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Design and Analysis of Passenger Aircraft Wing box

P. C. Vijayan[1]
Assistant Professor,
Department of Mechanical Engineering ,
Mailam Engineering College,
Mailam, Villupuram District, Tamilnadu[1] .

S. Durairaj[2], J. P. Sooriya Prakash[3], T. Ajith[4]
UG Scholar,
Department of Mechanical Engineering ,
Mailam Engineering College, Mailam,
Villupuram District, Tamilnadu[2,3,4].

***Abstract*— On the aspect of environmental impact today aviation industry is facing many challenges. By the design simplification the structural components made up of composite materials are used to reduce weight. For fuel consumption, drag reduction morphing wing structures are required for significant changes. In order to pave a way to smooth efficient fly mode in aviation, improvisation is made at each stage since from the past. In this paper an attempt was made which is structural analysis of morphing wing using composite material. We have done an approach for designing the wing of a passenger aircraft with feasibility of wing box set up using wing profile. From the airfoil profiles the wings where manipulated and drawn using modeling software CATIA-V5.Ribs and spars are coincide with drawn wing geometry using modeling software CATIA V5 and analysis is made with help of Finite Element Analysis method using ANSYS over ribs and spar of respective wing with boundary conditions taking load at different point of flight sortie. Later composite set up analysis is merely made and final result is compared along with aluminum and result are finally analyzed and discussed.**

Index Terms*—Morphed, fabric wing, optimization, loads, stress, lift force.

I. INTRODUCTION

In a fixed-wing aircraft, the spar is often the main structural member of the wing, running span wise at right angles (or thereabouts depending on wing sweep) to the fuselage. The spar carries flight loads and the weight of the wings while on the ground. Other structural and forming members such as ribs may be attached to the spar or spars, with stressed skin construction also sharing the loads where it is used. There may be more than one spar in a wing or none at all. However, where a single spar carries the majority of the forces on it, it is known as the main spar. Spars are also used in other aircraft aerofoil surfaces such as the tail plane and fin and serve a similar function, although the loads transmitted may be different to those of a wing spar. In sailing, a spar is a pole of wood, metal or lightweight materials such as carbon fiber used on a sailing vessel. Spars of all types (e.g. booms and masts) are used in the rigging of sailing vessels to provide (direct or indirect) support for the sails. Wooden ships from the age of sail often carried many extra spars of all types for repairs while at sea. The spar deck of a frigate was so named because it was used to carry spare spars [1]. Wing construction is basically common in all types of aircrafts. Most of the modern aircraft have metal wings, but many older aircraft had wood and fabric wings. To maintain its all-important aerodynamic shape, a wing must be designed and built to hold its shape even under extreme stress. Basically, the wing is a framework composed chiefly of spars, ribs, and (possibly) stringers. Spars are the main members of the wing. They extend lengthwise of the wing (crosswise of the fuselage). The entire load carried by the wing is ultimately taken by the spars. In flight, the force of the air acts against the skin. From the skin, this force is transmitted to the ribs and then to the spars [2]. Most wing structures have two spars, the front spar and the rear spar.

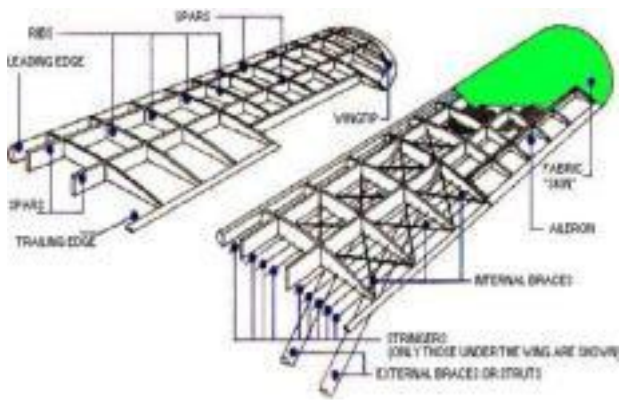

FIGURE I. WOOD AND FABRIC WING STRUCTURE

II. FORCES ON SPARS

Some of the forces acting on a wing spar are:
1. Upward bending loads resulting from the wing lift force that supports the fuselage in flight. These forces are often offset by carrying fuel in the wings or employing wing-tip-mounted fuel tanks; the Cessna 310 is an example of this design feature [3].
2. Downward bending loads while stationary on the ground due to the weight of the structure, fuel carried in the wings, and wing-mounted engines if used.
3. Drag loads dependent on airspeed and inertia.
4. Rolling inertia loads.
5. Chordwise twisting loads due to aerodynamic effects at high airspeeds often associated with washout, and the use of ailerons resulting in control reversal. Further twisting loads are induced by changes of thrust settings to

