МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет
Кафедра підтримання льтної придатності повітряних суден

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри
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"___" __________ 20__р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)
ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ
«МАГІСТР»

Тема; **Технічне обслуговування фюзеляжу з використанням сучасних технологічних систем для діагностики»**

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Київ 2020

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Aerospace faculty
Department of Aircraft Continuing Airworthiness

PERMISSION TO DEFEND
The Head of the department
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"___" _____________ 2020

MASTER DEGREE THESIS

(EXPLANATORY NOTE)

MAINTENANCE AND REPAIR OF AIRCRAFT AND ENGINES

Topic**: Maintenance of fuselage using modern technological systems for diagnostics»**

Fulfilled by:	____________	T.A. Udoh
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Kyiv 2020

NATIONAL AVIATION UNIVERSITY

Institute: *The Aerospace Institute*

Faculty: *The Aircraft Faculty*

Department of Continuing Aircraft Airworthiness

Educational and Qualifications degree: *Master Degree*

The specialty: 272 Maintenance and Repair of Aircraft and engines

Graduate Project Assignment

Student's name: Udoh Temidayo Akpama

1.The Work (Thesis) topic: **Maintenance of fuselage using modern technological systems for diagnostics.** approved by the Rector's order of October 02, 2020 №1881/ст.

2. The Graduation Project to be performed: *October 5, 2020--December 13, 2020 and since December 21, 2020—December 31, 2020.*

3.Initial data for the project: *Analysis of fuselage composite materials, modern technologies of nondestructive diagnostics of aircraft fuselage, integration of structural health monitoring technology and fibre sensors to back up maintenance. influences of composite fuselage on miantenance organizations, specialists and environment.*

4.The content of the explanatory note (the list of problems to be considered): *Diploma work assignment; abstract; contents; introduction; analytical part; project part; scientific research part; labour precaution; environmental protection; general conclusions; recommendations; references.*

5.The list of mandatory graphic materials:*list of tasks; analysis of composite materials, limitations of nondestructive diagnostics in composite fuselage inspection, Fiber optic sensors and structural health monitoring technologies, how it influences maintenance and its capability with humans, conclusions and recommendations.*

6. Time and Work Schedule

Stages of Graduation Project Completion	Stages Completion Dates	Remarks
Search for and analysis of reference material	03.10.2020-12.10.2020	
Analysis of technological process of fulfillment of work	13.10.202–21.10.2020	
Preparation for conducting experiments	22.10.202–01.11.2020	
Conducting necessary research	02.11.202–12.11.2020	
Processing of research results	13.11.202–20.11.2020	
Fulfillment of individual sections of degree work	21.11.202–02.12.2020	
Preparation of explanatory note	03.12.202–15.12.2020	

7. Advisers on individual sections of the work (Thesis):

Section	Adviser	Date, Signature	
		Assignment Delivered	Assignment Accepted
Labour precaution	O.V Konovalova		
Environmental protection	M.M Radomska		

8. Assignment issue date ____

Graduate Project Supervisor   Goncharenko O.V.________________
(supervisor signature)

Assignment is accepted for performing:

Graduate student   Udoh T.A _________________________________
(graduate student's signature)   (Date)

CONTENTS

ABSTRACT

Topic of explanatory thesis: «Modern methods of Nondestructive diagnostics of aircraft fuselage»:

95 pp., 41 fig., 2 tab., 43 sources.

The object of study is recognition of composite fuselage increase in the aviation industry and how it influences maintenance organization, maintenance specialist and environment.

The subject of this thesis is about integration of structural health monitoring technology to back up maintenance procedures when inspecting composite fuselage.

The purpose of this thesis is to undertake a broad research to find ways of improving high-performance composite fuselage inspection to assist maintenance process and predicting the structural and technical state of the aircraft structural units to help eliminate avoidable accidents and incidents.

The findings of this thesis can be used to further improve the current state of composite fuselage maintenance with substantial decrease in structural damages while in service.

COMPOSITE FUSELAGE, INSPECTION, NONDESTRUCTIVE INSPECTION, STRUCTURAL HEALTH MONITORING, FIBER OPTIC SENSORS, HUMAN FACTOR.

LIST OF ABBREVIATIONS

A/C - Aircraft

AE – Acoustic Emission

Al – Aluminium

ATAG – Air Transit Action Group

CDF – Cold diaphragm forming

CFRP – Carbon fibre reinforced polymer

DT – Destructive Testing

ECT – Eddy Current Testing

FAA – Federal Aviation Authority

FBGS- Fibre Bragg Grating Sensor

FRP – Fibre Reinforced Polymer

GFRP – Glass Fibre Reinforced Polymer

GHG – Greenhouse Gases

GLARE – Glass Laminate Aluminium Reinforced Epoxy

IIoT – Industrial Internet of Things

Km - Kilometer

LCA – Life Cycle Analysis

LED – Light Emitting Diode

LPI – Liquid Penetrant Inspection

Lm – Lumens

Lx – Lux

MO – Maintenance organization

MLG – Main Landing Gear

MPI – Magnetic Particle Inspection

MRO - Maintenance Repair Overall

NDI – Nondestructive Inspection

NFPA – National Fire Protection Association

NLG – Nose Landing Gear

OSHA – Occupational Safety and Health Administration

PEEK – Poly ether ether ketone

PVC – Polyvinyl Chloride

PPS – Polyphenylene Sulfide

RTM – Resin Transfer Moulding

SHM- Structural Health Monitoring

TP - Thermoplastic

UT – Ultrasound Testing

UV – Ultraviolet

VI – Visual Inspection

W – Watts

ε = Strain (mechanical + temperature)

α_{δ} = Change of the refraction index

ΔT = Change in temperature

ρ =Photo elastic coefficient

Pd = Pole distance

Gl = Grating length,

N = Fringe count

n = Refractive index

$\alpha_{\exp}$ = Expansion coefficient

G_{s} = Grid spacing

k = Gauge factor

$T_{\text{тр}}$ – laboriousness of the work for the system maintenance

K_1 – Loss working time coefficient

n – Number of crew members

T_0 – optimal frequency of maintenance

T_{cp} – average operating time to failure

$T_{в}$ – average time of restoring

INTRODUCTION

As in stands in today's modern age with all the technological advancement and knowledge of materials, the aviation industry is evolving in all aspects creating the necessity for the advancement of maintenance as well.

The aircraft fuselage is a very important unit and largest of all, which carries passengers and cargo. Several analysis have been carried out in regards to the substitution of aluminum alloys for composite materials as the structural material for most commercial fuselage construction. This move has been backed based on results of extensive analysis and broad research while considering both the positive and negative points, which we will analyze in part 1.

Maintenance is a very important aspect of an aircraft service life simply because it directly affects how much time the aircraft spends on the runway and hanger meaning it is vital to the productivity of the aircraft. Maintenance errors for the past several years have been kept to a minimum of about 5 percent, which is very much effective.

However, with a substitution in materials for construction of the fuselage and using a higher percentage of composite materials compared to older aircrafts, it's necessary to adopt a more effective method of diagnostics for the fuselage taking into accounts its size and certain non compatibilities with the conventional nondestructive inspection techniques that proved so effective on previous commercial aircrafts with their fuselage made primarily from aluminum alloys or steel, which we discussed in part 2.

Considering the new changes in structural materials, a modern method of diagnostics will be discussed, which is being used effectively in several industries outside aviation for monitoring and maintenance of vital structures made of composite materials. They can also be used on aircraft fuselage made of aluminum alloys, however with a different configuration to get the best out of the sensors used for structural monitoring. The different sensors considered are analyzed in part 3.

It is always important to consider the compatibility of these technologies with humans and how they influence the process either positively or negatively. The effect the production of composite fuselage has on the environment is also discussed in part 4 and the labor protocols and safety measures in part 5

PART 1
AIRCRAFT FUSELAGE AND COMPOSITE MATERIAL USED FOR CONSTRUCTION

1.1 Introduction to aircraft fuselage

The fuselage is the centralized part of the aircraft that is designed basically to accommodate passengers, cargo and crew during the course of flight. It is required to provide connection or carry other structural elements for the aircraft like the engine, tail and wings. There are several design structures. In older aircrafts the structural design often used was called the open truss structure, which was constructed of aluminium tubing, wood or steel. In modern day aviation, the most common types of structures used are;

- monocoque (single shell)
- semi monocoque.

Monocoque

In the monocoque construction, stressed skin is used to provide the necessary support for all loads. One advantage of this is the strength although they are not very tolerant to surface deformation. This is as a result of lack of internal support (stringers) spread out within the structure. This can be best explained by a beverage can, which can support or withstand a considerable amount of force if applied from both ends but not so much when applied from its sides. Due to lack of reinforcement that causes the structure to collapse easily in such situations. Examples of aircraft with monocoque structures are LFG Roland. II and Zeppelin D.I.

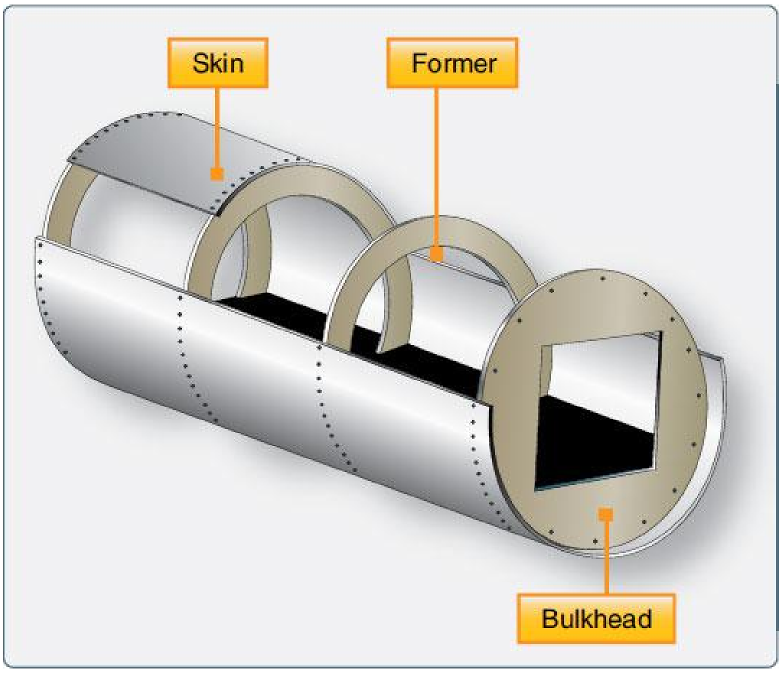


Figure 1.1 - Monocoque fuselage configuration

Since most of the twisting and bending moments are carried by the external skin and not the framework, the need for reinforcing the structure with braces is further reduced or eliminated, which in turn helps us save weight and provides additional space. The monocoque construction consists of structural elements like bulkheads, stressed skin and formers. The formers are used to layout the shape of the fuselage which the stressed skin is then attached to. The bulkhead is a partition, which serves as a demarcation between two areas.

Semi monocoque

The semi monocoque construction is a hybrid structure that combines the stressed skin with necessary reinforcements made of ribs and longerons or frames. The substructure is made up of bulkheads, stressed skin, stringers and formers. The difference between the monocoque and semi monocoque fuselage type is the addition of the stringers which helps improve the strength and increases its damage tolerance to surface deformation.

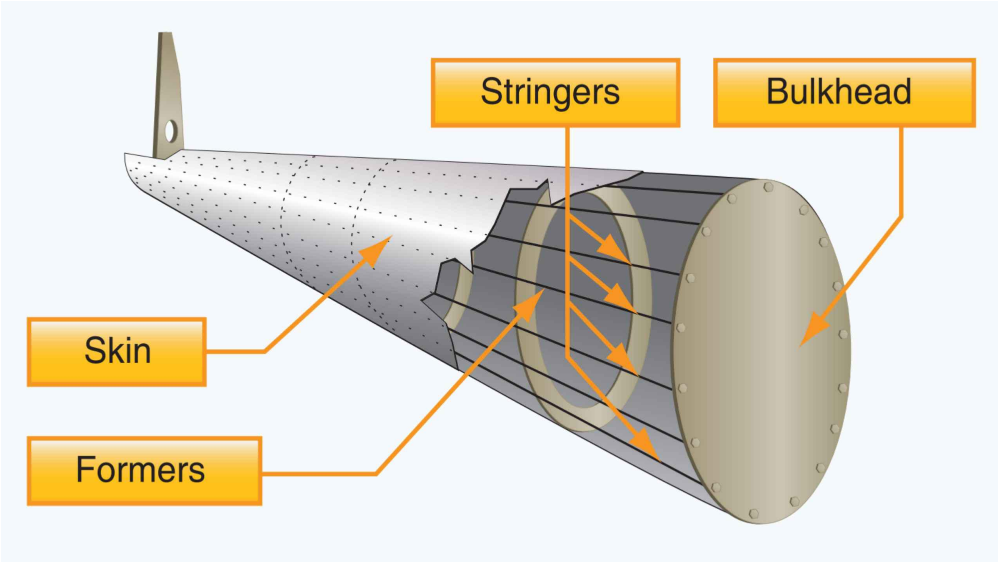


Figure 1.2 - Semi monocoque fuselage configuration

1.2 Materials used in fuselage construction

The materials used in the construction of fuselage is highly dependent on the purpose of the aircraft and the necessary cutbacks to be made. Based on research the various materials include;

Wooden fuselage

For clear reasons, the early aviation pioneers had concerns about the weight of planes. The wright brothers and others aviation engineers were limited in their creation by the type of engines available in their time and therefore they constructed the wooden planes to keep the overall plane weight as low as possible. Wooden fuselages are still being used in aircrafts till today, however they are only used foresight weight aircrafts.

Aluminium fuselage

In modern aviation, aluminium is one of the most used materials in aircraft construction. As a result of advancements in engine development, it allowed aviation engineers the opportunity to branch into the use of metal for construction of aircraft structure.

the aluminium used in the construction of aircraft fuselage is often blended with other materials to support its weaknesses and further improve the standard of the structure. One of the strengths of aluminium is its resistance to corrosion and significant strength to weight ratio. Although they cannot be used on supersonic planes because of the amount of heat generated as a result of friction due to the high speed at which the aircraft flies.

Steel fuselage

Steel fuselage is known for its high strength but also higher weight than aluminium. The considerable high weight of the steel further prevents it from being highly favoured in fuselage construction. However, they are highly used in constructing other parts of the aircraft where strength is a priority and weight cannot be sacrificed.

Titanium fuselage

Titanium fuselages are known for their high strength as steel and lighter weight. Titanium and its alloys are mainly ideal materials for construction of aircraft components and subcomponents. They have better resistance to corrosion compared to both aluminium and steel, which makes them highly favourable for construction of supersonic aircraft.

Figure 1.3 - Representation of titanium fuselage

Titanium is an expensive metal which makes the construction of aircraft fuselage with titanium highly expensive, making it the main reason they are not used for the construction of commercial aircraft.

Composite materials

Composites is one of the fast rising materials used in the construction of aircraft parts mainly the fuselage. This is due to its strength to weight ratio which saves a considerable amount of weight. It is gradually increasing in utilisation because of research-backed benefits.

1.3 Composite materials

Composite materials are materials that are formed by the combination of two different materials with different properties both physically and chemically [1]. The created material is designed to fulfill a given purpose for example satisfy strength requirements, weight or resistance to electricity requirements. They are known for their significant strength to weight ratio, which makes them highly recommended in several industries.

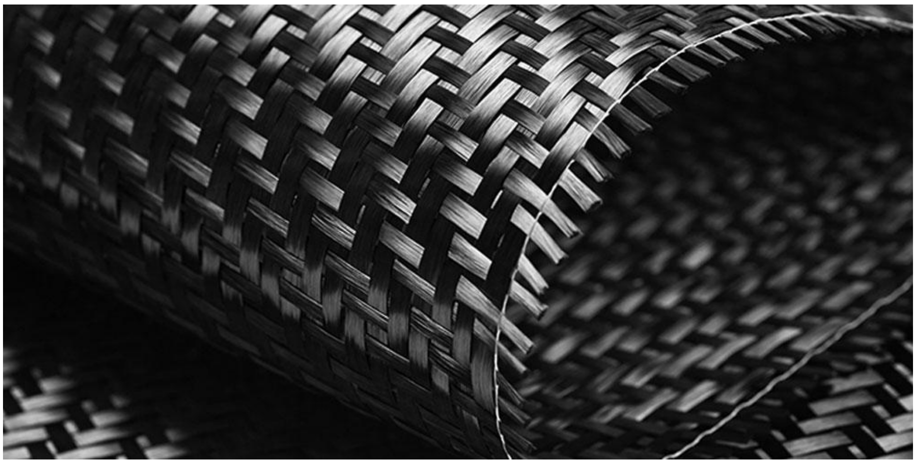


Figure 1.4 - Diagrammatic representation of different layers of composite materials

They are used in various industries for several purposes both for light structures and high performance structures. In the aviation industry composite materials are increasing in percentage of utilization for structural components of the aircraft. They are used in various parts of the aircraft where strength can be substituted for weight to reduce the overall weight of the aircraft. These areas include:

1) Tails
2) Wings

3) Fuselage

4) Propeller

5) Some engine constituents

1.4 Advantages and limitations of composite materials in aircraft advancement

They offer a higher degree of performance for a specific weight that enables us save fuel. They have an excellent ratio of strength to weight as well as stiffness to weight when used in structures. This ratio is usually expressed as the strength of the material divided by the density and stiffness divided by the density. These are referred to as specific modulus and specific strength characteristics [2] [3].

