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Modeling and Analysis of a RIBS and Spars of An Airplane Wing for Bending and Shear Loads

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Abstract: ***The ribs of the wing will give shape to the wing and spar will take most of the bending loads in the wing structure. In the present work, the rib and spars will be designed for twisting, bending and axial loads in terms of size, shape for a particular material considering engine mountings, landing gear, fuel tank attachments in addition to external aerodynamic loads. Analysis will be carried out using Ansys software and the values are validated using the standard theory.***

I. INTRODUCTION TO AIRCRAFT WING

For any airplane to fly, you must lift the weight of the airplane itself, the fuel, the passengers, and the cargo. The wings generate most of the lift to hold the plane in the air. To generate lift, the airplane must be pushed through the air. The jet engines which are located beneath the wings provide the thrust to push1 the airplane forward through the air. To control and maneuver the aircraft, smaller wings are located at the tail of the plane. The tail usually has a fixed horizontal piece (called the horizontal stabilizer) and a fixed vertical piece (called the vertical stabilizer). The stabilizers' job is to provide stability for the aircraft, to keep it flying straight.

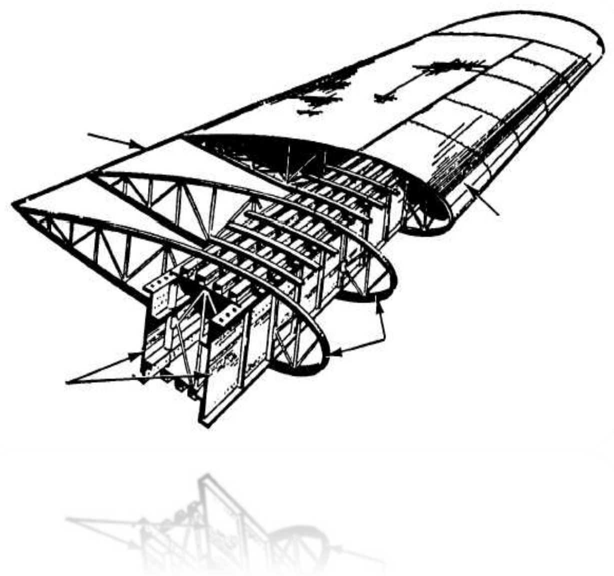

Fig.1.1-cross section of wing

The word originally referred only to the foremost limbs of birds, but has been extended to include the wings of insects (see insect wing), bats, pterosaurs, and aircraft.The term is also applied to an inverted wing used to generate downforce in auto racing.A wing's aerodynamic quality is expressed as a Lift-to-drag ratio. The lift generated by a wing at a given speed and angle of attack can be 1-2 orders of magnitude greater than the drag. This means that a significantly smaller thrust force can be applied to propel the wing through the air in order to obtain a specified lift. A fixed-wing aircraft, typically called an airplane, airplane or simply plane, is an aircraft capable of flight using forward motion that generates lift as the wing moves through the airplanes include jet engine and propeller driven vehicles propelled forward by thrust, as well as unpowered aircraft (such as gliders), which use thermals, or warm-air pockets to inherit lift. Fixed-wing aircraft are distinct from ornithopters in which lift is generated by flapping wings and rotary-wing aircraft in which wings rotate about a fixed mast. In the United Kingdom and most of the Commonwealth the term "airplane"

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is used. The word derives from the Greek αέρας (aéras-) ("air") and -plane, while in the United States and Canada the term "airplane" is applied to these aircraft. The form "airplane" is the older of the two, dating back to the mid- to late-19th century. The spelling "airplane" was first recorded in 1907.

II. DESIGN OF AIRCRAFT WING

Wing construction is basically the same in all types of aircraft. 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 (see figure2-1). Spars are the main members of the wing. They extend lengthwise of the wing.

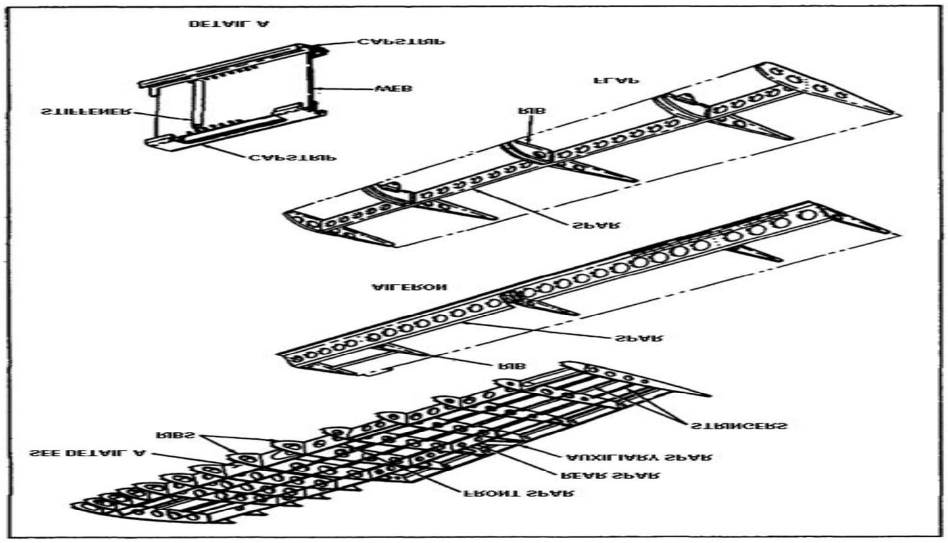

Fig-1.2 Interior of a wing

From the skin, this force is transmitted to the ribs and then to the spars. Most wing structures have two spars, the front spar and the rear spar. The front spar is found near the leading edge while the rear spar is about two-thirds the distance to the trailing edge
In addition to the main spars, there is a short structural member which is called an aileron spar

A. Spar

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 tailplane and fin and serve a similar function, although the loads transmitted may be different to those of a wing spar.

B. Spar loads

The wing spar provides the majority of the weight support and dynamic load integrity of cantilever monoplanes, often coupled with the strength of the wing 'D' box itself. Together, these two structural components collectively provide the wing rigidity needed to enable the aircraft to fly safely. Biplanes employing flying wires have much of the flight loads transmitted through the wires and interplane struts enabling smaller section and thus lighter spars to be used.

C. Forces

Main article: Aircraft flight mechanics
Some of the forces acting on a wing spar are 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.

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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.
Drag loads dependent on airspeed and inertia.
Rolling inertia loads.
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 underwing-mounted engines.
Many of these loads are reversed abruptly in flight with an aircraft such as the Extra 300 when performing extreme aerobatic manoeuvers; the spars of these aircraft are designed to safely withstand great load factors.
Materials and construction

D. Wooden construction

Early aircraft used spars often carved from solid spruce or ash. Several different wooden spar types have been used and experimented with such as spars that are box-section in form; and laminated spars laid up in a jig, and compression glued to retain the wing dihedral. Wooden spars are still being used in light aircraft such as the Robin DR400 and its relatives. A disadvantage of the wooden spar is the deteriorating effect that atmospheric conditions, both dry and wet, and biological threats such as wood-boring insect infestation and fungal attack can have on the component; consequently regular inspections are often mandated to maintain airworthiness.
Wood wing spars of multipiece construction usually consist of upper and lower members, called spar caps, and vertical sheet wood members, known as shear webs or more simply webs, that span the distance between the spar caps.
Even in modern times, "homebuilt replica aircraft" such as the replica Spitfires use laminated wooden spars. These spars are laminated usually from spruce or douglas fir (by clamping and glueing). A number of enthusiasts build "replica" Spitfires that will actually fly using a variety of engines relative to the size of the aircraft.

E. Metal spars

Basic metal-sparred wing using a honeycomb 'D' box leading edge
A typical metal spar in a general aviation aircraft usually consists of a sheet aluminium spar web, with "L" or "T" -shaped spar caps being welded or riveted to the top and bottom of the sheet to prevent buckling under applied loads. Larger aircraft using this method of spar construction may have the spar caps sealed to provide integral fuel tanks. Fatigue of metal wing spars has been an identified causal factor in aviation accidents, especially in older aircraft as was the case with Chalk's Ocean Airways Flight 101.

F. Tubular metal spars

The German Junkers J.I armoured fuselage ground-attack sesquiplane of 1917 used a Hugo Junkers-designed multi-tube network of several tubular wing spars, placed just under the corrugated duralumin wing covering and with each tubular spar connected to the adjacent one with a space frame of triangulated duralumin strips riveted onto the spars, resulting in a substantial increase in structural strength at a time when most other aircraft designs were built almost completely with wood-structure wings. The Junkers all-metal corrugated-covered wing / multiple tubular wing spar design format was emulated after World War I by American aviation designer William Stout for his 1920s-era Ford Trimotor airliner series, and by Russian aerospace designer Andrei Tupolev for such aircraft as his Tupolev ANT-2 of 1922, upwards in size to the then-gigantic Maxim Gorki of 1934.
A design aspect of the Supermarine Spitfire wing that contributed greatly to its success was an innovative spar boom design, made up of five square concentric tubes that fitted into each other. Two of these booms were linked together by an alloy web, creating a lightweight and very strong main spar.
A version of this spar construction method is also used in the BD-5, which was designed and constructed by Jim Bede in the early 1970s. The spar used in the BD-5 and subsequent BD projects was primarily aluminium tube of approximately 2 inches (5.1 cm) in diameter, and joined at the wing root with a much larger internal diameter aluminium tube to provide the wing structural integrity.

G Geodesic construction

In aircraft such as the Vickers Wellington, a geodesic wing spar structure was employed, which had the advantages of being lightweight and able to withstand heavy battle damage with only partial loss of strength.

