs rivets, pins, bolts, and other fasteners. These may be either metallic or composite material fasteners. Careful and precise hole making and accurate torqueing are required to prevent distortion and cracking of the composite material during fastening.[3]

2.3.2 Design for Manufacturing of Composite Structures for Commercial Aircraft - the Development of a DFM strategy at SAAB Aero structures

Historically, aircraft manufacturing, and especially assembly operations, has mainly been performed manually. This was due to long development times with continuous changes in aircraft design, making serial manufacturing not applicable. [1] It was not economically feasible to invest in expensive equipment, even when it was technically feasible. Previous commercial aircraft manufacturing and design was to a large extent conducted in-house, while today the design and manufacturing of parts and subsystems are often outsourced to several different sub-suppliers. This network of suppliers puts strong requirements on cost and time of delivery, since it is normally easier to change a supplier than shut down an inhouse division [2]. The amount of air travel is expected to increase in the coming 20 years, by around 5% per year according to Airbus [3] and Boeing [4]. This means a higher demand for aircrafts among the world’s aircraft manufacturers [2]. Besides the change from single-unit manufacturing to series manufacturing, this also requires a shorter time for product development and manufacturing in order to achieve low costs [5].

One way to meet these demands is to work more with design for manufacturing (DFM) strategies and methods, since DFM directly address the costs for manufacturing, which are a large part of the entire product cost [6]. DFM is a way to lower manufacturing costs while not lowering product quality [6]. DFM is not a new design method; as early as in the 1920s, Henry Ford was conducting a kind of DFM [7]. Although Ford performed DFM back in the 1920s, the traditional "overthe-wall" design approach was not common practice until the 1950s to at least the 1970s in Western companies [8]. In the 1980s, concurrent engineering spread rapidly in research and industry. Foremost, it was the American automotive industry that led the way in adopting new product development organizations and processes in order to compete with Japanese competitors. In addition, since concurrent engineering spread so fast among the manufacturing.

Companies of the Western world, it is likely that there must have been a tremendous need to improve the product development process in many countries [8]. Initially, many DFM efforts placed it at a general level. This changed, however, with the growing attention towards automation. According to Riley [9], the pace of automation in the USA accelerated during the 1950s due to high production volumes, increasing labor costs and the introduction of the vibratory bowl feeder. Interestingly, after redesigning for automatic assembly, many firms discovered that the redesigned product became so simple to assemble manually that automatic assembly was no longer economically feasible [10]. This means that DFM can significantly improve design both for manual and automatic assembly, e.g. reduction of components and easier part insertion. The consequence of not designing products for manufacturing can be prolonged product development and manufacturing, and at the same time, high costs for development and manufacturing. This is due to the high risk of creating products that are unnecessarily complex to manufacture, or that needs to be redesigned in order to manage problems not discovered until manufacturing ramp-up [8]. In aircraft manufacturing, there is also a high demand for lowering fuel consumption and environmental impact. One way that aircraft manufacturers are dealing with these demands is to reduce the weight of the aircraft by using new types of materials, especially composites of carbon fiber reinforced plastics (CFRP). Historically, these materials have not been used to a large extent in aircraft production, and it is important to incorporate and regard the specific material properties of these materials in the DFM methods that are going to be used in the aircraft industry. There has been limited implementation of DFM in the aircraft industry, since the main focus in aircraft design has traditionally been on functionality, weight reduction, material usage and durability. However, the increased importance of cost reduction, in combination with increased production volumes and usage of CFRP, makes it vital to implement DFM. It is important when working with DFM to regard the manufacturing process early in the product development process.An issue when working with DFM is that problems with assembly are usually not discovered until the manufacturing phase, when the costs for design changes are very high [11]. A majority of the problems in manufacturing are derived from an inadequate design [5], which depends much on weaknesses in both knowledge and communication between designers and manufacturing engineers [5, 11]. Therefore, there is an industrial need to develop and work with DFM

2.3.2.1 SAAB Aero structures

At SAAB aero structures in Linkoping, structural parts such as doors and ailerons for commercial aircrafts are being developed and manufactured. The major customers are

Airbus and Boeing. One of the products produced at SAAB in Linkoping is the large cargo door for the Boeing 787 program, as depicted in Fig.1. The product development process at SAAB is divided into two major phases, preliminary development and detail development. The focus in the development projects has traditionally been functionality, weight reduction, material usage and durability. Manufacturability, however, has not had the same strong focus. The execution of the development projects is adjusted to comply with the different requirements of the development processes of Airbus and Boeing.

Figure 5 Boeing 787 aircraft

2.3.2.2 Aircraft manufacturing

The most common materials in aircraft manufacture are aluminum, stainless steel, titanium and CFRP. CFRP is considered to have good weight and material features, in primary structural parts it is now used as well in all wing and stabilizer components such as skin panels, ribs and spars, control surfaces as in fuselage skin, stringers and frames. Historically it has been used extensively in secondary structures such as fairings, floor panels and interior. The manufacturing process for CFRP parts is very expensive, due to the high price of raw materials and the special tools needed for manufacture [2]. The process also has a high number of manual operations, which makes it expensive to perform in a high-wage country like Sweden. Composite parts are becoming more common in structures for civilian aircrafts [12]. At the same time as the use of composites is increasing, the competition between manufacturers has become more intense [13]. The areas of application for CFRP are increasing fast, which means that the development efforts within composites are also increasing [14]. The implementation of new materials and technologies requires new procedures for how to design and build aircrafts [15]. Some of the main reasons for increasing the use of composites in aircraft structures are the expectations of decreased life-cycle cost, weight and number of parts [15]. A suitable composite construction can contribute to good design flexibility, lighter components, simplified manufacturing and installation methods, higher resistance to corrosion and high fatigue strength, as compared to general metal structures [16].

