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Fabricational Analysis of Structural Composite Fuselage

Mr. Velugu Vamshi
Associate Professor
Department of Aeronautical Engineering
MLR Institute of Technology

A.Vinod Kumar
M.Tech- Aerospace
Engineering Department of Aeronautical Engineering
MLR Institute of Technology

Dr. M. Satyanarayana Gupta
Professor & HoD
Department of Aeronautical Engineering
MLR Institute of Technology

ABSTRACT

To increase the structural properties of aircraft components like Airframe of the Fuselage by replacing the individual materials with the composite material. Composite material is combination of two or more materials having compositional variations and depicting properties distinctively different from those of the individual materials of the composite. A composite material provides much better benefits against bending when applying loads. The composite materials are prepared with Polyesters, Vinyl esters and epoxy. Initially the Fuselage airframe is considered with individual and composite materials. To find the linear static and vibrational problems. There are different approaches has been done: Designed in CATIA V5, ANSYS analytical approaches. When some external loads acts on a beam a shear force and bending moment are set up at all sections of the beam. Due to the shear force and bending moment, the beam undergoes certain deformation. The material of the beam will offer resistance or stresses against these deformations. These stresses with certain assumptions can be obtained by different approaches. Thus, composite material provides more efficient structural properties than the individual metal alloys.

***Keywords:** Aircraft, Structural Properties, Composite Material, Fuselage, Shear Force, Stree, Alloys.*

INTRODUCTION

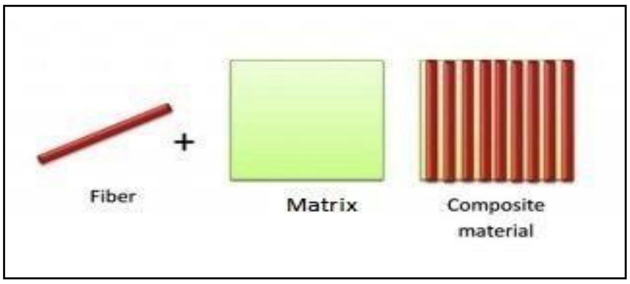
When designing an aircraft, it's all about finding the optimal proportion of the weight of the vehicle and payload. It needs to be strong and stiff enough to withstand the exceptional circumstances in which it has to operate. The main sections of an aircraft, the Fuselage, tail and wing, determine its external shape. The load bearing members of these main sections, those subjected to major forces such as Skin, Bulkheads, Stringers, Floor beams etc are called the airframe. The airframe is what remains if all equipment and systems are stripped away. Old aircrafts had skin made from impregnated linen that could hardly transmit any force at all. In most modern aircrafts, the skin plays an important role in carrying loads. Sheet metals can usually only support tension. But if the sheet is folded, it has the ability to carry compressive loads. Modern aircrafts such as Airbus A350 use skin made of composite materials such as CFRP – carbon fiber reinforced plastic.

The fuselage should carry the payload, and is the main body to which all parts are connected. It must be able to resist bending moments (caused by weight and lift from the tail), torsional loads (caused by fin and rudder) and cabin pressurization. The structural strength and stiffness of the fuselage must be high enough to withstand these loads At the same time, the structural weight must be kept to a minimum. In transport aircraft, the majority of the fuselage is cylindrical or near-cylindrical, with tapered nose and tail sections. The semi-Moncoque construction, which is virtually standard in all modern aircraft, consists of a stressed skin with added stringers to prevent buckling, attached to hoop-shaped frames. The fuselage also has member's perpendicular to the skin, that supports it and helps keep its shape. These supports are called frames if they are open or ring-shaped or bulkheads if they are closed.

Composite materials have been widely used in aerospace structural components, automobile industries and many other industrial applications, particularly in those which are technologically sophisticated, due to their high specific strength, high specific stiffness, anti-corrosion ability, workability, low density, superior performance reliability, ease in fabrication of complex shapes and several other attributes.

Composite Materials

Composite materials those are emerged in the middle of the 20th century as a promising class of engineering materials providing new prospects for modern technology.Generally speaking any material consisting of two or more components with different properties and distinct boundaries between the components can be referred to as a composite material. Composite materials consisting of stiff and strong fibers (glass, carbon, boron etc) embedded in compatible matrix (polymer, metal, and ceramic) have emerged as engineering materials of the future in aerospace. Due to their heterogeneous, anisotropic characteristics and non linear or inelastic behavior, engineering analysis of composite parts/structures/products demand the applications of FEM. composite materials that is under study are called “reinforced materials”. The basic components of these materials (sometimes referred to as “advanced composites”) are long and thin fibers possessing high strength and stiffness.



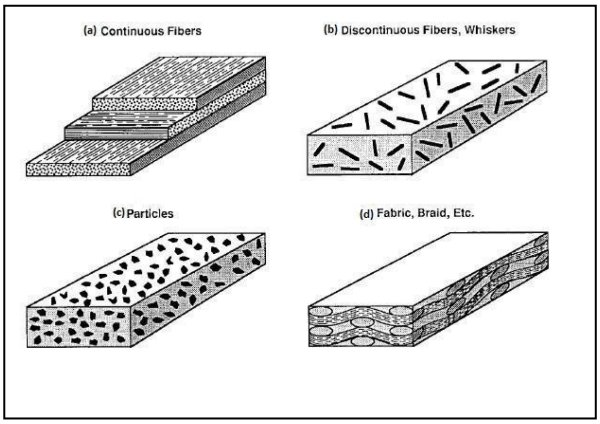
Conventional Composite material

Continuous fibers (the first type of fibers used in advanced composites) are made by pulling molten liquid form of fiber through 0.8-3.0 mm diameter dies and further high-speed stretching to a diameter of 3-19 µm. Usually carbon fibers have solid circular cross sections.

However there exist fibers with rectangular (square or plane), triangular, and hexagonal cross sections, as well as hollow circular fibers. Themechanical characteristics and density of fibers differ for different cross section.

Overall, the properties of the composite are determined by:

i) The properties of the fiber
ii) The properties of the resin or matrix
iii) The ratio of fiberto resin in the composite (Fiber Volume Fraction)
iv) The geometry and orientation of the fiber in the composite



Reinforcement forms (or) Fiber orientations

Fiber types:

i) Glass Fiber
ii) Boron fiber
iii) Aramid (or) Kevlar
iv) Carbon Fiber

Since scope of this thesis is focused on Carbon Fiber Reinforced Plastic (CFRP) and its application on the Airbus A350 XWB fuselage sections, hence the study is mostly done on carbon fibers their mechanical properties and their manufacturing process.