H. Composite construction

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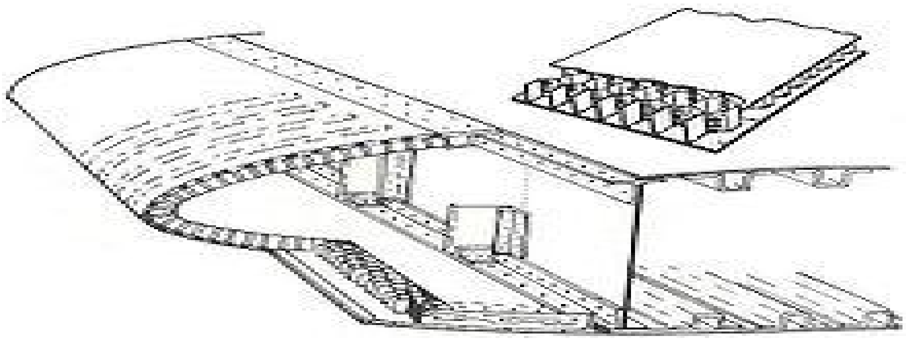
Many modern aircraft use carbon fibre and Kevlar in their construction, ranging in size from large airliners to small homebuilt aircraft. Of note are the developments made by Scaled Composites and the German glider manufacturers Schempp-Hirth and Schleicher.These companies initially employed solid fiberglass spars in their designs but now often use carbon fibre in their high performance gliders such as the ASG 29. The increase in strength and reduction in weight compared to the earlier fiberglass-sparred aircraft allows a greater quantity of water ballast to be carried.

I. False spars

False spars, like main spars, are load bearing structural members running span wise but are not joined to the fuselage. Their most common purpose is to carry moving surfaces, principally ailerons.



Basic metal-sparred wing using ahoneycomb 'D' box leading edge

J. Rib (aircraft)

Wing ribs of a de Havilland DH.60 Moth

In an aircraft, ribs are forming elements of the structure of a wing, especially in traditional construction.

By analogy with the anatomical definition of "rib", the ribs attach to the main spar, and by being repeated at frequent intervals, form a skeletal shape for the wing. Usually ribs incorporate the airfoil shape of the wing, and the skin adopts this shape when stretched over the ribs.

There are several types of ribs. Form-ribs, plate-type ribs, truss ribs, closed-ribs, forged ribs and milled ribs, where form-ribs are used for light to medium loading and milled ribs are as strong as it can get.

Form-ribs are made from a sheet of metal bent into shape, such as a U-profile. This profile is placed on the skin, just like a stringer, but then in the other direction.

Plate-type ribs consist of sheet-metal, which has upturned edges and (often has) weight-saving holes cut into it.

Truss ribs are built up out of profiles that are joined together. These joints require great attention during design and manufacture. The ribs may be light or heavy in design which make them suitable for a wide range of loads.

Closed-ribs are constructed from profiles and sheet metal and are suitable for closing off sections of the wing (e.g.: the fuel tank). Here too, particular care must be taken with the joints and this type of rib is also suitable for application in a variety of loading conditions.

Forged ribs are manufactured using heavy press-machinery. The result is fairly rough; for more refined parts, high-pressure presses are required, which are very expensive. Forged pieces (usually) have to undergo further treatment (for smoother edges and holes). Forged ribs are used for sections where very high loads apply - near the undercarriage for example.

Milled ribs are solid structures. They are manufactured by milling away excess material from a solid block of metal (usually using computer-controlled milling machines). The shape of these ribs is always accurately defined. Such ribs are used under similar conditions as those for forged ribs.

Ribs are made out of wood, metal, plastic, composites, foam. The wings of kites,[1] hang gliders,[2] paragliders,[3] powered kites,[4] powered hang gliders, ultralights, windmills [5] are aircraft that have versions that use ribs to form the wing shape.

For full size and flying model aircraft wing structures that are usually made of wood, ribs can either be in one piece (forming the airfoil at that rib's "station" in the wing), or be in a three-piece format, with the rib web being the part that the one-piece rib consisted of, with capstrips for the upper and lower edging of the rib, running from the leading edge to the trailing edge, being the other two component parts.

K. Problem Definition

The ribs of the wing will give shape to the wing and spar will take most of the bending loads in the wing structure. In the present work, the rib and spars will be designed for twisting, bending and axial loads in terms of size, shape for a particular material considering engine mountings, landing gear, fuel tank attachments in addition to external aerodynamic loads. Analysis will be carried out using Ansys software and the values are validated using the standard theory.

basically, the objective of the project is to develop the modal and static analysis of a ribs and spars of an airplane wing design against bending and shear loads. The primary functions of an aircraft's structure can be basically broken down into the following:

To transmit & resist applied loads.

To provide and maintain aerodynamic shape.

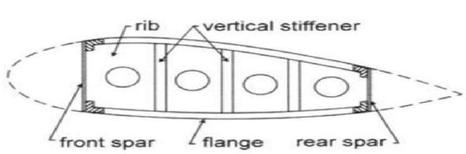
To protect its crew, passengers, payload, systems, etc.

For the vast majority of aircraft, this leads to the use of a semi-monocoque design (i.e. a thin, stressed outer shell with additional stiffening members) for the wing, fuselage & empennage. These notes will discuss the structural layout possibilities for each of these three main areas, i.e. the wing, fuselage and empennage.

L. Project Scope

The scope of the project is to Design and Analysis of a ribs and spars of an airplane wing against bending and shear loads using ANSYS. We are doing the both modal and static analysis by using the ANSYS tool. In these we are applying the pressure loads, structure loads, engine loads, these loads on the wing are subjected to bending and twisting.

III. THEORY AND LITERATURE REVIEW



The main structure of the wing in an aircraft are its spars. Spars essentially behave like beams

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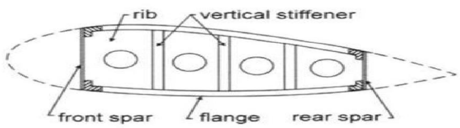
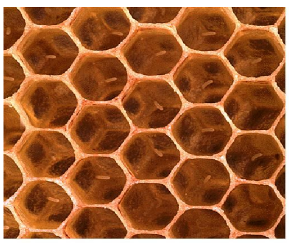
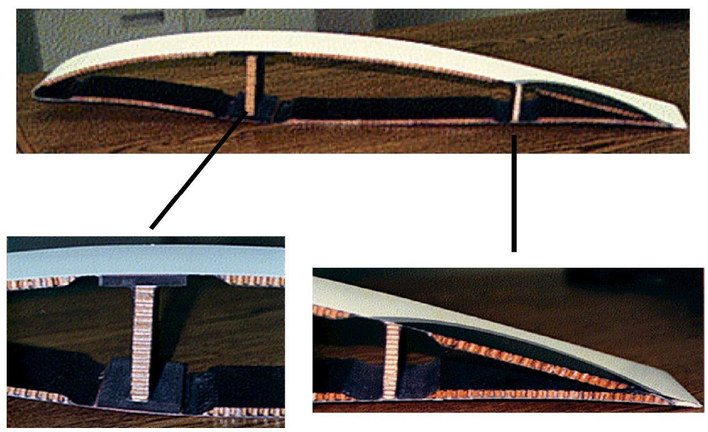


After the spar is prepared, ribs are attached to provide the shape of the wing. Ribs also function like beams.
Relationship between shear stress and bending moment
the shear force distribution can be determined by differentiating the bending moment distribution
The bending moment distribution can be obtained by integrating the shear force diagram
$M = \int V \partial x \quad V = \frac{\partial M}{\partial x}$





Honeycomb Wing Design Using spars
One design to improve the flexural strength of wings is to use honeycomb structure.
Honeycomb structure have high flexural strength to weight ratio.
Shear Stress
Shear stress eqn. $\tau = \frac{VQ}{It}$

V : shear force

– Q : first moment of area $\int y \partial A$

– I : second moment of area $\int y^2 \partial A$

– t : thickness of the beam cross-section

Q is zero at top and bottom of beam section .
Shear stress is zero at top and bottom of beam section .
A solid spar must normally cope with compression stresses along the upper edge, tension stresses along the lower edge and shear stresses in etween.
The web can be thinned to reduce weight.
The shear web has to be of sufficient thickness to resist the shear stresses

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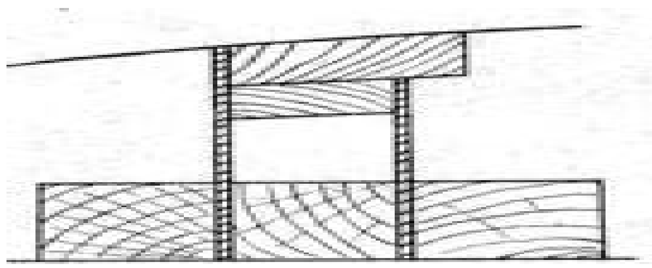
An alternate design is the box beam where plywood is laminated to both sides of the flanges forming a box structure.

