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Design & Analysis of Fuselage Structure using Solidworks & ANSYS

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Abstracts

This paper describes a conceptual design and analysis of fuselage structure for A320 NEO (New Engine Option) aircraft by using Solidworks and ANSYS software as a design tool. Specific size, configuration arrangements, weight and performance and some commanality of features with existing A320 aircrafts are need to be considered in the design process. This conceptual design develops the first general size and configuration for a new A320 NEO aircraft fuselage structure. The model of the fuselage structure is then undergoing model analysis, linear buckling and fatigue life. In this paper structural and model analysis of A320 fuselage structure, we aim to learn the process to solve many engineering problems with the help of a solver commonly known as SPARSE directs solver which is the default solver in ANSYS without preparing the prototype model and caring the actual experiments.

Keywords: aircraft structure design, finite element analysis, fuselage structure, optimization.

Introduction

Designing an aircraft can be an overwhelming task for a new designer. The designer must determine where the wing goes, how big to make the fuselage, and how to put all the parts together. The general arrangements of a new aircraft design should be based on a proper investigation into the interpretation of the transport function and a translation of the most pertinent requirements into a suitable positioning of the major parts in relation to each other. There are many aspects of design of aircraft structure. For modern jet aircraft, the design must incorporate with clear aerodynamic shapes for long range flight near or at supersonic speeds, and or wings to open up like parachutes at very low speeds. All structures must withstand hail and lightning strikes, and must operate in, and be protected against, corrosive environment indigenous to all climates. The structure must be serviceable from 15 to 20 years with minimum maintenance and still be light enough to be economically competitive. The design must incorporate new materials and processes that advance the state of the art. Using new techniques often require developing still newer processes.

A good overall structural concept incorporating all these factors is initiated during preliminary design. At the very beginning of a preliminary design effort, the designer writes a set of specifications consistent with the needs. It should be clearly understood that during preliminary design it is not always possible for the designer to meet all the requirements of a given set of specifications. In fact, it is not at all uncommon to find certain minimum requirements unattainable. It is there necessary to compromise. The extent to which compromises can be made must be left to the judgment must be exercised in considering the value of the necessary modifications and or compromises. The first task of the designer is to familiarize himself thoroughly with the specification of the airplane upon which the design is to be based. Also, if the airplane is to be sold to more than one customer, all available information should be obtained to minimize the design that might be required in the future. There should be no thought of making a general purpose airplane, suitable for any purchaser or any use, because that is an impossibility. However, it is frequently possible to arrange a design which would simplify future changes without sacrificing either structural or aerodynamic efficiency or taking weight penalty.

Next, the designer should familiarize himself with all existing airplanes of the same general type as that proposed. If possible, it is advisable to collect all comments, both positive and negative, of pilots, passengers, maintenance groups and operators using the existing equipments. The designer should not blindly just copy any existing design just because it happens to be available. On the other hand not to take advantage both on the successes and mistakes of others is inefficient. The modern aeronautical engineering of aircraft design has been an evolutionary process accelerated tremendously in recent times from the demanding requirements for safety and the pressures of competitive economics in structural design.

Fig.1 Aircraft structure

Design of fuselage structure

The proposed aircraft fuselage structure is a innovative fuselage concept. The whole fuselage is fabricated with Carbon Fiber Reinforced Plastic (CFRP). The main advantages in this new design are: (1) very good integration; (2) faster fabrication and assembly; (3) weight reduction (10-15%); (4) possibility of thickness variations; (5) less waste of raw material; (6) higher passenger comfort level; (7) possibility of larger windows; (8) longer structural life (less sensitive to fatigue).

The fuselage will be constructed in three parts along the longitudinal axis in order to facilitate the construction process and improve reparability. Each part of the fuselage will be manufactured by the FP (Fiber Placement) process resulting in a single non-circular panel. All the stringers will be positioned in the mandrel of the ATL process and these stringers will be already fabricated and cured at this process stage. The result of the FP process will be the stringers mounted in the single non-circular panel skin. The next fabrication process is the panel skin cure.