2. Objectives of the paper:

The objective of the present work is to analyze the static; free vibration Analysis of a composite fuselage section (section 15 of Airbus A350-XWB).To achieves this goal the scope of the present work is as follows:

- The formulation part of composite Structure for Linear-static, free vibration Analysis using first order shear deformation theory (FSDT) is studied.
- Modeling the fuselage structure using **CATIA V5**individually and assemble it
- Creating of a Finite Element model for fuselage section in **Hypermesh9.0** software.

- Pre-processing the composite properties to the finite element model in **Hypermesh9.0**
- **Linear-Static Analysis -** Evaluation of Stress & displacements of the fuselage due to mechanical loading (internal payload) and pressure with fixed boundary conditions using**ANSYS** as solver.
- **Free Vibration analysis -** the natural frequencies and mode shapes of the composite fuselage structureare Extracted in **ANSYS 13.0**
- Above project is also done experimentally by considering a small specimen

3. LITERATURE SURVEY

1) **Marco Aurelio Rossi, SérgioFrascino Müller de Almeida** developed a new methodology in the year 2013 developed for an analytical model of a composite fuselage. It also presents finite element analyses of a simplified model and comparisons with more complete models. These comparisons show that there is a very good correlation between both models for the cases studied. Therefore, the applicability of the proposed procedure was demonstrated. Based on finite element analyses, the present paper also presents a weight comparison between a composite fuselage and an aluminum alloy one. This comparison assesses the weight reduction obtained with the use of composite materials for designing the fuselage.
2) **Michel van Tooren& Lars Krakers.** Conducted a design study was started in the year 2012 to compare sequential versus concurrent multi-disciplinary design of a simplified fuselage structure. Design and Engineering Engine (DEE) has been built that is able to generate (input for) mechanical, acoustical and thermal models of stiffened and un stiffened simplified fuselage sections with optional floors subjected to mechanical, acoustical and thermal loads.
3) **Richard Varvill& Alan Bond** showed several different structural concepts exist for the primary load bearing structure in the year 2012. This paper explores the design possibilities of the various types and explains why an independent near ambient temperature CFRP truss structure was selected for the SKYLON vehicle (air breathing rocket engine). The construction of such a truss structure, at a scale not witnessed since the days of the airship, poses a number of manufacturing and design difficulties this paper describes the current design status of the overall truss geometry, strut construction and manufacturing route, and the final method of assembly
4) **Rodney Andrews and Eric's**In the year 2011,paper reports the mechanical and flow properties of these low density composites. Three point flexural strength tests were used to measure composite yield strength and flexural moduli. Composites containing over 10 pph binders had adequate yield strength of about 200 psi at activations up to 40% weight loss. The composites were anisotropic, having along-fiber to cross-fiber yield strength ratios between 1.2 and 2.0
5) **Alessandro Monaco, Jos Sinke&RinzeBenedictus** described that the results of a study to assess the potential weight and cost savings of using TMBs (tailor-made blanks) in a typical aerospace structure in the year 2010. A bonded structure representing the floor beam of an aircraft has been selected, analyzed, and tested to validate the numerical and analytical predictions made with MATLAB and finite-element method. The results show weight reduction of 12% and 37% for two studied configurations, compared to the reference beam.
6) **H. R. C. S. Bandara , M. D. Aravinda, J. C. P. H. Gamage , S. D. Weerakon** showed that use of Carbon Fiber Reinforced Polymers (CFRP) has become a most promising and affordable solution for strengthening of structures due to their superior properties in the year 2010. The major challenge of this

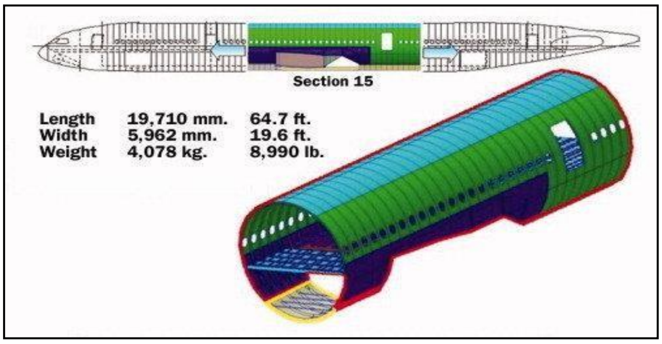
composite application in outdoor structures is the long term durability of the bond between CFRP sheet and the concrete substrate the short term and long term behavior of a composite member was predicted and validated with experimental results. The results showed that the bond between CFRP and concrete is sensitive to the environmental conditions, such as temperature and humidity fluctuations.

4. Modeling of Airbus A320-Xwb Fuselage Section-15

AIRBUS A320 XWB Specifications

The **Airbus A320** is a family of long-range, wide-body jet airlinersunder development by European aircraft manufacturer Airbus. The A320 will be the first Airbus with both fuselage and wing structures made primarily of carbon fiber-reinforced polymer (CFRP) about 53%. It will carry 200 to 300 passengers in three-class seating the redesigned A320 was marketed by Airbus as the A320 XWB, where the **XWB** stands for **Extra Wide Body**.

The new XWB fuselage will have a constant width from door 1 to door 4, unlike previous Airbus aircraft, to provide maximum usable volume, the skin will be made of 4 CFRP panels and The double-lobe fuselagecross-section will have a maximum outer diameter of 5.97 m (19.6 ft), compared to 5.64 m (18.5 ft) for the A330/A340 Airbus says that the seat width will be 1.3 cm (0.5 in) greater than a 787 seat in the equivalent configuration. In the nine-abreast, 3–3–3 standard layout(Economy class), the XWB's seat width will be 45 cm (18 in) which will be 1.3 cm (0.5 in) wider than the proposed equivalent seat layout for the Boeing 787.



