STRESS AND NORMAL MODE ANALYSIS OF NOSE LANDING GEAR DOOR FOR TYPICAL TRAINER AIRCRAFT

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ABSTRACT

The typical trainer aircraft have tricycle type of aircraft consisting of one nose landing gear and two main landing gears. To maintain the aerodynamically smooth surface the landing door bay should be covered with doors. The Nose Landing Gear Door is attached to the aircraft fuselage through three hinges which are driven by a hydraulic actuator attached to the central hinge. The NLG-Door structure is made of two aluminum skins between them the stiffener to make it a box structure with help of fasteners.

The hinges are machined from aluminum alloy, attached to the structure by steel alloy bolts. The Nose Landing Gear Door is designed to resist the critical aero dynamical loading in different conditions. The Nose Landing Gear Door structural analysis is carried out using MSC/NASTRAN for given boundary conditions and loading. The static strength and fastener check for critical load case is carried out. The normal mode analysis of NLG door is carried out to check the natural frequency of door with respect aircraft structure to avoid resonance.

Keyword: - *Nose Landing Gear Door, Normal Mode Analysis and Finite Element Analysis.*

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1. INTRODUCTION

Nose landing gear doors are the components of the nose landing gear. It consists of four doors i.e. two forward and two aircraft doors. The aerodynamic shape of fuselage is maintained by nose landing gear door. NLG doors serve to enclose the nose landing gear during flight. Doors provide aerodynamic pairing with fuselage skin. Nose landing gear door is completely enclosed by its door system when it is retracted.

Each door rotates about 87^0 about three hinges in left and right direction. Door hinges are positioned between the fuselage and gear side walls. Configurations of door hinges are lug and clevis type. In this type configuration half lug is attached to the door and half clevis attached to the airframe with four bolts.

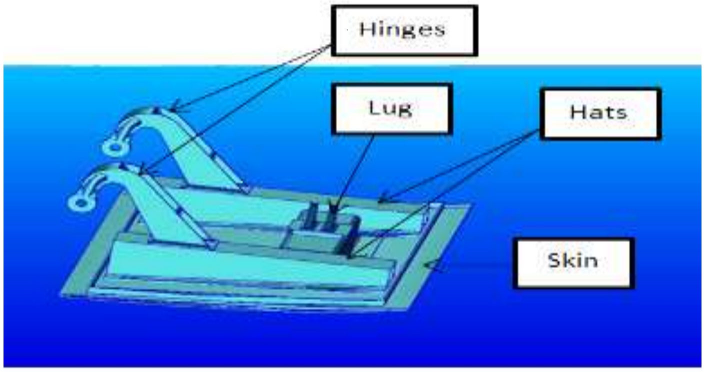

Fig -1: Nose landing gear door and its parts

The failure of the nose landing gear door was due to failure of lug. The analysis of lug will decide the design analysis of nose landing gear door. The main component of NLG door which is used to withstand maximum amount of load is lug. The failure of lug indicates the failure of NLG door.

Francisco K et al [1] were studied about the stress analysis of EMB-145 aircraft nose landing gear door. Nose landing gear door is attached to the fuselage through three hinges. NLG door is driven by hydraulic actuator. Panel buckling is avoided by using carbon tape and it is also used to increase the stiffness according to smoothness requirement for EMB-145 nose landing gear door. Aluminium alloys are used to machine the hinges. Titanium alloys are used to attach the hinges to structure. Nose landing gear door is going to resist aerodynamic loading even if one of three hinges fails. They have performed the stress analysis by FEM using data, boundary conditions and load acting on the nose landing door. The most critical condition in all subcases can be quickly obtained by using MSc Nastran as the output results. **Veerbhadrappa Prabhushetty et al [2]** were developed the aircraft door is designed using cad software. Meshing is done using FEM and MSc Nastran used as analysis software. Aluminium used for stress analysis and normal mode analysis of aircraft door. The door is analysed by placing vertical stiffeners are placed at the centre and the results obtained are within allowable range and less displacement and also reserve factor is greater than one. When aircraft frequency matches with natural frequency then there is a chance of resonance. In order to avoid resonance normal analysis sis performed. Frequency is lesser than the aircraft natural frequency. **Min Liaoa et al [3]** were performed the fatigue analysis of a CF-18 aircraft wing fold hears-tie slug. It involves multiple crack nucleation sites and short crack growth under complex geometry and loading conditions particles and porosities. FEM model was developed to understand the loading conditions in shear lug test and find out stress and strain distribution. According to failure mechanism, single crack model developed to analyse the multiple crack growth problem. 3D FE model provides stress distribution for uncracked structure and it is used for fatigue analysis. A simple model gives good estimation about the life of crack depth up to certain extent. Complexity of slug fatigue analysis involves complex geometry, multiple cracks and residual stress from forging process. This type of problem is solved by 3D FE model and advanced fracture mechanics models. Fatigue life of shear tie lug under test load spectrum is provided by stress correction curve calibrated with simple crack model and QF data. **Patrick E. Fenner et al [4]** were performed the buckling analysis of stiffened plate with fillet junctions. Generally aircraft wings are designed as thin walled structures. The various parts of wings are stiffened panel, spars and ribs. Buckling instability is caused due to compressive force acting on the top skin. All panels are produced from the single billet of metal. Buckling performance can be improved by increasing the fillet radius along the line junction between the skin and stiffener webs. The wings are modelled with two dimensional elements. 3D model for stiffened model exhibit increase in buckling associated with skin. Modern aircraft wings are thins-walled structures composed of ribs, pars and stiffened panels, where the top skin is subject to compressive forces in flight that can cause buckling instability. If these panels are machined from a single billet of metal then the initial buckling performance can be significantly improved by increasing the fillet radius along the line junction between the stiffener webs and skin. The 3D elements are required to model the stiffened panel with fillets. 3D model initiates skin associated buckling. The local and overall buckling load is measured accurately to avoid both load interactions. **Ravi Gera et al [5]** were studied about the modal analysis of plane frames. The analysis is used to determine the natural frequencies and mode shapes of a structure during free vibration. The axial effects in stiffness and mass matrices are considered during dynamic analysis of frames. In this analysis local coordinates are converted to global coordinates. They obtain the physical interpretation of Eigen values and Eigen vectors by solving system which represents the natural frequencies and mode shapes. The direct stiffness method is used to formulate stiffness matrix and mass matrix. ANSYS and MAT LAB codes are used to develop programmes. Modal analysis is defined as the structure is subjected to external excitation and dynamic responses are analysed and measured. When electromagnetic shaker is attached to scar, then the response of scar's body to vibration is measured by modal analysis. **J. E. Barnes et al [6]** were redesigned the nose landing gear door in order to reduce the costs. The cost is reduced by two methods first one is fabrication methods second one is installation and rigging times. NLG door redesign satisfies the additional requirements. Nose landing gear door are manufactured from composite material. The design involves sandwich of glass honey comb core with carbon epoxy resins. The hinges are made from aluminium. Hinges are assembled to the door with fasteners, so that it will penetrate the skins. The honey comb core is situated below the hinge in order to distribute the load into the skin. This design will provide the installation adjustability to the doors. The redesign considers an innovative method of assembly for making sandwich doors which was used in F-22A. The design process involves new analytical methods along with traditional methods. NLG door redesign represents the first flying application of some of new technologies.