Solid Works is a Parasolid-based solid modeller, and utilizes a parametric feature-based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allows them to capture design intent.

The first step of the analytical model is an estimative of the thickness, number of layers and stacking sequence of the skin laminate. Then, the skin cross section area and the moment of inertia of the cross section about axis y-y can be computed. Also, the effective Young's modulus and the Poisson ratio of the skin are computed. Next, an estimative of the thickness and number of layers of the stringer is made. As width, height and number of stringers are known, the cross section area and the moment of inertia of the cross section about axis y-y of the stringer can be computed.

Basically fuselage structure can be divided into three sections which are cockpit, tail section and cabin section. For this study the conceptual design is focussing on cabin structure of the fuselage.

Table 1.General Characteristics

Crew	2-3 crew members
Capacity	150 passengers
Cabin length	27.51m
Fuselage width	3.95m
Height	11.76m
Maximum takeoff weight	162900lb
Wing span	35.80m

In the first stage of design we develop three types of the basic concept of fuselage structure.

All the three concepts are distinguished by different number of components. However, the configuration of each component is simplified in order to produce new ideas based on the structure arrangement. The diameter of a fuselage is constant for each concept which is 3950mm.

For the first basic concept, the arrangement of the structure comprises of stringers, frame and floor beam. The frame spacing in this concept is smaller compared to the stringers spacing. By increasing the number of frames, the shape of the fuselage will be more rigid due to its function to support the shell.

Besides that, the capability of the frame in distributing the concentrated load will increase. According to the second basic concept, the arrangement of the structure is similar to the first concept but the frame spacing is larger compared to the stringers spacing. This concept provides more efficient resistance to compressive stress since more components carry axial load which cause by bending.

The third concept is the structure with the number of frame and stringers are equal. In this concept, the spacing for both frames and stringers is approximately equal. The reason for this idea is to provide a great stiffness of the structure. Loads subjected to this structure are carrying equally by both components. However, the number of components and joints are increased compared to the previous concepts.

From these concepts, by considering the weight and the strength of structure, the next configuration is chosen. Besides that, the space for window and door which is including in ergonomics point of view also be in consideration. This chosen structure is adjusted by doing optimization regarding the weight and the strength of structure using finite element method.

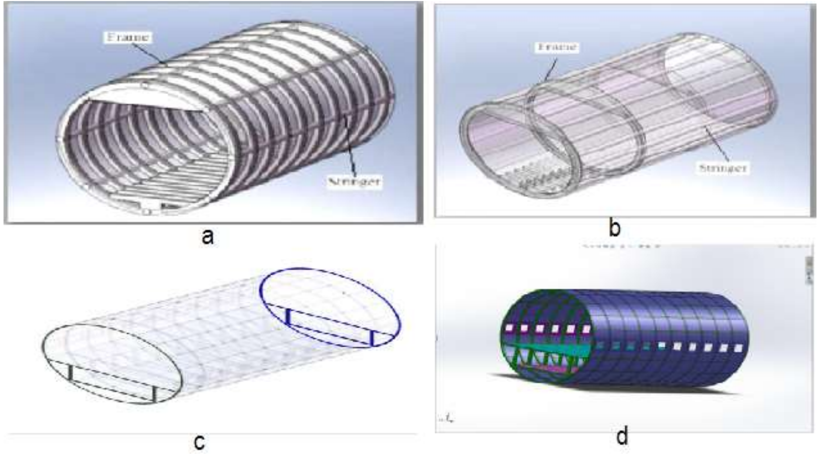

Fig.2 a) Concept-1, b)Concept-2, c)Concept-3, d) Concept-4

A) Shell

The word shell is an old one and is commonly used to describe the hard covering of eggs, crustacean, tortoises, etc. The dictionary says that the word shell is derived from the Latin *scalus*, as in fish scale. But to us now there is a clear difference between the tough but flexible scaly covering of a fish and the tough but rigid shell of, say, a turtle.