2.3.2.3 Success Factors for Design for Manufacturing (DFM)

Within the context of the literature study, different commercial DFM methods were charted. Many similarities between the different methods were found, the most important being that the majority of the methods were developed for high-volume products of metallic or plastic materials. The methods are also all designed for automatic assembly. There are many different ways a DFM method can be configured, but one general guideline is that the method should contain some kind of analytical evaluation of the design solutions [17].The benchmarking showed that none of the investigated companies used a commercial DFM method. Instead, the companies had developed their own DFM methodology and processes. But when comparing the structure of the different commercial DFM methods with the way the benchmarked companies work with DFM, some generic success factors were found. The identified success factors can be categorised into three groups: general, organizational and process related

2.3.2.4 General success factors

One of the most important factors is to set measurable aims for the DFM work to be able to ensure that the desired goal is obtained [18]. Adapted to the conditions at the company - Herbertsson [8] and Norstrom&Rimskog [19] state that the DFM methodology needs to be adapted to the manufacturing process and company, since what is efficient in one manufacturing system not necessarily efficient in another. Moreover, a DFM method does not automatically create collaboration between different departments in a company; rather, the right organizational prerequisites need to be in place. This corresponds well with the findings from the benchmarked companies that work with DFM. Designers educated in the manufacturing system - All of the benchmarked companies offered education in their manufacturing process to their designers to ensure that they understand the possibilities and limitations of the process. DFM method implemented within the whole company The DFM method needs to be accepted throughout the whole organization and to be an integrated part of the product development process [20]. This also corresponds well with the findings from the benchmarked companies. Understanding of which parameters in the product design affect the manufacturability – Herbertsson [8, 17] states that in order to develop a DFM method, the parameters in the product that have the most effect on the manufacturability need to be identified. This is needed to be able to either create design guidelines on how to design the product according to DFM, or to be able to simulate how changes in the design impact the manufacturability. The benchmarked companies had a good understanding of which parameters in the product design affect the manufacturability. In fact, this was a condition for being able to develop their DFM methodologies.

2.3.2.5 Organizational success factors

Cross-functional and collocated product development teams –Herbertsson's [8] studies clearly show the need for cross-functional teams to be successful in DFM work. The companies in the benchmarking all used these kinds of teams; the larger companies also co-located the different competence areas when executing big product development projects. Clear division of responsibilities - The benchmarking showed that the companies had a clear division of responsibilities within DFM. This is supported by theory within the area. Eskilander [21] stresses the need for division of responsibilities to be able to ensure that the aim of the DFM work is reached, as well as the continuous improvement of the DFM methodology. Link between design and production departments - One common challenge in product development is risk of conflicts between different departments due to differences in priorities and aim [6]. Many of the benchmarked companies have a group that is used as a link between the design and production departments in order to handle and prioritise the different demands on the product. Forum for communication of design changes - Many of the investigated companies stress the need to handle proposals for design changes in a structured way. Meetings between the design and production departments, where problem areas in the design are presented visually and suggestions for design changes are discussed, is common. In practise, simulations or physical prototypes are used for this purpose.

2.3.2.6 Process-related success factors

DFM is used early in the product development process Kuo et al. [20] state the need for the DFM method to be used early in the product development process, since the cost for making design changes increases as the development progresses. Almost all the investigated companies agree with this, and think that this is essential in order to succeed with DFM. Use of checklists when reviewing product designs - All the investigated companies used some form of checklist when reviewing the design, as this is an easy and efficient method to ensure that no essential aspect is overlooked and that all demands are met. DFM should be a help for the designer in the development process - The designer needs to understand why DFM is important and how the designs are being evaluated [17]. DFM should inspire and contribute to creative solutions [20]. Time to redesign problem areas in the design - The companies that were investigated have all seen the need to have sufficient time between design reviews and the start of production in order to be able to correct design flaws and improve problematic designs. The review and evaluation of designs need to be continuous during the development process, and not just occur at the end of the development project.

2.3.2.7 The new Design for Manufacturing strategy at SAAB Aero structures

Based on the interviews, workshop and observation studies held at SAAB, several areas for improvement were identified at the company. By comparing the success factors identified from the literature study and benchmarking against how SAAB's product development work is organized, some potential areas for improvement were found. Another important area that was identified was the trade-off between complexity in the manufacturing of CFRP parts and complexity in final assembly. A high integration of functions at the CFRP part level may reduce complexity and costs in final assembly. However, an unsuitable integration may create fewer but more complicated assembly operations, and thus increase assembly costs. Furthermore, high integration often induces costs and quality issues in the manufacturing of CFRP parts. This aspect is important to consider when developing a tool to be used in the product and production development process. From the identified success factors needed at SAAB to succeed with DFM, a strategy adjusted for SAAB and its development areas was designed. The DFM strategy developed for SAAB will create the potential to make the product development process more effective regarding the work with manufacturability. The DFM strategy is divided into three organizational levels (see also Fig. 6): x Strategic x Tactical x Operational.The strategy describes how the work with DFM should be performed on the different organizational levels. It also includes a DFM tool/method, specially adapted for the conditions at SAAB, for the designers to use in the concept development phase