The number of parts are reduced, which is also an important characteristic of the use of composite materials. They can be manufactured to suit the purpose of production with lesser connections thereby reducing the probability of failure in high performance structures.

There is a reduction in the cost of production considering there are several production methods and can be made using the production procedure that fits the estimated cost of production. They are usually made of a vast range of processes.

The material laminate pattern and ply buildup in parts can be manufactured to promote the mechanical properties in specific directions.

Due to the precise production techniques, the surface finishes enhances smooth aerodynamic profile that allows undisturbed flow of air over the surface of the structures that helps reduce drags.

They have excellent degree of resistance to corrosion, outdoor weathering, chemical attacks nonetheless some chemicals are damaging if brought in contact with composite materials.

Disadvantages

They are more brittle when compared to some wrought metals, which makes them easy to damage in that sense.

When carrying out repairs on composite structures there are some problems faced due to the structural configuration of the material

1) The requirement of hot curing, which requires a special equipment
2) When curing irrespective of hot or cold the procedures takes a significant amount of time
3) The procedure is not over after the installation of the last rivet.

In cases of damage to the rivets where uninstallation is required, it presents a more difficult task of uninstallation without further damage to the structure

Repairing of composite structures at its original cure temperature requires a significant degree of pressure and tooling of the structure.

The repair process requires more time compared to conventional materials as they need to be dried before repairs because resin matrices and fibers absorb moisture.

1.5 Components of composite materials and their requirements in the mixture

Composite materials consist of two main constituents, they include:

1) Reinforcement
2) Matrix

Reinforcement

The reinforcement [4] [5] is

Strong

Hard

Discontinuous

The reinforcement is required to play certain roles in a composite structure mainly attributed to the strength of the structure.

Functions of the reinforcement

1) They are tasked with carrying the load
2) They help transfer strength to matrix considering they are not as strong as the reinforcement.
3) The add desired properties

According to our research, we can classify reinforcements into four types

Fibers

Flakes

Whiskers

Particulate

Based on our research, fibers and particulates are considered in several books and studies but mainly fibers are used in composite production industries.

Fibers

Fibers are filaments that have a very high aspect ratio (of order 1000). Aspect ratio is the ratio of the length of the fiber to the diameter. The diameter of the fiber affects the strength as its length is inversely proportional to its strength.

Composites made of fibers as the reinforcement are called fibrous composites. Thin fibers are more expensive compared to fibers with greater diameter because they are stronger and strength is a major factor with fibrous composite as they are usually used in high performance structures such as aircraft.

The number of flaws in a thin fiber is less compared to thick fibers because they have greater strength, higher ductility, flexibility and tougher than thicker fibers.

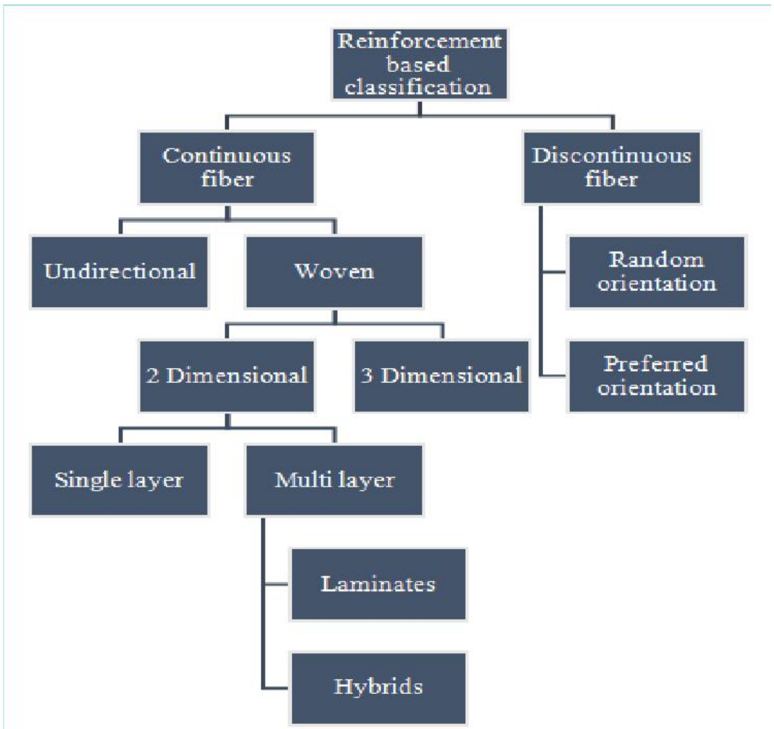


Figure 1.5 - Classification of fiber reinforcement

Fibers can be divided into two types:

Advanced fibers

Glass fibers: In ancient times, Egyptians made containers from coarse fibers that were drawn from glass that had been softened under heat. They are produced at a temperature of 1200 degree Celsius by extruding molten glass. They are then passed through about 1 to 2 mm diameter spinnerets. The filaments are drawn to produce fibers with diameter of about 1 to 5 micrometers. Generally, glass fibers are isotopic by nature.

E glass: they have high resistance and strength

R glass: they possess improved mechanical characteristics

C glass: they have good resistance to acid in a corrosive environment

D glass: possess dielectric properties

Carbon fibers: carbon fibers just like the element itself carbon has a covalent bond, which is the strongest in nature. Thomas Edison made the first carbon fiber during the course of his experiment for light bulb from a bamboo. Carbon fiber has about 80 % to 95 % of carbon compared to the 99 % of carbon in graphite. They are produced at a temperature of 1300 degree Celsius while graphite is produced at temperatures that exceed 1900 degree Celsius.

Organic fibers: organic fibers like aramids are from the family of nylons and are called Aromatic polyamide. They are melt spun from a liquid solution. They have radially arranged crystalline sheets that gives them anisotropic properties. The filaments have a diameter of about 12 micrometers and are partially flexible with high tensile strength.

Ceramic fibers: when considering ceramic fibers, we have different examples of such composite. They include boron, alumina and silicon carbide.

Natural fibers

Animal fibers

Vegetable fibers

Mineral fibers

Particulate

Particulates are non-fibrous without long dimensions. Composite materials made with particulate as their reinforcement are called particulate composite. Due to their short dimensions they are not as strong as fibrous composite but are cheaper making them favorable in structures where high strength is not a main requirement.

Matrix

The matrix is Continuous.

The matrix is fundamentally a homogeneous material where the fibers system are embedded.

Functions of the matrix

1) The main function of the matrix is that they hold the fibers together.
2) They provided a better finish to the composite structure after production
3) They help in distributing the load applied on the structure evenly between the fibers.

4) They serve as a protector of the fibers from harsh environmental or external conditions.
5) The matrix help avoid abrasion between fibers
6) The matrix also helps improve some properties of the structural component like

   Impact resistance and

   Transverse strength of lamina

   This is because the fibers on their own cannot impart.

According to the classification of matrix, we can break them into four main groups [6] [7]

Polymer

Metals

Ceramic

Carbon and graphite

Polymer matrix: Polymer matrix can be classified into three main categories namely;

Thermoset

Thermoset materials are materials that is hardened irreversibly by curing (heating) from a soft solid or resin. Curing is usually done by heating or radiation and may be improved by the application of high pressure or mixture with given catalyst. Examples of thermoset are

Polyester

Epoxy

Polyimides

Thermoplastic

Thermoplastic materials are materials that become soft at high temperature (heated) and hard at low temperature (cooled). They can be continuously heated and cooled without a change in their mechanical or chemical properties. Examples of thermoplastic materials are PVC, nylon, polysulpone, polyurethane etc. they have higher toughness, volume and a low cost of processing.

They are highly preferred to thermoset because

1) The time of process is faster compared to thermoset composite because curing reaction is not required in thermoplastic processing. They require only heating, shaping and cooling.
2) They have better toughness and chemical resistance than thermoset as well as low moisture absorption.
3) Low toxicity however they have cost of processing

Elastomer

These are placed in between thermoset and thermoplastic composites as they have a lighter configuration. They return to their normal shape when relieved but can deform at strain values that exceed its limit.

Polymer matrix materials have some limitations, which affects their preference in composite production and they include;

1) They have limited range of temperature

2) They possess low transverse strength
3) They are susceptible to environmental degradation as a result of radiation, atomic oxygen and moisture
4) They cannot be applied in structures where the temperature is close to or above that of glass transition.

1.6 Factors affecting the mechanical performance of Fibers

There are four main factors that influence the performance of fibers used in composite structures production in one way or the other [8]. These are:

1) Material
2) Length
3) Orientation
4) Shape

Material: the materials used in production of the fiber is important because it determines the strength of the fiber. Based on recent studies the two materials that have been found to be tougher than glass are graphite and aramids but more expensive.

Length: the length is an important characteristic of the fiber because it also relates to the strength of the fiber. Mainly long fibers are more beneficial compared to short fibers including the strength. Based on the purpose of production, the fibers are to fulfill certain functions in a structure. Long fibers have a better resistance to impact because of their high aspect ratio compared to shorter fibers but short fibers are cheap compared to longer fibers.

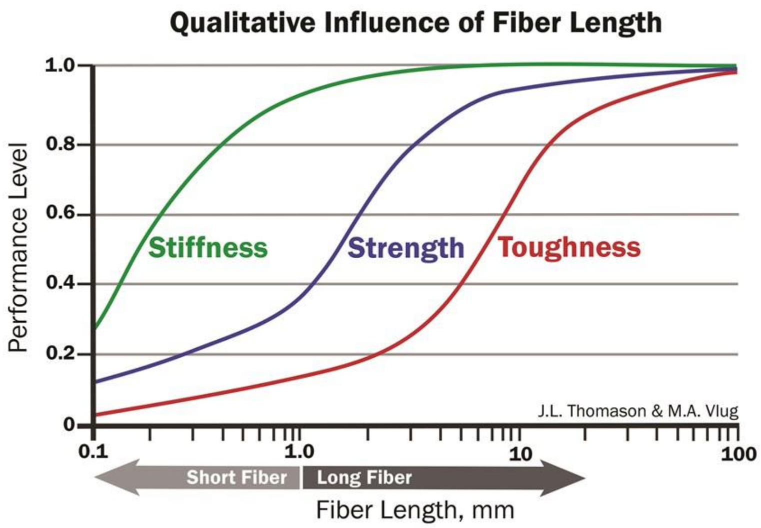


Figure 1.6 - Influence of fiber length on mechanical properties

Orientation: the arrangement of the fibers, which is also known as the orientation is important because they can be patterned in a multi-directional or one directional pattern. This determines the degree of stiffness of the fiber considering one directional orientation has a higher stiffness as well as strength than the multi-directional orientation.

Shape: this is an important factor as the shape of the fiber tends to influence performance but nonetheless circular fibers are the most commonly used fibers in various industries.

1.7 Application of fibrous composites

Aerospace industry

1) They are used in the manufacturing of helicopter blades

2) They are used for the construction of fuselages in modern commercial aircraft.

3) They are used in the production of several parts of the light combat helicopters like side shell, top shell, sliding doors, stabilizer, blades, hub plate, doors, tail boom, cockpit etc.

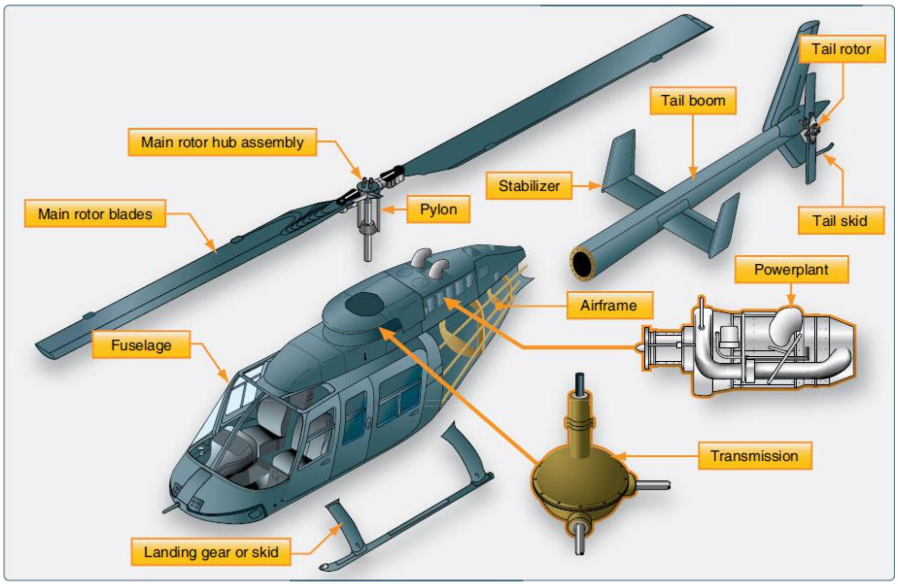


Figure 1.7 - Light combat aircraft with composite parts

Automobile / Transport industry

They are used in the manufacturing of several automobiles for the various modes of transportation like:

1) Cars
2) Trains
3) Ships

Figure 1.8 - Train made of carbon fiber

Sport industry

They are used in the production of various sporting equipment's like

1) Helmet
2) Rackets
3) Bats
4) Bicycle

They are used in other areas like civil / infrastructure, medical, marine and wind energy for production of wind turbine blades, marine boats with water lubricated propeller bearing shafts and many more.

1.8 Fabrication method of Fibrous composites

There are several methods of fabrication that are used in manufacturing industries but here we will be considering five methods [9] [10]. These five methods are

1) The spray layup process

This method is also called the chop method used for the production of fiber glass structures /objects by spraying from a pneumatic gun short strands of glass. This method is mostly used when time and money are important factor.

This method is quite different compared to the hand layup process. As the name implies, they vary in the application of fiber and resin materials to the mould. The spray layup process is an open method of molding where the reinforcement and resin is sprayed on the mould either simultaneously or separately until the desired thickness is achieved [11].

The most used reinforcement for this method of fabrication is the carbon and Kevlar rovings and E glass while the most common resin used is the general purpose polyester, vinyl ester resins and isophthalic polyester.

Advantages

1) It is quite economical in the manufacturing of minor parts
2) It is well suited for the production of small to medium volume parts
3) Different materials like steel, wood, GRP or any other material can serve as the mould.
4) Mistakes during processing can be reversed by respraying.

Disadvantages

1) Due to its open mould nature, the emission of styrene is a major concern.
2) It has a good surface finish on one side and a rough surface finish on the other side.

3) Greater difficulty in the control of fiber volume fraction and thickness.

4) It is a good processing technique for making parts that have high structural requirements.

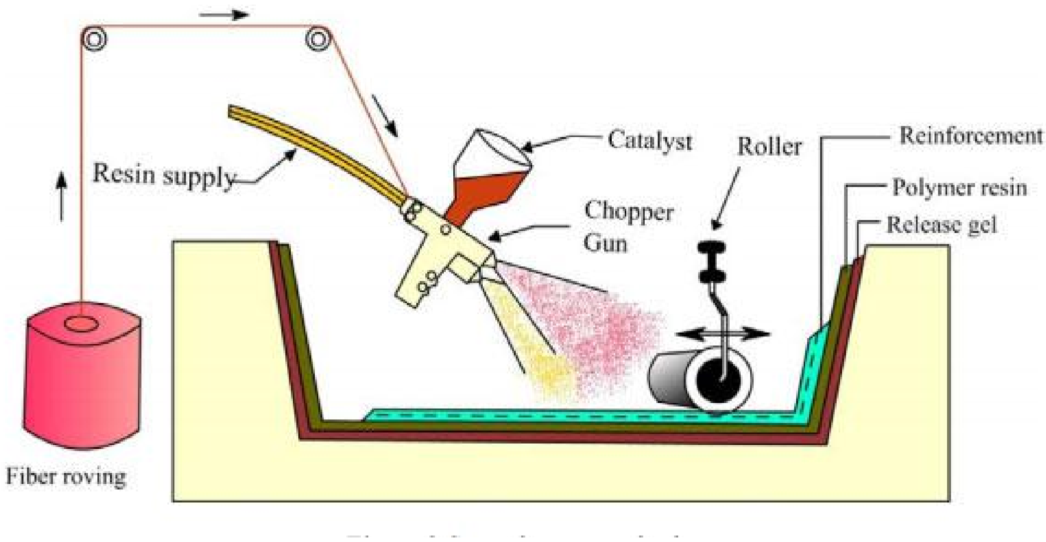


Figure 1.9 - Spray layup fabrication method

2) Pultrusion process

This is a highly automated method for the processing of continuous fiber lamination with high fiber volume profiles. Due to the high fiber volume profiles, this method is better at the production of structural components with a high strength and weight ratio.