The shell of fuselage structure designed in solid works by estimating the skin thickness using Denis Howe's method the thickness of skin is 2mm.

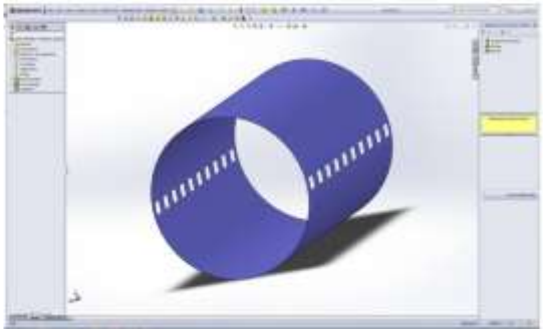

Fig.3 Fuselage shell

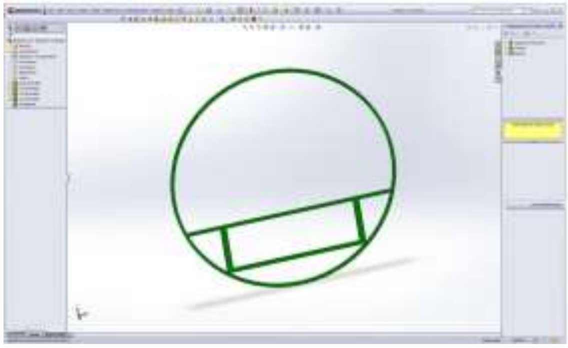

Fig.4 Bulkhead

B) Bulkheads

A bulkhead is a wall inside a craft such as a ship, airplane, or spacecraft. Bulkheads serve a number of structural functions, and there are wide arrays of variations on the basic bulkhead design which can be used in specific applications. The term "bulkhead" may also be used to describe a retaining wall in a mine or along seashore used for control of flood and erosion.

The Chinese appear to have been the first to use bulkheads in their ships. When mariners from other regions encountered Chinese ships, they took note of the bulkhead design and adopted it for themselves, causing it to spread rapidly across many shipbuilding cultures. Prior to the use of bulkheads, the entire hull of a ship would be open, creating a cavernous space.

Bulkheads also contribute to the structural stability and rigidity of a craft. In heavy seas, a ship with bulkheads will usually withstand the conditions better than a ship which lacks these internal walls, and the same holds true for aircraft, which must endure violent shearing forces on a regular basis. Engineers have refined bulkhead designs to provide maximum structural stability while adding minimal amounts of weight to ensure that craft are still capable of moving.

The final and perhaps most important reason to install a bulkhead is for safety. The compartmentalized design created with bulkheads allows people to contain fire, flooding, and other issues so that an entire craft is not ruined when accidents or sabotage occur. Requiring bulkheads for safety reasons is common in many areas of the world, and this concern also dictates the materials used in their construction, and the fittings which may be attached to them

C) Stringers

In aircraft construction, a longeron or stringer or stiffener is a thin strip of material, to which the skin of the aircraft is fastened. In the fuselage, stringers are attached to formers (also called frames) and run the longitudinal direction of the aircraft. They are primarily responsible for transferring the loads (aerodynamic) acting on the skin onto the frames/ formers. In the wing or horizontal stabilizer, longerons run span wise and attach between the ribs. The primary function here also is to transfer the bending loads acting on the wings onto the ribs and spar.