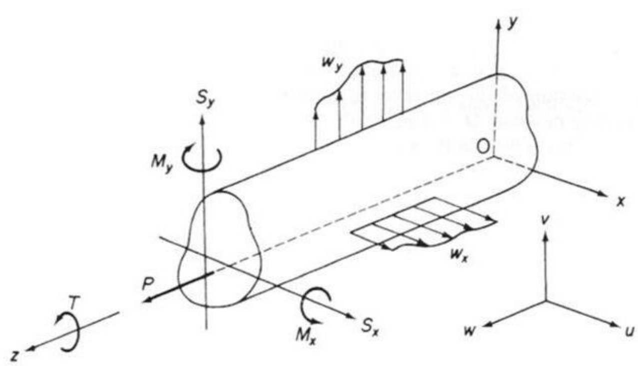


A. Unsymmetrical Bending

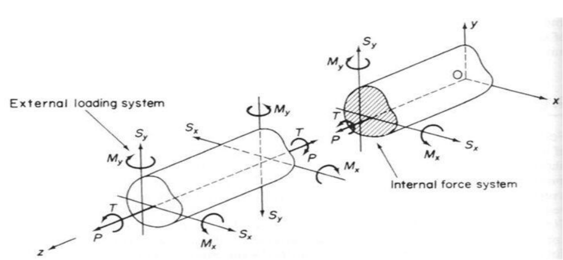
Stress at a point in the cross-section of a beam subjected to bending depends on

Position of point
Applied loading
Geometric properties of the cross section

This applies regardless of whether the cross-section is opened or closed
It is important to establish the notation and sign conventions in advance



Resolution of bending moments



B. Material

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Material is anything made of matter, constituted of one or more substances. Wood, cement, hydrogen, air and water are all examples of materials. Sometimes the term "material" is used more narrowly to refer to substances or components with certain physical properties that are used as inputs to production or manufacturing. In this sense, materials are the parts required to make something else, from buildings and art to stars and computers. Several factors influence the selection of the structural material for an aircraft, but among these, strength allied to lightness is probably the most important. Other properties having varying, though sometimes critical, significance are stiffness, toughness, resistance to corrosion, fatigue, the effects of environmental heating, ease of fabrication, availability and consistency of supply, and, not least important, cost. The main groups of materials used in aircraft construction have been wood, steel, aluminum alloys with, more recently, titanium alloys, and fiber-reinforced composites. In the field of engine design, titanium alloys are used in the early stages of a compressor, while nickel-based alloys or steels are used for the hotter later stages.

C. Aluminum alloys

Pure aluminum is a relatively low-strength, extremely flexible metal with virtually no structural applications. However, when alloyed with other metals, its properties are improved significantly. Three groups of aluminum alloy have been used in the aircraft industry for many years and still play a major role in aircraft construction. In the first of these, aluminum is alloyed with copper, magnesium, manganese, silicon, and iron and has a typical composition of 4% copper, 0.5% magnesium, 0.5% manganese, 0.3% silicon, and 0.2% iron, with the remainder being aluminum. In the wrought, heat-treated, naturally aged condition, this alloy possesses a 0.1 percent proof stress not less than 230N/mm2, a tensile strength not less than 390N/mm2, and an elongation at fracture of 15 percent. Artificial aging at a raised temperature of, for example, 170◦C increases the proof stress to not less than 370N/mm2 and the tensile strength to not less than 460N/mm2, with an elongation of 8 percent. The second group of alloys contains, in addition to the preceding 1 to 2% of nickel, a higher content of magnesium and possible variations in the amounts of copper, silicon, and iron. The most important property of these alloys is their retention of strength at high temperatures, which makes them particularly suitable for aero engine manufacture. A development of these alloys by Rolls-Royce and High Duty Alloys Ltd replaced some of the nickel with iron and reduced the copper content; these RR alloys, as they were called, were used for forgings and extrusions in aero engines and airframes. The third group of alloys depends on the inclusion of zinc and magnesium for their high strength and has a typical composition of 2.5% copper,5%zinc,3%magnesium, and up to1%nickel, with mechanical properties of 0.1 percent proof stress 510N/mm2, tensile strength 585N/mm2, and an elongation of 8 percent. In a modern development of this alloy, nickel has been eliminated and provision made for the addition of chromium and further amounts of manganese.

D. Steel

The use of steel for the manufacture of thin-walled, box-section spars in the 1930s has been superseded by the aluminum alloys described in Section 10.1. Clearly, its high specific gravity prevents its widespread use in aircraft construction, but it has retained some value as a material for castings for small components demanding high tensile strengths, high stiffness, and high resistance to wear. Such components include undercarriage pivot brackets, wing-root attachments, fasteners, and tracks. Although the attainment of high and ultra-high tensile strengths presents no difficulty with steel, it is found that other properties are sacrificed and that it is difficult to manufacture into finished components.

To overcome some of these difficulties, types of steel known as *maraging* steels were developed in 1961, from which carbon is either eliminated entirely or present only in very small amounts. Carbon, while producing the necessary hardening of conventional high-tensile steels, causes brittleness and distortion; the latter is not easily rectifiable, as machining is difficult and cold forming impracticable.

E. Titanium

The use of titanium alloys increased significantly in the 1980s, particularly in the construction of combat aircraft as opposed to transport aircraft. This increase continued in the 1990s to the stage where, for combat aircraft, the percentage of titanium alloy as a fraction of structural weight is of the same order as that of aluminum alloy. Titanium alloys possess high specific properties, have a good fatigue strength/tensile strength ratio with a distinct fatigue limit, and have some retain considerable strength at temperatures up to 400 to 500◦C. Generally, there is also a good resistance to corrosion and corrosion fatigue, although properties are adversely affected by exposure to temperature and stress in a salt environment. The latter poses particular problems in the engines of carrieroperated aircraft. Further disadvantages are a relatively high density so that weight penalties are imposed if the alloy is extensively used, coupled with high primary and high fabrication costs, approximately seven times those of aluminum and steel. In spite of this, titanium alloys were used previously in the airframe and engines of Concorde, while the Tornado wing carry-through box is fabricated from a weld able medium-strength titanium alloy. Titanium alloys are also used extensively in the F15 and F22 American fighter aircraft and are incorporated in the tail assembly of the Boeing 777 civil airliner. Other uses include forged components such as flap and slat tracks and undercarriage parts.

F. Composite materials

Composite materials consist of strong fibers such as glass or carbon set in a matrix of plastic or epoxy resin, which is mechanically and chemically protective. The fibers may be continuous or discontinuous but possess strength very much greater than that of the same bulk materials. For example, carbon fibers have a tensile strength of the order of 2400N/mm2 and a modulus of elasticity of 400000N/mm2. A sheet of fiber-reinforced material is anisotropic—in other words, its properties depend on the direction of the fibers. Generally, therefore, in structural form, two or more sheets are sandwiched together to form a lay-up so that the fiber directions match those of the major loads.

G. Properties of materials

1) *Ductility:* A material is said to be ductile if it is capable of withstanding large strains under load before fracture occurs. These large strains are accompanied by a visible change in cross-sectional dimensions and therefore give warning of impending failure. Materials in this category include mild steel, aluminum, and some of its alloys, copper, and polymers.
2) *Brittleness:* A brittle material exhibits little deformation before fracture, the strain normally being below 5 percent. Brittle materials therefore may fail suddenly without visible warning. Included in this group are concrete, cast iron, high-strength steel, timber, and ceramics.
3) *Elastic Materials:* A material is said to be elastic if deformations disappear completely on removal of the load. All known engineering materials are, in addition, linearly elastic within certain limits of stress so that strain, within these limits, is directly proportional to stress.
4) *Plasticity:* A material is perfectly plastic if no strain disappears after the removal of load. Ductile materials are elastoplastic and behave in an elastic manner until the elastic limit is reached, after which they behave plastically. When the stress is relieved, the elastic component of the strain is recovered, but the plastic strain remains as a permanent set.
5) *Isotropic Materials:* In many materials, the elastic properties are the same in all directions at each point in the material, although they may vary from point to point; such a material is known as Isotropic. An isotropic material having the same properties at all points is known as homogeneous (e.g., mild steel).
6) *Anisotropic Materials:* Materials having varying elastic properties in different directions are known as anisotropic.
7) *Orthotropic Materials:* Although a structural material may possess different elastic properties in different directions, this variation may be limited, as in the case of timber, which has just two values of Young's modulus, one in the direction of the grain and one perpendicular to the grain. A material whose elastic properties are limited to three different values in three mutually perpendicular directions is known as *orthotropic.*

III. METHODOLOGY

A. Overview of project flow

Today the finite element method (FEM) is considered as one of the well-established and convenient technique for the computer solution of complex problems in different fields of engineering: civil engineering, mechanical engineering, nuclear engineering, biomedical engineering, hydrodynamics, heat conduction, geo-mechanics, etc. From other side, FEM can be examined as a powerful tool for the approximate solution of differential equations describing different physical processes.

The success of FEM is based largely on the basic finite element procedures used: the formulation of the problem in variational form, the finite element dicretization of this formulation and the effective solution of the resulting finite element equations. These basic steps are the same whichever problem is considered and together with the use of the digital computer present a quite natural approach to engineering analysis.

The objective of this course is to present briefly each of the above aspects of the finite element analysis and thus to provide a basis for the understanding of the complete solution process. According to three basic areas in which knowledge is required, the course is

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divided into three parts. The first part of the course comprises the formulation of FEM and the numerical procedures used to evaluate the element matrices and the matrices of the complete element assemblage. In the second part, methods for the efficient solution of the finite element equilibrium equations in static and dynamic analyses will be discussed. In the third part of the course, some modelling aspects and general features of some Finite Element Programs (ANSYS, NISA, LS-DYNA) will be briefly examined.