1.1 Geometrical Configurations

The configuration of component was shown in above Fig. 1. The dimension of the component is 570*260mm. door component contains skin, lug, actuator and it also contains two hats. Lug is present at the centre of the door. Hats are present at the top surface of skin. Two hinges are placed above the two hats.

2. NOSE LANDING GEAR DOOR MODEL AND ANALYSIS

2.1 Modelling

Design Software's such as unigraphics, catia, and solid works are used to model the component. Weight of aircraft is the main factor deciding the dimensions of component and nose landing gear door etc. The current nose landing gear model is prepared for the commercial aircraft with a weight of 3600kg. The door model is shown in Fig. 2.

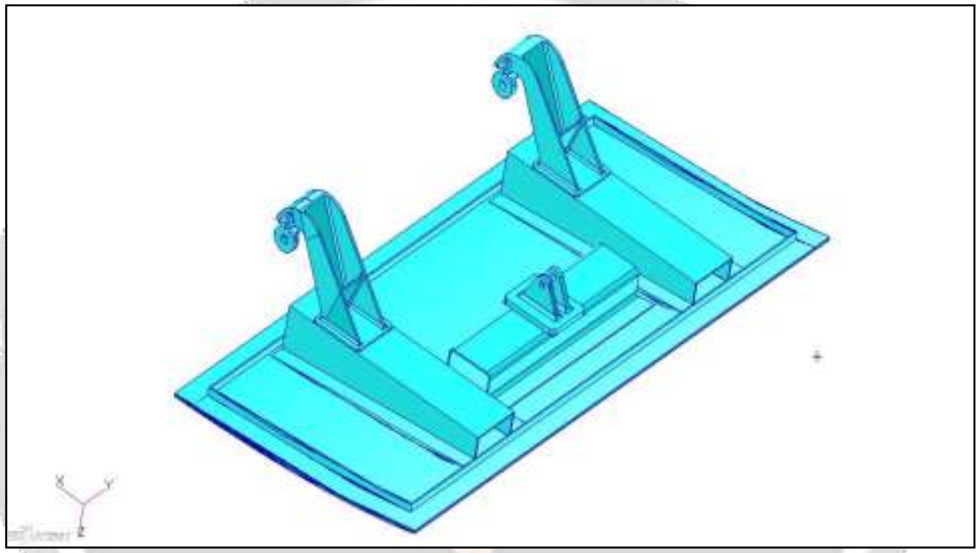

Fig -2: Nose landing gear model

3. FINITE ELEMENT MODEL

Aluminium alloy is the material which is used to manufacture nose landing gear door. Aluminium is widely used material in aeronautical field due to wide range of applications. The main properties of alloy are mechanical and thermal properties. These properties will play major role in designing process of component. Light weight is main property of aluminium metal.
The properties of the Aluminium and steel are appeared in **Table. 1 and 2**.

Table -1: Material properties of Aluminium

Young's modulus	E = 70,000 N/mm^2
Poison's ratio	v = 0.3
Ultimate tensile strength	σ_u = 480 N/mm^2
Yield stress	σ_y = 350 N/mm^2
Density	ρ = 2.7000001E-006
Thermal expansion co-efficient	α =2.32E-005

Table -2: Material properties of steel

Young’s modulus	E = 210000 N/mm^2
Poison’s ratio	v = 0.3
Ultimate tensile strength	σ_u = 550 MPa
Yield stress	σ_y = 250 MPa
Density	ρ = 7.800000E-006
Thermal expansion co-efficient	α =1.2E-005

3.1 Boundary Conditions

The door model is free to rotate about the axis. Hence it will be fixed at the hinges during the process of takes-off and landing the aircraft. The load acting on the door skin is transferred to the hinges. The angle of rotation of the NLG door is directly proportional to the movement of hinges. The translational movement of aircraft is restricted while the rotational movement of the aircraft is not fixed. Hence the angle of rotation of door can be found. Boundary Conditions of NLG Door is shown in Fig. 3.