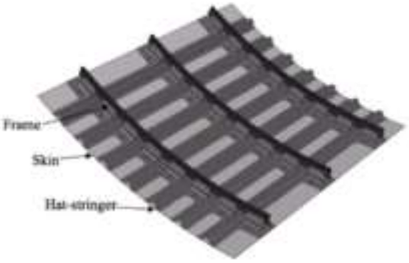

Fig.5 Stringer

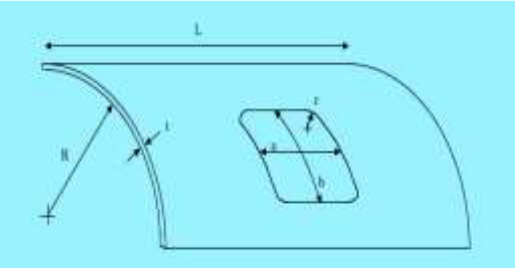

Fig.6 Window

D) Window

An aircraft fuselage structure must be capable of withstanding many types of loads, and stress Concentrations near cut outs are of particular concern. In this exercise, internal pressure in a structure similar to an A320 aircraft fuselage is considered. The objective of the analysis is to determine the stress state and the factor of safety in a square fuselage panel containing a window cut out. The geometrical, material, and dimension specifications for the panel are given in below table.

Table.2 Window dimensions

Radius of curvature	R=1925mm
Skin wall thickness	t=2mm
Windows dimensions	a=16mm,b=16mm
Windows corner radius	r=0.25mm
Span length	L=600mm
Material used	Aluminum alloy

In order to resist the loads and structural damage we give structural strength to the window cut out in the form of window panel.

E) Floor beam in passenger cabin

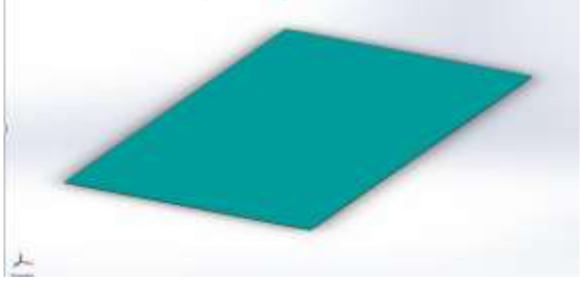

Fig.7 Floor beam of passenger cabin (snapshot taken from solid works)

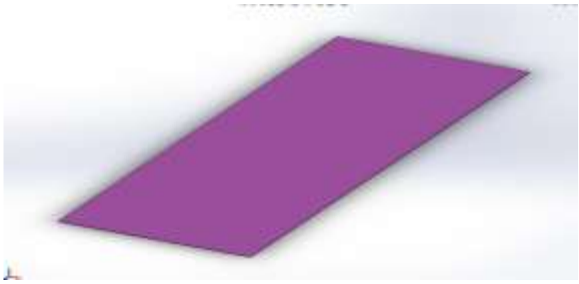

Fig.8 Floor beam of cargo cabin(snapshot taken from solid works)

Floor Beams - they represent the floor structure of the aircraft, with longitudinal beams, transversal beams and supporting beams. These beams can be machined or formed depending of the strength involved. They represent the basic structure of the floor.

F) Assembly of fuselage

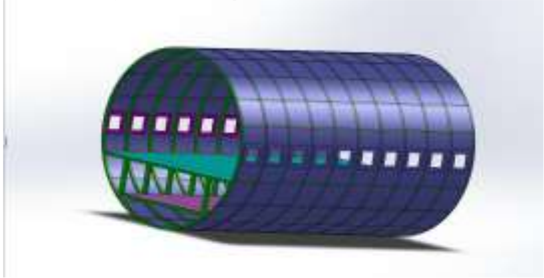

Fig.9 Assembly of Fuselage

Fig.10 Assembly of complete fuselage of length 36m

Static structural analysis of fuselage

This is the basic and most important FEA software tool and includes facilities to control part materials, contact regions, FE mesh, supports (constraints), loads, results and report production. This is part of the ANSYS Mechanical software.

The Engineering Data modules have a library of materials data. This can be edited to input data for new materials. (Design Exploration) These tools enable a systematic and automatic variation of parameters to optimize designs. Powerful but not recommended for this course. Design Explorer optimizations need to be treated with care as, although they can be amazingly effective for problems controlled by only “well behaved” functions with no step changes, step changes are common in engineering and the wrong optimum is easily presented.