The first step of production, raw materials (rovings filaments) are fed into the automated machine through the guides. Next the resin impregnating followed by the heated pool and finally separation [12].

•Silicon

•Epoxy

•Other thermosetting polymers

Advantages

1) It is an eco-friendly processing technique

2) Good control of the material quality

3) The pultruded structure are highly durable with lesser weight compared to aluminium.

4) Due to their non corrosive nature, they require less maintenance

5) It is a quick process

Disadvantages

1) The die is expensive

2) The die can easily become messed up

3) They are mainly thermoset matrix.

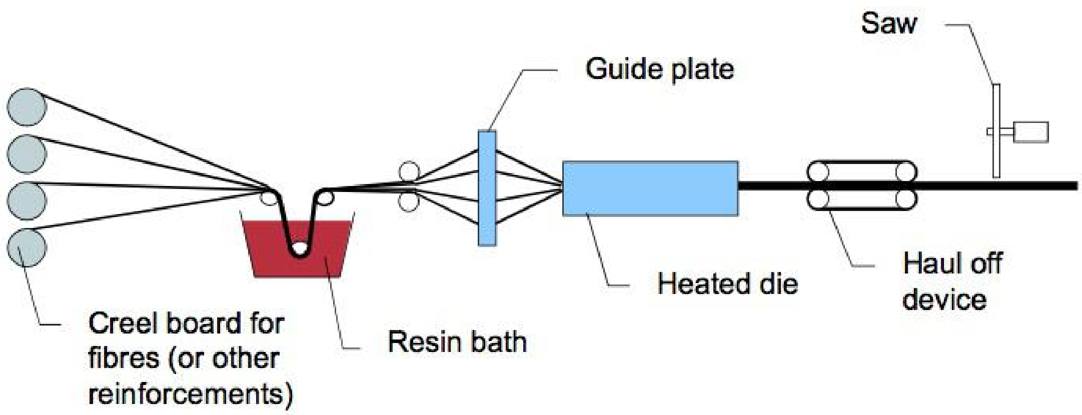


Figure 1.10 - Pultrusion technique for fabrication of fibrous composites

3) Vacuum bagging process

This fabrication method is used to create a mechanical pressure on laminate while undergoing its cure cycle. They are used for race cars, speed boats and other large structures. Applying pressure to a composite laminate serves various purposes. Firstly, it helps remove the air trapped between layers. Secondly, it presses the layers to ensure efficient force transmission to avoid the layers shifting when force is applied. Thirdly, it reduces the degree of humidity. The vacuum bagging method help improve fiber to resin ratio in composite structures..

Advantages

1) This processing method can be used in manufacturing large parts like wind turbine.it is one of the simplest methods of fabrication

2) It is simplistic

3) Low pressure helps keeps tiling cost

Disadvantages

1) One major drawback is that they only provide good surface finish on the tool side of the part and Since it requires human labour input it is quite slow

2) Inconsistency

3) Temperature is required to be controlled and monitored as they cannot be heated too much.

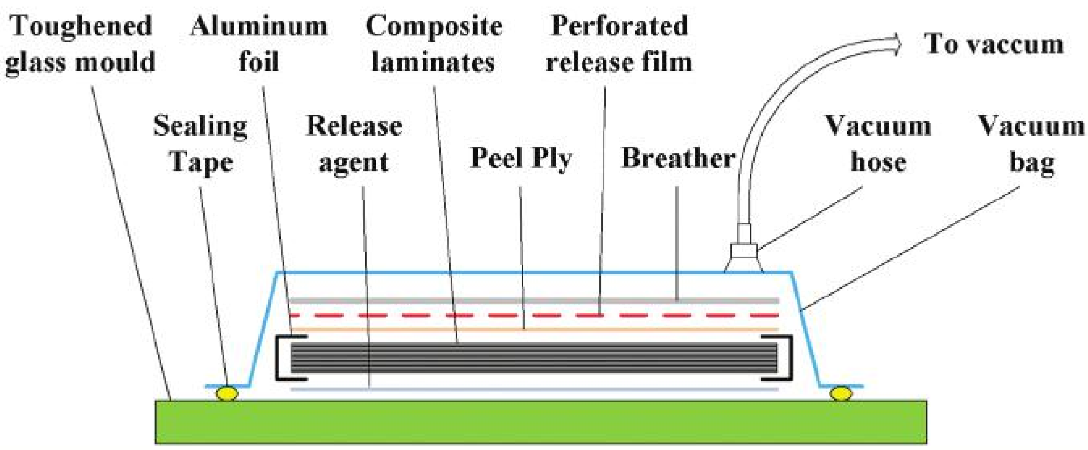


Figure 1.11 - Vacuum bagging fabrication method

4) Hand layup process

This method is the oldest woven composite fabrication technique. It. Is an open forming method used in the manufacturing of composite materials. It I one of the simplest methods and can be used for the production of large units. Reinforcement like carbon fibers, polymeric or glass is placed in the mould after the application of resin. Manually using a roller it is necessary to spread the suspension properly around the mould [11].

Advantages

1) It is cheap

2) Higher control over the quality of production

3) Can be used in the production of large structures

4) Can be used in the production of a vast range of products or structures

Disadvantages

1) It is time consuming

2) It can develop air bubbles

3) It requires a great deal of precision

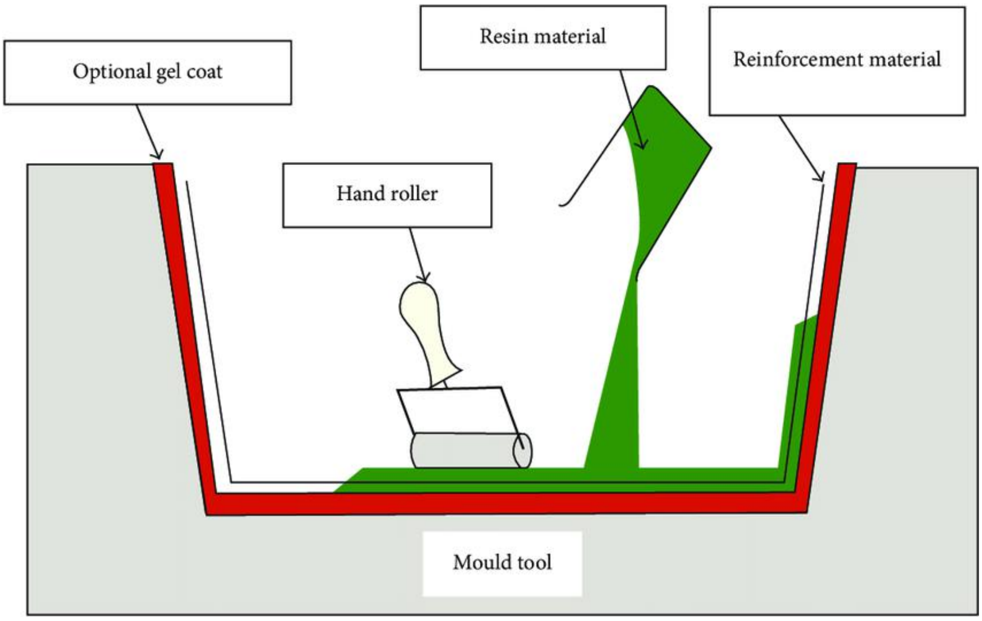


Figure 1.12 - Hand layup fabrication technique

5) Filament winding process

The filament method is a mechanized process of fibrillation of fibrous composites. The fiber is directed straight to a resin bath after which it is wound around the shape of the mould. This process is continued until the desire thickness is achieved before curing.

After curing, the mould is removed to give the mixture its final shape . They are mostly used in the manufacturing of circular products like bottles, shafted etc. This processing technique is critical to some factors such as filament winding process is usually critical to several factors such as

1) The length of each layer

2) Cycle length

3) The angle

4) The number of cycle's length of layers.

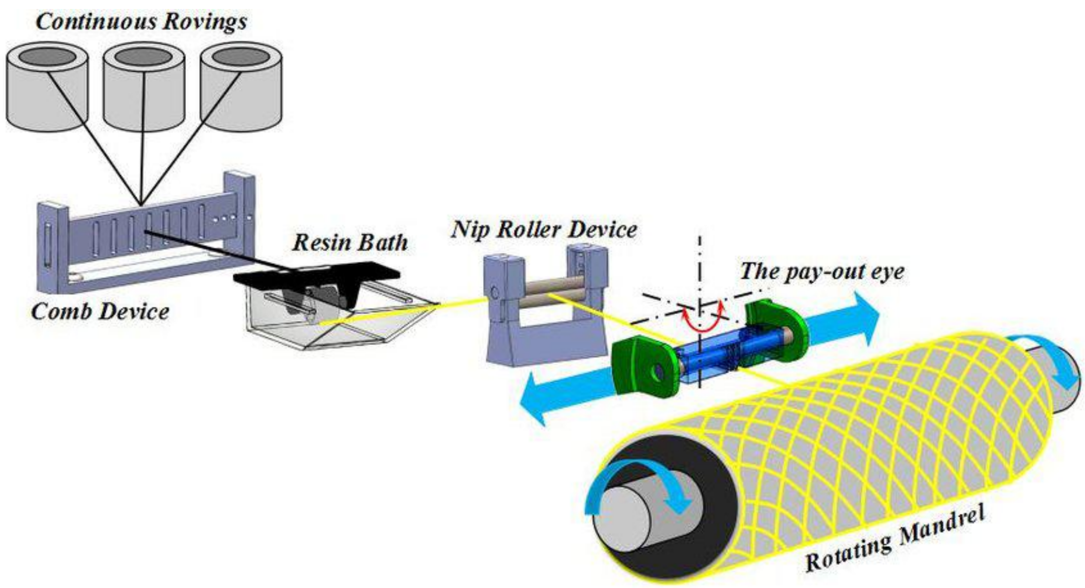
Advantages

1) This method is quick
2) Easy to handle
3) Can be used to produce large units
4) Since it is mechanized, it has a high accuracy.

Disadvantages

1) It has a limited variety of shapes for production
2) The curing process using heat is not so easy to apply
3) The speed of production is limited as spinning speed is controlled to prevent splashing and pouring of resin.

It is an expensive method as it involves automated



tools

Figure 1.13 - Filament winding process of composite fabrication

1.9 Summary of composite materials used for fuselage structural improvement

The introduction of composite materials at a higher percentage for the production of aircraft fuselage is growing and according to forecast would be in full production within the next 10 to 20 years.

According to in-depth research results available to us, we can see the reasons for the growing use of these materials for production not only in aircraft but in other high performance structures where strength is an important factor. The use of these materials reduces the weight and reduces fuel consumption, which is a luring factor.

However, it is important to consider an important aspect to the composite materials in regards to how they can be properly maintained to improve or maintain performance at a high level and reduce damages. [13].

Conclusion to part 1

In this part, we considered the main purpose of the fuselage to the aircraft as well as the main materials used in the manufacturing of the aircraft in the modern era.

Based on research we focused on the composite materials due to their rising involvement in the construction of aircraft fuselage. As a result of increase in technologies and better understanding of materials we have been able to better understand certain materials and how to better improve them for high performance structures.

Comparing composite materials to aluminum structures, we can understand the reason for changes in structural material based on their strength and weakness. Composite materials offers the high strength required for high performance structures but with a cut down in the weight, which makes it a favorite within the aircraft manufacturing industry for areas where weight can be compromised specifically the fuselage in our case.

PART 2

MAINTENANCE OF AIRCRAFT FUSELAGE USING MODERN DIAGNOSTICS TECHNIQUES

2.1 Introduction to the types of diagnostics used in maintenance industry

In engineering, when carrying out maintenance of structures and structural components, there are two main forms of inspection.

Destructive inspection

Nondestructive inspection

Destructive inspection as the name implies is a form of research where the test material is damaged to achieve a better understanding of the structure. It determines vital information about the physical, chemical, technical and structural characteristics of the test material. Destructive diagnostics is used to determine certain material characteristics like hardness test, compression test, tensile test etc.

The pros of destructive testing includes;

1) They have used for long in engineering to improve maintenance
2) It gives engineers the possibility to study materials on a molecular level to understand what the makeup of the material is.

The limitations of destructive testing is the biggest, which is the fact that it leads to the destruction of the material / structure or part of it rendering it out of use.

However, nondestructive inspection is a form of engineering diagnostics where the test material is not altered in any form during inspection but values are achieved to determine the state of a structure.

Figure 2.14 - Diagrammatical expression of destructive diagnostics

The pros of nondestructive inspection includes

1) The main benefit of nondestructive diagnostics is the fact that the material or structure remains intact after testing procedures without changes in the physical, chemical or structural makeup of the material or structure.
2) As a result of technological advancements, it has been made possible to carry out this method of testing with less difficulty and more reliable results.
3) Highly beneficial when inspecting items or structures that are not mass produced or one of a kind.
4) There is little or no loss in monetary values on the inspected material as there is no destruction of material.
5) Several Methods that can be used for inspection where suitable.
6) It is highly reliable

Figure 15.2 - Diagrammatical expression of nondestructive diagnostics

The limitations and disadvantages of nondestructive diagnostics includes;

1) The main disadvantage of the nondestructive inspection technique is that it requires the skill of a well trained expert as in consist of more complex and technical methods that require interpretation only by a skilled technician.
2) It is more expensive than the destructive method as it requires the use of highly automated devices for inspection.

2.2 Methods of nondestructive diagnostics

In this modern era, there are various method of NDI used in maintaining aircraft structures to ensure they remain airworthy and spend less time for repairs. However, we will be considering the 6 main types namely;

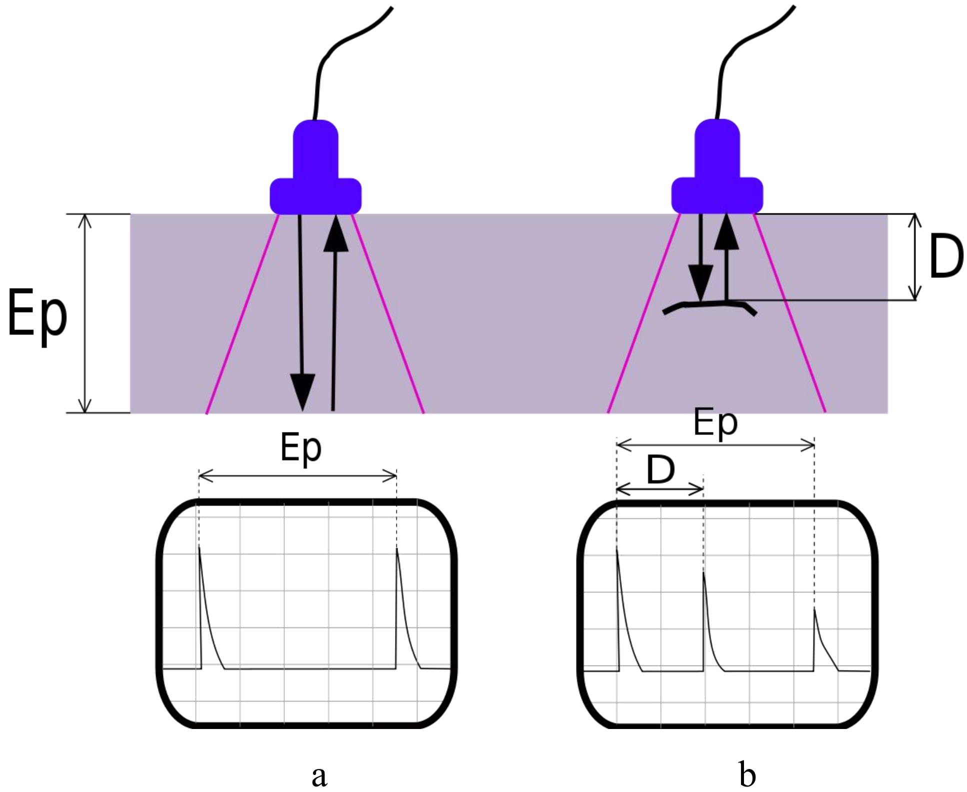
1) Ultrasonic inspection
2) Magnetic particle inspection
3) Liquid penetrant inspection
4) Eddy current

5) Visual inspection

6) Radiography

Ultrasonic inspection

The ultrasonic method of inspection is one of the most widely utilized due to its qualities. This method of diagnostics involved the use of short waves with high frequency to penetrate the tested unit. A sensor transfers the waves, which is also the receiver. The wave transmitted is reflected and the time taken for the sound to travel from one wall to another is being interpreted on a computer in a graphical format. Through these waves, the internal properties of this material can be summarized. Ultrasonic Testing devices consists of display monitors where we receive the graphical interpretation of these waves, transducers, pulsars and receivers [14] [15].



a) Absence of defects b) Defect present

Figure 2.16 - Ultrasonic inspection

Advantages

1) The possibility to detect internal discontinuities and defects within the test object and sized.
2) It requires access to only one side of the test object unlike RI.
3) Test object takes roughly similar time for inspection irrespective of their thickness variation.
4) There is no health related concerns as it does not use radiations.
5) Cracks inside the material or structure can be detected irrespective of its orientation.