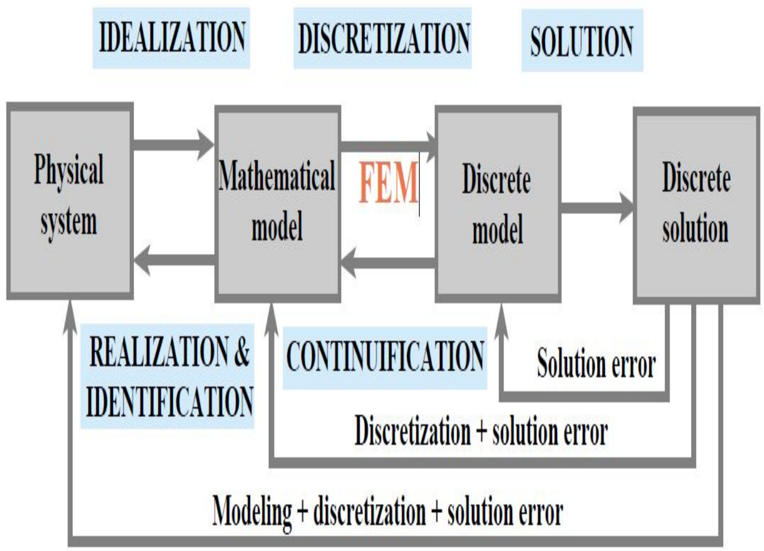

Fig 3.1 Fem algorithm

B. Ansys

ANSYS is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

In general, a finite element solution may be broken into the following three stages. This is a general guideline that can be used for setting up any finite element analysis.

Pre-processing: defining the problem; the major steps in pre-processing are given below:

Define keypoints/lines/areas/volumes

Define element type and material/geometric properties

Mesh lines/areas/volumes as required.

The amount of detail required will depend on the dimensionality of the analysis (i.e. 1D, 2D, axi-symmetric, 3D).

Solution: assigning loads, constraints and solving; here we specify the loads (point or pressure), contraints (translational and rotational) and finally solve the resulting set of equations.

Postprocessing: further processing and viewing of the results; in this stage one may wish to see:

Lists of nodal displacements

Element forces and displacements , Deflection plotsStress .contour diagrams

C. Degree of freedom

In mechanics, the degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration. It is the number of parameters that determine the state of a physical system and is important to the analysis of systems of bodies in mechanical engineering, aeronautical engineering, robotics, and structural engineering.

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D. Analysis on Spar And Ribs

The design of spars and ribs of airplane wing has been sketch out by using the Ansys 12.0, in order to have a clear view of the overall part and structure of spar and ribs.The below figure shows the overview of the spars and ribs of an airplane structure. Structural analysis incorporates the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural analysis is thus a key part of the engineering design of structures.

Preferences	Structural
Element	10 node 92

Table: 3.1 Element type

Material properties→ Material models→ Structural→ Linear→ Elastic→ Isotropic

Physical quantity	Values
Young modulus	7*e4
Poission's ratio	0.3

E. Static Analysis

Static analysis, static projection, and static scoring are terms for simplified analysis wherein the effect of an immediate change to a system is calculated without respect to the longer term response of the system to that change. Such analysis typically produces poor correlation to empirical results.