A) Pressure Based Analysis

Aircraft are flown at high altitudes for two reasons. First, an aircraft flown at high altitude consumes less fuel for a given airspeed than it does for the same speed at a lower altitude because the aircraft is more efficient at a high altitude. Second, bad weather and turbulence may be avoided by flying in relatively smooth air above the storms. Many modern aircraft are being designed to operate at high altitudes, taking advantage of that environment. In order to fly at higher altitudes, the aircraft must be pressurized. It is important for pilots who fly these aircraft to be familiar with the basic operating principles.

In a typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine-powered aircraft to pump air into the sealed fuselage.

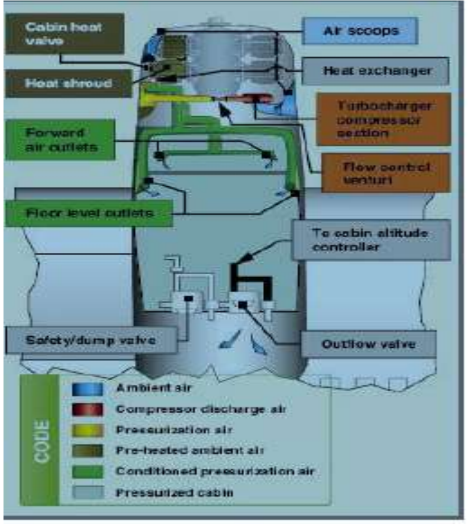

Fig.11 Cabin pressurization

Piston-powered aircraft may use air supplied from each engine turbocharger through a sonic venture (flow limiter). Air is released from the fuselage by a device called an outflow valve. By regulating the air exit, the outflow valve allows for a constant inflow of air to the pressurized area. Fig a cabin pressurization system typically maintains a cabin pressure altitude of approximately 8,000 feet at the maximum designed cruising altitude of an aircraft. This prevents rapid changes of cabin altitude that may be uncomfortable or cause injury to passengers and crew. In addition, the pressurization system permits a reasonably fast exchange of air from the inside to the outside of the cabin. This is necessary to eliminate doors and to remove stale air.

Pressurization of the aircraft cabin is an accepted method of protecting occupants against the effects of hypoxia. Within a pressurized cabin, occupants can be transported comfortably and safely for long periods of time, particularly if the cabin altitude is maintained at 8,000 feet or below, where the use of oxygen equipment is not required. The flight crew in this type of aircraft must be aware of the danger of accidental loss of cabin pressure and be prepared to deal with such an emergency whenever it occurs.

The pressure we gave on the shell is:
Internal pressure = 0.1 bar
External pressure= 0.2 bar

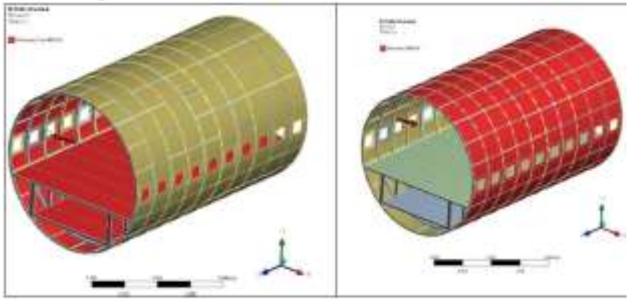

Fig.12 Internal pressure & External pressure

B) Buckling Analysis

Buckling is the general term frequently used in aircraft analysis to describe the failure of a structural element when a portion of the element moves normal to the direction of primary load application. The deformation alters the mechanism by which loads are transmitted. In all instances, regardless of the complexity of the system or the nature of the primary loading (compression, shear, torsion, etc.), it is the compression stress component that forces the buckle to occur. Correspondingly, it is the compression load capability that is interrupted by the buckle formation. The general term may be applied to beam-column behaviour, crippling, or any of the many complex failure modes as well as to the classical buckling behaviour.

Linear buckling (also called as Eigen value buckling) analysis predicts the theoretical buckling strength of an ideal elastic structure. Thus, linear buckling analysis often yields quick but non-conservative results.