Disadvantages [16] includes;

1) They require a high level of skill and integrity and can only be carried out by a skilled personnel be used to detect flaws both internally and on the surface of a test material.

2) There is no permanent record of inspection results for future reference purposes.

3) Inspection of materials like austenitic steel can cause attenuation, which can hide defects due to large grains in weld.

4) Requires surfaces cleaning and preparation before inspection.

Figure 2.17 - Fuselage inspection using ultrasonic diagnostic

Magnetic particle inspection

In the Magnetic Particle Inspection, we have two different kinds of testing which are the Dry Magnetic Particle Testing and the Wet magnetic Particle Testing. This form of diagnostics is used in the inspection of ferromagnetic materials where the use of magnetic powder is used to create EMF around the metal. This helps in the identification of the flaws or cracks within the material because a void in the material causes the current to leave the material at the place where the defect is present, creating two separate poles. The North Pole (N) and the South Pole (S) which are two opposites drawing the particles of the sprayed component into the void causing the defect to become more visible to the inspector. The spray could be red or black, which is a colour of contrast to make the flaws more visible. The magnetic particle testing consists of two different forms famously used, which is the colour contrast and fluorescent methods [17]. The colour contrast technique is shown in figure 2.4 below.

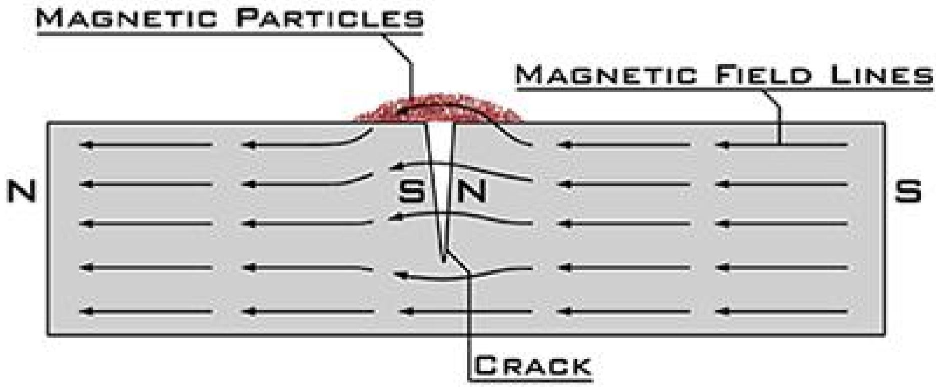


Figure 2.18 - Colour contrast magnetic particle inspection technique

The fluorescent MPI technique is similar to the contrast technique but in the case of the fluorescent, it first involves the application of a liquid, which would make the material glow in UV light, which makes the material glow and the defect visible to the inspector. The florescent MPI technique is shown indicated in figure **2.5.**

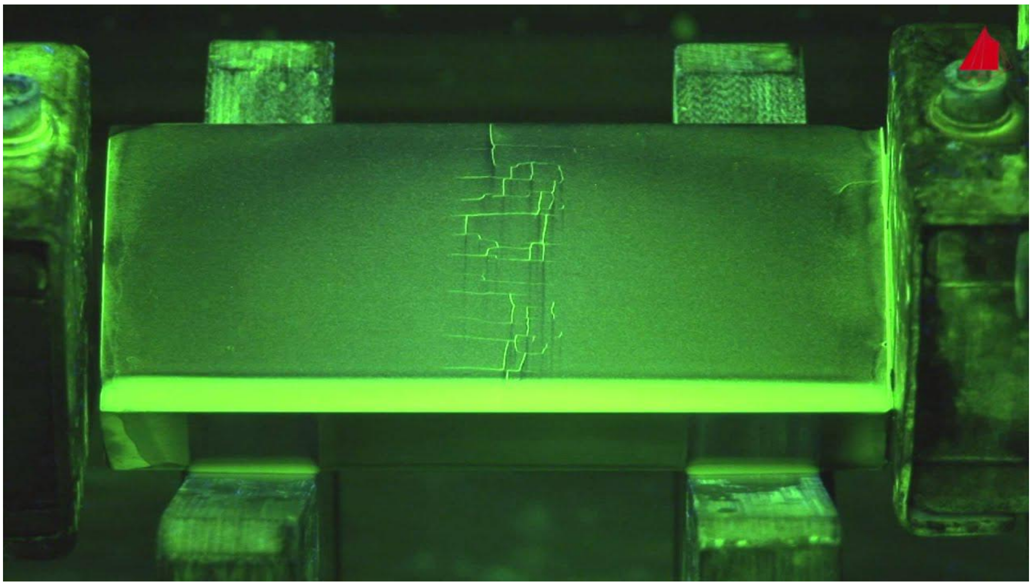


Figure 2.19 - Magnetic particle fluorescent inspection

Advantages [18]

1) It is a relatively quick procedure
2) It is uncomplicated

3) If defects are present within the structure, it can be identified immediately.
4) This method can be used in both shops as well as workshops.
5) Possibility of inspecting both small and large test objects effectively.
6) It is cheaper compared to RI.
7) Does not require elaborate cleaning and preparation before inspection.

Disadvantages

1) It is quite messy
2) It cannot be used for objects with thick surface finishes.
3) It requires electricity
4) The main disadvantage is that they are limited to only ferromagnetic materials.
5) Requires a skilled worker.

Liquid penetrant inspection

The liquid penetrant inspection (LI) is a simple method of inspecting materials for surface abnormalities or flaws. It is widely used in engineering because they can be used on various materials for inspection. It involves the use of a bright colored fluid for absorption and a developer to make the flaws very visible to the human eyes under normal light or a fluorescent light.

Advantages [19] include;

1) They can be used on shapes with complicated geometry.
2) They are compact
3) They have few limitations in terms of materials they can be used for a wide range of materials.
4) They are very cost effective
5) It is a quick procedure.

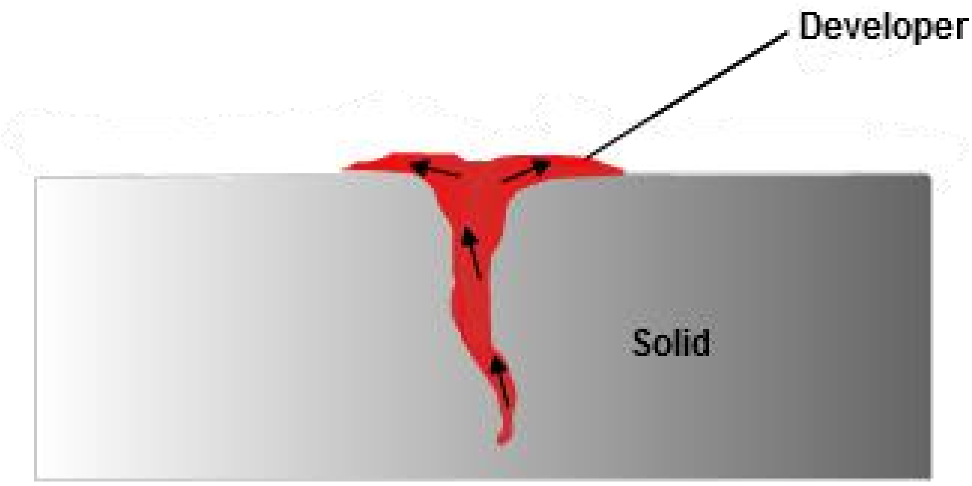


Figure 2.20 - Representation liquid penetrant inspection technique

The LI method is very sensitive to surface defects, which makes it one of the most important methods when detecting surface flaws in water resistant structures. They can be used in combination with ultraviolet lights to better show they defects on the surface of the material or structure. This method is called the fluorescent liquid penetrant inspection.

Disadvantages [19] include;

1) The LPI cannot determine the depth of defect.
2) It has multiple processes
3) Requires elaborate surface cleanup and preparation before inspection.
4) It is also quite messy
5) No recorded data to show the progress of monitoring.

Figure 2.21 - Fluorescent liquid penetrant inspection

Eddy current inspection

Eddy current inspection is mainly used in maintenance organizations for inspection of ferromagnetic materials and structures. They require electricity and can only be used on materials that can conduct electricity, which limits their usage. The eddy current probes are configured to pick up signal changes that indicate presence of flaws or discontinuities on the surface of a test object. Different probes are configured differently to beat suit different situations when inspecting surface flaws [20] [21].

Figure 2.22 - Eddy current inspection carried out on the fuselage

Eddy current testing has its various advantages as well as disadvantages [22]**.** The advantages include:

1) They are effective in detecting surface discontinuities and flaws like crack due the their high sensitivity.
2) It is quite portable
3) Quick result after inspection
4) Can detect through coated materials
5) The process can be automated
6) It requires very little cleaning before inspection.

Disadvantages

1) They are susceptible to magnetic permeability
2) They cannot pick up defects that are parallel to the surface.
3) The can only be used for conductive materials.
4) Their values can be affected by surface roughness or finishes.
5) They are not ideal for inspecting large geometries.

2.1.1 Modes of probe operation

When speaking about the modes of operation, we are discussing about the arrangement of the coils and how it influences their ability to pick up signal when testing for defects. There are four main modes namely;

Absolute

Differential

Hybrid and

Reflection probes

Absolute probes: Absolute probes are single test coils, which is used to cause eddy current generation in the tested material and sense changes that might be taking place in the material because of the eddy current. The eddy current generates a magnetic field because of the AC transferred to the material, which opposes the magnetic field of the coil. This causes a change in the inductive resistance of the coil. Measurement of the changes in impedance of the coil is taken, which helps us determine if defects are present within the material.

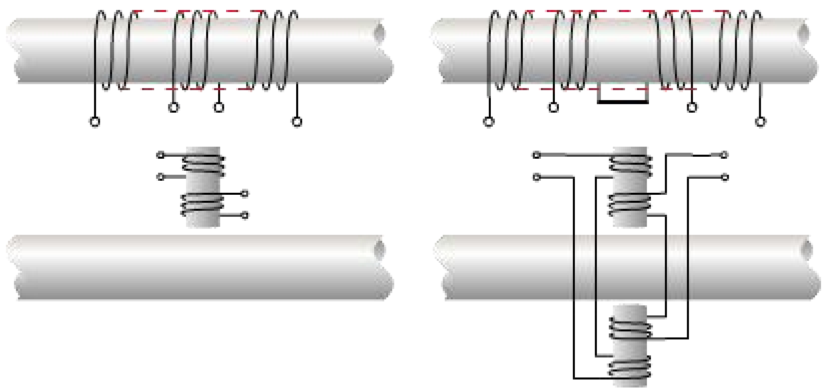


Figure 2.23 - Representation of the absolute mode of operation

a) – Absolute probes, b) – Differential probes

Differential probes: Differential probes consist of two coils wound in opposite direction. The technique of operation is quite similar to the absolute probe using AC from a source to create eddy current in the tested material.

However, in the differential probes, they are normal when placed over a surface without defect. When one coil passes over the defected area, there is a differential signal received by the probes between the two coils. This method can help us determine the length of the defect. It is quite sensitive for detecting discontinuities but quite insensitive to other abnormalities such as temperature variation.

Figure 2.24 - Different configurations of probes

Reflection probes: Reflection probes consist of two coils wound in the same configuration as the differential probe and additional coil with the main function of exciting the material while the two coils pick it up and senses for defects. The advantage of this type of probes is that each coil could be separately improved or optimized to serve its required function.

Hybrid probes: The hybrid consist of two coils with D shape, which is surrounded by a driver coil. The main function of the driver coil is to excite the material. It operates in the reflection capacity while the two D shaped coils operate in the differential capacity.

Visual inspection

Visual inspection method is the most common method of inspection because it is used in the day to day operation of aircraft before flight departs and after arrival. The visual inspection can be executed using equipments like;

Borescope

Fiberscope

Microscope

Magnifying lens

Figure 2.25 - Defects checked using visual inspection

It is used mainly during line maintenance to first determine if the unit being inspection has any visible reason for progressing to Phase 2 of inspection. The visual inspection method does not bring into force other instruments for inspection or other forms of NDI. It, therefore, relies on the pure senses of the specialized inspectors, which are sight, smell, touch, hearing etc. This involves checking for flaws like:

1) welds

2) cracks

3) corrosion

4) Signs of stresses or overloading

5) Right pressure including tires, hydraulic actuators, struts etc.

6) Creases or cracks in the skin or web

7) Skin wrinkling that crosses a line of fastener

8) Pulled apart structure

9) Bent components

10) Interference

11) Loose paints

12) Fasteners pulled out or missing

13) Misalignment

14) Twisted parts (Distortion)

15) De-lamination

16) Other visible signs of damage.

Advantages includes;

1) They demand minimum preparation before inspection
2) It is cheap
3) Requires a skilled and well trained technician
4) Portable testing materials and devices
5) It's quick
6) Can be used for inspection of both large and small object

Disadvantages are listed below;

1) It can only help find defects visible to the human eye.
2) Requires experience in predicting defected sites and using all senses to detect small discontinuities.
3) Misinterpretation of defects
4) High percentage of mistakes since it's dependent on human eye.
5) Depth of flaws cannot be determined by the eyes.

Figure 2.26 - Diagram of visual inspection taking place on the fuselage

Radiographic inspection

This method is used in a vast range of applications including areas like medicine, forensic investigation, engineering etc. In nondestructive inspection, radiographic inspection is one of the most important as well as used method due to the fact that it offers several advantages over other methods of nondestructive inspection.

However, the major con of this method is health related due to its relation with radiation. It is used in engineering to expose flaws hidden in structures [23] [24] and materials by sending short wavelength electromagnetic radiation into materials. The intensity of this penetration is captured on the film placed on the other side of the test object.

Equipment's used for this process includes

X-ray generator

Radio isotopes source (gamma rays)

Radiographic film

Conventional Radiography

This form of radiography functions in the conventional method where radiation is used to portray the image of the flaw or discontinuity within the material on the opposite side.

Digital Radiography

This form of radiography unlike the conventional method used electrical detectors to portray the image of the discontinuity or defects within the test object. However, it is faster than the conventional radiographic method since it involves digital approach.it offers the possibility to save the result of inspection for reference purposes in future maintenance procedures.

The advantages of Radiographic inspection includes:

1) The ability to detect both surface defects and internal discontinuities
2) They are very handful in testing for defects in hidden areas, which refers to areas difficult to access inside the test object.
3) They require minimal preparation unlike other methods of NDI
4) The have few limitations in terms of test material
5) They can be be used to check variations in composition
6) They records from inspection is saved, which provides us with permanent test data.
7) Portability

The limitations and disadvantages of radiographic inspection include:

1) It is hazardous to the operators and nearby personnel as it involves radiation.
2) This is an expensive technique because it uses a highly automated device, which is expensive.
3) The depth of the flaws within the test object cannot be determined using this technique.
4) It's a generally slow technique and is not preferable in situations where time is an important factor.

5) It requires access to both sides of the test object.

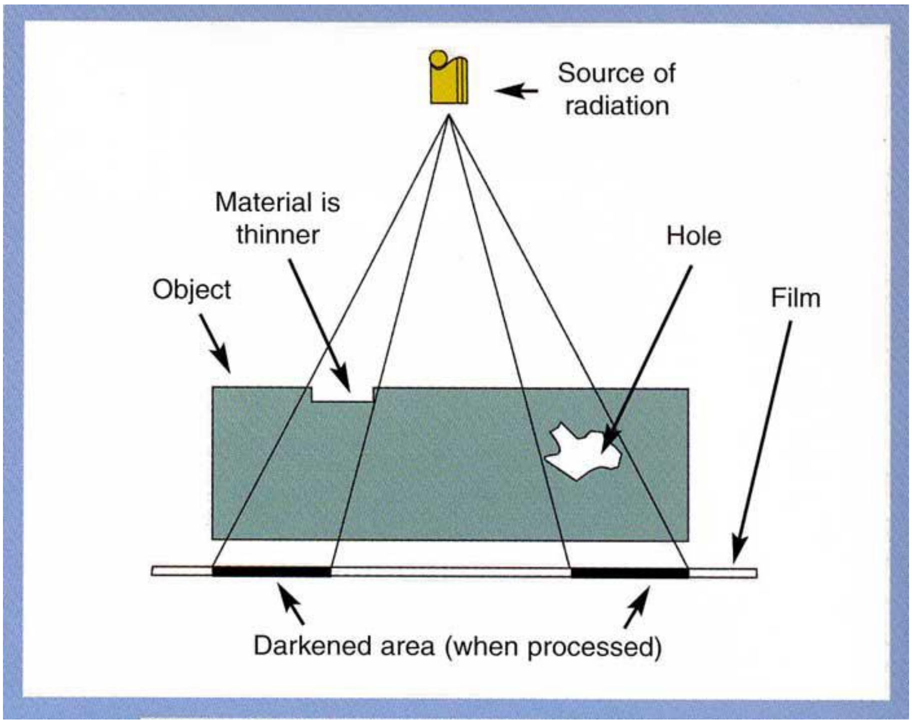


Figure 2.27 - Radiographic inspection technique representation

2.2 Limitations of nondestructive diagnostics in fuselage inspection

Large surface area for inspection using smaller tools

For inspection of small or medium structures, the nondestructive inspection techniques are used for the determination of defects. The EDT, radiography, liquid penetrant, UT, MPI AE are used for inspection of components within a specific size. This makes inspection process simpler and effective. Unlike those structures, the aircraft is large which requires a greater surface area for inspection making it impossible to use some NDI techniques since they require access to both sides of the tested component. This requires dismantling of the structure to smaller units, which increases the restoration time and reduces maintenance efficiency.