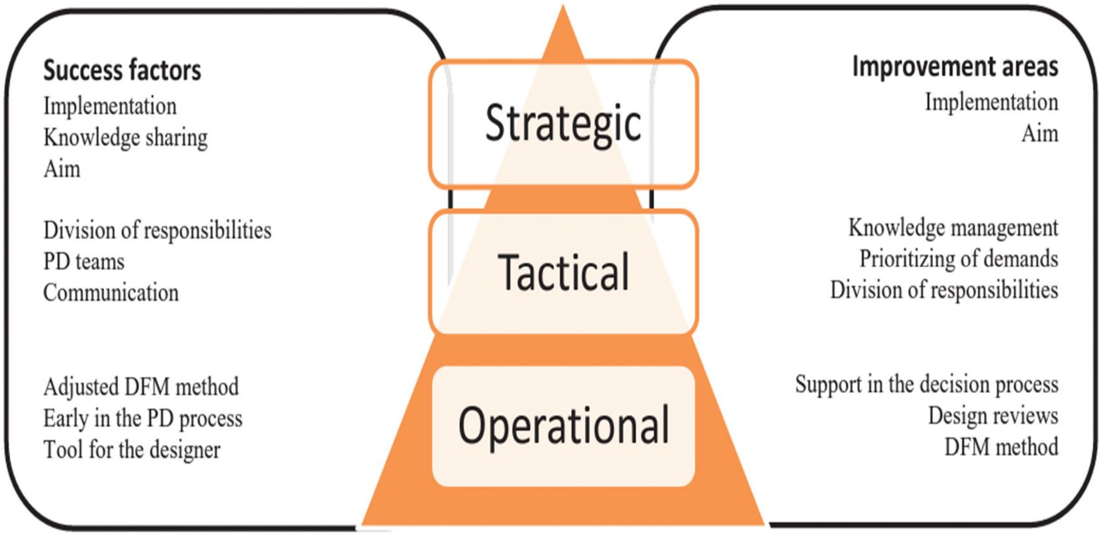


Figure 6 Identified success factors and areas for improvement important for SAAB to succeed with DFM

The strategic level consists of several guidelines on how the aims for the DFM work should be stated and implemented. It is important that the aim with DFM complies with the overall aims at SAAB. The DFM work should be implemented in the whole organization, and contribute to good coordination and communication between disciplines within the company. It is important that the designers know what in the design contributes to lower/higher costs and less/more complex manufacturing, including the trade-off between costs in the manufacturing of CFRP parts and the final assembly. The tactical level describes how the work with DFM should be organized. It is preferable that the development core team is cross-functional. Another major change in the organization is the implementation of a design and production coordination (DPC) team. This team will function as a link between different disciplines within the organization and development team. The members of the DPC team have the overall responsibility for the DFM work. They will facilitate the communication between different product development projects, and prioritize between requirements from different departments regarding design maters. In the long run, the company should set up a system for knowledge sharing to be able to spread good solutions to DFM problems. On an operational level, a DFM method is implemented for the designers to use during the concept and design development. In addition, the routine for the design review is extended with a set of aspects to consider when evaluating the design. Both the DFM method and the review procedure aim to ensure that no important aspect of DFM is neglected during the development process. Finally, a decision matrix was developed. The matrix is to be used when making decisions about the design, and should function as a guide for the project team to make informed decisions, and be an easy way of weighting different requirements put on the design.

2.4 Non-Destructive Testing (NDT)

Composite structures have been becoming increasingly popular especially in the aerospace industry because of their unique properties, such as excellent strength/weight ratio, corrosion resistance and a possibility of manufacturing elements of complicated shapes. However, in order to ensure a structural integrity and safety of composite elements of an aircraft they should be tested periodically during the operational life. Considering the fault-tolerant control of the structural elements of aircraft practiced nowadays by the most aircraft maintaining and service companies, the evaluation of structural integrity, evolution of existed damage and residual life of structural elements has a key importance in their maintenance. Structural integrity is a formalized process which utilizes advanced non-destructive testing (NDT) methods in order to detect, localize and determine a size of damage. Besides the great accuracy of detection and localization of damage, these NDT techniques should allow for possibly early damage detection. Polymer composites, usually used for manufacturing of elements of aircraft, due to their complex internal structure are subjected to different types of damage at various stages of their operational life.[25]

Damage which can be encountered during the manufacturing process of composites are for example delamination or foreign objects inclusions, whereas during the aircraft operation damage are mainly caused by impacts and service loads. Such damage can decrease the residual strength and durability of the structure leading potentially to a failure and jeopardizing the safety of the aircraft operation. Polymer composites are vulnerable to impacts, even the low velocity ones. Such events occur often during a ground service of an aircraft. These are for example a tool drop, stone lofting from runways or hail storms. Low energy impacts can cause a complex net of matrix cracking and delamination inside a composite, which can decrease its strength and durability. The danger of such damage is that in most cases they are invisible on the surface and cannot be detected during visual inspections of the structure, hence they are often called Barely Visible Impact Damage (BVID)[1].

Several NDT techniques has been developed for composites diagnostic purposes. The Ultrasonic Testing (UT) is one of the most universal NDT methods allowing detecting different types of damage. There are many studies on application of this method to aircraft structures. Grondel et al. [1] used ultrasonic measurements in order to detect BVID and disbond in a composite wingbox. An interesting approach was presented in [3], where the authors proposed new ultrasonic techniques and tested them on carbon fiber reinforced plastic (CFRP) composite plates with BVID. The wide popularity of the guided wave ultrasonic techniques has been observed due to their superior accuracy of damage detection and localization. Diamanti and Soutis [6] presented several attempts of application of guided Lamb waves technique for detection and localization of BVID. Staszewski et al. [4] applied the Lamb wave technique for detection and localization of BVID in a composite wingbox structure. A similar approach was used by Park et al. [7], whose study was focused on detection and localization of debonding and delamination in a composite aircraft wingbox. An advanced NDT technique was developed by the authors of [8], where they describe its application to the damage identification procedure of CFRP aerospace composites. The procedure is based on three-dimensional (3D) wave interaction and allows for identification of a damage as a 3D array. Some UT techniques utilize networks of piezoelectric transducers (PZT) permanently embedded in a structure. In such a case the transducers can be point sources of elastic waves or can be used as wave receivers. Such methods are often called in situ NDT or Structural Health Monitoring (SHM) [4]. Such an approach was successfully applied by the authors of [6].

Another intensively developed technique of inspection of aircraft composite structures is based on acoustic measurements. Aymerich and Staszewski [11] proposed a technique based on nonlinear acoustic measurements, which allows for detection of damage in a tested structure. The experimental verification of this technique was performed on the composite laminated plate with low-velocity impact damage.