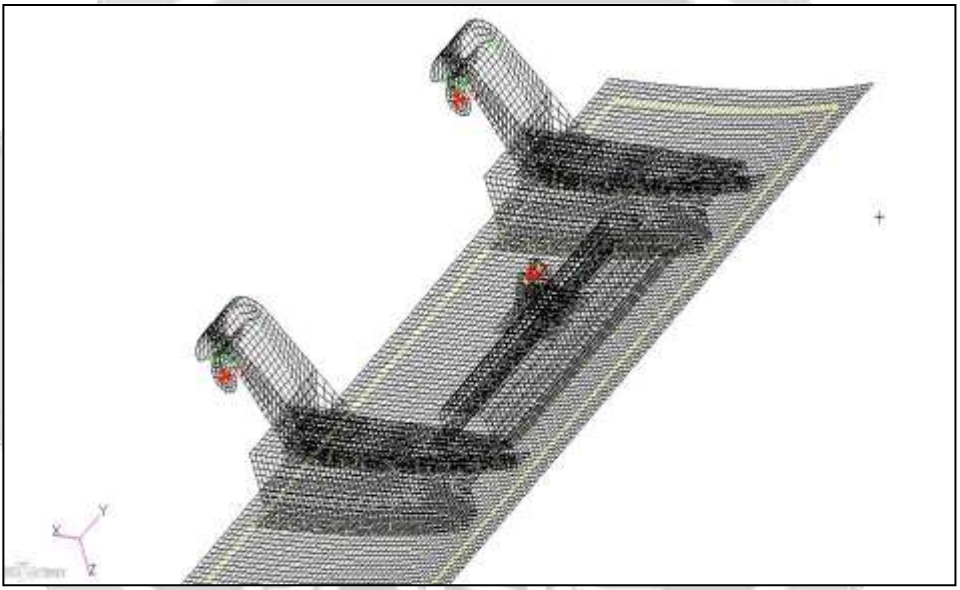

Fig -3: Boundary Conditions of NLG Door

3.2 Meshing

Meshing is the process of discretization of the component for the application of load. Without meshing the component cannot transfer the load. Meshing process require more time. Paver meshing is used when the component or part is not critical. Quad meshing is used when the component is critical. Type of meshing is selected based upon the complexity of the element. For example analysing the plate with whole problem quad mesh is selected instead of paver mesh. The meshed model of nose landing door component is shown Figs. 4.1-4.5.

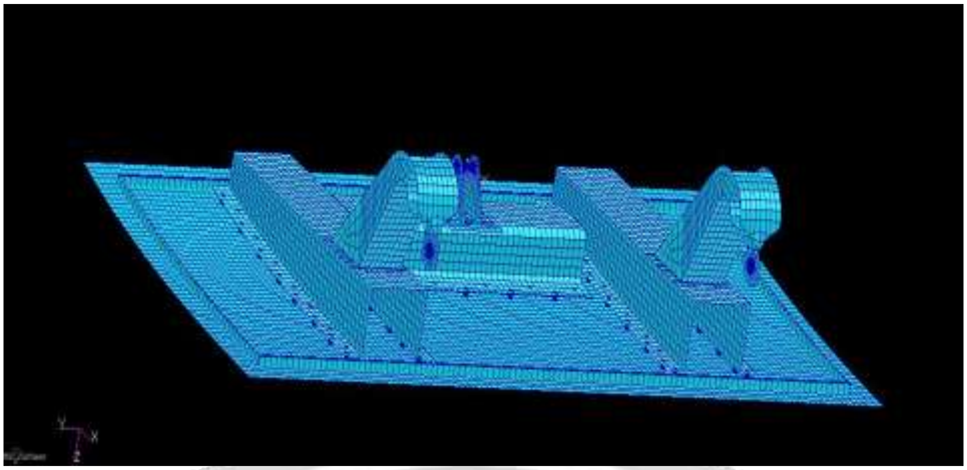

Fig -4.1: Meshed Model of NLG Door

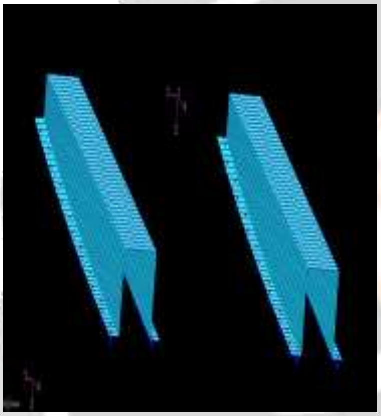

Fig -4.2: Meshed Model of Hats

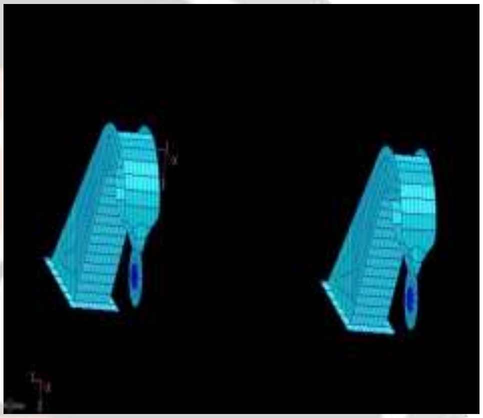

Fig -4.3: Meshed Models of Hinges

Fig -4.4: Meshed Model of Skin

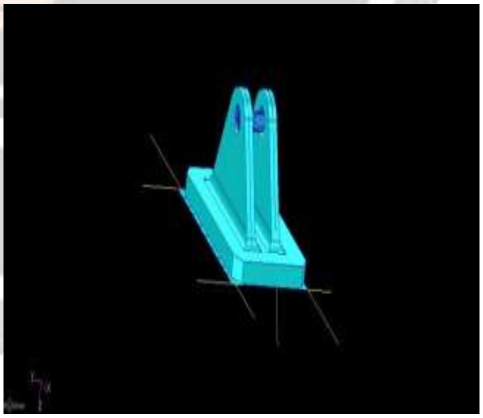

Fig -4.5: Model of Jack Lug

3.3 Loads

There are two types of load acting on the aircraft. Ground load is the load acting when the aircraft is moving on the ground. Air load is the load acting when the aircraft is in flight condition. The load is distributed uniformly throughout the nose landing gear component. In Fig. 5. Shows that the distribution of load on the NLG component.