6. Underwing-mounted engines. The "D" box construction is beneficial to reduce wing twisting. Many of these loads are reversed abruptly in flight with an aircraft such as the Extra 300 when performing extreme aerobatic maneuvers; the spars of these aircraft are designed to safely withstand great load factors.

III. CARBON FIBER REINFORCED POLYMER

The Carbon-fiber-reinforced polymer, carbon-fiber reinforced plastic or carbon-fiber reinforced thermoplastic (CFRP, CRP, CFRTP or often simply carbon fiber, or even carbon), is an extremely strong and light fiber reinforced polymer which contains carbon fibers. The binding polymer is often a thermoset resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester or nylon, are sometimes used. The composite may contain other fibers, such as aramid e.g. Kevlar, Twaron, aluminum, or glass fibers, as well as carbon fiber. The properties of the final CFRP product can also be affected by the type of additives introduced to the binding matrix (the resin) [4]. The most frequent additive is silica, but other additives such as rubber and carbon nanotubes can be used. CFRPs are commonly used in the transportation industry; normally in cars, boats and trains, and in sporting goods industry for manufacture of bicycles, bicycle components, golfing equipment and fishing rods. Although carbon fiber can be relatively expensive, it has many applications in aerospace and automotive fields, such as Formula One racing[5]. The compound is also used in sailboats, rowing shells, modern bicycles, and motorcycles because of its high strength-to-weight ratio and very good rigidity. Improved manufacturing techniques are reducing the costs and time to manufacture, making it increasingly common in small consumer goods as well, such as certain Think Pads since the 600 series, tripods, fishing rods, hockey sticks, paintball equipment, archery equipment, tent poles, racquet frames, stringed instrument bodies, drum shells, golf clubs, helmets used as a paragliding accessory and pool/billiards/snooker cues [6]. The material is also referred to as graphite-reinforced polymer or graphite fiber-reinforced polymer (GFRP is less common, as it clashes with glass-(fiber) - reinforced polymer). In product advertisements, it is sometimes referred to simply as graphite fiber for short.

IV. COMPOSITE WING SPARS

Composite wing spars for large aircraft are, for all intents and purposes, new technology, having been used only twice in the past in notable but limited aircraft programs. The first instance was on Howard Hughes' plywood-airframe H-4 Hercules Flying Boat, better known as the Spruce Goose (a composite of thin wood layers and plastic resin), which was prototyped for the U.S. military during WWII, flown once, but never placed into production. The other was the B2 Spirit stealth bomber, of which only 21 were built and placed into service for the U.S. Air Force beginning in 1993. GKN Aerospace (Cowes, Isle of Wight, U.K.) recently joined this select group as it completed the design and built the first composite components for the ~18.3m/60-ft main wing spars on Toulouse, France-based aircraft manufacturer Airbus Industries' A400M military transport aircraft [7]. The A400M was conceived as a larger-sized replacement for aging C- 130 Hercules and C-160 Transail military transport fleets maintained in Europe. Airbus has, thus far, fielded 192 orders for the airlifter, which is scheduled for first flight in mid-2007, with entry into service in 2009. "Softfield" capable, the A400M is designed to take off and land on short (<1,150m/3,773 ft), unpaved runways powered by four of the Western world's most powerful turboprop engines. Each of the A400M spars must carry all the normal flight loads for the aircraft and highly concentrated loads from the two flaps, ailerons and four spoilers [8]. The front spars, however must carry the engine loads like major design driver in wing spar development. The engines drive the aircraft through the propellers by means of torque, which is reacted at the attachment points on the front spar. Each engine produces over 7,500 kW or 10,000 shp (shaft horsepower) to drive eight composite propellers per engine through a speed reduction gearbox. Each of the four sets of eight propellers, made by Ratier-Figeac (Figeac, France), weighs about 250 kg/550 lb 1 metric ton per aircraft. The propellers, rotating at 850 rpm at take-off power, develop over 8,700 Nm (6,500 lb-ft) of torque. This torque is taken through the fittings bolted to the front spars. In general, spar web thicknesses are about 5 mm to 6