Dickinson and Fletcher [2] studied the ability of detection and localization of BVID in an aircraft sandwich panel using this technique. The obtained results by the authors indicate a great accuracy in detection and localization of a damage.

The other NDT technique which can be applied for damage identification of composite aircraft structures is thermography. The general idea is to excite a structure by an external heating source and observe the differences in a temperature distribution on its surface in order to detect and localize damage. The authors of [6] presented the results of damage detection and localization (notches, delamination and drilling defects) in aircraft composite structures using the transient thermography approach. The latest studies of variousthermographic techniques [2] show a great effectiveness and accuracy in detection and localization of low-velocity impact damage.

Vibration-based methods belong to a yet another wide group of NDT techniques which was successfully applied in inspections of aircraft composite structures. The authors of [6] proposed a damage detection technique based on analysis of frequency response functions (FRFs) of a vibrated structure. The experimental verification was performed on a scaled model of an aircraft wing. The authors of [18] used a modal response of a stiffened aircraft panel in order to detect damaged regions on its skin. An interesting approach with MEMS accelerometers used for vibration measurements in Airbus A320 stabilizer was described by Ratcliffe et al. [19]. They used a net of MEMS accelerometers in order to detect and localize the damage occurred in a vertical stabilizer of damaged aircraft.

Another approach with use of fiber Bragg grating (FBG) sensors WHERE used the responses from the multiple FBG sensors in order to detect the damage in aerospace composite structures.[23]

Additional NDT methods applied in the inspection of aircraft composite structures cover: lighting protection sheet (LPS) sensing, shearography, digital image correlation (DIC), X-ray computed tomography (CT) and others.[23]

However, these methods have limited applicability due to many reasons, e.g.: poor detection ability (e.g. shearography), very high cost of inspections or limitation of their use only under the laboratory conditions (e.g. CT). Considering a variety of available NDT methods applied for inspection of composite aircraft structures the analysis of effectiveness of these methods as well as conditions and limitations of their applicability and costs of inspection is necessary.

2.5 Composite materials joining

Mechanical fasteners, adhesives, or both are used to join composites. The joining technique used on a particular composite depends on the application and the material composition. For instance, composites used in aircraft are usually joined by a combination of mechanical fasteners and adhesives, whereas those used in automobiles are often joined only with adhesives.[29]

Theoretically, all composites could be adhesively bonded. However, many manufacturers avoid adhesive bonds where joints undergo large amounts of stress; thus, fasteners are still specified for many joints. Also, some structures and components are so large that they preclude the use of the special lay-up tooling and curing equipment needed for most adhesive applications, making fasteners cost-effective for such cases.[30]

Mechanical fasteners: Rivets, pins, two-piece bolts, and blind fasteners made of titanium, stainless steel, and aluminum are all used for composites.[26] Several factors should be considered when specifying fasteners for composite materials:

- Differential expansion of the fastener in the composite.
- The effect of drilling on the structural integrity of the material, as well as delamination caused by fasteners under load.

  Water intrusion between the fastener and composite.
- Electrical continuity of the composite and arcing between fasteners.
- Possible galvanic corrosion at the composite joint.
- Weight of the fastening system.
- Fuel tightness of the fastening system, where applicable.

Aluminum and stainless-steel fasteners expand and contract when exposed to temperature extremes, as in aircraft applications. In carbon-fiber composites, contraction and expansion of such fasteners can cause changes in clamping load. Potential clamping changes should be determined before the fastening system is chosen so joint design can be modified accordingly.[21]

Drilling and machining can damage composites. The number of defects, such as delamination, resin erosion, and fiber breakout allowed in any structure depends on the application.[21] For instance, because joint failure in carbon-fiber composites is caused primarily by localized bearing stress rather than overall stress, delamination is a much more serious defect than fiber breakout in a carbon-fiber composite application.[27]

Drilling techniques and the tools selected are determined by the resin, the fiber or fiber combinations in the resin, the way the fibers are configured, and the composite/metal composition of the structure.[28]

Fasteners for composites should have large heads to distribute loads over a larger surface area. In this way, crushing of the composite is reduced. Fasteners should also fit closely to reduce the chances of fretting in the clearance hole. Interference fits may cause delamination of the composite. Special sleeved fasteners can limit the chances of damage in the clearance hole and still provide an interference fit. Fasteners can also be bonded in place with adhesives to reduce fretting.[30]

When carbon-fiber composites are cut, fibers are exposed. These fibers can absorb water, which both weakens the material and adds weight to the structure. Sealants can prevent moisture absorption, but this both complicates the process and adds cost. It also defeats any effort made to maintain electrical continuity between the composite fibers and the fasteners.[26] Sleeved fasteners can provide fits that reduce water absorption, as well as provide fuel tightness.[25]

Additionally, carbon-fiber composites may corrode galvanically if aluminum fasteners are used, due to the chemical reaction of the aluminum with the carbon fibers. Coating the fasteners guards against corrosion but adds cost and time to assembly. Aluminum fasteners are often replaced by more expensive titanium and stainless steel when carbon-fiber composites are used.[25]

Adhesive bonding: Composite bonds with adhesives generally are not weakened by drilling or other machining. Adhesives have been used to assemble composite components, such as rotor blades and airplane wings, and are sometimes used to join structural components. Bond reliability of adhesive joints is sometimes questioned, however, and fasteners may be specified as reinforcements for many composite applications.[30]

Three adhesives are often used to bond composites: epoxies, acrylics, and urethanes. Epoxies are especially reliable when used with epoxy-based composites because they have similar flow characteristics.[30]

Careful preparation of adherend surfaces is essential to making a quality adhesive bond, but it varies depending on the adherend and adhesive used. Recommended preparation of many composite adherends consists of a solvent wipe, to remove loose surface dirt and oil, and an abrading operation. Abrasion should be done carefully to avoid damaging composite surface fibers.[20]

In some cases, primer is required to coat the composite before applying the adhesive. When bonding composites to metals, the metal substrate can be prepared by blasting with sand, grit, or metal oxides; abrading with a wire brush; and machining or scoring with cutting tools. Metal surfaces can also be prepared chemically. To protect freshly prepared metal surfaces from corrosion and contamination, adhesive should be applied as soon as possible.[5]

2.6 Repair

Composites are used in a wide range of applications in aerospace, marine, automotive, surface transport and sports equipment markets. Damage to composite components is not always visible to the naked eye and the extent of damage is best determined for structural components by suitable Non Destructive Test (NDT) methods.