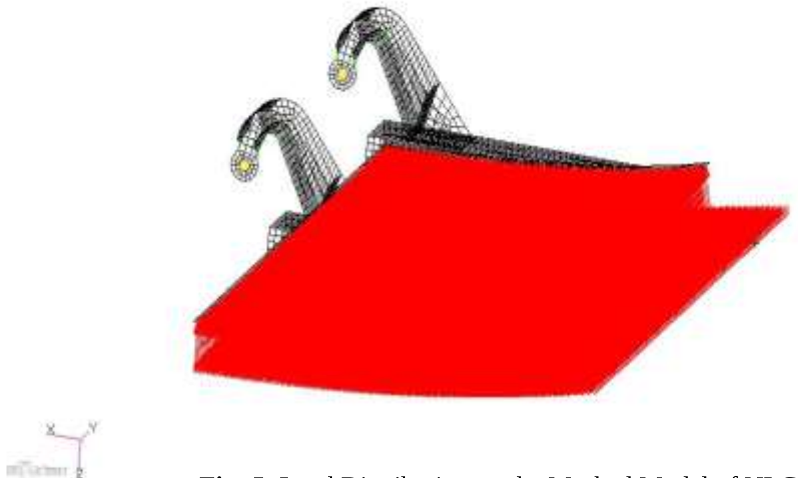

Fig -5: Load Distribution on the Meshed Model of NLG Door

4. RESULTS AND DISCUSSIONS

4.1 NORMAL MODE ANALYSIS

Normal mode analysis is the process in which natural frequencies and mode shapes are determined using free vibration equation which contains stiffness and mass. Stiffness is determined by multiplying young's modulus (E) with cross section inertia (I_x, I_y and J)

4.1.1 Natural Frequency

The natural frequencies of a structure are the frequency at which the structure naturally tends to vibrate if it is subjected to a disturbance. For example, the strings of a piano are each tuned to vibrate at a specific frequency. Some alternate terms for the natural frequency are characteristic frequency, fundamental frequency, resonance frequency, and normal frequency.

The normal frequencies of a structure are the recurrence at which the structure actually has a tendency to vibrate in the event that it is subjected to an unsettling influence. For instance, the strings of a piano are each tuned to vibrate at a particular recurrence. Some substitute terms for the common recurrence are trademark recurrence, major recurrence, reverberation recurrence, and ordinary recurrence.

4.1.2 Mode Shape

The distorted state of the structure at a particular characteristic recurrence of vibration is named its typical method of vibrations. Some different terms used to portray the ordinary mode will be mode shapes, trademark shapes, Eigen vector and major shape. Every mode shape is connected with particular common recurrence. Natural frequencies and mode shapes are elements of the basic properties and limit conditions.

A cantilever haft has an arrangement of normal frequencies and related mode shapes. On the off chance that the auxiliary properties change, the common frequencies changes, yet the mode shapes may not really change. For instance, if the versatile modulus of the cantilever pillar is changed, the normal frequencies change yet the Mode shapes continue as before the off chance that the limit conditions changes, then the regular frequencies and mode Shape both changes. For instance, if the cantilever pillar is changed with the goal that it is tuck at the finishes, the Natural frequencies and mode shapes changes. The regular frequencies and mode shapes are imperative parameters in the outline of a structure for element stacking conditions. There are many motivations to figure the characteristic frequencies and mode states of structures. One reason is to survey the dynamic communication between a part and its supporting structures. For instances, if a pivoting machines, for examples, an aeration and cooling system fan, is to be introduced on the top of a buildings, it is important to figure out whether the working recurrence of the turning fan is near one of the common frequencies of the buildings. On the off chance that the frequencies are closes, the operation of the fan may prompt to basic harm or disappointments. First Four Modes of Cantilever Beam and First Four Modes of Simple Cantilever Beam are shown in Figs. 6.

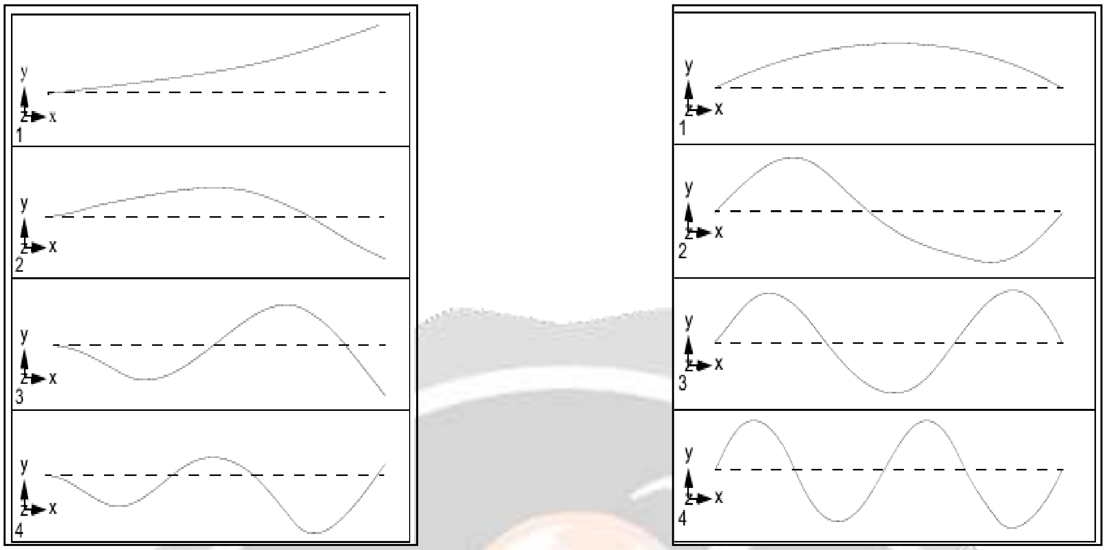

Fig -6: (a) First Four Modes of Cantilever Beam (b) First Four Modes of Simple Cantilever Beam