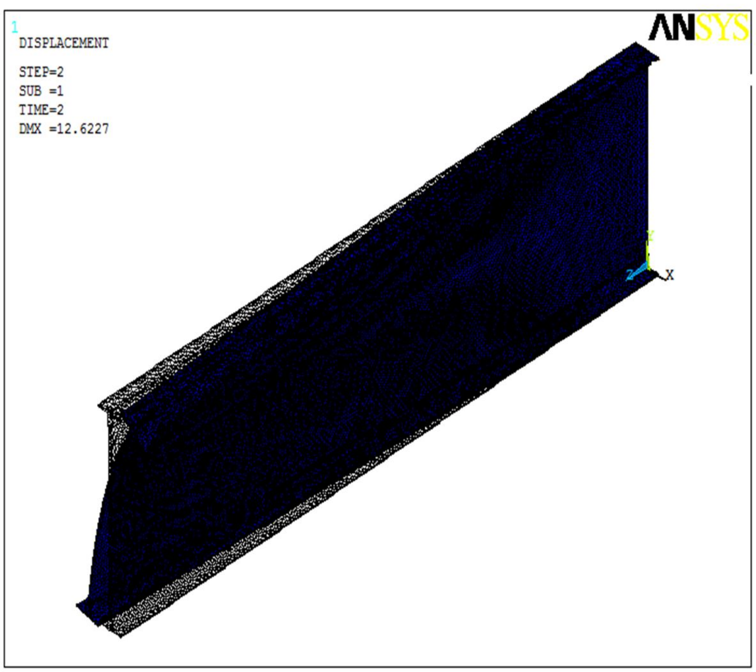

Fig 1.1 Deflection over I section

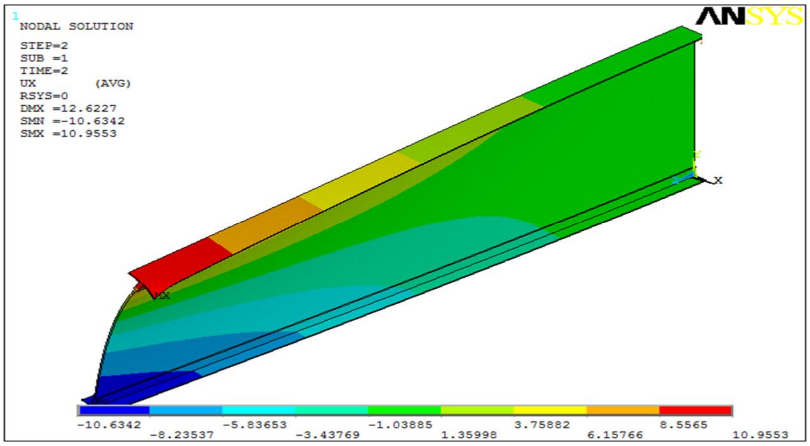

Fig 1.2 X-component of displacement

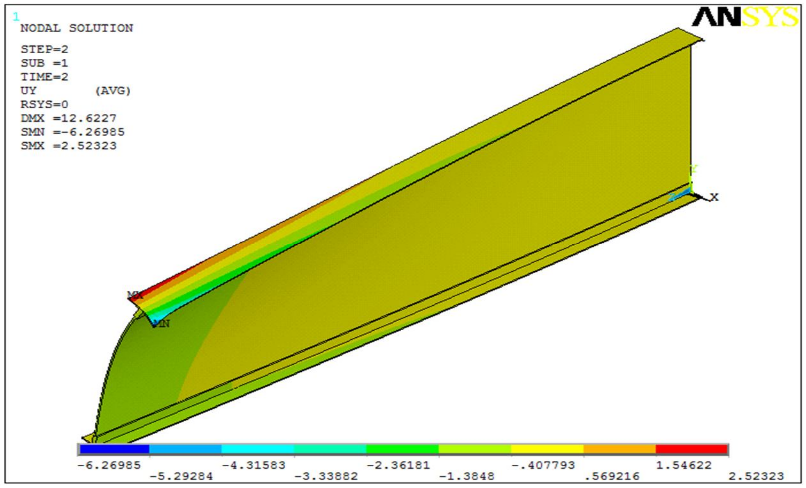

Fig 1.3 Y-component of displacement

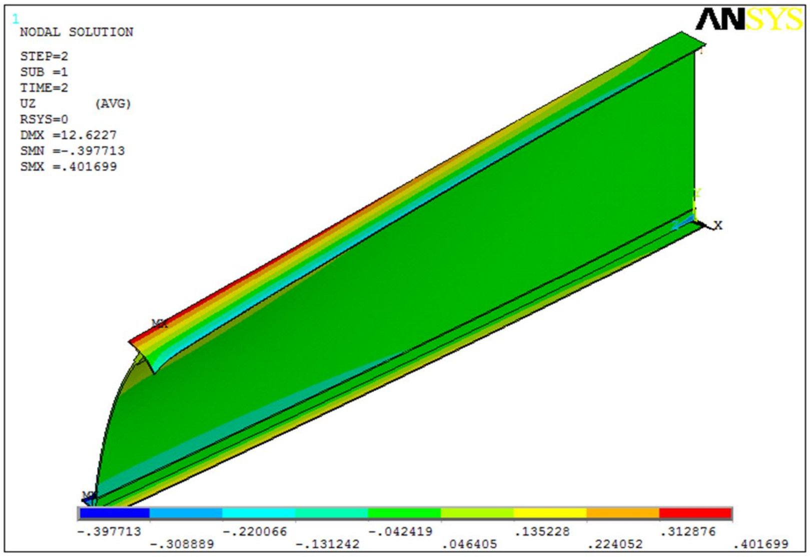

Fig 1.4 Z-component of displacement

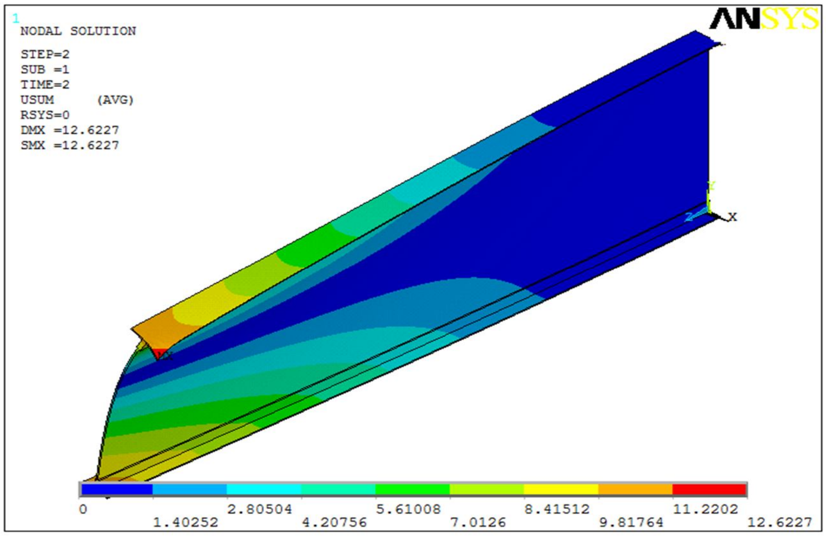

FIG 1.5

F. Static analysis of ribs

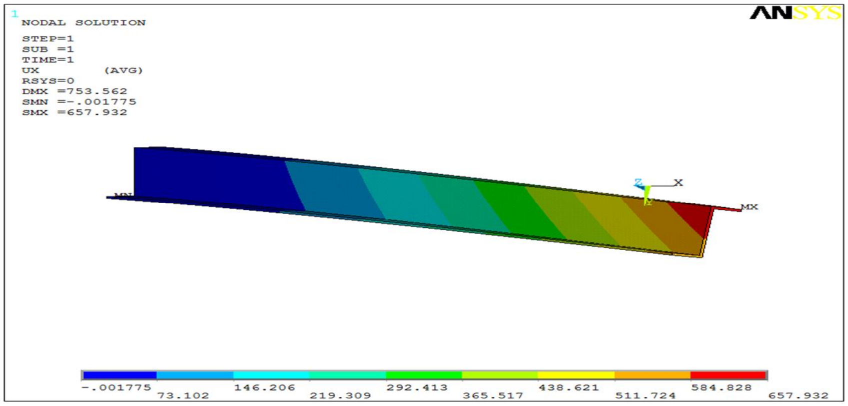

Fig 2.1 X component of displacement

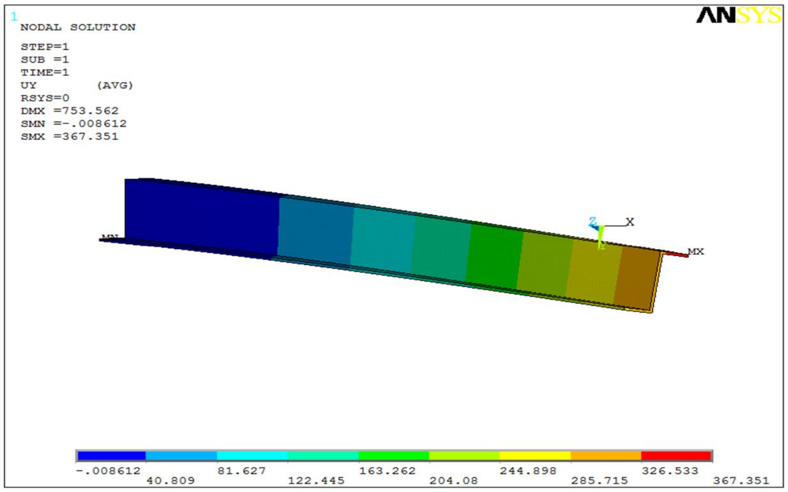

Fig 2.2 Y-component of displacement

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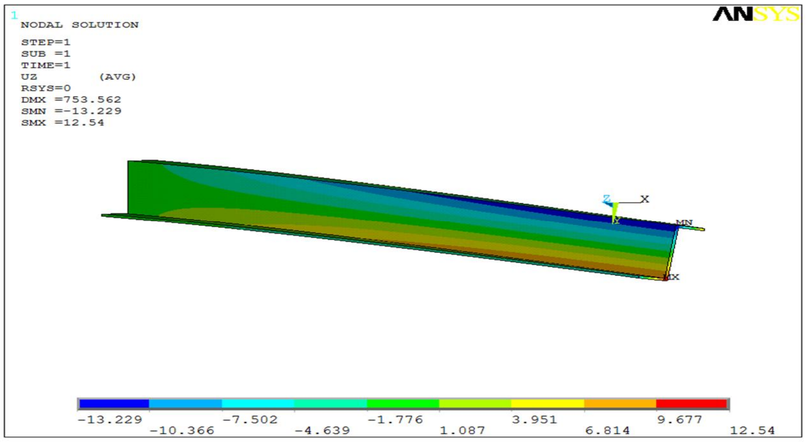

Fig 2.3 Z-component of displacement

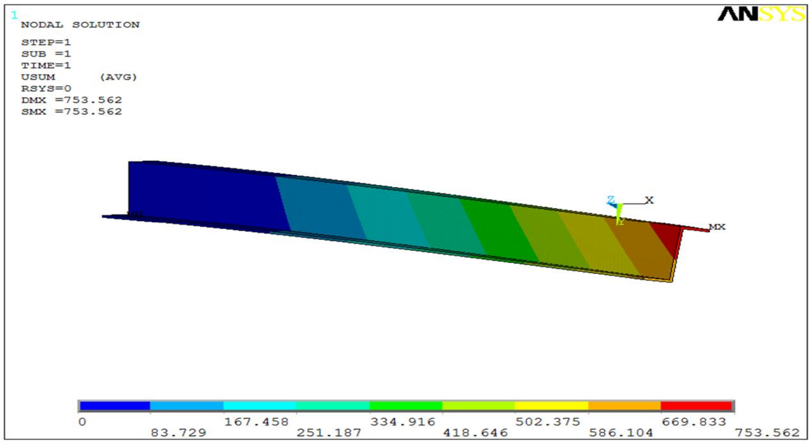

Fig 2.4

G. Static analysis of spars over a cantilever

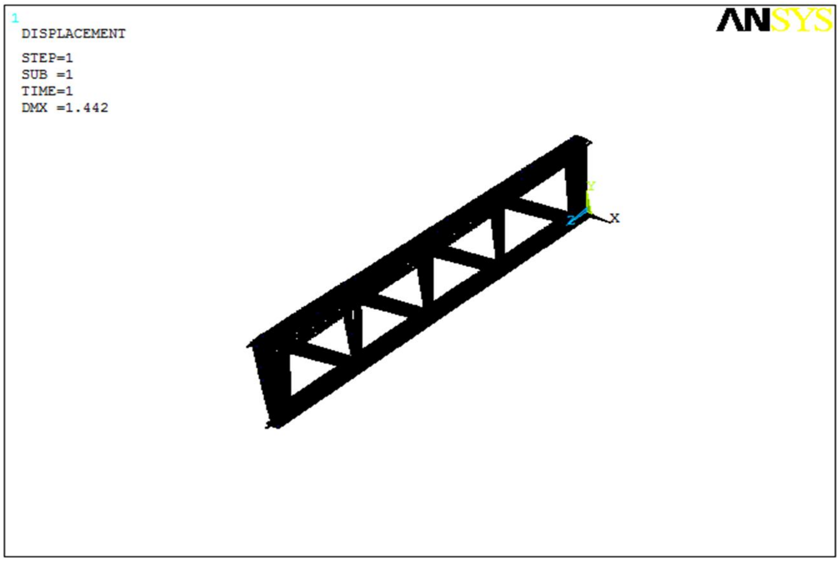

Fig 3.1 Deflection over a spar

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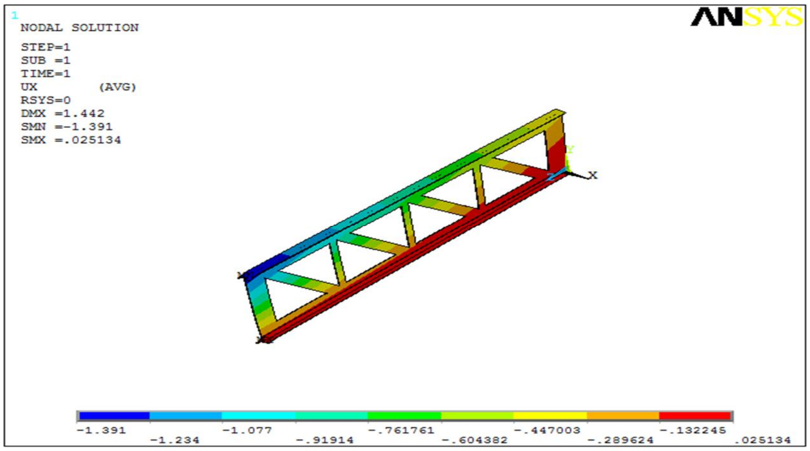