Alternatively the damaged areas can be located by simply tapping the composite surface and listening to the sound.[17] The damaged areas give a dull response to the tapping, and the boundary between the good and damaged composite can easily be mapped to identify the area for repair.

Awareness of and inspection for composite damage should be included in the regular maintenance schedules for composite structures. Particular attention would be made to areas which are more prone to damage.[19]

Repairs to aircraft structures are controlled and should be carried out according to the Aircraft Structural Repair Manual (SRM). For other applications the repaired components would normally be expected to meet the original specification and mechanical performance requirements.

2.6.1 Repair classification

Divided into four categories[6]:

2.6.1.1 Cosmetic repair

cirrus classified cosmetic repair as that which is designed to repair localized surface defects to the original profile and to prevent UV damage and moisture ingress. Cosmetic repair related to minor defects which have no signficant effects on structural strength of the structure.

2.6.1.2 Minor repair

Cirrus defines minor and major repair the same as the FARs do. So, minor repair would be repair that is not major repair.

2.6.1.3 Major repair

Is the repair that if done in properly might appreciably effect weight balance, structural strength, performance, powerplant operation, flight charactaristic or other qualities effecting airworthiness or repair that is not done according to acceptable practise or can not be done by elementary operations.

2.6.1.4 Restricted repair

Any repairs occur in no repair zones as listed in the maintenance manual are restricted. The mechanic needs to contact cirrus design for disposition.

2.6.2 Repair environment

One thing we need to be aware of is the repair environment. For cosmetic repair, the environment is not as critical. However, cirrus stringent environment requirements for minor and major repair.

From our own safety perspective, you want to make sure the repair is carried out in an area that has adequate ventilation.[10]

We also need to ensure that we are performing the repair in a controlled environment to ensure proper integrity of the repair and avoid any contamination issues.[6]

3 Chapter three:

3.1 Analytical solution

One of the primary advantages of using composites in the wing spar is that the spar cap and shear web thickness can be decreased towards the tip of the wing so that a lightweight structure can be realized, however before the spar can sized it is necessary to determine the bending moment along the span of the wing.

Fiber glass which made out of carbon fiber, used in structural applications according to its specifications which are, light weight and height strength. The wing spar could withstand the loads applied on it as we will prove in the analytical solution section.

We can now design the wing spar mounted at 30% from the leading edge to take bending moment and shear load and it is divided into ten equal segments along the span, the maximum height is in the root of the spar and it decreases gradually to the tip (tapered).

We assume that the airload distribution is proportional to the chord length so that the wing airload distribution for an aircraft having a gross weight less wing weight of W and designed to a limit load factor of n can be given as

$$W=\frac{2*w*n}{B\,(C_R+C_t)}\ \left(C_R-\frac{2*X*C_R}{B}+\frac{2*X*C_t}{B}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Since the shear load is defined as integration of both sides to give:

$$V=\frac{2W*n}{B(C_R+C_t)}\left(C_R*X-\frac{X^2*C_R}{B}+\frac{X^2*C_t}{B}\right)-\frac{W*n}{2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

If the wing has a constant chord so that C_R=C_t =C

$$V = W * n \left(\frac{X}{B} - \frac{1}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

The bending moment along the span wing is

$$M = \frac{2W*n}{B(C_R+C_t)}\left(\frac{C_R*X^2}{2} - \frac{C_{R*}X^3}{3B} + \frac{C_{t*}X^3}{3B}\right) - \frac{W*n*X}{2} - \frac{W*n*B}{12(C_R+C_t)}(2C_R + C_t) + \frac{W*n*B}{4} \ldots \text{(4)}$$

For a constant chord wing the equation is

$$M = W * n \left(\frac{X^2}{2B} - \frac{X}{2} + \frac{B}{8}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

With the load distribution known, we can now design the wing spar with NACA 63415 airfoil section. Since the shear stresses due to the wing torsional loads are proportional to the cross section area of the wing or box beam, and since the spar cross section area is normally an order of magnitude smaller than the wing cross section area ,we will assume that all torsional loads are reacted by the wing skin and that no torsional load shear stresses are reacted by the wing spar.

The spar cap made out of UD material with all the fibers oriented along the longitudinal axis of the spar. The shear web is fabricated out of B.D. fabric with the warp inclined to the longitudinal axis of the spar so that the maximum shear strength is obtained. The fabric is laminated over a foam core which helps stabilize the spar caps and shear webs.