4.2 STRESS ANALYSIS

Stress analysis is carried out for the nose landing gear door model. Different types of stresses are obtained as numerical values which indicate structure component is safe. When the pressure load is applied on NLG door stresses are the output values. Maximum principal and minimum principal stresses are less than the ultimate stress of the material. Maximum shear stress also less than the ultimate stress of the material. Maximum Von mises stress is also less than the ultimate stress of the material the various types of stresses are tabulated below. Different Stress acting in Nose Landing Gear Door is shown in Figs. 7-10.

Table 3: Stress Values from Stress Analysis

Structure	Material	Type of Stress	Developed Stress (MPa)	Ultimate Stress (MPa)	Reserve Factor (RF)	Remarks
NLG Door	Aluminum	Maximum Principal Stress	175	480	2.74	RF>1 Component is Safe
		Minimum Principal Stress	134	480	3.58	RF>1 Component is Safe
		Maximum Shear Stress	169	247	1.46	RF>1 Component is Safe
		Von-mises Stress	212	480	2.26	RF>1 Component is Safe

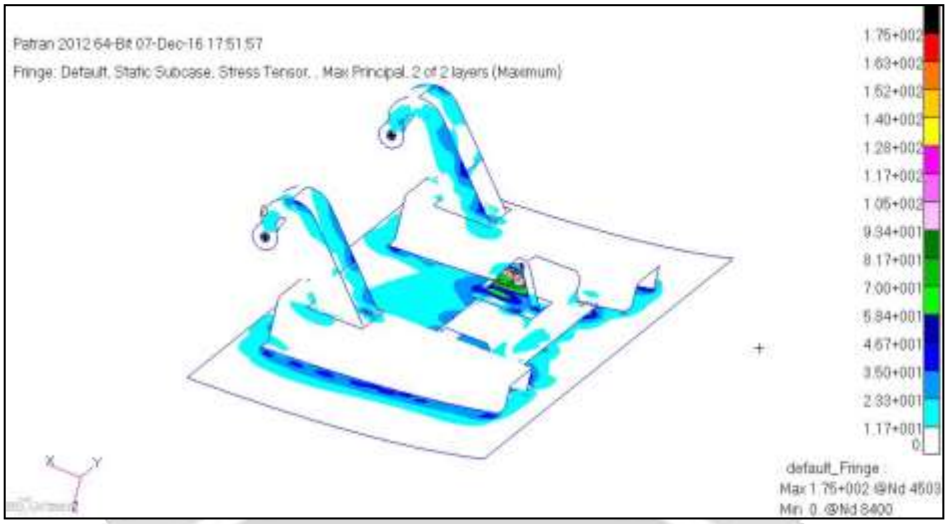

Fig -7: Maximum Principal Stress acting in Nose Landing Gear Door

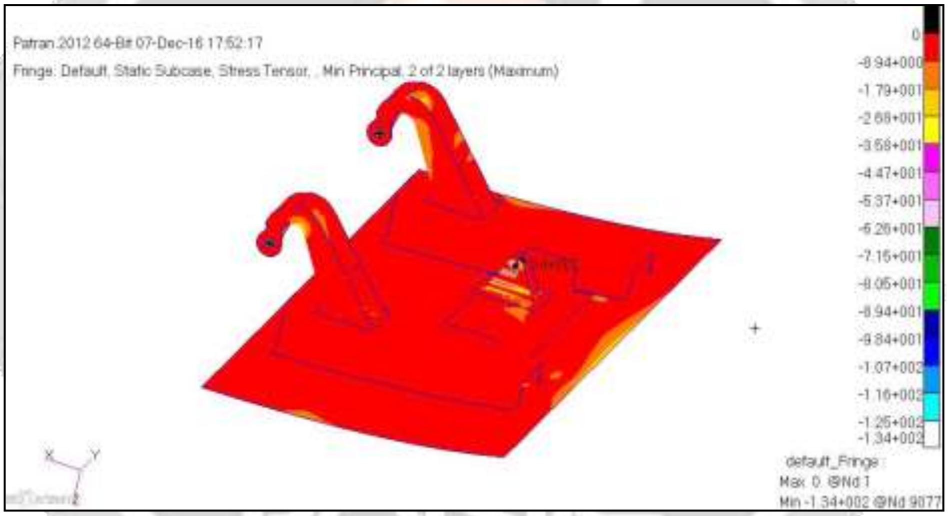

Fig -8: Minimum Principal Stress acting in Nose Landing Gear Door

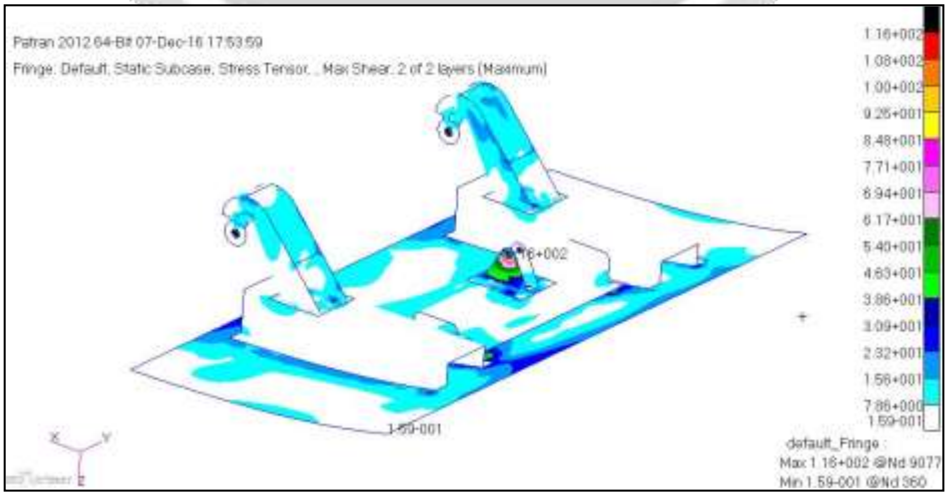

Fig -9: Maximum shear stress in Nose Landing Gear Door

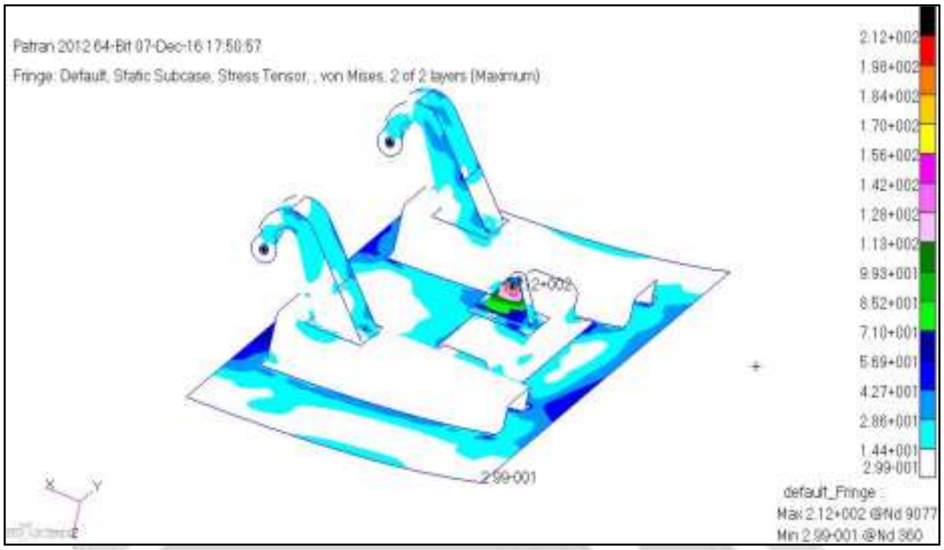

Fig -10: Von mises stress acting in Nose Landing Gear Door

4.3 DISPLACEMENT

The displacement or position of nose landing gear door component for the applied pressure load is measured. Since the applied load is constant as per the standard for typical trainer aircraft. Displacement changes as the weight of the aircraft changes. Displacement is measured to check the load carrying capacity of structure. For the given applied load maximum displacement can be measure at the edge of nose landing gear door structure. The Fig. 11. Shows that the displacement at different regions of the NLG structure and the Fig. 12. Shows that the reaction forces acting in Nose Landing Gear Door.