Initially, composite materials were used for the construction of large and thin plate-like structures like aircraft wings and tail units. But with increasing percentage of composite materials in aircraft design to above average, the inspection requirements increases because of greater surface area. This creates the necessity for development of a high-speed inspection technology with the ability to critically inspect large units for defects and determine their airworthiness without dismantling of the structure.

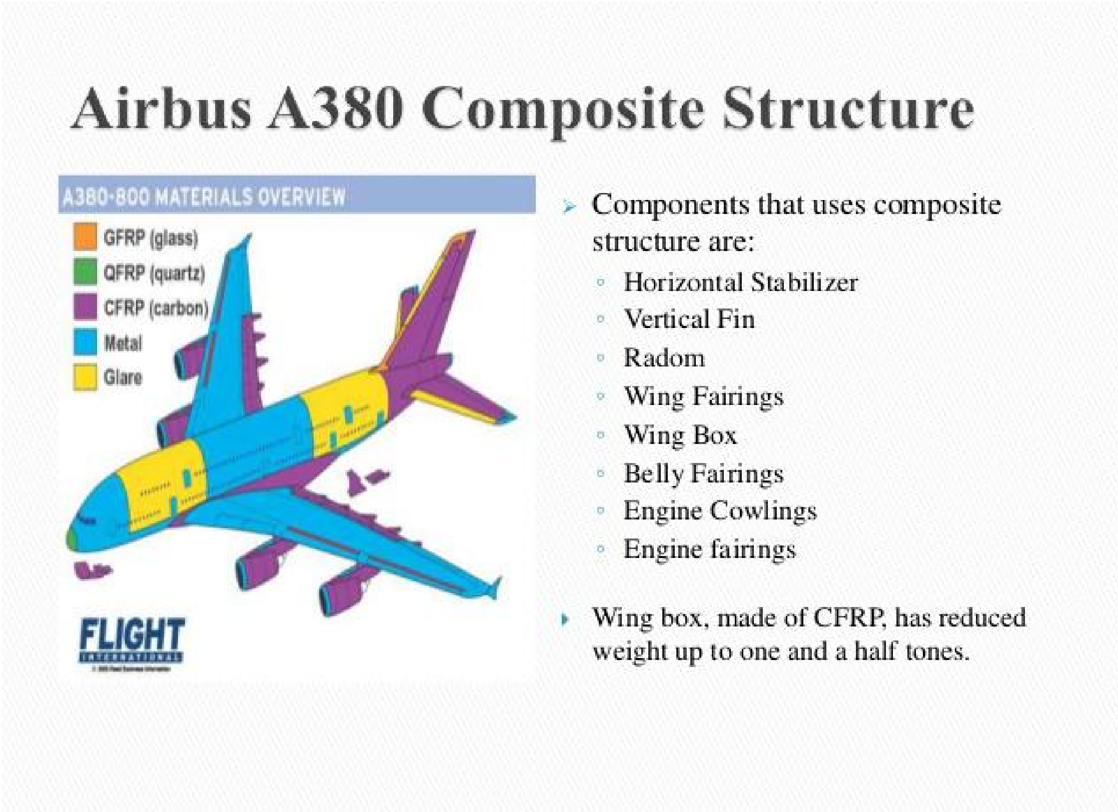


Figure 2.28 - Increasing percentage of composite materials in aircraft structure

Limitations of Visual inspection in inspection of composite fuselage

Most of the aircraft designed in this era are made of about 40% of composite materials. The fuselage is one of those parts where strength can be sacrificed for weight using composites because it’s served just as good as the conventional metal materials previously used like aluminium alloys and steel. The composite materials used in fuselage structure are required to possess a certain degree of strength and stiffness and flexible to withstand the degree of forces they will be subject to during their service life. Due to this requirement, the material configuration is aligned to promote these qualities. One of the main forms of inspection is a visual inspection.

Figure 2.29 - Aircraft fuselage made of carbon fibre epoxy composite

When metallic materials are used for the construction of the fuselage of the aircraft, inspection personnel can identify signs of defects or potential defects using magnifying glasses and lights or borescope. Unlike those materials, due to the strength of composite materials, they are difficult to inspect using visual inspection, as they break from the inside but the outside of the structure still remains intact. This makes the maintenance process a lot difficult as visual inspection reduces effectiveness due to the reduction in the ability to detect possible defects within the composite structure.

Time consumption for maintenance and inspection composite fuselage

Given the size of the fuselage, it is impossible to use certain methods of inspection without dismantling the structure. Inspection can also be carried out using alternative methods, however it requires precise attention to details and areas. This results in more time spent carrying out maintenance on the aircraft fuselage constructed with composite materials. This in turn reduces the maintenance accessibility value of the aircraft fuselage and reduces the efficiency of maintenance. The average complexity of the additional work measured in man-hours, which varies depending on the area where maintenance is necessary on the fuselage increases in cases of composite fuselage structures due to their composition, which further reduces the accessibility to the maintenance area.

Conclusion to part 2

Nondestructive methods of inspection has been used in the aviation industries for many years for the maintenance of the aircraft fuselage effectively. However, taking into account the limitations surrounding these methods and its compatibility with the future material used to further advance production and save weight, there are several question marks around the efficiency of maintenance using conventional NDI methods for diagnostics.

PART 3

NEW TECHNOLOGICAL METHODS FOR FUSELAGE STRUCTURAL MAINTENANCE

3.1 Introduction to structural health monitoring

Structural health monitoring is a modern method of nondestructive inspection that refers to the inspection and monitoring, which is aimed at gaining information about the structural integrity of the material in real time. Unlike other methods of nondestructive diagnostics, the structural health monitoring technique implements changes in measurements at a particular location at different time intervals to identify what state or condition the structure is in.

Structural health monitoring is made possible by sensors that continuously monitor the structural behaviour of the unit in service. The main aim of structural health monitoring is constantly evolving and can be defined using several features that are important for SHM. These essential features include:

1) Real time monitoring of the structure

2) In-service structures using

3) A network of sensors collecting data

4) Changes in the condition of the structure

5) Communicated over a network

6) Algorithms used for data processing if possible for damage detection, classification, residual life prediction as well as assessment.

3.2 Reasons for introduction of SHM to improve fuselage structural maintenance

As considered in the previous section,[25] there is a glaring need for improvisation of modern maintenance techniques to suit the increasing use of composite materials for fuselage construction. Conventional nondestructive testing techniques have been efficient so far to a degree in the maintenance of the aircraft structure.

However, it is necessary to keep up with ever changing technological advancements taking into account the vulnerabilities of the conventional NDI techniques used for aircraft manufactured with conventional materials. Previous aircrafts were designed with minimal use of composite materials for aircraft structure and maximum use of aluminium and steel. This is a major factor why conventional NDI techniques were so efficient but considering the quality of composite materials used in modern aircraft and the higher percentage used for construction, it is necessary for more effective maintenance schemes and procedures.

3.3 Systems for Structural health monitoring of composite structures

The SHM systems have been studied for a given period of time to ensure the durability and safety of the composite structures they are used on. The SHM relies on sensors that are embedded into the composite structure to monitor its performance either actively or passively by receive values and transfer feedback for comparison and analysis. It is important for the sensors to be light to prevent a substantial increase in weight and also should not affect the structure performance in any way. The sensors used for SHM, which can operate both in static and dynamic areas are:

1) Fiber optic sensors (fiber Bragg grating sensors)
2) Conventional electrical resistance strain gauges
3) Piezoelectric wafer active sensors
4) Electrically sensitive sensors

3.3.1 Fiber optic sensors (fiber Bragg Grating sensors)

The fibre Bragg Grating Sensor (FBGS) is already being used in other industries for SHM of structures not only to monitor but also to help predict when next the structure requires maintenance [26]. In civil engineering, these sensors are used to monitor bridges for several years to determine flaws and also predict the time till next maintenance.

The fiber consist of three main sections.

The core

The fiber cladding

The polymer coating

The outer part is called the polymer coating with the main purpose of protecting the fiber itself from harsh external conditions. In cases where the sensor will be exposed to hard and harsh conditions, the polymer coating protects the fiber from being affected. The coating can last as long as the fiber itself and is strong enough to withstand certain conditions.

The second part is called the fiber cladding. It also helps protect the fiber and prevent the refraction of light waves that passed through the fiber core. The innermost part is called the fiber core. This is there the light waves travel and changes wavelength due to structural changes. The FBG sensors are embedded in the composite structures to improve sensitivity and ensure accurate values. The also protect the sensors from tough environmental conditions during the course of flight, which could influence the values negatively.

The FBGS can help improve maintenance during SHM as the values obtained during the course of flight can be compared to normal reference values to determine what areas of the fuselage requires repair or maintenance.

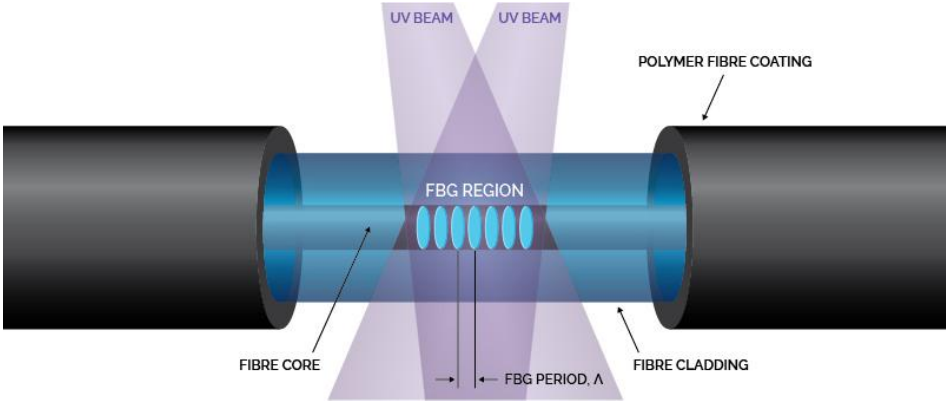


Figure 3.30 - Fiber optic sensor representation

In the absence of unforeseen circumstances during the course of aircraft operation (atmospheric conditions, pilot errors, hard landing due to overweight etc.), there would not be any need for a more clinical maintenance technique for preventing and controlling the growth of defects within the structure.

However, it is important to monitor the structure to ensure better control and knowledge of the state of the fuselage. Defects present within the structure grows due to continuous application of loads for a given period of time. Therefore it is necessary to monitor these structures to ensure that they are well controlled and maintained when these defects exceed the acceptable values.

The main parameter monitored by the FBGS is the strain values (mechanical and temperature induced strain), temperature changes within the structure, vibration, impacts etc.

Fibre Bragg Grating System operation mechanism

The FBG serves as an optical filter in to reflect or block certain wavelength. The FBGS consists of the fibers itself, the sensing system and the computer, which helps translate what is going on within the structure.

The reflected spectrum in the fiber is based on Bragg wavelength and is dependent on the effective refraction index as well as the Bragg period (Λ_B)of the grating within the fiber, which is represented by the formula (3.1) [27]

$$\lambda_B = 2\eta_{eff}\Lambda_B \tag{3.1}$$

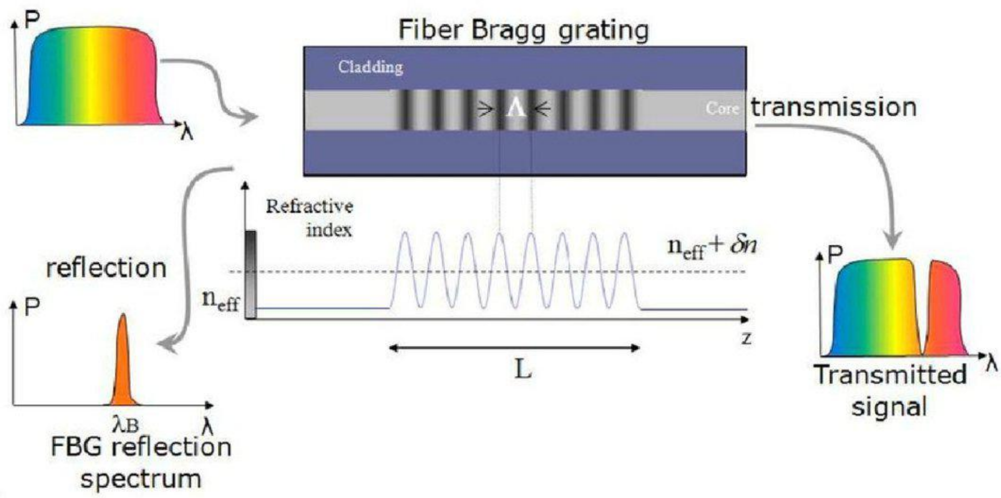


Figure 3.31 - Fiber Bragg grating principle of operation

Flaws or changes within the structure or component is indicated by a change in the wavelength of the fiber. This changes are picked up by the gratings within the fiber, which interprets if the fiber is undergoing expansion or compression.

Using the formula for strain in materials, we can derive the formula for strain in fibers as shown in the formula (3.2) below [28]

$$\frac{\Delta\ell}{\ell} \tag{3.2}$$

Since we would be dealing with lights and waves, we will be replacing the length with wavelength as seen in formula (3.3)

$$\frac{\Delta\lambda}{\lambda_0} \tag{3.4}$$

Where $\Delta\lambda$ is the change in wavelength and λ_0 is the base wavelength.

The wavelength changes due to two main reasons, which are Mechanical strain ε_m or temperature strain ε_T. The formula can be expanded to achieve the main formula for calculating strain caused by temperature change, mechanical strain and the necessary temperature compensation for determining accurate strain values. The strain formula takes into account the two types of strain (mechanical + temperature).

However it is important to derive their values differently and compare to ensure the values are correct based on set algorithms.

Firstly, we determine the grid spacing G_s of the fibre, used in the structure [28].

$$G_s = \frac{\lambda_0}{2n} \tag{3.5}$$

Where n = Refractive index if the fibre,

Gl = Grating length,

N = fringe count

We from (3.6) to (3.8) to derive the formula for Pole distance (3.8) [28]

$$N = \frac{Gl}{Gs} \tag{3.6}$$

$$N = \frac{2nGl}{\lambda_0} \tag{3.7}$$

$$Pd = \frac{\lambda_0}{N} = \frac{\lambda_0^2}{2nGl} \tag{3.8}$$

Pd = Pole distance

These are the formula for the basic parameters of a Fibre when considering the FBG sensors.

The sensor placement is highly important when considering the FBG system. The arrangement of the sensor is vital because it affects the effectiveness and efficiency of the system in capturing changes within the structure of the component. It also affects the sensitivity, which is vital to ensure accurate values during the course of monitoring. The main issue encountered is the embedding of sensors during production and how the sensors should be arranged for accurate results. The sensors are embedded into the composite structure during the manufacturing process to improve the sensitivity and necessary test analysis should be carried out on the fuselage, which has already been done to note key areas where sensors should be located for efficient monitoring. The diagram in figure 3.3 shows the arrangement of the FBGS in monitoring structural changes, which includes the sources of light, optical fibers, data acquisition unit, test material, computer and interrogator.