Fig 3.1 X-component of displacement

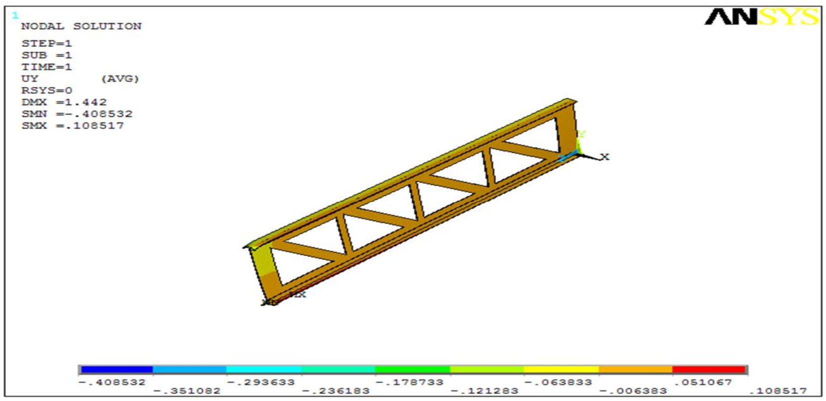

Fig 3.2 Y-component of displacement

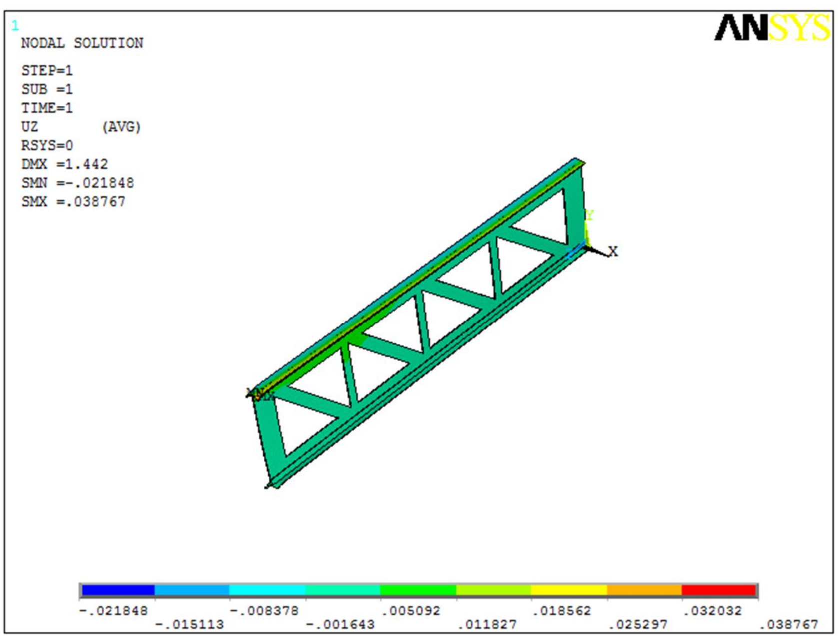

Fig 3.3 Z-component of displacement

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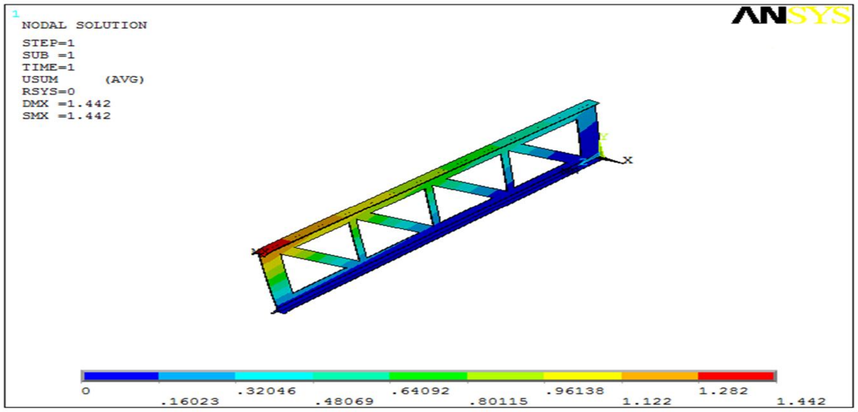
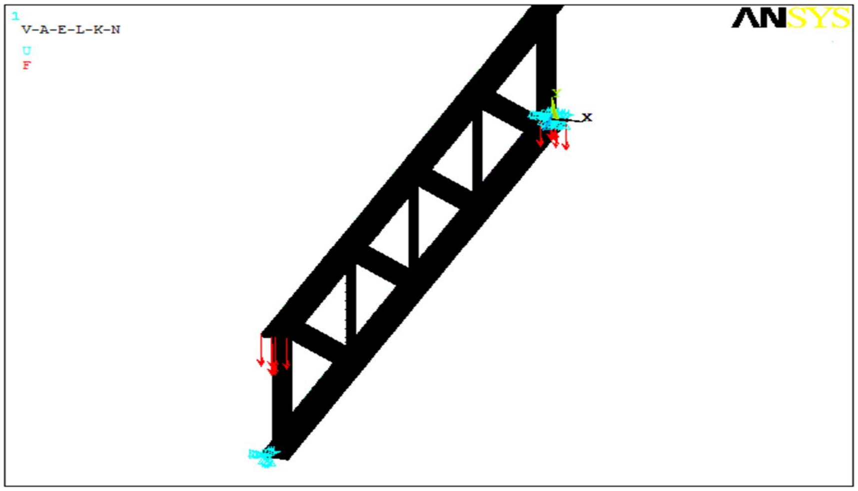
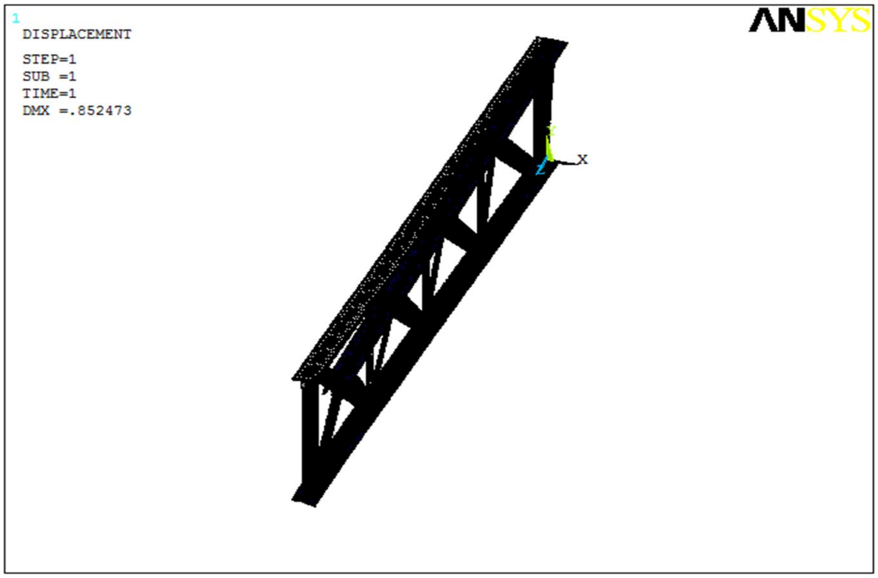


H. Analysis of spars over simple supported beam



I. deflection for simple supported beam



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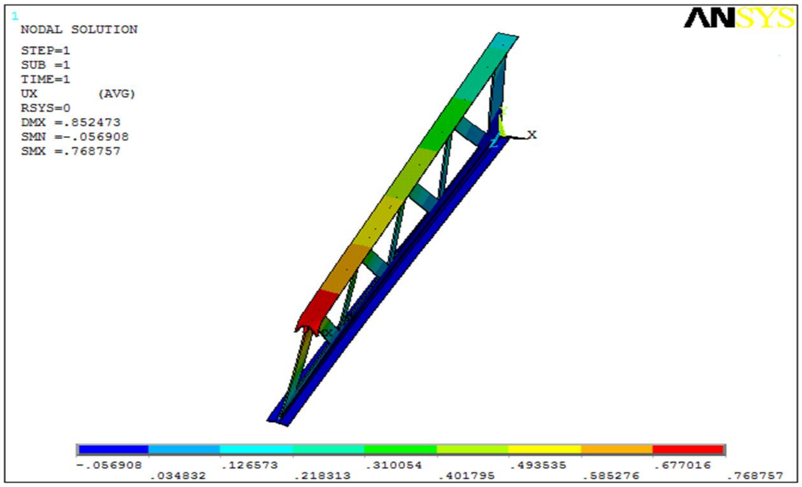
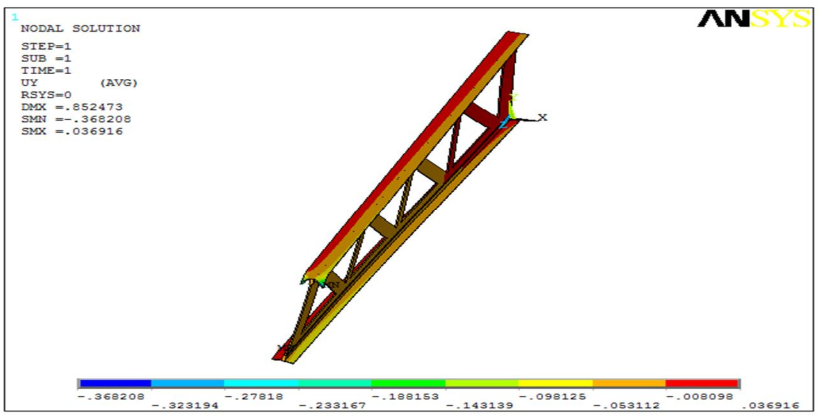
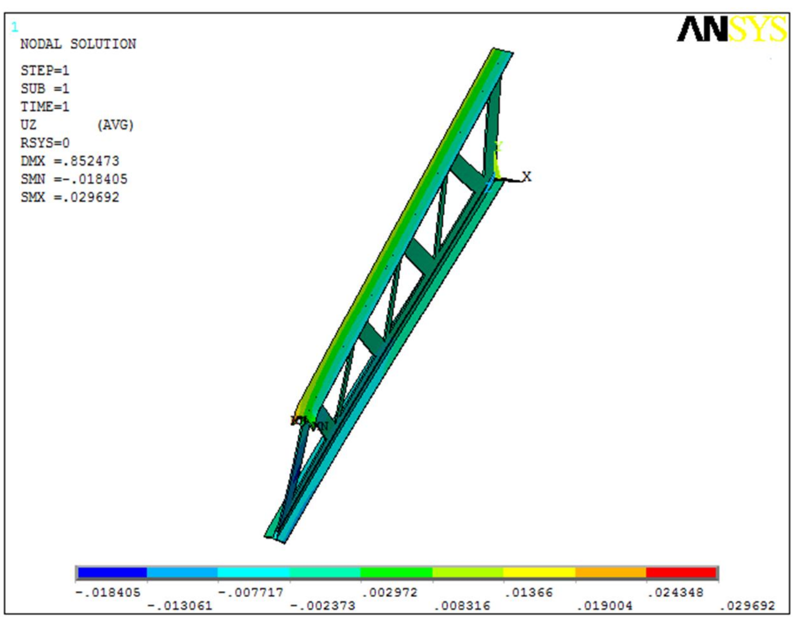