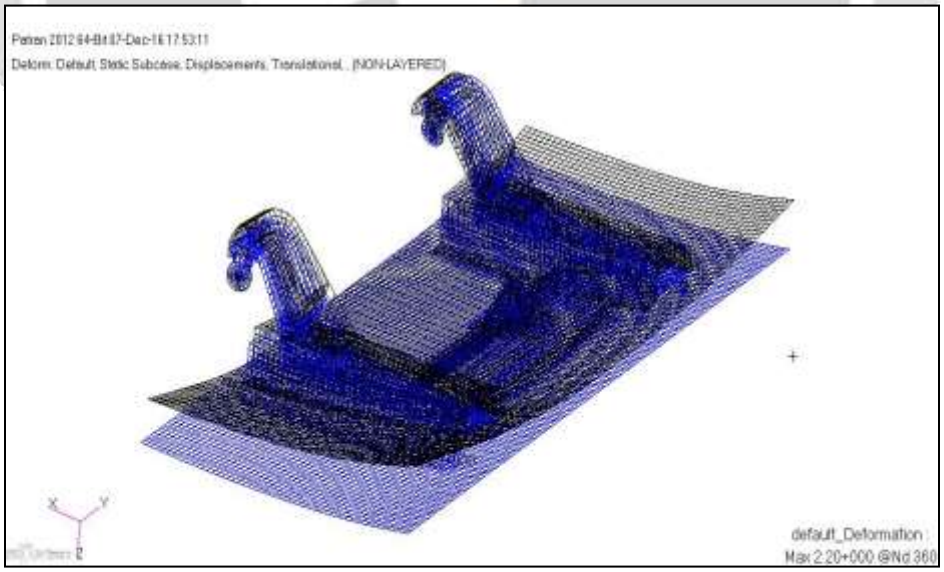

Fig -11: Maximum Displacement acting in Nose Landing Gear Door

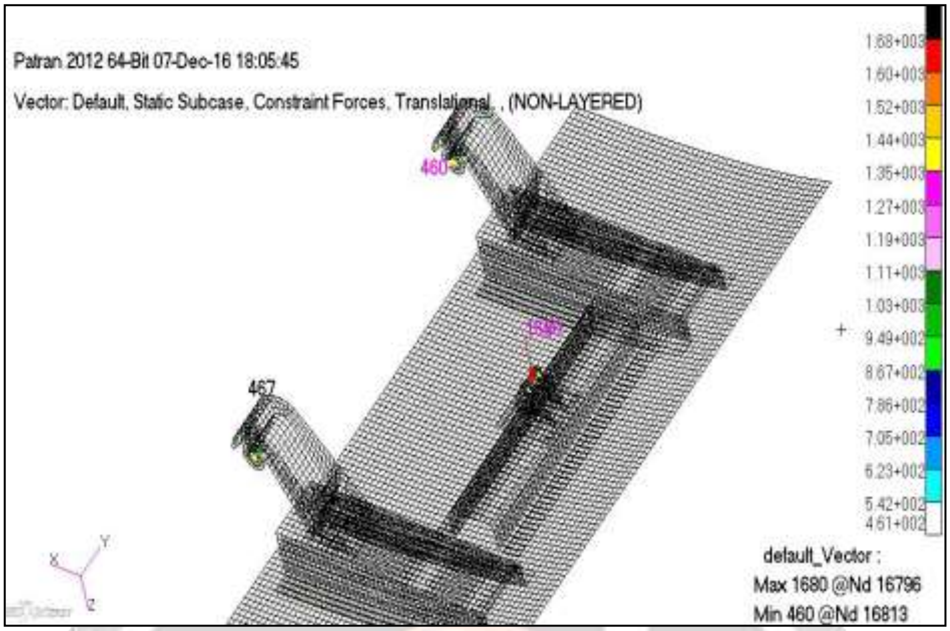

Fig -12: Reaction forces acting in Nose Landing Gear Door

4.4 NORMAL MODE ANALYSIS

Normal mode analysis is performed to determine the vibrational characteristics of a NLG door structure during the design process. Mode shape and natural frequencies are important parameters considered during design of the structure under dynamic loading conditions. Normal mode analysis is used to check resonance conditions. If typical strainer aircraft frequency matches with natural frequency of door structures, then there will be resonance formation. To avoid resonance normal mode analysis is carried outs. In general the aircraft natural frequency is in the range 10-15Hz but the NLG door natural frequencies are below the natural frequency of aircraft so resonance is not formed due to above condition as shown in the below results Table 3. Different shape of modes shown in Figs. 13-17.

Table 3: Results of Normal Mode Analysis

Mode	Frequency	Shape
1	1.4375	Twisting or tilting
2	3.3277	Bending towards edge
3	4.7358	Twisting and bending
4	5.1788	Bending towards hinge
5	5.6601	Full twisting