We first size the cap thickness, t_1, by setting the cap stress equal to one-half the ultimate tensile strength, F_{TU}, of the cap material. The cap stress is

$$f_t = \frac{12*M*C}{I} = \frac{F_{TU}}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

And, $\frac{I}{C} = h * t_1 * a$………………………………………………………………….... (7)

The spar height is approximately equal to the maximum thickness of the airfoil. Therefore, for a tapered wing,

$$c = C_R - \frac{2*X*C_R}{B} + \frac{2*X*C_T}{B} \quad \text{(8)}$$

$$h = 0.15\left(C_R - \frac{2*X*C_T}{B}\right) \quad \text{(9)}$$

From The values of moments distributed along the spar we calculate the force value in each point by using the following equation:

$$F = \frac{M}{X} \quad \text{(10)}$$

Table 2The dimensions of the wig spar

X	H
0	0.219456
0.42672	0.208534
0.85344	0.197612
1.28016	0.185928
1.70688	0.175514
2.1336	0.164592
2.56032	0.153416
2.98704	0.142494
3.41376	0.131572
3.84048	0.12065
4.2672	0.109728

Table 3 shows the thickness of wing spar

T1 (m)	T2 (m)	T3 (m)
0.009144	0.0013208	0.006096
0.00762	0.0012192	0.00508
0.00635	0.0010922	0.004064
0.004826	0.0009652	0.003302
0.00381	0.0008636	0.00254
0.002794	0.000762	0.001778
0.001778	0.0006096	0.00127
0.001016	0.0004572	0.0006858
0.000508	0.0003048	0.0003048
0.000127	0.0001524	0.0000762
0	0	0

According to the value of weight and span, root chord, tip chord for the wing and width of spar are shown in table (4)

Table 4 specification of the wing and wing spar

W	5339.69 (kg)
B	8.5344 (m)
C_R	1.46304 (m)
C_t	0.73152 (m)
A	0.0762 (m)

3.2 CATIA drawing

The spar was drawn using catia software by drawing tip and root cross-section and then create multisurface to connect these surfaces with specified thickness as shown in the figures (7,8):