Fuselage center section (or) section-15

Airbus A350-XWB family Specifications

Specifications	**A320-800**	**A320-900**	**A320-1000**
Overall length (m)	60.54	66.61	73.88
Wing span (m)	61.10	64.74	68.75
Wing area (m^2)	335	362	442
Fuselage width (m)	5.96	5.96	5.96
Max Takeoff weight	245000kg	268000 kg	295000kg
Wing loading	731.34 kg/m^2	740.33 kg/m^2	--
Mach no	0.86	0.86	0.86
Service Entry	Mid – 2014	Mid - 2013	Mid - 2016

Modeling software – CATIA V5

CATIA (**Computer Aided Three-dimensional Interactive Application**) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. CATIA version 5 is a process-centric computer-aided design/computer-assisted manufacturing/computer-aided engineering (CAD/CAM/CAE) system that fully uses next generation object technologies and leading edge industry standards. It enables users to simulate the entire range of industrial design processes from initial concept to product design, analysis, assembly, and maintenance. The CATIA V5 product line covers Aerospace, mechanical and shape design, styling, product synthesis, equipment and systems engineering, NC manufacturing, analysis and simulation, and industrial plant design.

CATIA V5 has an innovative and intuitive user interface that unleashes the designer's creativity. Context-sensitive integrated workbenches provide engineers with the tools they need for the task at hand, and they are beneficial for multi-discipline integration. The workbenches have powerful keyboard-free direct object manipulators that maximize user productivity. Its applications are based on a hybrid modeling technology.

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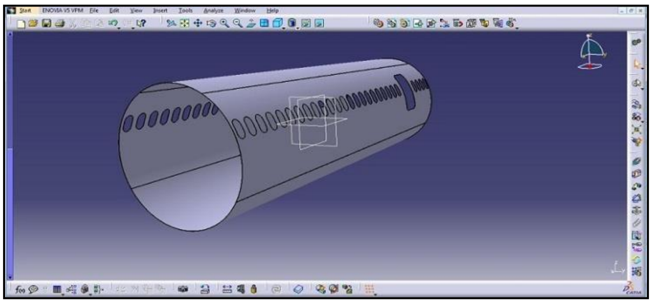
The Airframe

The primary load bearing members of fuselage section are Skin, Bulkheads, Stringers, and Floor beams;the airframe is what remains if all equipment and systems are stripped away. In most modern aircrafts, the skin plays an important role in carrying loads; all major loads such as pressure, shear, and bending loads are transferred from one member to other.

(a) Skin

The skin of Airbus A350 XWB aircraft is a 4 panel skin concept made from carbon fibers reinforced polymer (CFRP)

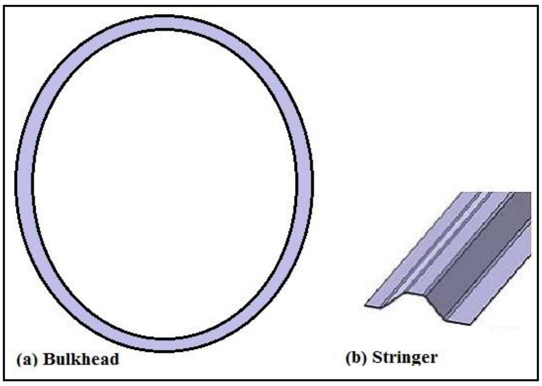


Width: 5,962 mm Length: 19,710 mm Thickness: 3 mm

panel Skin created in CATIA V5

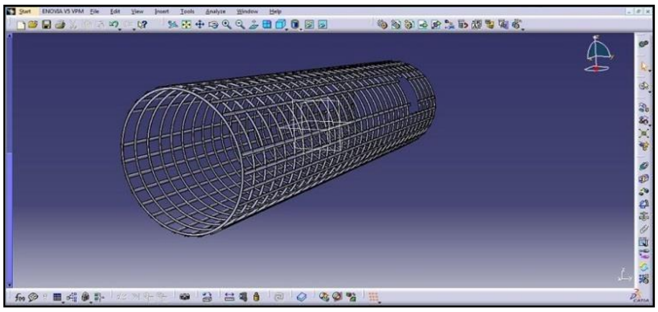
(b) Bulkheads and Stringers

Bulkheads are the circular frames kept at regular intervals throughout the fuselage section and considering the section – 15 the diameter of a bulkhead is 5960 mm with a thickness of 6 mm constant along the length, 30 bullheads are kept at an interval of 657 mm over a length of 19,710 mm



Bulkhead and Stringer profiles

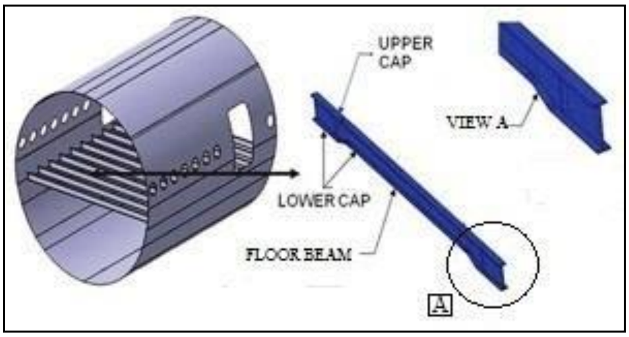
Stringers are long sender members which run longitudinally along the length of the fuselage section. We used Omega stringer with a 50mm height and thickness of 6 mm. Bulkheads and stringer are considered to be made of Aluminum Frames.



Bulkhead and Stringers made in CATIA V5

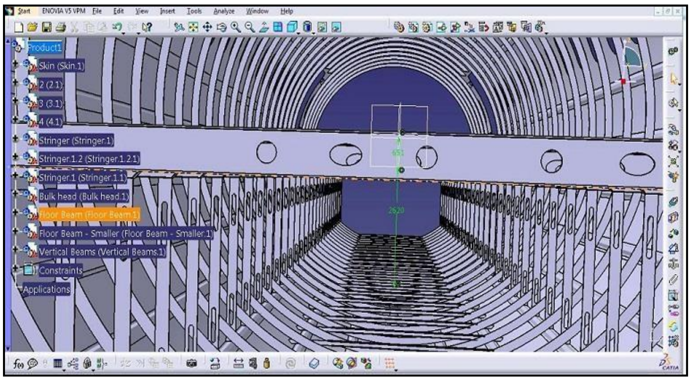
(c)Floor beams and Vertical Beams

Major loads acting on an aircraft are transferred and distributed from one airframe to other in this case they are transferred from skin to bulkheads & stringers and from there to floor beams and vertical beams therefore floor beams are considered to be I – section beams which should withstand high amount of loading.