mm (about 0.2 inches) near the engine attachment points, but at the point of attachment of the engine mounting structure, the thickness of both the web and the caps is doubled to about 10 mm/0.4 inch. Similar increases in thickness occur in the vicinity of the root end where the spar is attached to the wing box. These local changes in thickness created a significant design challenge for both the structural and manufacturing engineers on the A400M program.

V. APPLICATION OF CARBON EPOXY IN AEROSPACE ENGINEERING

The Airbus A350 is built of 53% CFRP including wing and fuselage components, the Boeing 787 Dreamliner, 50%. Specialist aircraft designer and manufacturer Scaled Composites have made extensive use of CFRP throughout their design range including the first private spacecraft Spaceship One. CFRP is widely used in micro air vehicles (MAVs) because of its high strength to weight ratio. In the MAVSTAR Project, CFRP reduces the weight of the MAV significantly and the high stiffness of the CFRP blades overcome the problem of collision between blades under strong wind. Concrete is the most common artificial composite material of all and typically consists of loose stones (aggregate) held with a matrix of cement.

Concrete is a very robust material, much more robust than cement, and will not compress or shatter even under quite a large compressive force. However, concrete cannot survive tensile loading (i.e. if stretched it will quickly break apart). Therefore to give concrete the ability to resist being stretched, steel bars, which can resist high stretching forces, are often added to concrete to form reinforced concrete.

Fibre-reinforced polymers or FRPs include carbon-fibre reinforced plastic or CFRP, and glass-reinforced plastic or GRP. If classified by matrix then there are thermoplastic composites, short fibre thermoplastics, long fibre thermoplastics or long fibre-reinforced thermoplastics. There are numerous thermoset composites, but advanced systems usually incorporate aramid fibre and carbon fibre in an epoxy resin matrix.

Shape memory polymer composites are high-performance composites, formulated using fibre or fabric reinforcement and shape memory polymer resin as the matrix. Since a shape memory polymer resin is used as the matrix, these composites have the ability to be easily manipulated into various configurations when they are heated above their activation temperatures and will exhibit high strength and stiffness at lower temperatures. They can also be reheated and reshaped repeatedly without losing their material properties. These composites are ideal for applications such as lightweight, rigid, deployable structures; rapid manufacturing; and dynamic reinforcement [9]. Composites can also use metal fibres reinforcing other metals, as in metal matrix composite (MMC) or ceramic matrix (CMC), which includes bone (hydroxyapatite reinforced with collagen fibres), cermet (ceramic and metal) and concrete. Ceramic matrix composites are built primarily for fracture toughness, not for strength. Organic matrix/ceramic aggregate composites include asphalt concrete, mastic asphalt, mastic roller hybrid, dental composite, syntactic foam and mother of pearl.

Chobham armour is a special type of composite armour used in military applications. Additionally, thermoplastic composite materials can be formulated with specific metal powders resulting in materials with a density range from 2 g/cm^3 to 11 g/cm^3 (same density as lead). The most common name for this type of material is "high gravity compound" (HGC), although "lead replacement" is also used. These materials can be used in place of traditional materials such as aluminium, stainless steel, brass, bronze, copper, lead, and even tungsten in weighting, balancing (for example, modifying the centre of gravity of a tennis racquet), vibration damping, and radiation shielding applications. High density composites are an economically viable option when certain materials are deemed hazardous and are banned (such as lead) or when secondary operations cost (such as machining, finishing, or coating) are a factor.

VI. RESINS

Typically, most common polymer-based composite materials, including fiberglass, carbon fiber, and Kevlar, include at least two parts, the substrate and the resin.