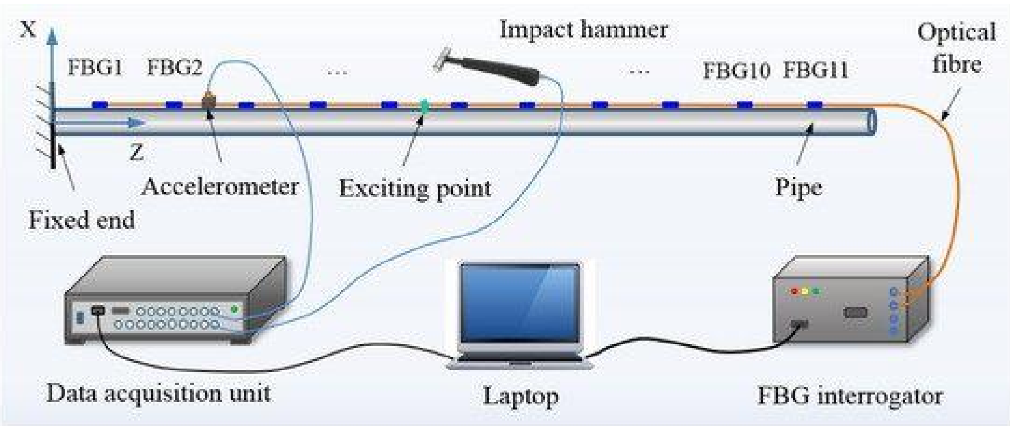


Figure 3.32 - Arrangement pattern of the FBGS on the surface of composite materials

According to the arrangement, we can see the interrogator supplies the light to the optical fiber while the changes in wavelength within the beam is monitoring by the computer as the beam is impacted by the hammer.

The values during the course of monitoring is acquired by the data acquisition unit and saved for future reference purposes.

This process perfectly depicts the SHM technique as the values saved for future references can be used for inspect and maintenance of the necessary unit.

3.3.2 Piezoelectric wafer active sensors

SHM is a multidisciplinary process that requires several disciplines that are required to work closely together. The use of guided waves techniques for NDI and SHM application is growing rapidly due to their ability to cover large areas with a relatively small number of sensors. The piezoelectric wafers are attached directly to the structure that requires monitoring. They are well favored due to their low cost, simplicity and versatility [29].

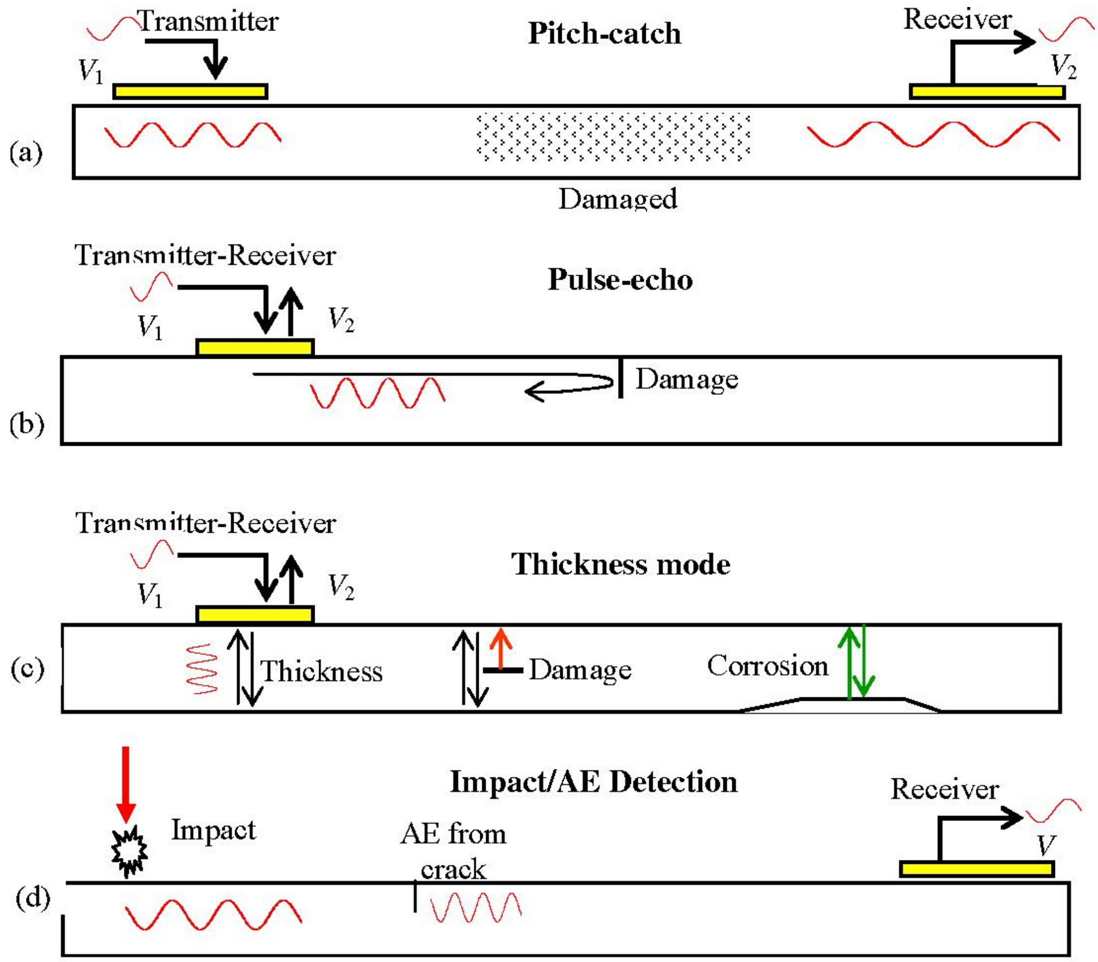


Figure 3.33 - Functional process of the piezoelectric wafer active sensors

The PWAS has become a major technology when considering SHM because the same installation of sensors can be used in various number of ways for damage detection such as:

a) Embedded guided wave ultrasonic
b) High frequency modal sensing
c) Passive detection

However, PWAS transducers merge electrical and mechanical effects using the piezoelectric constitutive equations.

The main advantage, which the PWAS has over the conventional ultrasonic probes, is they are low profile, lightweight, very small and cheap. These make them better options for SHM sensors for the fuselage considering they have to be distributed around the fuselage composite structure. Using lamb waves, it is possible to detect structural anomaly within a thin walled compound structure such as delamination, cracks etc.

The transducers for PWAS acts both as a transmitter and receiver of lamb waves that travels within the structure. The PWAS transmitter generates lamb waves that are reflected or refracted by the structural boundaries, damages within the thin walled structure or discontinuities. The transducers can be used as a) resonator, b) high bandwidth strain sensor, c) embedded modal sensors with EM impedance method and d) high bandwidth wave exciters and receivers [30].

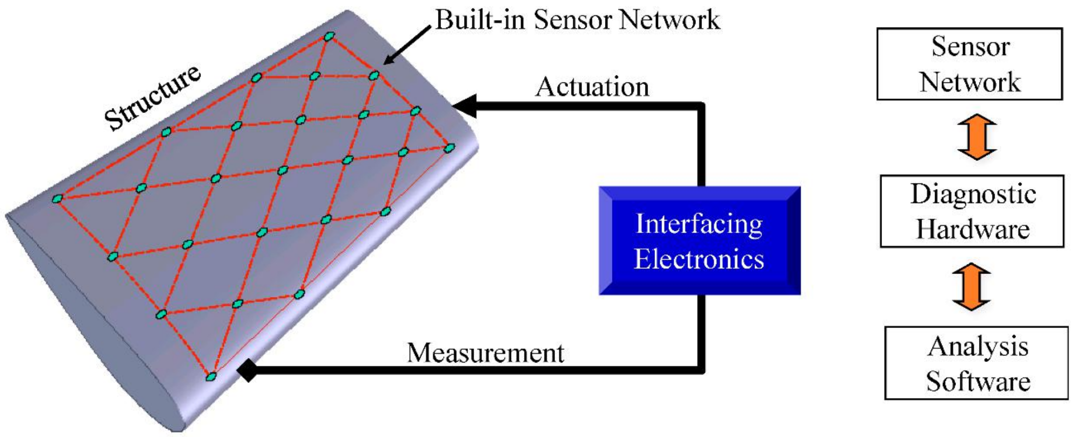
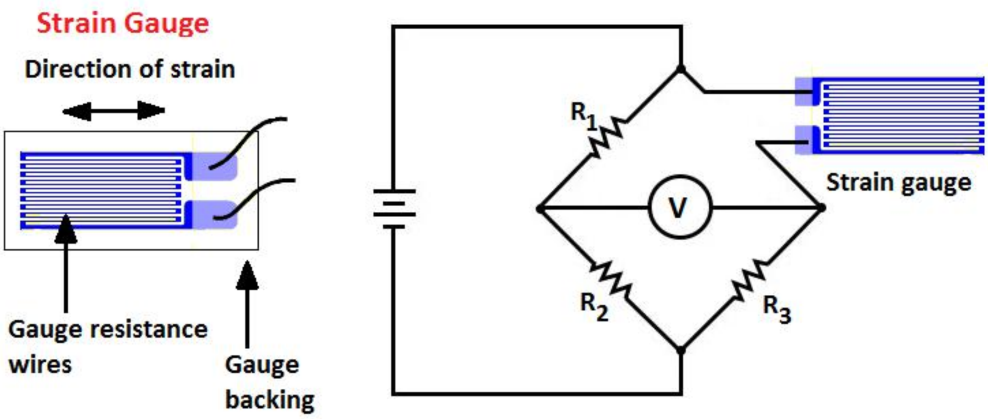


Figure 3.34 - Example of damage detection using the piezoelectric wafer active sensors

3.3.3 Conventional electrical resistance strain gauges

Several methods are used to determine the values of moments and force using electrical devices, all of which requires increasing the effects that small deflections have on the capacitance, resistance or inductance of a system. Strain gauges work in the principle that all materials offer resistance to electricity of which the value is determined by a multi-meter. The conventional resistance strain gauge is designed to detect strains within the structure by being embedded into the structure for greater sensitivity.



a) Strain gauge b) strain gauge functional diagram

Figure 3.35 - The representation electrical strain gauge

The conventional strain gauge can be used in connection with other sensors to further improve the sensing network around the fuselage structure by comparing values received from various sensors during maintenance to better understand the condition fuselage structure and pay maximum attention to areas where values are higher than normal.

3.3.4 Electrical sensitive sensors

These are materials that acts as sensors. Carbon fibers are good conductors of both heat and electricity whereas epoxy is an insulator. Therefore, if the CFRP has a volume fraction of carbon fiber it becomes conductive and presence of defects like cracks and delamination within the material can be noticed as it hinders electrons flow which causes a change in the conductivity of the material. GFRP composites are good insulators, which have dielectric properties. However, a change in the dielectric properties will occur if there are flaws within the composite structure like micro cracks, delamination etc. due to a smaller dielectric constant of air compared to that of the GFRP composite.[31]

3.4 How SHM technologies influences maintenance and its compatibility with humans.

Based on research, about 20 % of accidents caused in aviation is down to technical errors and a massive 80 % is down to human errors. More than 25 % of this is down to individual errors and 5 % maintenance errors.

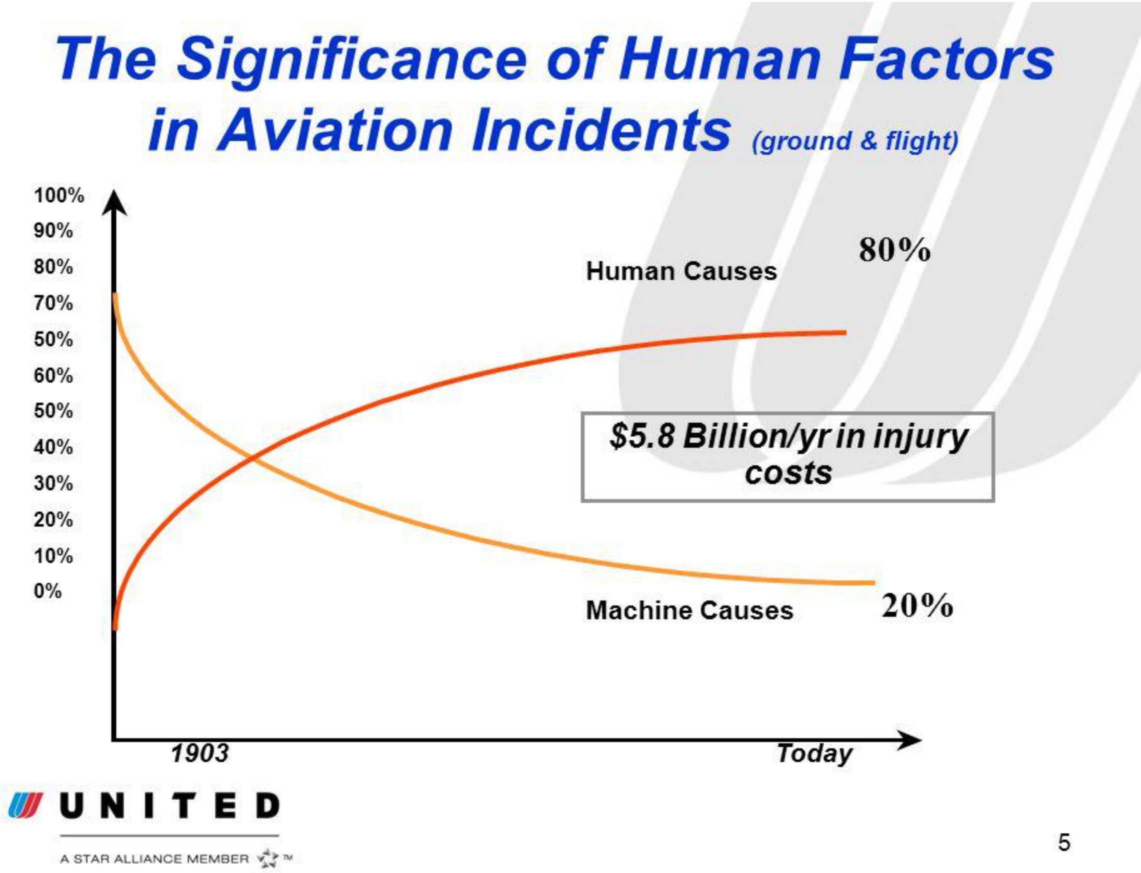


Figure 3.36 - Significance of human factors in aviation incident

Humans play a vital role in the aviation industry and cannot be replaced by technology considering the role they play. However, humans are not immune to certain situations such as mental, emotional, physical fatigue, illness etc., which could result in errors. As considered in human factor, human performance is accessed by their

a) Mental state

b) Emotional state

c) Physical state

d) Human capabilities

e) Human limitations

f) Environmental conditions

These factors are vital to the efficiency of the aviation personnel in executing tasks effectively. However, the introduction of these sensors, which sheds more light on the flight data indicating areas, which require in-depth diagnostics, reduces the amount of workload on the maintenance technicians, which reduces the amount of hours spent on maintenance, thus improving human efficiency. These sensors send information to the cockpit, which gives the pilot information on the load situation of the structure and areas with unusual impact. The sensors are sensitive to vibration, which is caught by sensors within the structure, in case of occurrence, which gives the pilot more information to make decisions. These sensors are embedded in the composite structures so they can detect defects and damages in areas, which are possibly difficult to reach within the structure. The electrical strain gauges remains onboard to provide redundancy, which increases the probability of faultlessness of the structure and vice versa. The electrical strain gauges require electricity, therefore could be affected by harsh weather conditions such as lightening, electrical malfunctions etc. but the FBG sensors are passive to harsh conditions and can still provide information on the structure regardless of the situation.

Methodical instructions

The frequency of maintenance T_0 can be determined from the condition of achieving the maximum value of the operational readiness coefficient of $K_{ОГ}$ [32]

$$K_{ОГ} = P(T_0)K_Г . \qquad (3.9)$$

In accordance to exponential law of distribution for operating time to failure and restoring time we derived the following formula (3.9-3.12) [33];

$$P(T_0) = e^{-\frac{T_0}{T_{cp}}};$$
$$K_Г = \frac{T_{cp}}{T_{cp} + T_в}, \qquad (3.10)$$

Where T_0 – optimal frequency of maintenance;

T_{cp} – average operating time to failure;

$T_в$ – average time of restoring.

If we designate the number of maintenance procedures with a frequency T_0 for the period between product failures by Z, then we can write down:

$$T_{cp} + T_в = zT_0;$$
$$T_0 = \frac{T_{cp} + T_в}{Z}. \qquad (3.11)$$

Substituting in expression (3.11), we get

$$P(T_0) = e^{-\frac{T_{cp} + T_в}{ZT_{cp}}} . \qquad (3.12)$$

During maintenance of the product with a frequency of T_0 the restoring time will be $ZT_в$. By substituting this value into the formula for determining the readiness coefficient [34], we obtain:

$$K_Г = \frac{T_{ср}}{T_{ср} + ZT_в}. \quad \text{......................................} \quad (3.13)$$

Where Z - number of maintenance procedures with a frequency T_O for the period between failures.