Floor beam detailed view

They are considered to be made of Steel with a thickness of 10 mm



Floor beams model in CATIA V5

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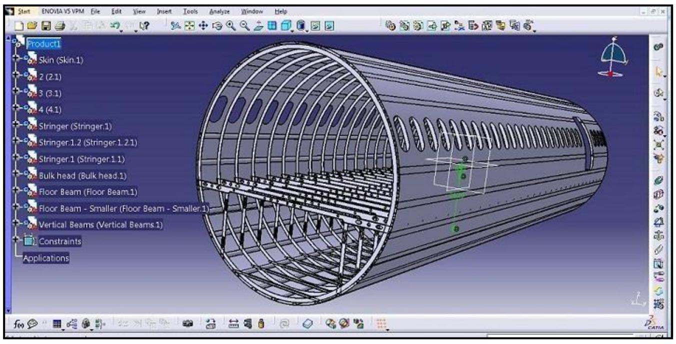
Final Assembled Structure

The assembly of all airframes i.e. Skin, Bulkheads, Stringers, Floor beams Etc is done to make complete Section – 15 of AIRBUS A350 XWB making it a composite structure



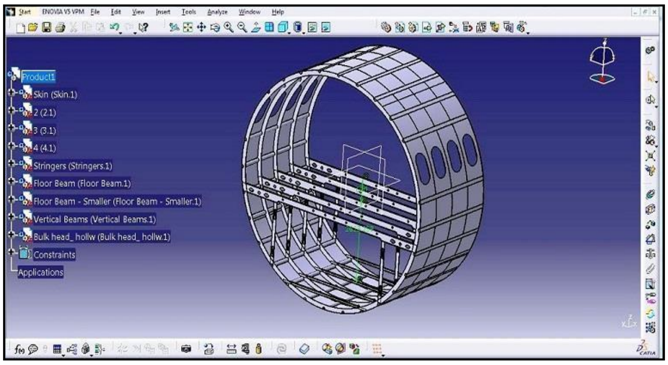
Assembly of structure in CATIA V5

Meshing Software – HYPERMESH 9.0

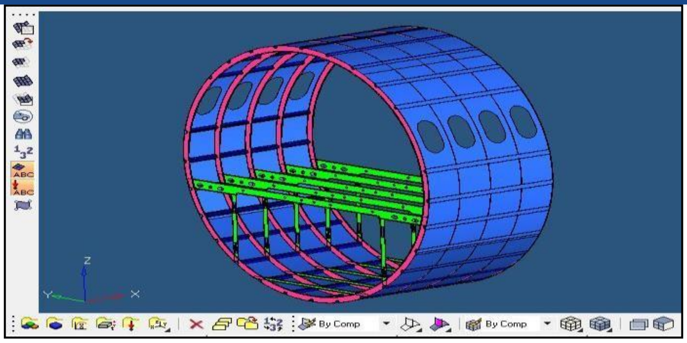
Altair Hypermesh is a high-performance finite element pre-processor that provides a highly interactive and visual environment to analyze product design performance.

Optimization of the fuselage section for analysis

Meshing the complete section – 15 will create lakhs of nodes and elements, it will take several hours to solve in an high performance super computers and the results may still be approximate therefore we take a small section of the fuselage of about 5 bulkheads length(3285mm). Since section – 15 has a uniform diameter the results obtained for this small section will be same throughout. Shown below is CATIA product file saved in format supported by Hypermesh as (.igs) or (.stp) after opening the Hypermesh software import this .igs file



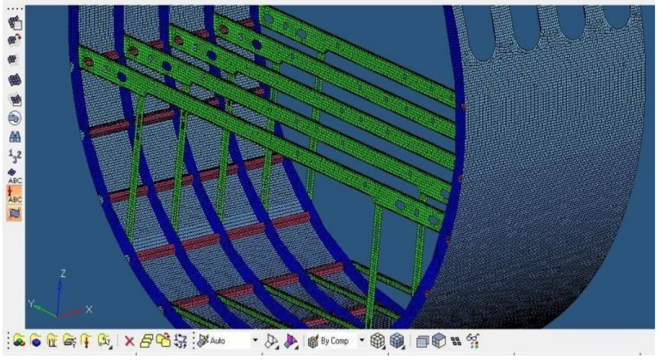
Small section of fuselage section



Section after imported in Hypermesh 9.0

Meshing

The geometry is meshed with an element size of 25 maintaining least number of triads and also maintaining node to node and element to element connectivity. The complete mesh generated 1, 33,845 elements



After meshing the model in Hypermesh 9.0

5. ANALYSIS

LINEAR STATIC ANALYSIS:

When loads are applied to a body, the body deforms and the effect of loads is transmitted throughout the body. The external loads induce internal forces and reactions to render the body into a state of equilibrium.Linear-static analysis is used to calculate the structural response of bodies spinning with constant velocities or travelling with constant accelerations since the generated loads do not change with time.

Linear Static analysis calculates displacements, strains, stresses, and reaction forces under the effect of applied loads. The figures below show the force vs. displacement and Stress vs. strain curves where a structure behaves in a linear fashion

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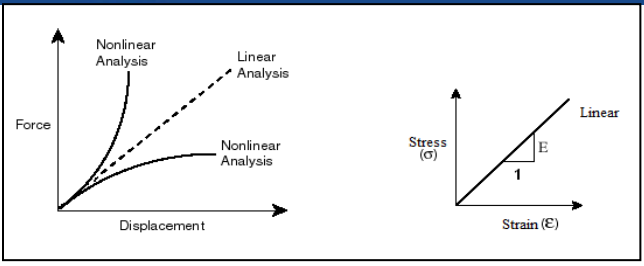


Force Vs displacement and Stress Vs strain curves.