Polyester resin tends to have yellowish tint, and is suitable for most backyard projects. Its weaknesses are that it is UV sensitive and can tend to degrade over time, and thus generally is also coated to help preserve it [10]. It is often used in the making of surfboards and for marine applications. Its hardener is peroxide, often MEKP (methyl ethyl ketone peroxide). When the peroxide is mixed with the resin, it decomposes to generate free radicals, which initiate the curing reaction. Hardeners in these systems are commonly called catalysts, but since they do not re-appear unchanged at the end of the reaction, they do not fit the strictest chemical definition of a catalyst.

Vinyl ester resin tends to have a purplish to bluish to greenish tint. This resin has lower viscosity than polyester resin, and is more transparent. This resin is often billed as being fuel resistant, but will melt in contact with gasoline. This resin tends to be more resistant over time to degradation than polyester resin, and is more flexible. It uses the same hardeners as polyester resin (at a similar mix ratio) and the cost is approximately the same. Epoxy resin is almost totally transparent when cured. In the aerospace industry, epoxy is used as a structural matrix material or as structural glue [11].

Shape memory polymer (SMP) resins have varying visual characteristics depending on their formulation. These resins may be epoxy-based, which can be used for auto body and outdoor equipment repairs; cyanate-ester-based, which are used in space applications; and acrylate-based, which can be used in very cold temperature applications, such as for sensors that indicate whether perishable goods have warmed above a certain maximum temperature. These resins are unique in that their shape can be repeatedly changed by heating above their glass transition temperature (Tg). When heated, they become flexible and elastic, allowing for easy configuration. Once they are cooled, they will maintain their new shape. The resins will return to their original shapes when they are reheated above their Tg. The advantage of shape memory polymer resins is that they can be shaped and reshaped repeatedly without losing their material properties. These resins can be used in fabricating shape memory composites.

Epoxy is the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group

[12]. Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups.

VII. MODELING OF THE WING

The ribs are the parts of a wing which support the covering and provide the airfoil shape. These ribs are called forming ribs and their primary purpose is to provide shape. Some may have an additional purpose of bearing flight stress, and these are called compression ribs. The most simple wing structures will be found on light civilian aircraft. High-stress types of military aircraft will have the most complex and strongest wing structure.

S. no	Specification Area	Dimensions(m)
1.	Wing Span	60.3
2.	Length	59.39
3.	Height	16.74
4.	Wing Area	363.12

TABLE I. SPECIFICATION OF THE WING PARAMETERS

For the modeling purpose and in order to get the accurate results when importing to the analysis part, the structural part of wing is divided into solid and surface sections [10]. Modeling of the wing normally is done using CAD packages which can be easily ported to the analysis packages.

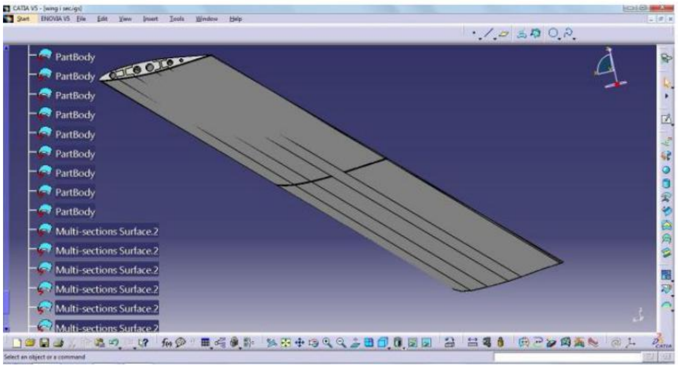

FIGURE II. WING STRUCTURE

VIII. ANALYSIS OF THE WING BOX

The software used for the analysis of wing structure of transport class aircraft with spar and ribs is ANSYS V12.The ANSYS program is capable of analyzing problems in a wide range of engineering disciplines. However, this project focuses only on the following disciplines of analysis.
Static Structural Analysis

TABLE II MATERIAL PROPERTIES OF ALUMINUM ALLOY

Property	Value	Unit
Density	2.77	g cm^{-3}
Isotropic Elasticity		
Young Modulus	71000	Mpa
Poisson Ratio	0.33	
Strength		
Tensile Yield Strength	280	Mpa
Tensile Ultimate Strength	310	Mpa