J. Xcomponent of displacement



K. Y-component of displacement



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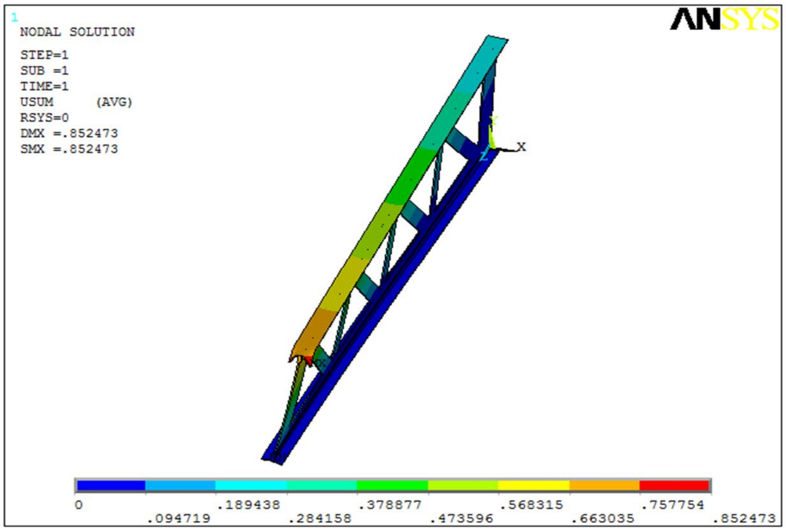
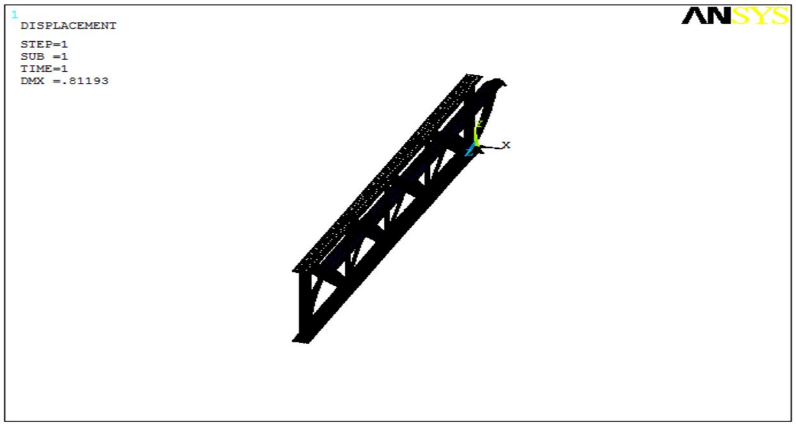
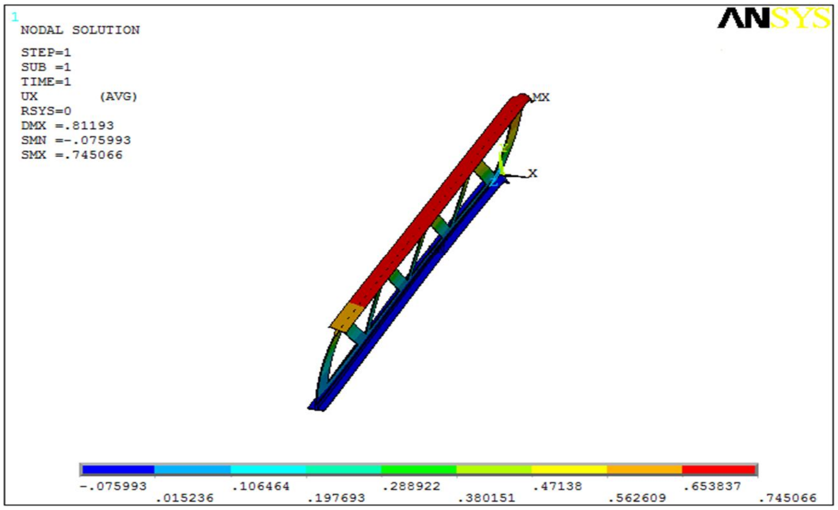
L. Z-component of displacement



M. Displacement



N. deflection of I section over cantilever beam with change in dimensions



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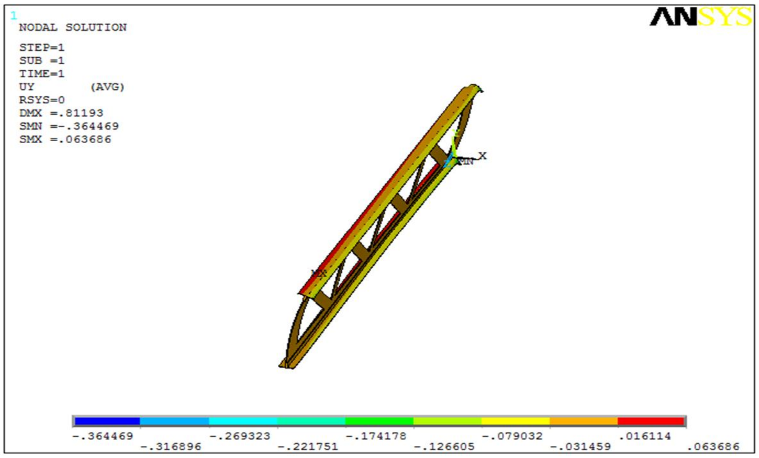
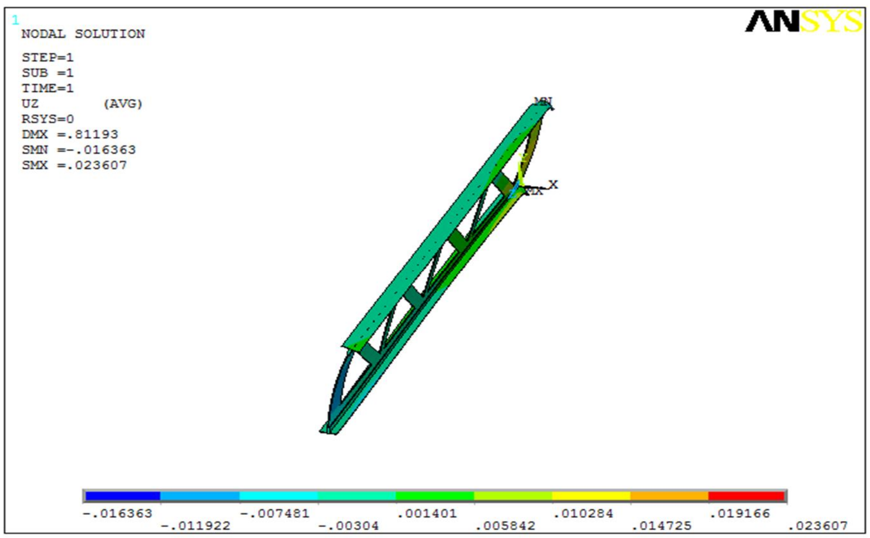
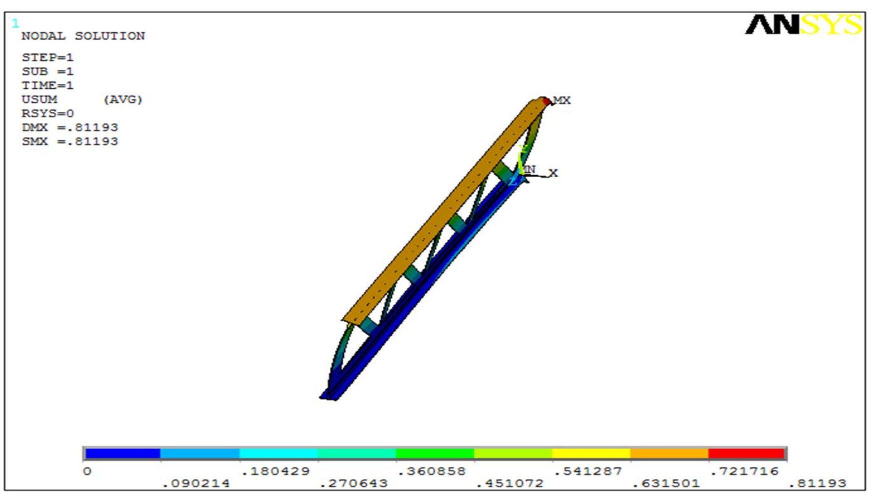
O.component of displacement