Linear means straight line, the equation of straight line is y = mx passing through origin which is similar to the equation **$\sigma = \varepsilon$ E**where E "elastic modulus" is slope of the curve and is a constant. In real life after crossing yield point material follows non linear curve but the software follows same straight line i.e. component brake into pieces after crossing ultimate strength but software based analysis never show failure in this fashion but it shows single unbroken part only with a dark red color zone at location of failure. We have to conclude the component is safe of failed by comparing the Maximum stress value with Yield and ultimate stress of material.

i) Assumptions

Linearity assumption, the relationship between loads and induced responses is linear. For example, if you double the loads, the response of the model (displacements, strains, and stresses) will also double. Linearity assumption made if:

a. All materials in the model comply with Hooke's law, that is stress is directly proportional to strain
b. The induced displacements are small enough to ignore the change in stiffness caused by loading
c. Boundary conditions do not vary during the application of loads.
d. Loads must be constant in magnitude, direction, and distribution. They should not change while the model is deforming

ii) Governing Equation

The governing equilibrium equation for the static analysis without thermal load can be obtained as a special case of dynamic analysis and it may be written as

$$[K]\{d\} = \{F\}$$

Where, $[K]$ is stiffness matrix
{d} is displacement matrix
{F} is force matrix

iv)Material properties

In our analysis composite structure will be composed of high strength Carbon fiber, Aluminum and steel making the aircraft lighter than a comparable complete aluminum fuselage, with the added benefit of less maintenance thanks to carbon fibers superior fatigue resistance, high strength and rigidity

FREE VIBRATION ANALYSIS

The study of free vibration behavior is very important to analyze fuselage since it a composite structure, different materials will have different natural frequencies and if their frequencies match then they produce vibrations and noise (phenomenon is called resonance) free vibration analysis will help in designing sensors and actuators to control vibrations.

Static analysis does not take into account variation of stress with respect to time. Output in the form of stress, displacement etc with respect to time can be predicted in vibration analysis in form of mode shapes; this analysis is also generally known as Modal analysis.

i) Governing equation

The governing equation for free vibration analysis , it is written as

$$[M]\{\ddot{d}\}+[K]\{d\} = 0$$

Where $[M]$ and $[K]$ are global mass and stiffness matrices and $\{d\}$,$\{\ddot{d}\}$ are global displacement and acceleration matrices respectively.

ANSYS 13.0

ANSYS is a general purpose finite element modeling package for numerically solving a wide variety of mechanical problems, used widely in industry to simulate the response of a physical system to structural loading, Thermal, Modal and Electromagnetic effects. It uses the finite-element method to solve the underlying governing equations and the associated problem-specific boundary conditions.

ANSYS can carry out advanced engineering analyses quickly, safely and practically by its variety of contact algorithms, time based loading features. It act as a pre processor, post processor and solver tool. After defining loadings and boundary conditions analyses are carried out, results can be viewed as numerical and graphical.

Reading Input file

Based on Finite Element Method a FE model is created with given data in Hypermesh.After assigning all the material properties, boundary conditions and solution set required, the file is saved in Ansys format (.cdb) and the same file read in Ansys software and solved

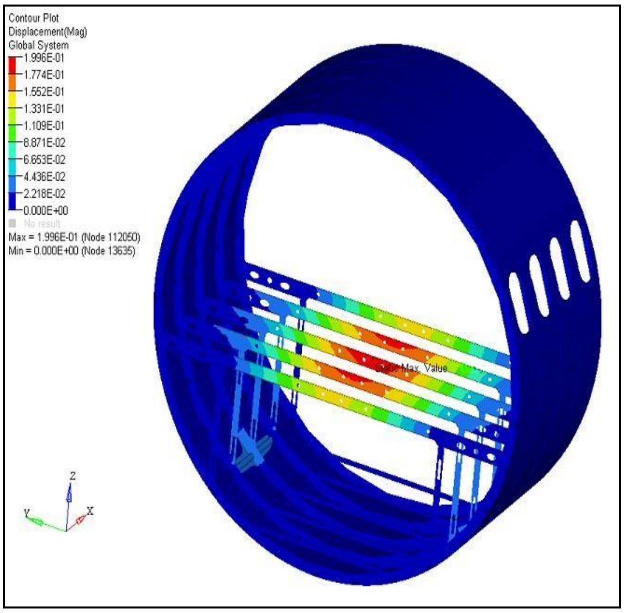
Natural frequencies obtained for no load conditions in Ansys 13.0

***** INDEX OF DATA SETS ON RESULTS FILE *****	
SET	TIME/FREQ (Damped)
1	$0.53480E^{-04}$
2	$0.28633E^{-03}$
3	$0.28849E^{-03}$
4	$0.22482E^{-01}$
5	$0.28761E^{-01}$
6	$0.30359E^{-01}$
7	2.2141
8	2.2319
9	2.2556
10	2.2679

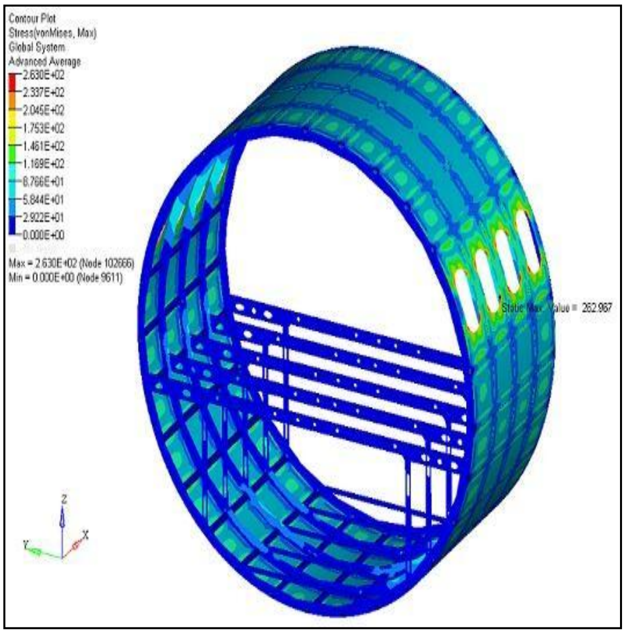
The natural frequencies obtained for the first 6 set specifies for the 6 DOF, three translational and three rotational. The frequency values shown are almost zero for the first 6 set hence we can say that the structure is rigidly fixed and it does not have any gaps between the structures.