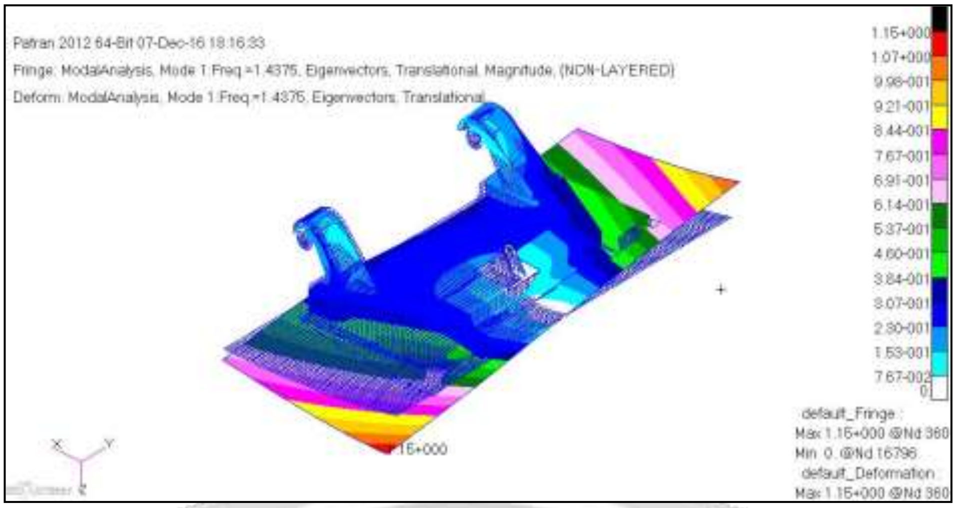

Fig -13: Mode1 with Twisting or Tilting Shape

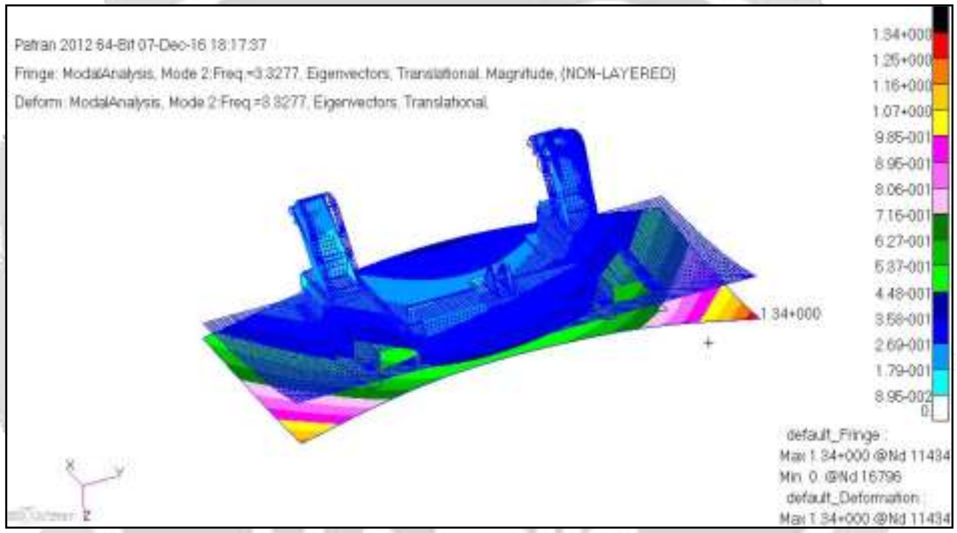

Fig -14: Mode2 with bending towards edge Shape

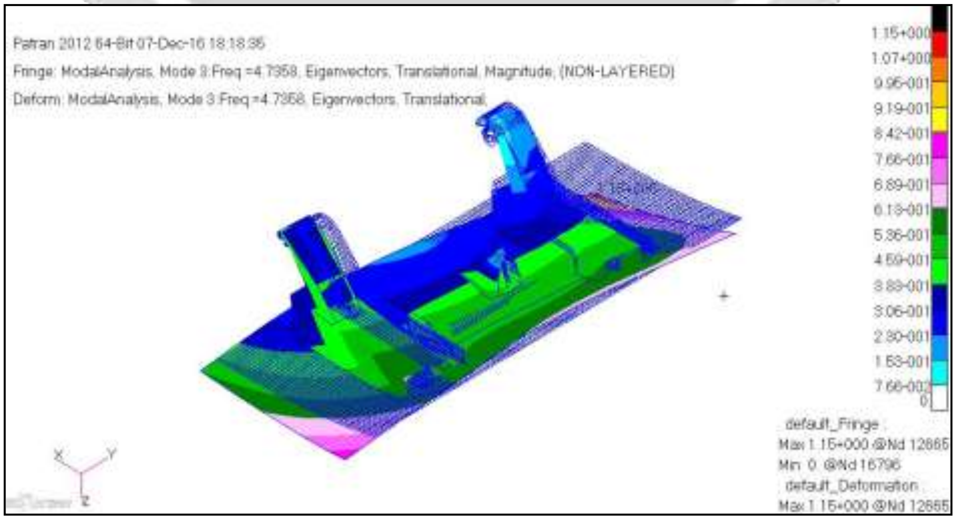

Fig -15: Mode 3 with combined twisting and bending shape

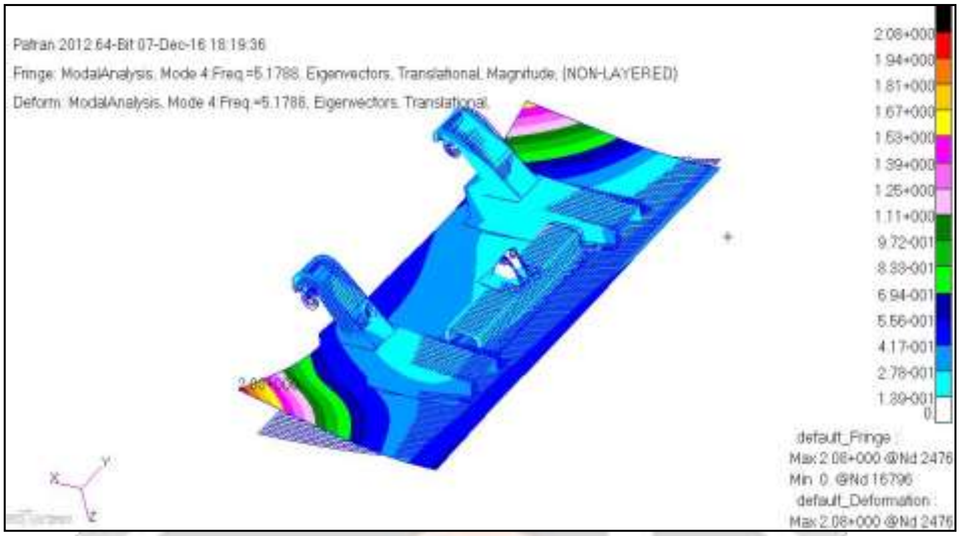

Fig -16: Mode 4 with bending towards hinge shape

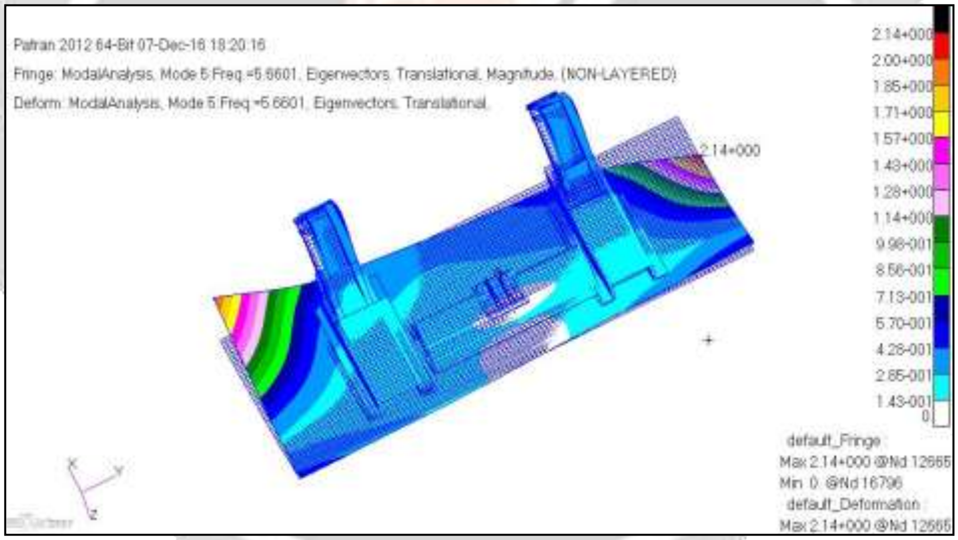

Fig -17: Mode 5 with full Twisting Shape

5. CONCLUSIONS

From the stress analysis of nose landing gear door maximum and minimum principal stresses, maximum shear stress and Von mises stress are lower than the limiting stress of the structures. Hats acts as stiffeners for the door and it also provide strength and resistance to the door for the applied pressure load. Due to hats strength displacement is also within the limits. Normal mode analysis provides natural frequency and mode shapes. The natural frequencies of the door are in the range 1- 5Hz. but aircraft natural frequency is in the range 15-20Hz. It concludes that natural frequency of door is less than the normal frequency of aircrafts. In this way resonance is avoided by normal mode analysis

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