A. Meshing and applying Boundary Conditions

In the FEM analysis of high pressure turbine rotor blade meshing is the initial step that is to be followed after the model is being imported for the purpose of analysis. Meshing is the process that divides the model into finite number of elements for the analysis .In general, a large number of elements provide a better approximation of the solution. However, in some cases, an excessive number of elements may increase the round-off error. Therefore, it is important that the mesh is adequately fine or coarse in the appropriate regions. An analysis with an initial mesh is performed first and then reanalyzed by using twice as many elements. The two solutions are compared. If the results are close to each other, the initial mesh configuration is considered to be adequate.If there are substantial differences between the two, the analysis should continue with a more-refined mesh and a subsequent comparison until convergence is established.

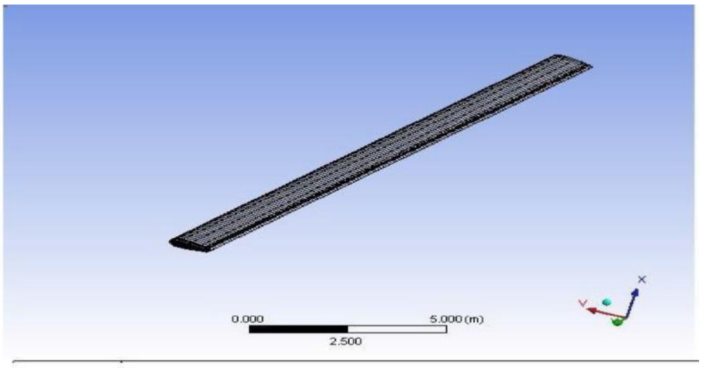

FIGURE III. MESHED MODEL OF WING STRUCTURE

After meshing the structural part of the wing, the wing is fixed at one end and other end is free. The force is applied on the top layer of the wing as shown in the Fig IV.

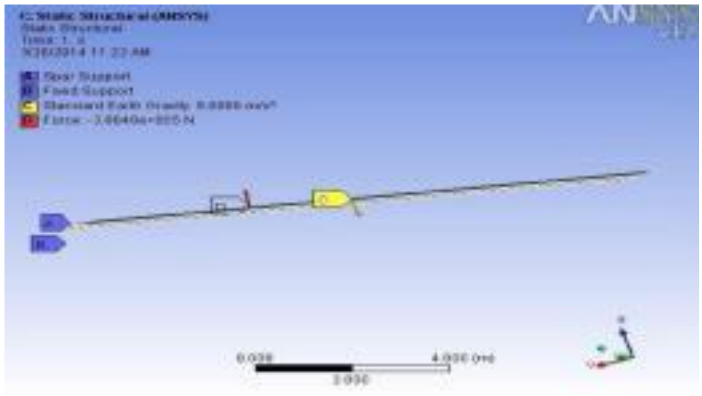

FIGURE IV. SUPPORT AND LOADING CONDITIONS

The wing box is now allowed to analysis process in ANSYS 12 and the data is to be present as a result with the difference of Aluminium alloy and Carbon Epoxy. Further the strength of the wing box is to be identified. Because the material property of both material are different.

IX. RESULTS AND DISCUSSION

A. Aluminium Alloy

The three solutions for the aircraft wing section. In which each analysis should be carrying the three loads. The name of the three analysis are given below