6. RESULTS AND DISCUSSIONS FOR LINEAR STATIC ANALYSIS

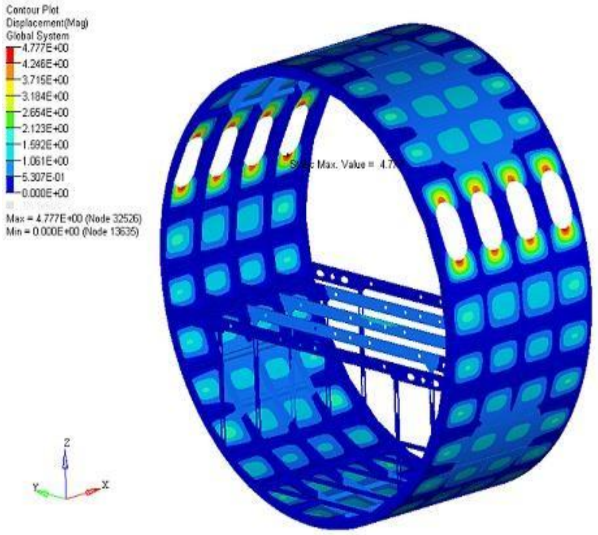
TheMaximum displacement due to point load on floor beam made of steel, solved in Ansys is given 1.99 mm approximately 2 mm.



Maximum displacements at center

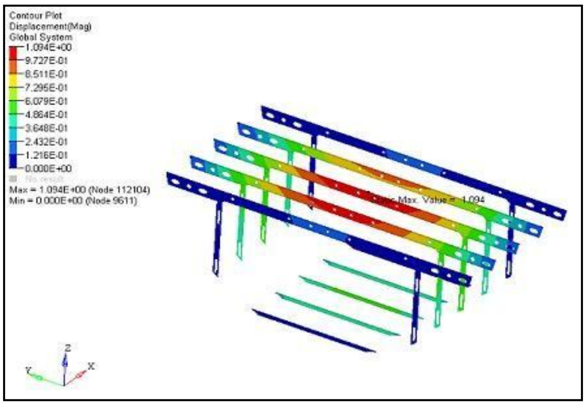


The maximum stress (von mises) obtained is 262.967 N/mm^2

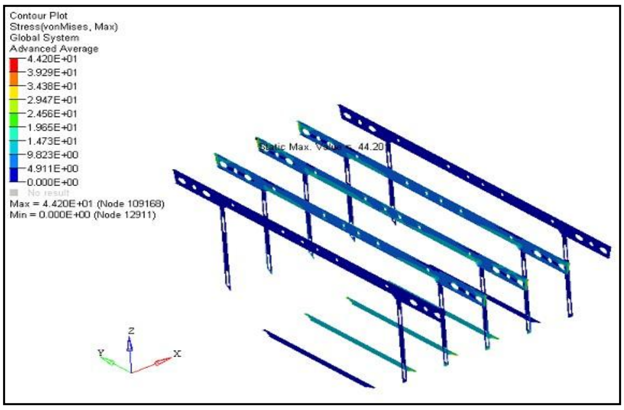


The maximum displacement obtained is 4.7 mm

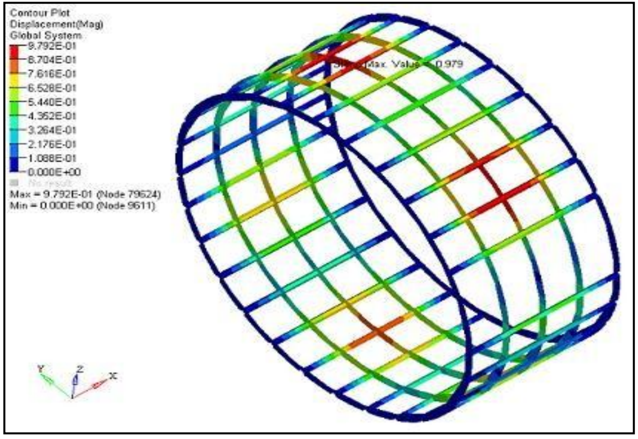
Results of individual component



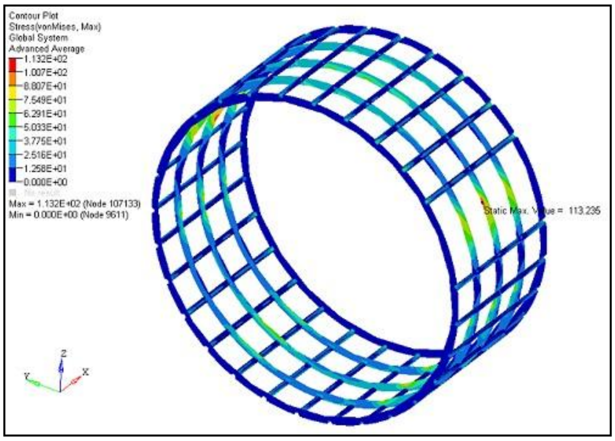
The maximum displacement of steel floor beam is 1.09 mm



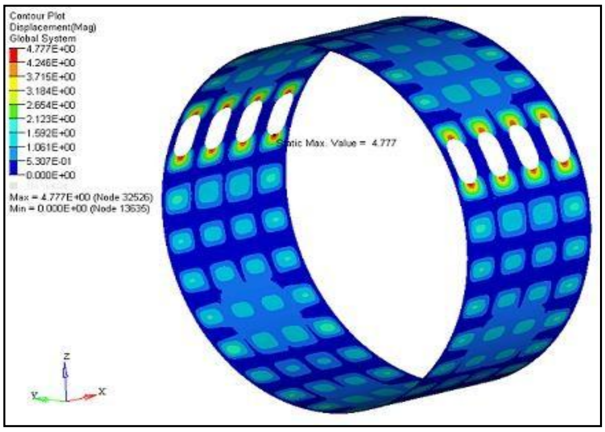
The maximum stress (von mises) obtained on steel



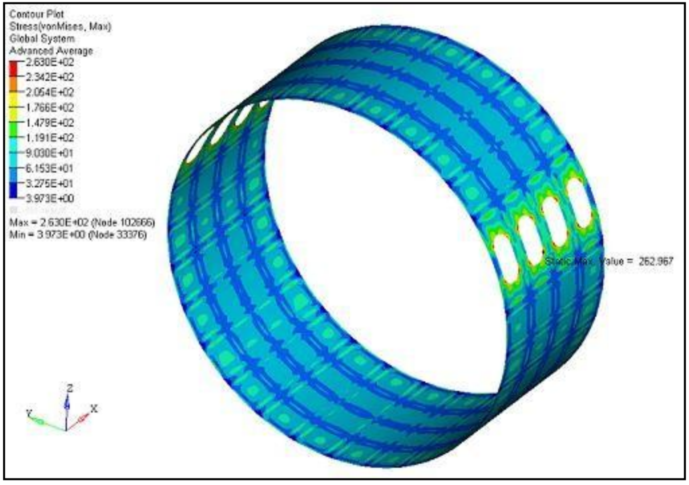
The maximum displacement of Aluminum alloy components is 0.97 mm