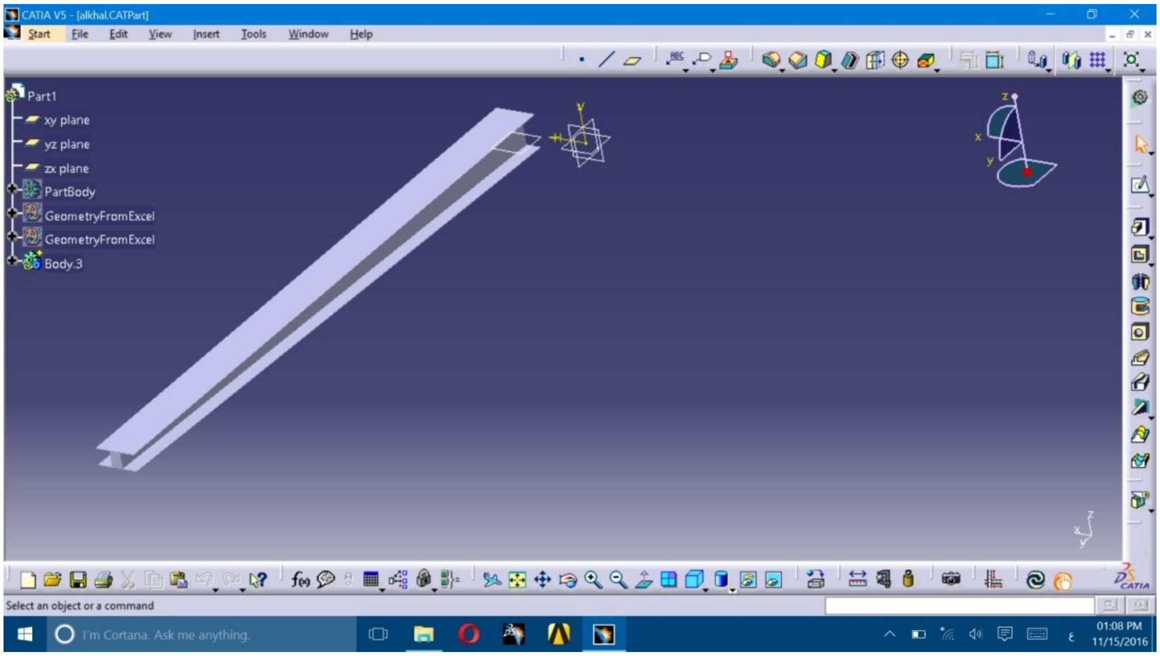


Figure 7The front surface of Spar

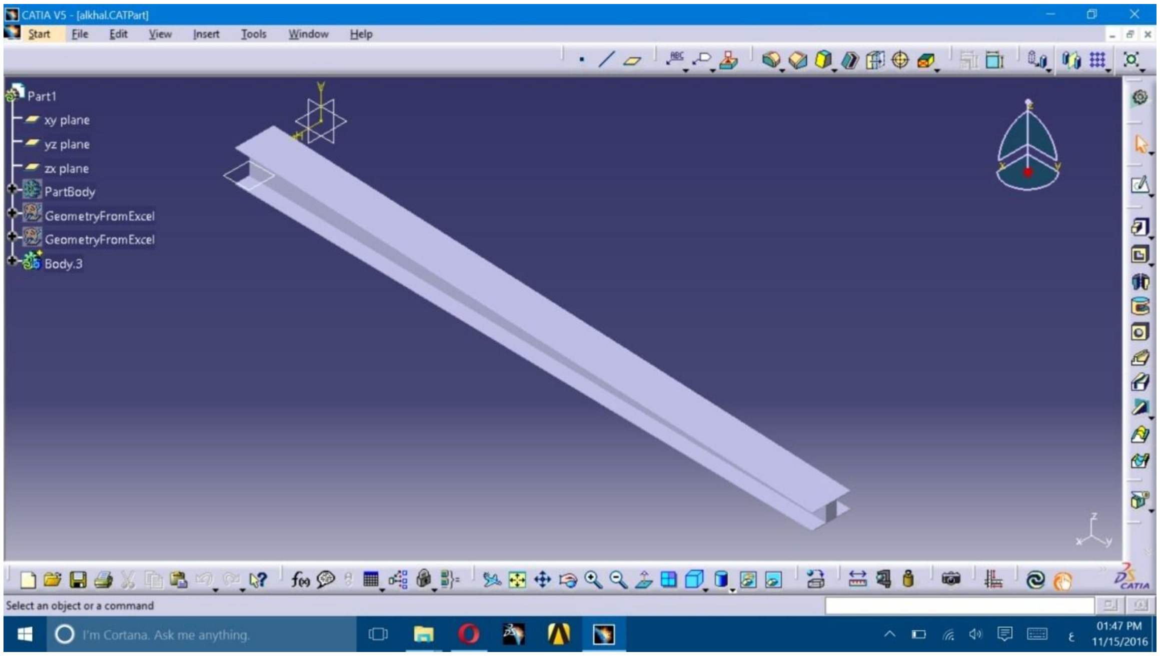


Figure 8The side of Spar

3.3 Structure analysis

In order to ensure that the dimension and material selection of the spar are suitable and the spar is strong enough, we had to test it using ansys software by applying the loads distribution along the spar un-equally and then observe the spar behavior under this load.

The model was imported to the ansys from CATIA software and then generate mesh. After that the load was inserted as remote force along the spar and then apply the solution.

4 Chapter Four: Result and Discussion

Bending moment, shear load and force have been calculated by equations and the results are shown in table (5)

From the table (5) we found that the force value along the wing spar from root which has the maximum value of height of the spar decreases rapidly towards tip.

The bending moment value along the wing spar as shown in table (5) also decreases gradually from root to tip.

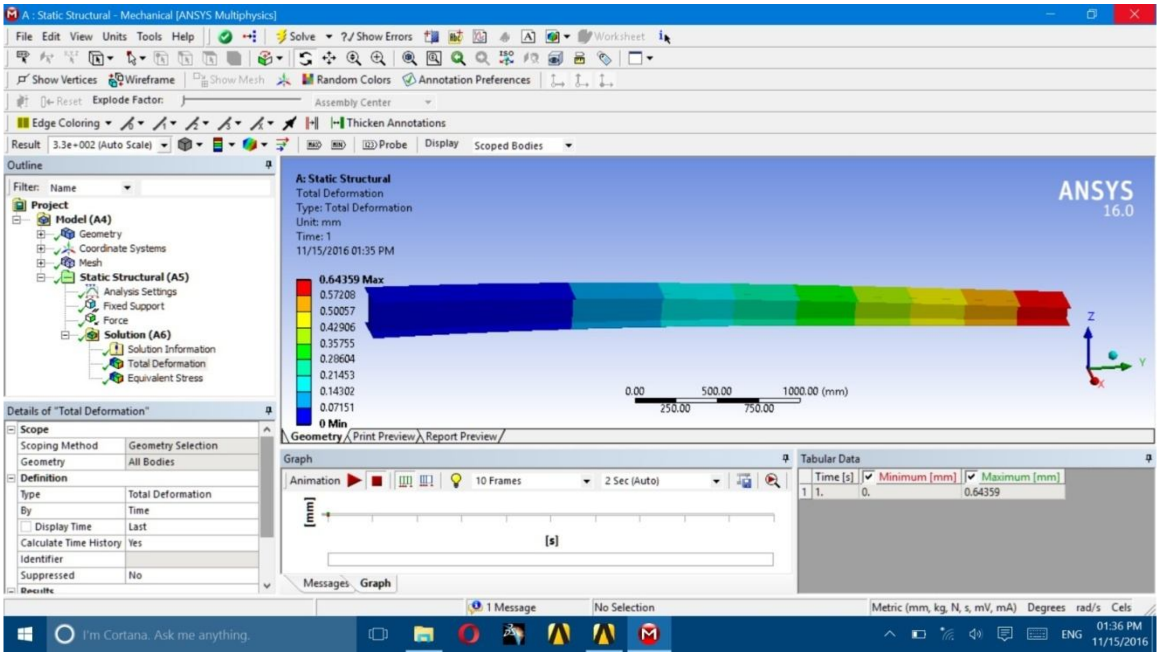
We have also calculated the shear load value and we have found that its value increases rapidly from root to tip shown in table (5).

The result shows that the spar is strong enough and can handle with the applied loads on it and the deformation is very small and can be neglected shown in figure (9).

From this graph, we show that the force starts from zero and increases linearly with increasing the distance to the maximum point which represents the maximum force and then decreases non-linearly to the minimum value with increasing the distance from root to tip shown in figure (11).

Table 5 Result of bending moment, shear load and force

X (m)	h (m)	V (N)	M (Nm)	F(N)
0	0.219456	12277.09169	23283.46165	0
0.42672	0.208534	10680.180129	18387.603037	43105.28104
0.85344	0.197612	9163.3365541	14156.095215	16592.768
1.28016	0.185928	7931.1797163	10552.331104	8245.79468
1.70688	0.175514	6383.198036	7542.415255	4420.341366
2.1336	0.164592	5115.454872	5089.74058	2386.332769
2.56032	0.153416	3927.7796	3161.767459	1235.332982
2.98704	0.142494	2820.1725	1723.2461	577.1042222
3.41376	0.131572	1797.08153	737.564964	216.1302987
3.84048	0.12065	854.05855	170.83306	44.49741444
4.2672	0.109728	0	0	0



