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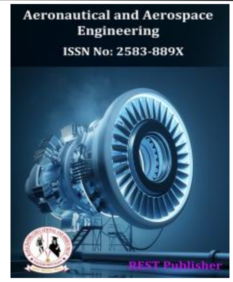

Vibration Analysis of Nose Landing Gear for A Propeller Aircraft

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Abstract: *The main problem in the landing gear dynamics of the aircraft is either shimmy or brake induced vibration or ground induced longitudinal and lateral excitation due to runway unevenness. Neither of these vibrations is catastrophic, but still causes huge discomfort to pilots and passengers. Investigations on brake vibration were required, where a study of landing gear vibration due to brake chatter and squeal during taxi and landing was performed. It is essential to analyze vibration in aircraft due to the fact that while take-off and landing a very massive force acts on the landing gear, which tends to produce kinetic energy. The vibration is imparted from the kinetic energy by the forward movement of aircraft. Vibration would lead to the gradual deterioration of aircraft structure, which in turn affects both the passengers and crew. Basic dynamic theoretical studies of landing gear by modal and frequency response analysis using FEA method points out the design considerations required to reduce the level of vibration. An attempt is made to reduce the vibration by providing stiffeners at the sensitive locations obtained using strain energy values and results were presented and compared for nose landing gear (NLG) with and without stiffeners.*

Keywords: *Propeller aircraft, Vibration, Nose landing gear and Finite element method.*

1. INTRODUCTION

Landing gear or undercarriage is the most extensive component of aircraft, which is principally used for both take-off and landing. Landing gear should bear the fulfilled weight of aircraft while landing, take-off and taxing. Landing gear is classified into two configurations viz. Nose landing gear, mainlanding gear. Maximum magnitude of loads would be experienced by the main landing gear rather than nose landing gear[1, 2] while the aircraft landing. Many aircraft utilize flexible spring steel, aluminum or composites that receive the impact of landing and transfer it to the air frame at a safe rate.

NLG[3] accommodates the principal components viz. spacer, piston, axle housing, upper and lower toggle, torque link, retraction actuator, radius rod, links, turning sleeve, shimmy damper and barrel. The stiffeners are proposed in the present paper in between the radius rod in form of cross sectional beam links. The type of propeller aircraft landing gear specified in this paper is retractable tricycle NLG with oleo pneumatic shock absorber. Tricycle gear is a type of aircraft undercarriage, or landing gear, arranged ina tricycle fashion. The tricycle arrangement has a single nose wheel in the front and two or more main wheels near to aft of the centre of gravity. Tricycle gear aircraft are the easiest to take-off, land and taxi, and consequently the configuration is the most widely used in aircraft. Oleo pneumatic cushions the impact of landing and while taxing and damps out vertical oscillations.

Ashwin C Gowda[4] modeled NLG by using CATIA V5™ software and studied the behavior of landing gear under varying working load environment with a focus on the structural analysis of landing gear under cyclic loading. Nikhil[5] proposed on stress and fatigue analysis of NLG axle of trainer aircraft and modeled the axle using NX Unigraphics and analyzed using MSC NASTRAN™. It was observed that maximum principal stress is about 1090 MPa and from the fatigue analysis results the design satisfies the requirement of 1000 landings. Imran[6] analyzed the structural safety of landing gear for static and spectrum loads wherein the maximum possible loads are applied through RBE 3 connection at the axle end. Imran[6] proposed aluminum as the principal material for the landing gear components to check the strength perspectives under several loadingconditions.

The present study consists of modeling of NLG of propeller aircraft with fuselage floor using CATIA v5™ and detailed study of dynamic characteristics of the landing gear using MSC PATRAN/MSC NASTRAN. During design process, it is essential to accomplish an appropriate assessment of the dynamic behavior, which would guide to build an accurate finite element model with loading environments. An attempt is made to reduce the vibration[7]by providing stiffeners at suitable locations in the NLG and the floor to make the pilot and the crew more comfortable. The principal parts of nose gear structure are shown in Figure 1.