Designating $\frac{T_в}{T_{ср}} = a$ and substituting into (3.13) expression [34], we get:

$$K_{ОГ} = e^{-\frac{1+a}{Z}} \frac{1}{1 + aZ}. \quad \text{........................} \quad (3.14)$$

As can be seen from the expression above, the operational readiness coefficient is a function of one variable Z. The optimal maintenance frequency will correspond to the maximum value $K_{0Г}$.

The optimal value of Z_0, at which $K_{0Г}$ has the maximum value, is determined from the expression:

$$Z_0 = \frac{1+a}{2}\left[1 + \sqrt{1 + \frac{4}{a(1+a)}}\right]. \quad \text{........................} \quad (3.15)$$

And the value of the optimal maintenance frequency of system [35]

$$T_0 = \frac{T_{ср} + T_в}{Z_0}. \quad \text{......................................} \quad (3.16)$$

Operational readiness coefficient $K_{ОГ}$ is a function of restoring time $T_в$ and depends on the number of aviation personnel involved in maintenance of the system, the means of mechanization used and methods for monitoring the technical condition of products, the organization of specialists work in the crew and the quality of their work, the losses of working time by specialists during aircraft maintenance.

The coefficient of loss working time depending on the number of specialists working together with one object is presented in Table 3.1

Table 3.1– Coefficient of lost working time K_1

Number of crew members	1	2	3	4	5	6	7

Loss working time coefficient K_1	0,10	0,2	0,28	0,35	0,40	0,44	0,47

Time for restoration of system serviceable condition [35] $T_в$ is:

$$T_в = \frac{T_{тр}}{(1-K_1)\cdot n} \quad \text{.................................}(3.17)$$

Where $T_{тр}$ – laboriousness of the work for the system maintenance (man-hours);

K_1 – Loss working time coefficient;

n – Number of crew members.

Table 3.2 - Calculation results

Number of crew members	$T_в$	a	Z_0	T_0
1	44.4	0.00555	13.98	575.4
2	25	0.00313	18.43	435.4
3	18.52	0.0023	21.38	375.05
4	15.385	0.0019	23.47	341.5

The graph showing the relationship between $T_в$=f(n), T_0=f(n) is represented below;

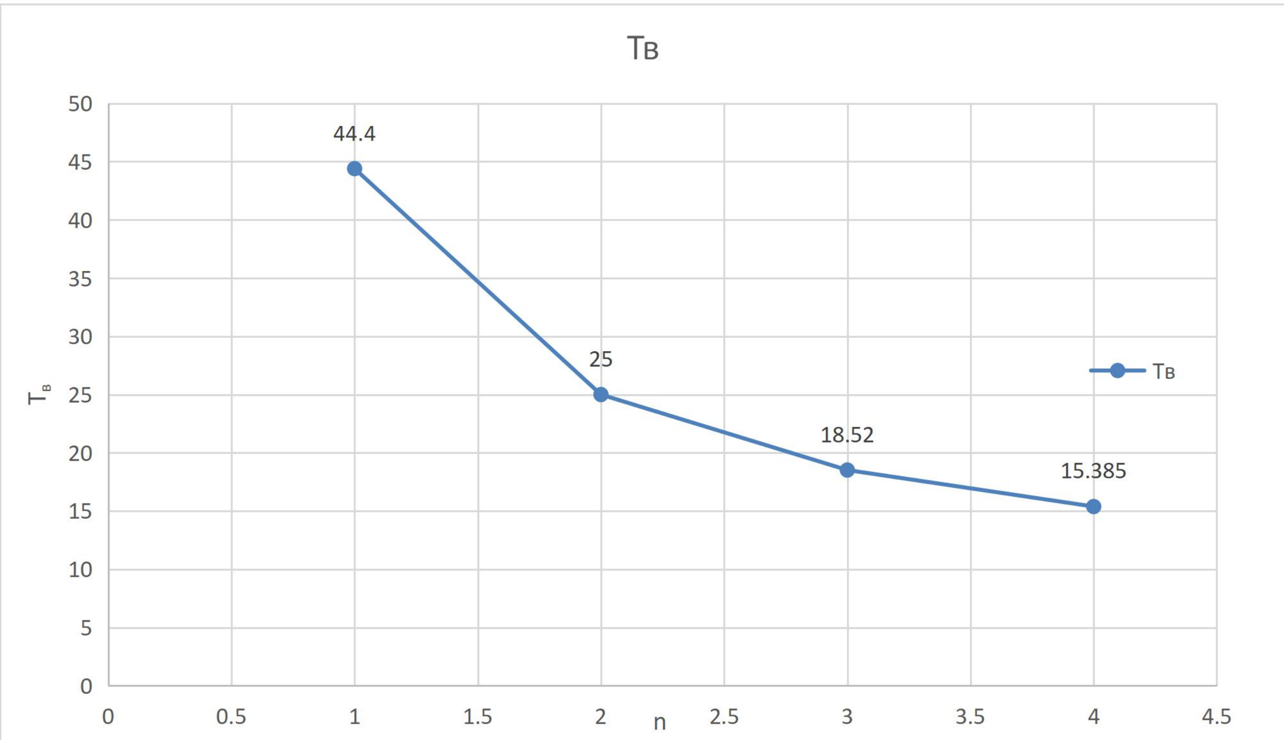


Figure 3.37 - Graph showing the relationship Тв=f(n)

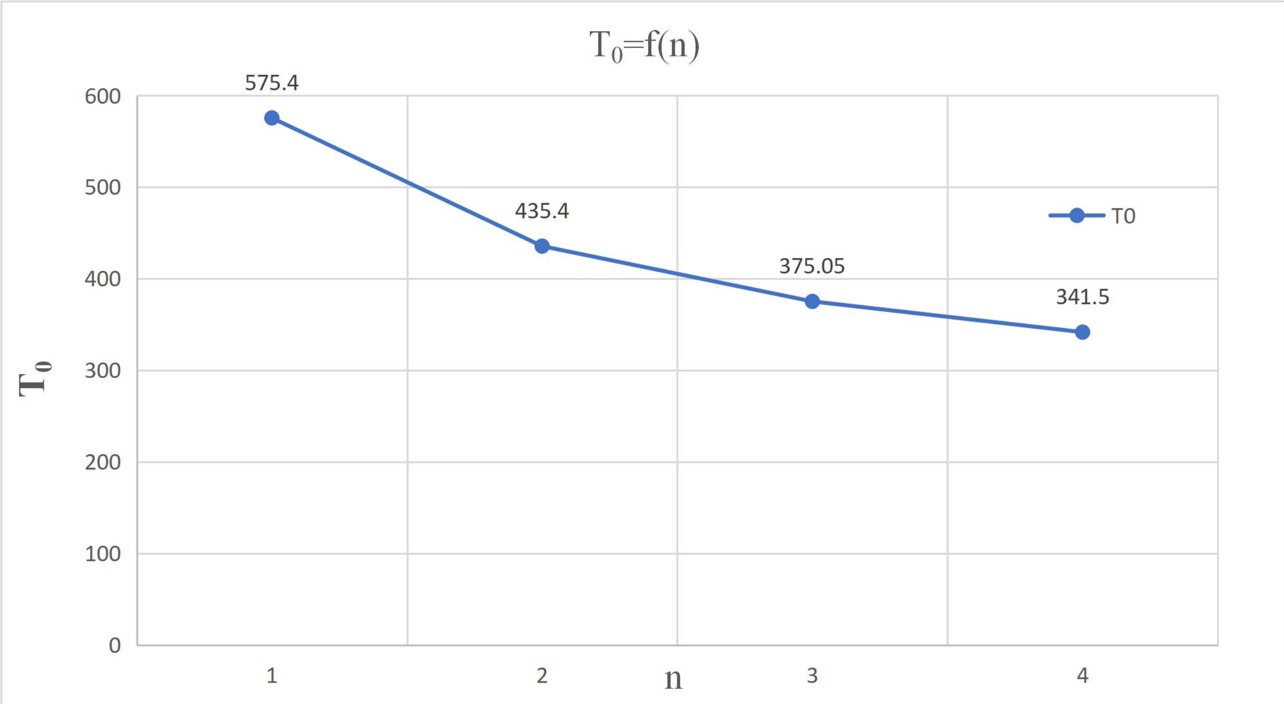


Figure 3.38 - Graph showing the relationship T0=f(n)

Conclusion to part 3

In this section we considered the reasons for introduction of SHM in improvement of fuselage structural maintenance, the influence it has and compatibility with humans. As a result calculating the optimal frequency of maintenance with time used in restoration of system, we can summarise that the frequency of maintenance reduces as workers are increased which is being influenced by the number of scheduled maintenance.

PART 4
ENVIRONMENTAL PROTECTION

4.1 Effects of composite fuselage construction on the environment

Composite materials are known for their superior strength and stiffness, which is what makes it a highly favored material for the construction of the fuselage structure. However, these characteristics are often compromised by their uncertainty under impact and cyclic loading. They are also compromised by several environmental factors like water vapor or other corrosive environment, temperature changes, water vapor, exposure to water and change in long term physical and chemical stability.

However, with more research and studies, better understanding and of composite structures and manufacturing procedures has been achieved. This has brought a better knowledge of composite structures and how they can be constructed to reduce their flaws. Taking into consideration the rapid increase in production of fuselage with a higher percentage of composite materials, it is important to determine and analyze the effects it would have on the environment.

Using the United States as a reference point, the total number of commercial aircrafts as of 2019 was 7628 aircrafts. Considering more than half of those aircraft will be replaced by newer aircrafts made of composites in the next 5-10 years, the new aircrafts produced will have a massive effect on the environment given the mass production increasing the importance of live cycle analysis of composites and necessary steps to take to reduce environmental pollution.

4.2 Life cycle analysis of composite materials used in aircraft

Composite materials are widely used in the aircraft manufacturing industry for replacement of Aluminum for better general performance. For example, the A350 uses 52 % while B787 uses 50 % of CFRP. It is important to take into account that the selection of composite is an early stage of a long line of procedure where it has to be tested on several criteria before it is certified as a structural material. As much as composite materials are beneficial to the performance of the aircraft and financial aspect, it is important to determine how these materials affect the environment.

LCA of Carbon polymers also known as life cycle assessment is a method, which is used to evaluate the impact of carbon polymers as we are considering on the environmental state taking into account the various points of their service life from when they were manufactured (extracted) to point they are disposed or recycled to be used again. The main two types of polymers of composite materials used in the aeronautical sector for designing high-performance structures are thermoplastic and thermoset composites. The thermosetting composites which usually consist of Carbon Fibre reinforced epoxy is used due to their high strength, low viscosity, low temperature for processing and their strong adhesion to fibres. Nevertheless, considering the negative impact of this material on the environment by its long curing cycles and questions raised about the end of life treatments, attention has been turned to determine a different solution. New policies have been put in place to protect the environment, which has led to a reduction in the production of Carbon Fibre reinforced epoxy to reduce environmental impact.

Thermoplastic has a less compact configuration compared to thermosetting composites, which allows it to melt when reheated, cooled forming a new shape. This allows for the use of faster processing techniques for composite materials as well as minimum processing time. Thermoplastic composite materials are preferred due to their very long shelf life, ability to withstand impact, resist chemicals and combine with other substructure materials through welding. They have a massive impact on the environment, as they require significantly high temperatures and pressures for processing, which leads to an increment in the energy consumption based on the amount of voltage used. The process is quite automated and expensive to get the tools required for this procedure. Also taking into consideration the constant deterioration of the materials mechanical properties during recycling it is difficult to take advantage of recyclability.

Using the LCA method, [36] developed a model to track the carbon emission of the twin star helicopter, which was the object of investigation. The helicopter used composite materials for its structural components to track the footprint of carbon emissions. Therefore the stages that were taken into account was the production of the carbon Fibre, epoxy, polyetheretherketone production process, manufacturing methods which include resin transfer moulding, autoclave, cold diaphragm forming. The recycling was also taking into account and the methods used to recycle the materials to determine their recyclability and environmental impact.

When considering the LCA of composite materials it is necessary to analyze them based on four groups;

1) Goal and scope definition

2) Inventory analysis

3) Impact assessment

4) Interpretation

Considering polymer used for composite material matrix, epoxy resin is commonly used in several industries specifically in the structural components of the aircraft. This has led to the widespread application of tougher epoxy. However, it is important to note that due to their limited temperature they are restricted in areas of application. This makes it impractical for them to be used in high-performance structures as they begin to deteriorate at a given temperature, which causes the material to lose its structural integrity due to loading, toughening agents and moisture. The limit temperature for advanced epoxy resins ranges from 150 degrees to 180 degrees Celsius. Epoxy resins are brittle, which is another problem associated with their use in aircraft structures as well as moisture absorption. However, epoxy resins have good attractive features and good processing ability and handling properties, which makes them favorable in other areas.

PEEK, which means PloyEtherEtherKetone was also taken into consideration during the research as they are commonly used for the matrix of Thermoplastic prepreg, which is made up of carbon fibres and is the most widely, used Thermoplastic resin used in the construction of Aeronautical structural components. They have the mechanical strength to withstand a repeated operating temperature of 260 degrees in low-stress areas and 120 degrees in high-performance structures like the A/C. PEEK has good resistance to hydrolysis, which is their ability to resist water absorption that can potentially destroy the material and reduce the operating temperature they are capable of withstanding. They are resistant to corrosion, radiation and chemical exposure. Considering their environmental effect, they can be recycled and this has a significant effect on the environment because it reduces the waste product that affects humans, aquatic lives and the environment. The use of PEEK ensures the material has a good coefficient of expansion and thermally stable.

The model for analysis used epoxy (Bisphenol) resins for Thermosetting and PEEK for Thermoplastic reinforced with carbon fibers to tract the environmental impact. Three processes used were autoclave, RTM and CDF. Autoclave and RTM are the most commonly used processes for aeronautical parts due to their controlled quality to suit aeronautical standards and CDF is a cheap process with promising signs. Autoclave and RTM were used for thermosetting and thermoplastic composites while CDF was used for only thermoplastic composites as it cannot break thermosetting matrixes. This process was used to compare recyclable material made of PEEK reinforced with carbon fiber against a non-recyclable material made of epoxy reinforced with carbon fiber.

All three processes required electricity to carry out the procedure and the product of electricity is the discharge of carbon to the atmosphere shown in figure 4.1 and taking into account that the processing temperature for PEEK is almost three times that of epoxy, its energy requirement for manufacturing will be three times that of epoxy . For recycling of the composite pyrolysis was used for the situations that involved thermosetting composites while mechanical recycling was used for both Thermosetting and Thermoplastic composites.

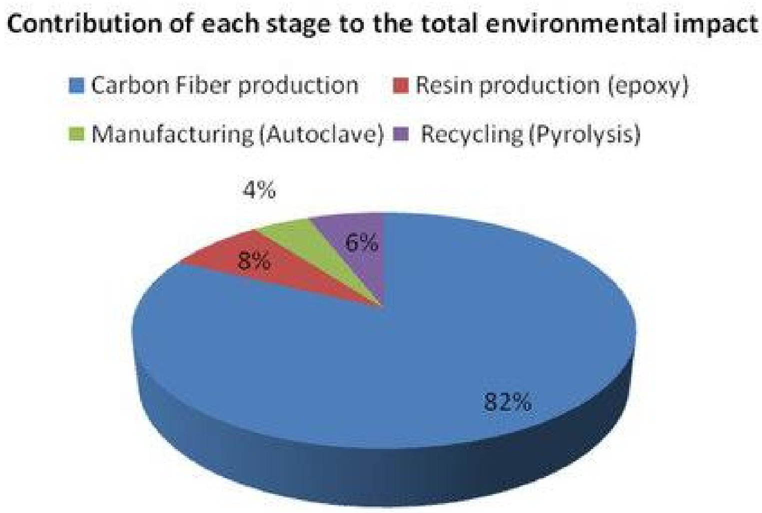


Figure 4.39 - Distribution of carbon footprint for composite life cycle [36]

The result of this analysis indicated that the production of Carbon fiber guarantees over 80 % of the carbon footprint. Since production is responsible for 80 % of the carbon print, reduction in the production of carbon fibres will reduce these values significantly by switching focus to recycling and new ways to recycle these materials. Production of thermosetting composites using epoxy resins with reinforced carbon fiber and RTM process for manufacturing and mechanical recycling registered the lowest carbon print. On the other hand, the production of thermoplastic composites using PEEK reinforced with carbon fiber and autoclave process for manufacturing registered the worst carbon print due to the high temperature for processing PEEK. The environmental impact can be reduced by using the RTM or CDF processes for manufacturing but not enough for a lower lifecycle carbon impact.

4.3 Influence of composites on carbon emissions in aviation

As discussed in section 4.1, using the United States as a point of reference the total number of commercial flights as of 2019 was 7628 aircrafts. While the number of flights in a year was 1.0 billion flights as of 2018 by the United States FAA air traffic organization (ATO). These is a mass sample size which releases a large amount of carbon into the atmosphere yearly.