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
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Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
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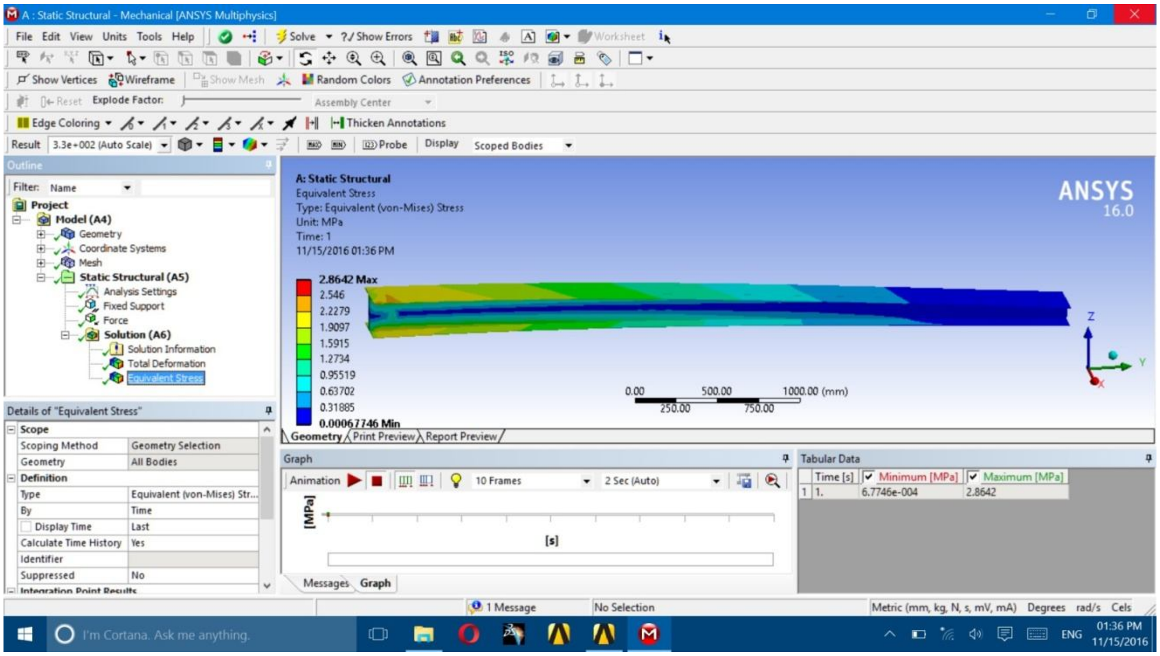
☐ Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	

	Time [s]	☑ Minimum [mm]	☑ Maximum [mm]
1	1.	0.	0.64359

Figure9 Deformation of wing spar



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
11/15/2016 01:36 PM

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Str...
By	Time
☐ Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]
1	1.	6.7746e-004	2.8642

Figure10 equivalent stress of wing spar

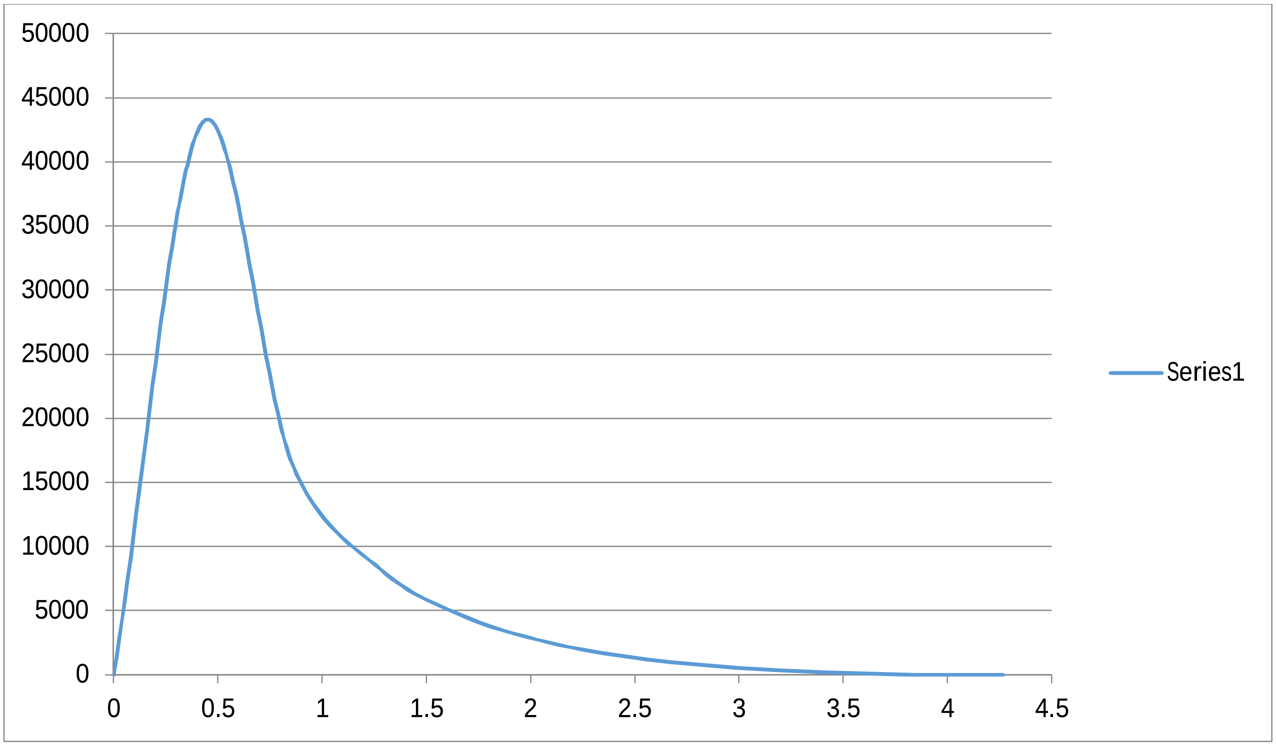


Figure 8 Force distribution along the spar

5 Chapter five: Conclusion and Recommendation

5.1 Conclusion

From our as theoretical study about composite materials in aircrafts we used carbon fiber as a structural application inside the aircraft wing we found that the spar which made out of carbon fiber could withstand the loads that applied on it during flight.

5.2 Recommendation

As we saw the test results were good and acceptable we recommend to students who want to continue in this project to try other composites and use them in other parts of aircraft.

5.3 Future work

- Study specifications of composite materials as advance ways.

- Fabricate the whole airframe of aircraft from composite materials

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