The maximum stress (von mises) obtained on Aluminum alloy is 113.236 N/mm^2



The maximum displacement of CFRP skin is 4.77 mm



The maximum stress (von mises) obtained on CFRP skin is 262.967 N/mm^2

Results Summary

Material	Max disp (mm)	Stress (Von mises) (N/mm2)	Yield Stress (N/mm2)	Factor of safety Y S/ S(von mises)	Remarks
Steel	1.09	44.20	250	5.6	safe
Aluminum alloy	0.97	113.236	165	1.45	safe
CFRP	4.77	262.967	3500	13.3	safe

From the above results it can be concluded that the composite structure of the fuselage section is within safe limit having high factor of safety value.

1. Result for complete composite structure

Shows the maximum stress (von mises) obtained for compete structure is 262.967 N/mm^2

Shows the maximum displacement obtained for complete structure is 4.7 mm

2. Results of Floor Beam made of steel

Shows the maximum displacement of steel floor beam is 1.09 mm

Shows the maximum stress (von mises) obtained on steel floor beam is 44.20 N/mm^2

3. Results of Bulkheads and stringers made of Aluminum alloy

Shows the maximum displacement of Aluminum alloy components is 0.97 mm

Shows the maximum stress (von mises) obtained on Aluminum is 113.236 N/mm^2

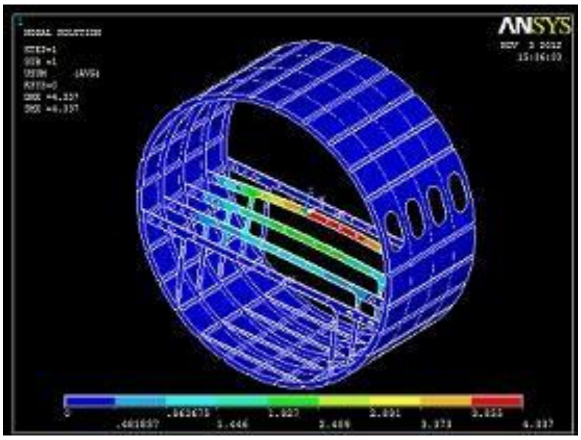
4. Resultsof Fuselage skin made of CFRP

Shows the maximum displacement of CFRP skin is 4.77 mm

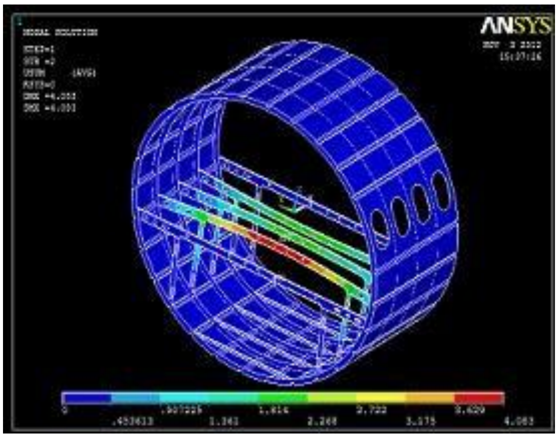
The maximum stress (von mises) is obtained on CFRP skin is 262.967 N/mm^2

Mode shapes

The mode shapes are extracted after fixing the boundary conditions for the structure in this case fixing the first and the last bulkhead including skin.



Mode 1



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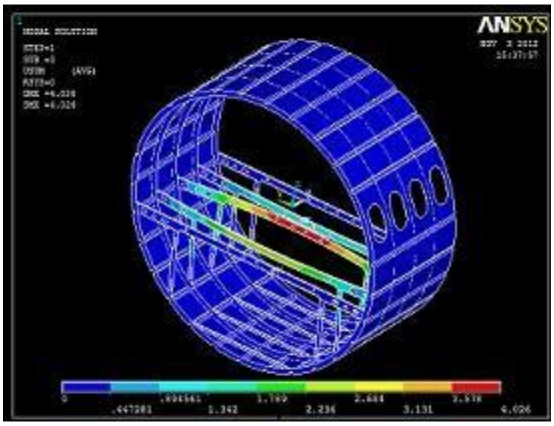

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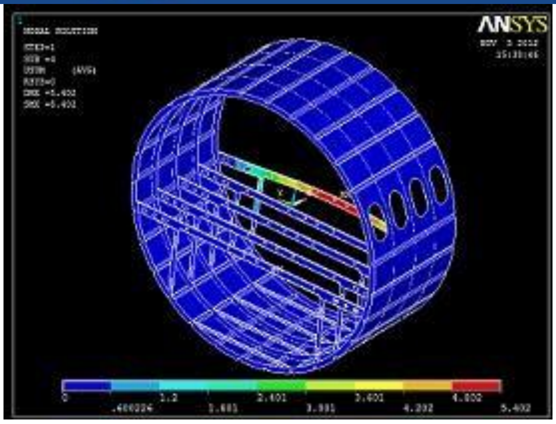

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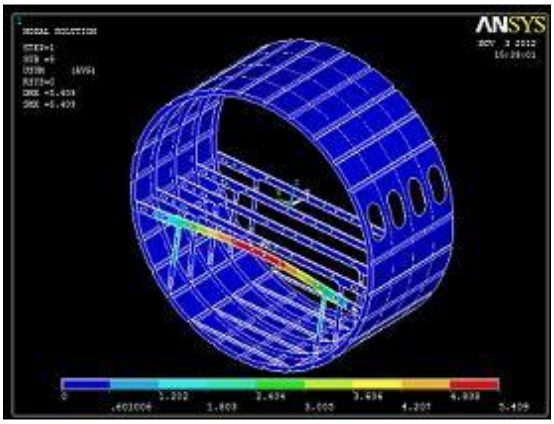