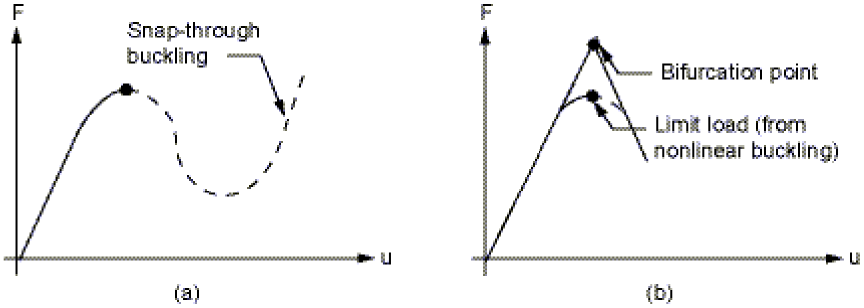

Fig.12 a) Linear buckling b) Non-linear buckling

A more accurate approach to predicting instability is to perform a nonlinear buckling analysis. This involves a static structural analysis with large deflection effects turned on. A gradually increasing load is applied in this analysis to seek the load level at which your structure becomes unstable. Using the nonlinear technique, your model can include features such as initial imperfections, plastic behavior, gaps, and large-deflection response. In addition, using deflection-controlled loading, you can even track the post-buckled performance of your structure (which can be useful in cases where the structure buckles into a stable configuration, such as "snap-through" buckling of a shallow dome).

ANSYS will by default solve for the frequencies of the first 6 vibration modes; however, we would also like to see how this affects the geometry. We can accomplish this task by looking at the total deformations of the airfoil to see where the nodes occur and how the geometry deforms.

C) Modal Analysis

Modal analysis is used to determine a structure’s vibration characteristics natural frequencies and mode shapes. It is the most fundamental of all dynamic analysis types and is generally the starting point for other, more detailed dynamic analyses.

Natural Frequency

The natural frequency is the rate at which an object vibrates when it is not disturbed by an outside force. Each degree of freedom of an object has its own natural frequency, expressed as ω_n . Frequency is equal to the speed of vibration divided by the wavelength.

$$\omega = \text{speed} \cdot \lambda$$

Other equations to calculate the natural frequency depend upon the vibration system. Natural frequency can be either undamped or damped, depending on whether the system has significant damping. The damped natural frequency is equal to the square root of the collective of one minus the damping ratio squared multiplied by the natural frequency.

$$\omega_d = \sqrt{1-\zeta^2 \cdot \omega_n}$$

Mode Shape

Deformation patterns (bending, twisting) at resonant frequencies take a variety of different shapes depending on the excitation force frequency. These deformation patterns are referred to as the structure's mode shapes.

Table.3 Natural Frequencies

S.No	Mode	Frequency (HZ)
1	1.0	20.108
2	2.0	20.806
3.	3.0	28.092
4	4.0	28.351
5	5.0	33.137