In a year, it has been noted that about a billion passengers are transported around the world and this number is bound to keep on increasing as time goes on. According to Airbus, the number of flights in the Middle Eastern region is going to increase by two times in 10 years and within the next 14 to 15 years; about 2365 new commercial aircraft will be introduced to the sky.

As much as this growth would be beneficial financially and economically, it would have a massive effect on the environment because the carbon emission rate would double relatively as a result of this increase in aircraft moving from one region to the other. It was estimated based on research that as at present the aircraft carbon emission is responsible for 2.5 % of the total carbon emission and has the potential to rise to 22 % while other causes reduce due to technological advancements such as replacing fuel with the electrical and solar panel in both households and automobiles. The Intercontinental panel on climate change, which is a renowned body in the United States stated, based on research analysis stated that air travels is responsible for 4.9 % of climatic changes caused by humans. A vast degree of research project have been conducted and billions of dollars has been dedicated towards ideas to come up with measures to reduce fuel consumption, which will also reduce environmental pollution.

A brief indication of the level of toxicity the environment is subject to because the end product of fuel combustion is a flight from somewhere in Europe to Australia will result in a Carbon monoxide emission of about 4.5 tonnes. If a car was to be driven for about 2000 plus km it still would not burn that amount of Carbon. One of the main reasons why the aircraft consumes a far larger amount of fuel is simply down to its weight, which requires more fuel to be burnt to generate the necessary lift for the A/C.

However, with the increase of composite consumption for construction of aircraft structural unit specifically the fuselage in our research, which is backed by embedded sensors for proper maintenance and reliability, there will be massive drop in the amount of carbon released into the atmosphere. The research studies estimated a decrease in weight of about 25 to 40 % using higher percentage of composites in aircraft structures when compared to aluminum aircraft structures.

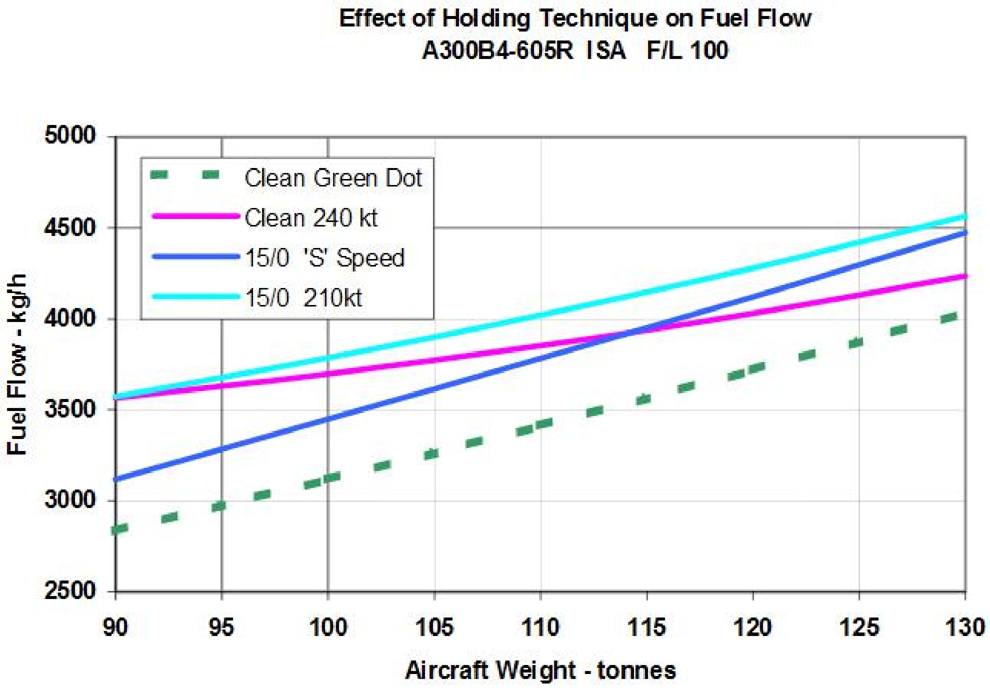


Figure 4.40 - Relationship between A/C fuel consumption and weight [37]

Using the correlation between weight and fuel consumption, we can estimate that it would substantially reduce the carbon emissions due to reduction in the quantity of burnt fuel during the course of flight.

4.4 Recycling of composite structures

Composite manufacturing industries also produce a large amount of carbon as a result of the manufacturing process of various composite structures as well as breaking down out of service composites.

New Studies have shown that several methods can be used to recycle Fiberglass materials. Methods like

1) Incineration
2) Pyrolysis
3) Grinding

Figure 4.41 - Commercial scale environmental friendly recycling machine in UK [38]

In Germany, a breakthrough has been reached for the recycling of composite materials. The finished CFRP is fed into the machine where decomposition of the material done by pyrolysis. The pyrolysis structure is shown in figure 4.3 below. The composite material is heated to a temperature of 500 degrees Celsius in the absence of oxygen causing evaporation of smaller particles. The gases released from this process is used to power the machines if the process remains stable making it an environmentally friendly process with minimum energy consumption. There are gas cleaners on standby to purify the gases to suit environmental regulations. After this process, a pure carbon Fibre is achieved which is combined with polyamide granulate in different cylinders to producing new alternative components.

Conclusion to part 4

Air Transit Action Group (ATAG) released a statistic [39] breaking down the numerical values of air transportation and aircraft fuel consumption on the environment. Approximately 895 million tonnes of carbon was released to the atmosphere by aircraft compared to 42 billion tonnes released by humans. Aviation is responsible for 12 % of carbon emission compared to other means of transportation, which is 2 % globally from the aviation industry. This was due to the transportation of 4.4 billion passengers worldwide in 2018.

These values are not alarming compared to other sources of carbon to the environment but with the increase of composite materials for structural components, it will further reduce these values and improve fuel efficiency by a significant percentage.

However, the production and destruction of out of service composites structures considering their mass accounts for a high carbon emission but necessary measures are being used to reduce carbon emissions by recycling of composite materials. Also gases released during production processes are filtered to prevent air contamination.

The continuous usage of composites for aircraft structures depends of the effectiveness of maintenance and with the availability of these new technologies for SHM of the structures to enhance reliability and predictability of the structure , there will be continuous growth in composites for structural components, which is more environmental friendly compared to conventional materials.

PART 5
LABOR PROTECTION

5.1 Analysis of harmful and dangerous production factors

The production process of composite materials is important to analyze because these systems are embedded into the fuselage composite structures during manufacturing. The production process of composite is slightly toxic for laborers considering the processes involved and state of the air due to the release of several gases during production.

Methods like Resin Transfer Moulding (RTM) and Pultrusion methods has been integrated by Airbus [40] in the development of Advanced Composite Technology program for manufacturing high performance aircraft structural components. These methods are highly automated and require less human input, unlike other processes, used in the manufacturing of smaller structures, requiring higher human input.

Figure 5.1 - Aircraft composite production workspace

However, after the fabrication process, it is necessary for the next stage of production to occur, which is curing of the fibrous composite structure. The state of the workplace is highly critical to the degree of productivity achieved as it influences the level of worker performance. Production of composite structures with embedded sensors is naturally a toxic environment taking into account the high temperature and pressure required for curing the mixture, the resins and other chemicals inhaled by the workers and by product of curing stage. Due to the increase in automated procedures, the amount of time the workers are exposed to this environment is further reduced thereby minimizing the risk of health impact.

Using the composite manufacturing company for Boeing Commercial Airplanes in Canada, which is the largest composite manufacturing facility in the country, it has nearly 1600 workers operating in the facility, and a massive 800 000 square ft. of production space [41]. This space is where all production processes are carried out, which requires strict regulations to ensure safety.

This workspace consists of all required machines to carry out fabrication processes depending on the chosen techniques. These equipment's are Prepreg production unit, Autoclave, Hot presses, Resin Transfer Moulding equipment, Two component low pressure injection equipment, Drumwinder, Fontjine press, Haco press. The curing unit for heating and pressurization of the mixture at high temperature and pressure values, chemicals required to complete the process like resins (epoxy, PEEK, coating gel etc.) used for wetting the fibres [42].

The harmful and dangerous production factors that are met in composite manufacturing industries according to the standard ГОСТ 12.0.003-74 are:

5.1.1 Increased dustiness and gassiness of air of a working zone (physical factor)

When using manual production techniques like the hand layup method for precise finishes, the surface finishing releases dust particles into the working atmosphere which results in dustiness. Gassiness comes as a result of the mixture of the harmful gases released during the production process. From material science, thermoplastic composite made with PEEK resin requires a high temperature for processing and evaporation of resin pollutes the air at the workplace thereby increasing the toxicity level.

5.1.2 Increased or decreased temperature of equipments (physical factor)

During production, highly automated machines are used to carry out certain manufacturing processes and they operate at a very high temperature which can be inconvenient for workers of exposed to for a specific period of time.

5.1.3 Increased or decreased temperature of the working area (physical factor)

This comes as a result of the high temperatures of machines used in the work place.

5.1.4 Nature of impact on the body on toxicity (chemical factor)

The production process of composite structures results in the release of toxic gases mainly carbon, which is toxic for humans if exposed to them for a given period of time.

5.1.5 By penetrating into the human body through sense organs (chemical factor)

The dust particles and gases released into the atmosphere affects workers if they are inhaled during production. Therefore, it is necessary to take precise steps to ensure they are not taken into the body. When working with organic, volatile substances exposure through inhalation is relevant at all times. Areas of the skin or eyes exposed during production is at a high risk of absorption whenever toxic substances are involved and eating in such areas can cause ingestion of harmful substance. When dealing with fibres specifically impregnated fibres, which are sharp and capable of penetrating the skin, there is the risk of exposure in form of injection. This risk can be avoided or kept in check when certain measures are made and followed to prevent accidents and incidents.

5.2. Measures to reduce the impact of harmful and dangerous production factors

Necessary steps taken by aircraft composite manufacturing industries to protect the health and safety of workers as well as prevent possible workplace accidents from occurring include:

5.2.1 Improvement in workplace ventilation

Proper ventilation is important in any workplace for workers to maintain a good working environment especially in situations where a certain percentage of the air inhaled will be toxic for the working personnel. Accumulation of the gases in large facilities where numerous production processes are going on at the same time, the working environment is toxic for personnel. However, better ventilation improves the quality of air available within the environment for working. The gases released form the facility to the environment in cases of large facilities has the possibility to exceed the regulated value as set by the government to meet this value the air need to be filtered within the facility before it is released into the environment. This helps the facility to be in correspondence with the government set values making the environment and atmosphere safe of harmful factors.

In Germany, a modern composite facility has been developed and set to continuously purify the air from the machines used for recycling of composite structures for re-production to prevent exceeding the environmental emission limit set by Governmental agencies.

Automated methods like pultrusion and filament winding, where there is evaporation at the impregnation stage and exposed surface of the composite. These evaporated gases accumulate within the workplace. However, this can be solved by the enclosure of these machines and directing the gases out of the facility by temperature resistance pipes to a filtering facility where the gases are filtered to promote a healthy atmosphere.

Dust particles are also constituents of the air because of the end-product of the production process. Composite structures are usually filed to achieve the right surface roughness and shape during the production process hence increasing the level of dust particles in the air. This can have a potential health impact on certain workers, which is an important factor. It is important to have an adequate procedure to extract the dust particles from the atmosphere to enable better ventilation within the facility as these particles can spread wide if not properly filtered and affect the workers.

5.2.2 Constant rotation of workers in the workplace

During production process, several measures are taken into account to reduce the effects of the workplace toxic emissions and factors on the environment. However, it is important to understand that despite steps taken to reduce the impact on workers' health, a certain amount of these factors still affects the workers' health, which can affect the level of productivity and create room for little errors during the manufacturing process mainly in cases where the production is controlled by the workers' and not automated. The production techniques like wet layup, which could be Hand controlled or Sprayed, the personnel have their heads lowered close to the fabrication process. The use of mask for eye and skin protection reduces the risk of exposure by injection and contact but despite the use of nose mask, inhalation of little volume of the concentration of this process for longer period can have a massive effect in the long-run. This is also dependent on the level of ventilation available within the facility, which determines the level of effect it has on the workers.

5.2.3 Use of appropriate facial covers

When working within the workplace, the use of appropriate face masks and covers would prevent the inhalation of toxic gases and dust in the atmosphere, thereby playing a vital role in the prevention of respiratory diseases linked to the workplace.

5.2.4 Adequate lightening

The provision of necessary lighting is important within the workplace because it gives just the required level of brightness for vision to carry out production procedures during they day and night period. Without affecting the sights of workers and preventing workplace accidents due to dark areas.

Determination of Artificial Lighting values

According to Flight Aviation Centre, the area of Boeings Factory in Everett is 28000 square feet and the manufacturing facility uses fluorescent lights. The emission in lumens of these lights are 800 lm per fluorescent. We estimate the required lumens to be 800799.225 lm, while the light type has 800 lm/fluorescent. Therefore, the required number of fluorescent lights will be over 1001000 lights. Direct replacement of this fluorescent lights with LED T8 tubes due to their superior properties such as

1) Requires less maintenance
2) Longer service-life of over 70000 hours.
3) Excellent compatibility with existing ballast.

$$lumens = lux \cdot area \tag{5.1}$$

According to formula 5.1 [43], we estimate the lux to be lux required and from the previous calculation, we determined that we need 1001000 tubes. Hence, the total lumens is $1.3 \cdot 10^9$ which makes the lux 152323 lux (14151.27 foot-candle).

The cost of one T8 LED tube is approximately 459 UAH and considering we need 1001000 tubes, the total cost of light for this maintenance facility will be 459 000 000 UAH. The power required by one is $13 \cdot 10^6$ W making the total power consumption for the 28000 square feet facility W.

5.3 Occupational safety instructions

5.3.1 General safety requirements

1) The should be safety guidelines listed and enforced at the working place

2) Only individual above the age of 18 that have completed the necessary training, medical exams, induction instructions, initial instructions and trained in safe working methods are allowed to operate highly automated machines.

3) Slippery floors must be attended to either on demand or personally.

4) In situations of physical, mental or emotional discomfort it is necessary to stop work and seek medical attention.

5.3.2 Safety requirements before starting work

1) Workers must be properly dressed and covered before commencing work protocols.

2) The necessary tools and machines required for operation must be clean and ready before starting work.

3) Check the list of materials required and ensure the availability of every indicated item.

4) Check the machines for lubrication

5) Ensure the lighting is up to the recommended values issued by government safety agencies.

5.3.3 Safety requirements during operation

1) Only remove parts from machines after they have been switched off.

2) On case of temporary suspension of work it is important to switch off tools and machines.

3) If abnormal sounds are heard during operations, the machine should be turned off and booked for repairs.

4) There shouldn't be any cleaning of machines or workplace during operation hours only after.

5) Workers should ensure to distance themselves from high temperature machines during operation and wear recommended gloves and googles.

5.3.4 Safety requirements after work

1) Ensure the machines and tools are cleaned after work

2) Ensure they are also switched off

3) Overalls and protection gears should be removed and placed in closet and the ones that require washing should be sent for washing.

4) Clean up the workplace

5) Clean and wash your hands and face after work completion

5.3.5 Safety requirements at emergency situations

1) Stop operations of machines with indications of faults until malfunctions have been rectified.

2) In cases of fire outbreak, kindly notify the fire safety department with quick evacuation of the building.

3) In case of accidents, gently grant first aid treatment while calls for medical assistance is made to the medical department.

Conclusion to part 5

In this section, we considered the ways SHM systems affects the workers and how the production of composite aircraft fuselage influences the workers productivity. It is important for necessary measures to be taken to ensure the safety of workers.

Based on research statistics, about 80% of accidents and incidents are down to human errors spreading through pilot, maintenance and manufacturing flaws. With the introduction of automated facilities for the production of composite structures and SHM technologies, the burden is reduced on the laborers. This reduces the possibility of mistakes that could lead to problems, which increases the efficiency of production and maintenance.

GENERAL CONCLUSION

In this research work, we considered briefly the main purpose of the fuselage and its vital role to the aircraft. The main materials used for construction and the changes in structural materials moving forward according to modern aircraft manufacturing industries due to extensive studies of materials and better knowledge and understanding of material behavior in certain situations.

Composite materials were considered primarily because according to research statistics majority of the aircraft fuselage mainly in commercial aircraft moving forward will be made of composites. This is due to the major advantages they have and how strong they are compared to their weight.

As considered in part 2, we analyzed the short comings of conventional nondestructive diagnostics methods in the inspection of composite structures due to their structural makeup. This led us to the introduction of SHM for the real time monitoring of the situations occurring around the aircraft fuselage during flight. These sensors helps improve the quality of maintenance as it provides us with real time data for comparison and analysis during maintenance.

The increase in the production of fuselage composite tends to increase the carbon footprint of the atmosphere but with protocols put in place by manufacturing facilities and modern structures installed to help with the recycling of out of service composites.

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