Equivalent Stress (Von Misses
Stress) Normal Stress
Total Deformation

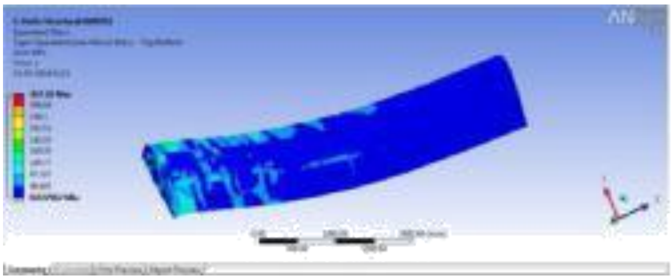

FIGURE V. EQUIVALENT STRESS OF THE WING BOX

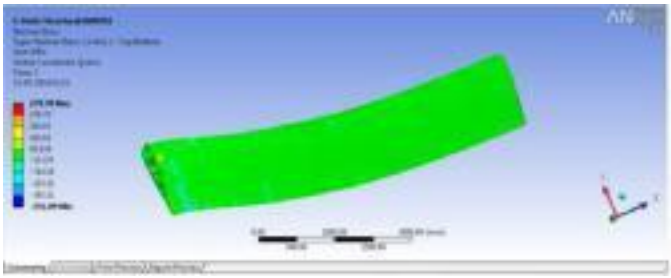

FIGURE VI. NORMAL STRESS OF THE WING BOX

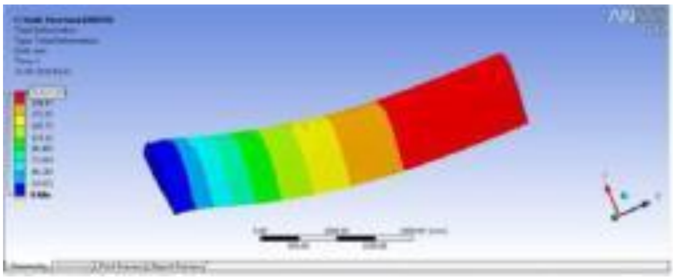

FIGURE VII. TOTAL DEFORMATION OF THE WING BOX

B. Carbon Epoxy

TABLE III. MATERIAL PROPERTY OF CARBON EPOXY

Property	Value	Unit
Density	1.6	g cm^{-3}
Isotropic Elasticity		
Young Modulus	70000	Mpa
Poisson Ratio	0.33	
Strength		
Tensile Yield Strength	280	Mpa
Tensile Ultimate Strength	1100	Mpa
Compressive yield Strength	900	Mpa