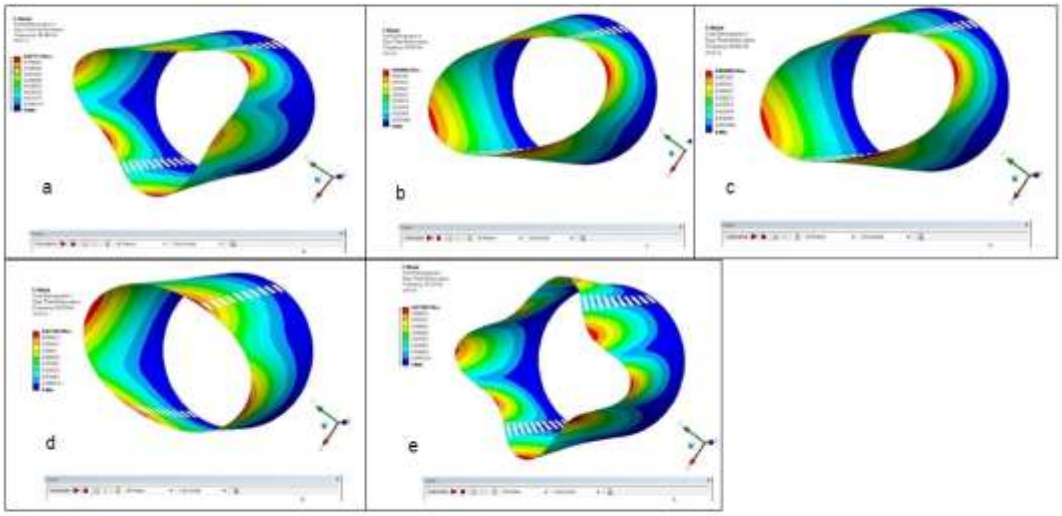

Fig.13. a) First Mode Shape, b) Second Mode Shape, c) Third Mode Shape, d) Fourth Mode Shape, e) Fifth Mode Shape

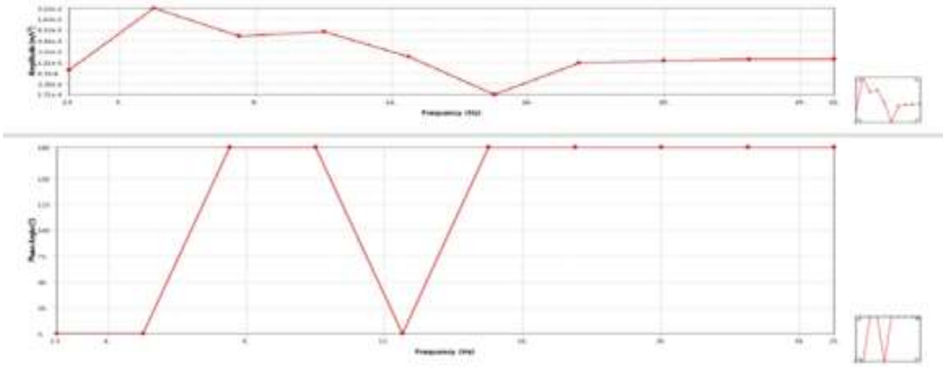

Fig.14 Frequency Response for Floor Plate

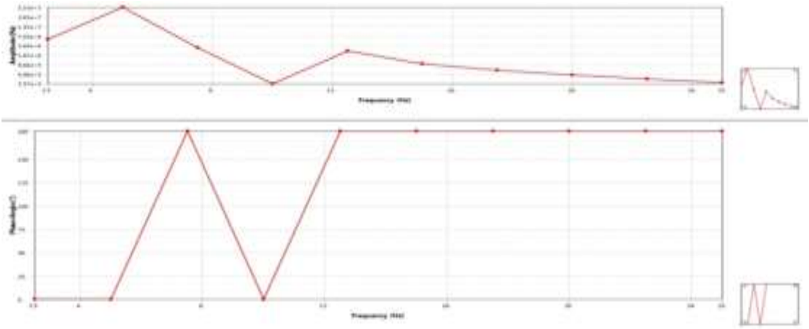

Fig.15 Frequency Response for Shell

Conclusion

From the above results we can conclude that the static analysis, modal analysis are minimal. So the results obtained are validated and verified. Although all the results through ANSYS are approximate. If the stresses induced in the body exceeds the ultimate strength of the material than there are chances that the material will fail. ANSYS will not show that at what instant of stress, the material will break. Its users part to analysis the reading and compare it with some standard reference data and arrive at some reasonable conclusion with the help of some considerable assumptions all the stresses are within the limits and we achieved factor of safety more than 1.5. Only the sharp/corner stresses are high due to the finite element mesh and localization problems with ANSYS. Such results can be omitted and at all other stations the stresses are well within the limits. Thus, we can conclude that at the above assumed loading conditions and constraints our fuselage structure will not fail due to material properties. The problems solved above are very simple in nature. In actual practice, the problems, loading conditions, constrains encountered are very different and even more complex in nature. The cad modal and analysis performed on fuselage structure can be performed on cockpit section, tail section also.

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