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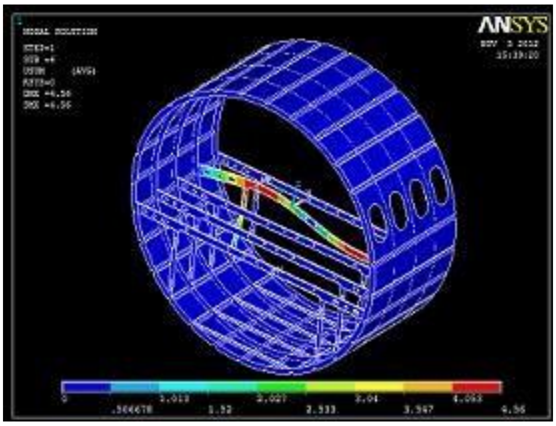

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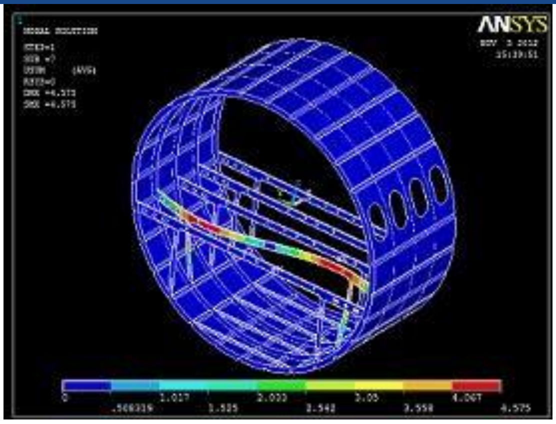
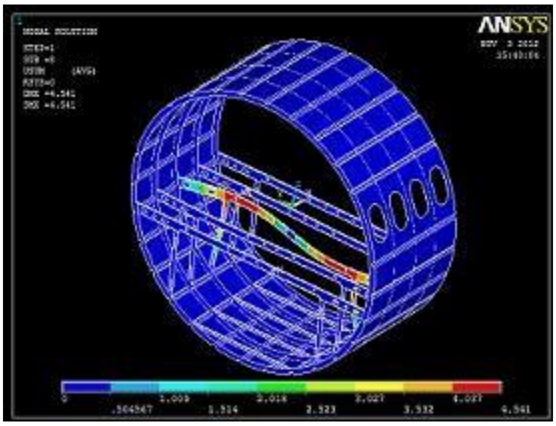
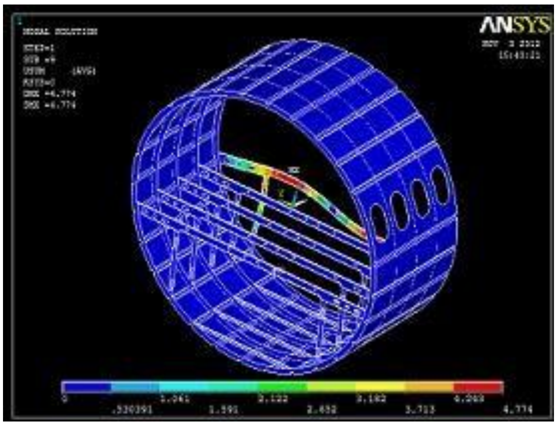


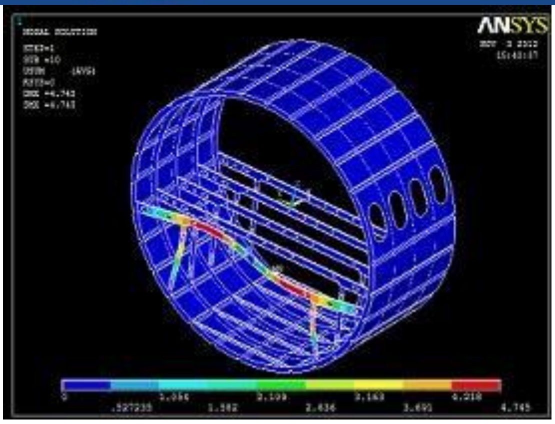
Mode 7



Mode 8



Mode 9



Mode 10

10 mode shapes were extracted in Ansys 12.0 to the understand the structural behavior, when it is exited with a natural frequency of 100 Hz

The results

Set No	Mode Shape No	Time/Frequency	Displacement (mm)
1	Mode 1	2.2592	4.337
2	Mode 2	2.2610	4.083
3	Mode 3	2.2712	4.026
4	Mode 4	3.9007	5.042
5	Mode 5	3.9367	5.409
6	Mode 6	7.1801	4.560
7	Mode 7	7.1942	4.575
8	Mode 8	7.1966	4.541
9	Mode 9	10.169	4.774
10	Mode 10	10.243	4.745

The maximum displacement obtained is for mode shape 15 and the minimum is for mode shape 1 which shows that as the frequency with which the structure is exited is increased the displacement also increases.

CONCLUSION

Linear-static and free vibration analysis is carried out to investigate the performance of a fuselage section made of composite structure due to mechanical load. In the present work, a CAD model of Airbus A320 XWB fuselage section-15 is Designed inCATIA V5 SOFTWARE and optimized, the geometry is meshed in Hypermesh to create a finite element mathematical model. A 8-noded shell63 element is used for present study. The element contains six-degree of freedom and it is effective for static and dynamic problems. Hypermesh was used as a preprocessor to generates code for present FE mathematical model according to given material properties, boundary conditions and loads. Using these generated codes solves for the static Analysis and ANSYS is usedto solves the Model or Free vibration Analysis. The present analysis is also validated by comparing the numerical results with the standard yield stress values of the materials considered.

Now, based on the finite element analysis carried out for linear-static and free vibration, problems, the following important conclusions are made.

- **From the Linear-static analysis** it was observed that the composite structure is within the yield stress of the materials and in fact with a higher margin of factor of safety , the maximum displacement value is 4.7 mm and Max stress is 262.967 N/mm^2
- **From the free vibration analysis**, it is found that the composite structure is rigid without any gap which helps in maintaining structural integrity , the mode shapes specified that as the frequency increases the displacement increases and also the displacement obtained 4.33 mm which approx matches with static analysis

Future scope of present work:

During the course of research work, various problems have been found interesting in this area. However, only a very few issues are attempted in the present work. The following important problems may be focused for the future investigation.

- Thermo-elastic behavior i.e. effects of temperature on the structure can be considered and present work extended to static and dynamic analysis in thermal environment.
- Present work can be extended to Fatigue analysis.

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