P.component of displacement



Q. Z-component of displacement



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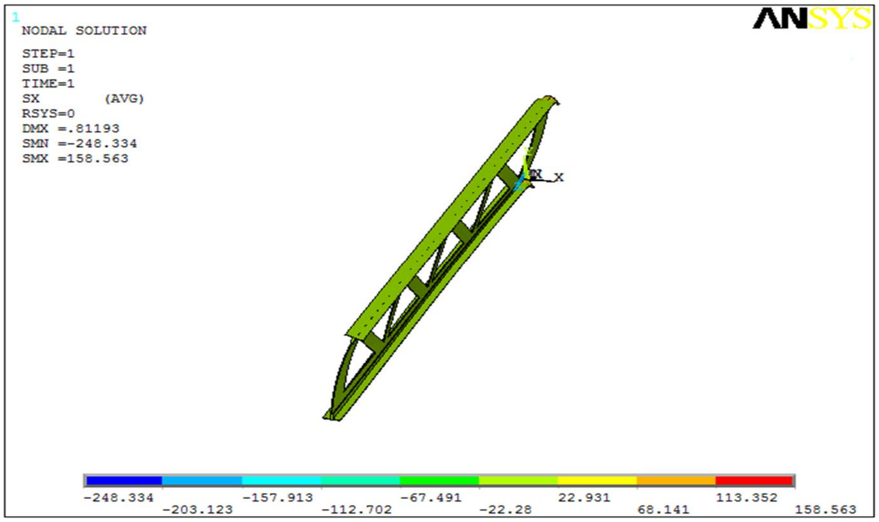
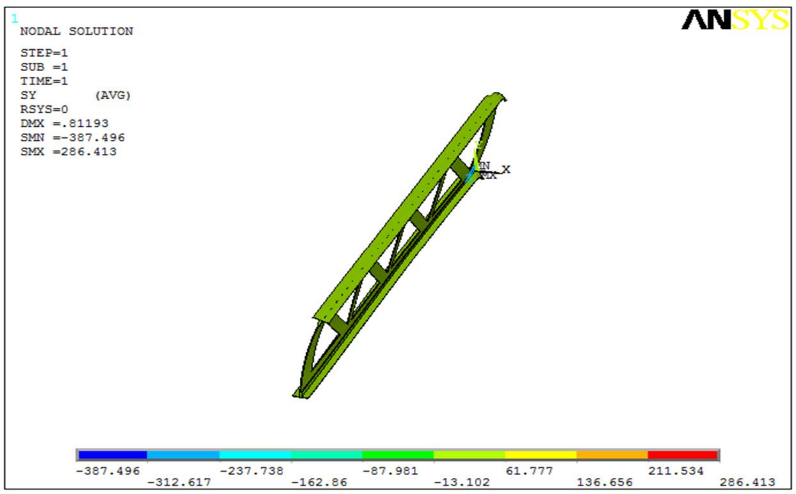
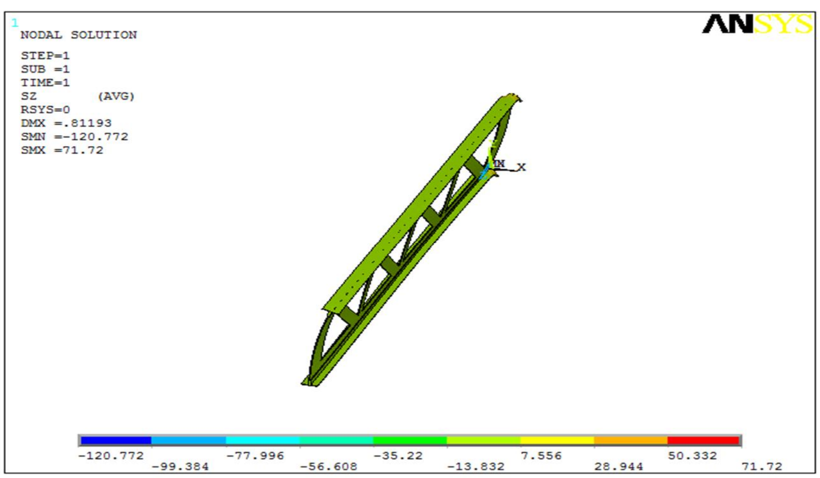
R. deflection components of I section of stress



S. component of stress



T. component of stress



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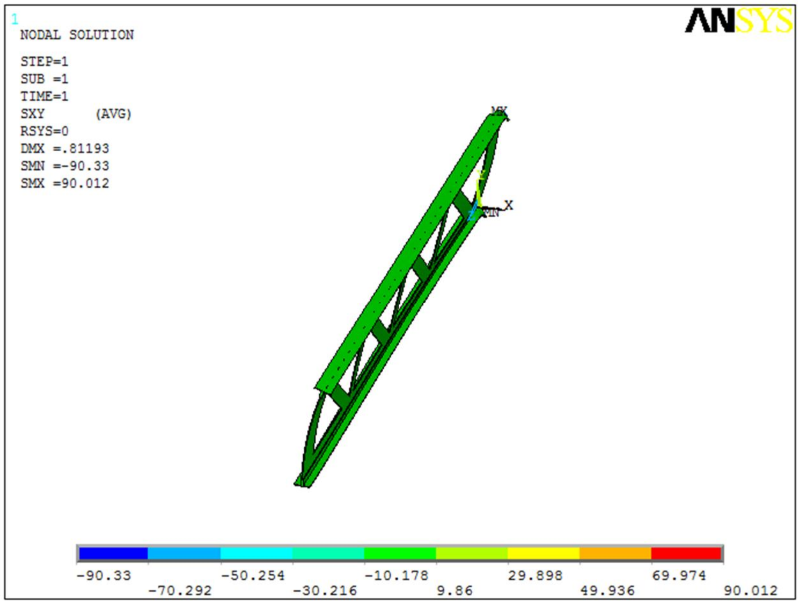
U. Z-component of stress



V.Component Static Analysis

In the static analysis we apply the structural loads,fuel loads and engine loads on the spars,so that loads will tend to bending,

Deflection = $w * l^3/3EI$

=12760*125/2*e11*0.01125

=0.027907

IV. CONCLUSION

Although a single best case was not found for the entire regime of the studies, the model still proved to be a practical system. It was shown that implementing the actuation system, with the selected shape memory polymer as a skin material, would be beneficial in weight comparison. The proposed system has more favorable attributes for a given weight than a similarly weighted system of a different material.

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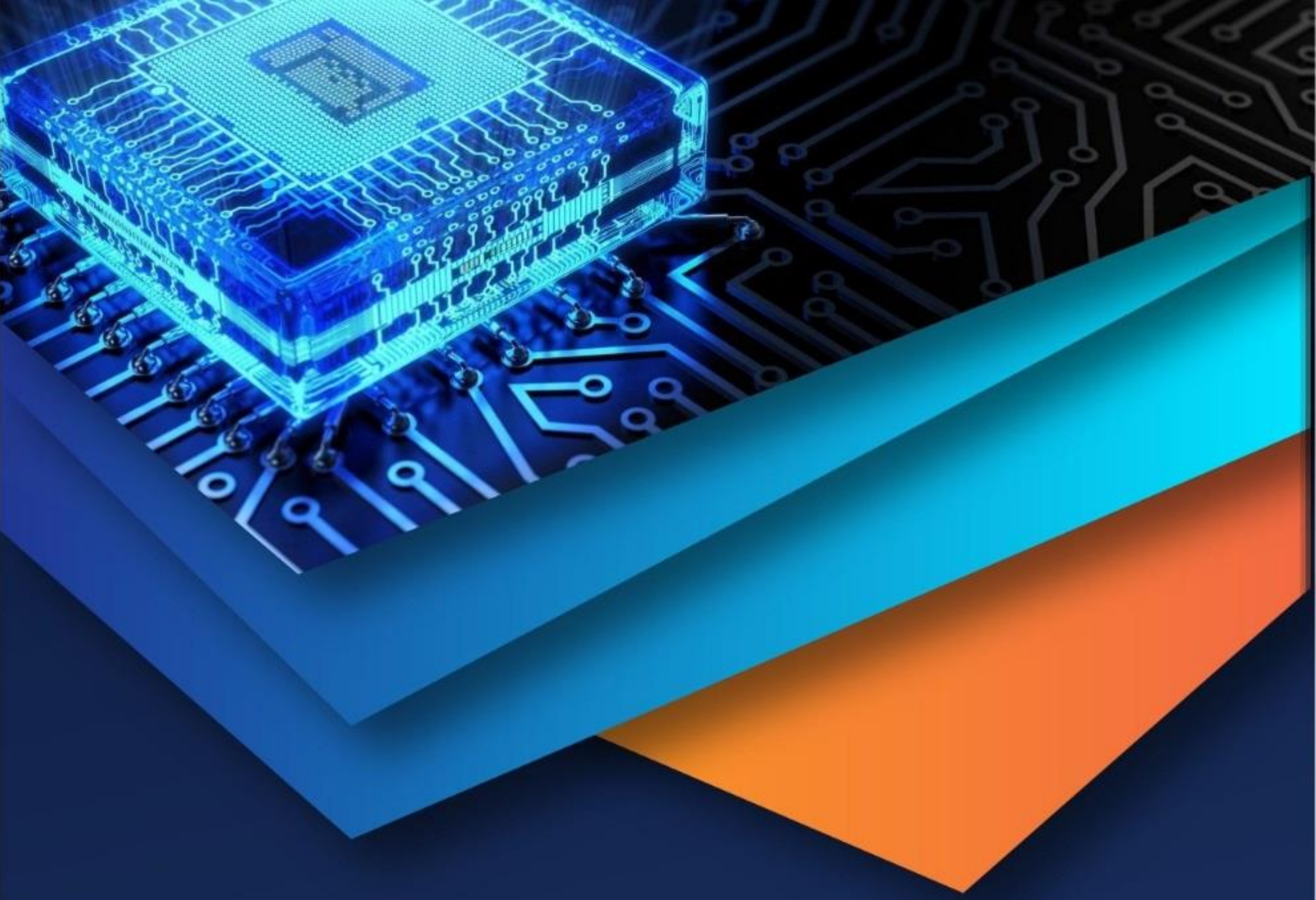

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