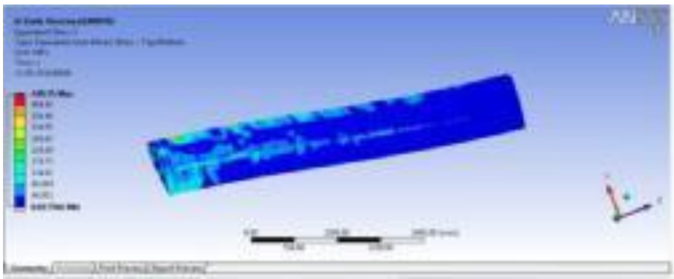

FIGURE VIII. EQUIVALENT STRESS OF THE WING BOX

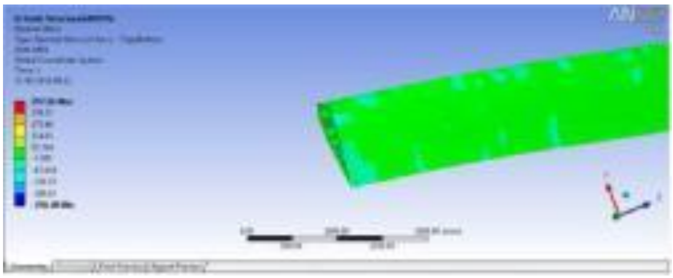

FIGURE IX. NORMAL STRESS OF THE WING BOX

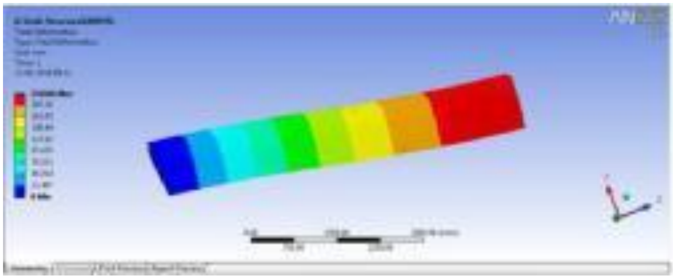

FIGURE X. TOTAL DEFORMATION OF THE WING BOX

C. Result Representation as Comparison

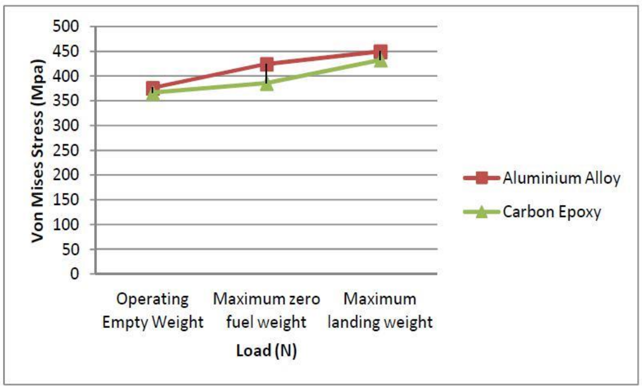

FIGURE XI. EQUIVALENT STRESS COMPARISON OF THE WING BOX

Further the process of comparison is continues to give the results of normal stress and total deformation.

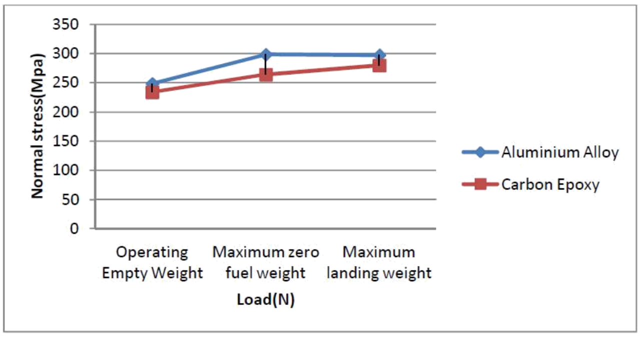

FIGURE XII. NORMAL STRESS COMPARISON OF THE WING BOX

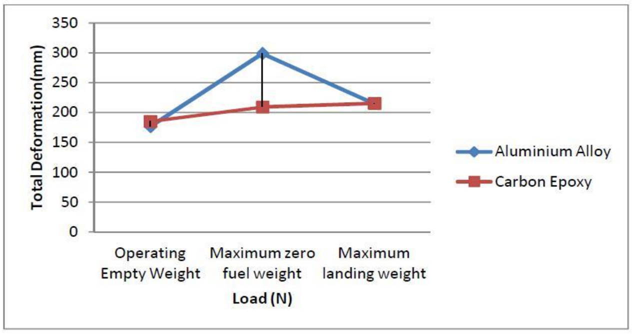

FIGURE XIII. TOTAL DEFORMATION COMPARISON OF THE WING BOX

From this analysis we proved that the Composite material can carry more load as compare to the Aluminium Alloy.

X. CONCLUSION

In aspect of analysis provided on the structural part of wing the list given below, shows the comparison data of morphed composite wing and unmorphed wing which is Aluminium.

TABLE IV. COMPARISON OF STRESSES

Loading conditions	Equivalent stress (Mpa)	Normal stress (Mpa)	Total Deformation (mm)
Operating empty weight	Aluminium 200 - 375	Aluminium 44 - 248.6	Aluminium 97 - 176
	Carbon epoxy 162 - 365	Carbon epoxy 36 - 233	Carbon epoxy 82 - 185
Maximum zero-fuel weight	Aluminium 235 - 424	Aluminium 58 - 280	Aluminium 13 - 198
	Carbon epoxy 229 -436	Carbon epoxy 41 - 264	Carbon epoxy 92 - 209
Maximum landing weight	Aluminium 224 - 449	Aluminium 53 - 297	Aluminium 117 – 218
	Carbon epoxy 194 - 437	Carbon epoxy 43 - 279	Carbon epoxy 123 – 267

From the above obtained result that carbon epoxy provide more strength to the wing when it is morphed along with ribs and spar by providing maximum yield capacity and long life. It indirectly defines that good airworthiness and valuable strength to the aircraft by using Carbon Epoxy the acceptable material strength of carbon epoxy is 600-900 Mpa at compression and 750-1600 Mpa at tension.

XI. FUTURE WORK

The exercise carried out given further more analysis to discuss which are to be executed in future

Changing the airfoil shape with slight modification and flow pattern in positivity is to be checked.

Life assessment test.

Type of fatigue what wing carries and in proper analysis on composite over life cycle.

Fracture test and residual life test.
Thermal analysis over creep.

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