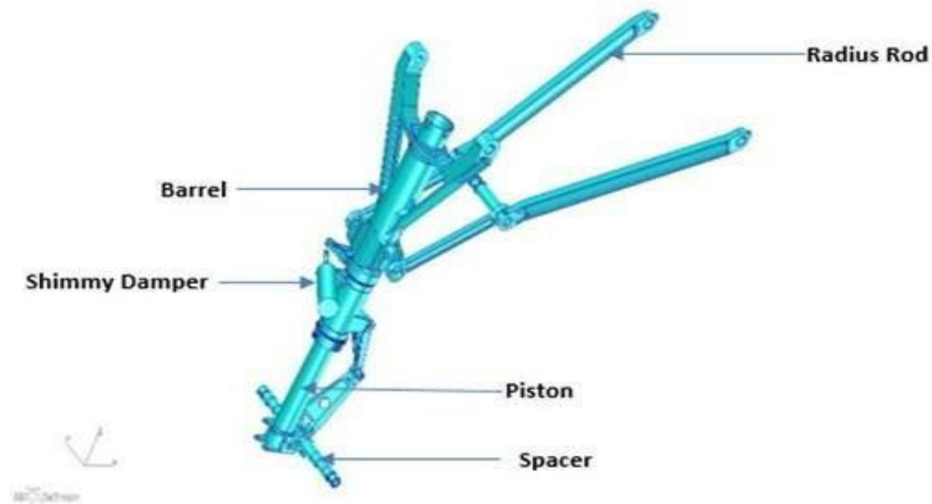

FIGURE 1. Nose Landing GearAssembly

2. PROBLEM DEFINITION

Landing gear vibration includes self-induced oscillations referred to as shimmy and brake-induced vibration. Shimmy[8, 9] may be caused by a number of conditions such as low torsional stiffness, excessive free play in the gear, wheel imbalance, or worn parts. Brake induced vibration includes conditions known as gear walk, squeal and chatter, which are caused by the characteristics of friction between the brake rotating and non-rotating parts. Squeal refers to the high frequency rotational oscillation of the brake stator assembly whereas chatter and gear walk refer to the low frequency fore and aft motion of the gear. Because of the above, during ground run and the flight, unwanted vibrations are transferred to the fuselage floor, which makes the passengers, pilot and the crew uncomfortable. It is more important to control, dampen or isolate this kind of vibrations either using the passive, active damper or by a possible design change. Finite element modeling (FEM) has become a useful tool for studying dynamic stability issues of landing gear. The modal behavior and the acceleration response study of the landing gear by detailed finite element analysis (FEA) give useful information for controlling the level of vibration. The Finite Element Model includes aircraft mass simulated fuselage floor, landing gear, wheels, brakes, and tires with their stiffness and inertial properties for detailed dynamic analysis. Design sensitivity studies are carried out to evaluate changes in the dynamic characteristics during the design modification process.

3. FINITE ELEMENT MODELLING

4.1 Landing Gear Arrangement:

In general landing gear arrangements consists of many parts and assemblies which includes air /oil shock struts gear alignment units, support units, retraction and safety devices, steering systems, wheels and brake assemblies. It is necessary to attach the landing gear with the primary structural members of the aircraft to transfer the vibration and shock energy throughout the airframe at different rate and time during taxing, take-off and landing. The NLG assembly with aircraft mass simulated fuselage floor of a trainer propeller aircraft is considered in the present study for prediction of modal properties and determination of its response at critical locations. Based on the results, design changes were suggested for dampening the undue and excessive vibration.

4.2 Assigned Elements and Materials Properties:

FEM is used in the present study for predicting the modal behavior and vibration response of the NLGassembly of a propeller aircraft. The barrel, toggles, radius rod, shimmy damper, cylinder, piston and spacer of landing gear are modeled using 3D tetrahedral elements[10, 11]. By providing mesh seeds, the mesh resolution is controlled at the surface's outline. Mesh seed option also supports the adaption of the mesh around corners and holes. The floor attachment over the landing gear is meshed using 2D quad elements. The stiffeners are modeled using 1D rod elements; bolted joints are modeled using 1D beam elements. The wheel and brake assembly are modeled as point element with their respective masses and inertial properties. Suitable material properties are assigned for the components of landing gear. Most of the components are made of aluminum to reduce the weight of the landing gear, which is most important in an aircraft industry. The assigned material properties are listed in Table 4.1.

TABLE 1. Materials

Part Name	Material
Barrel	Al – Alloy
Turning Sleeve	Steel bar
Piston	Steel bar
Toggle link	Al – Alloy
Spacer	Al – Alloy
Axle Housing	Steel bar
Radius rod	Steel bar
Links	Steel bar
Sleeve	Al – Alloy
Floor	Al

4.3 Boundary Conditions and Acceleration Input

The acceleration input of "11g" for the frequency range of 10 Hz to 1000 Hz is applied at the spacer ends (wheel attachment point) in Z – direction. The boundary conditions are applied on the floor attachment of the fuselage structure, where the translations are arrested in X, Y and Z directions and the rotational degree of freedoms are left free. The applied boundary conditions on the floor along with the 1D beam stiffeners are shown in 2.

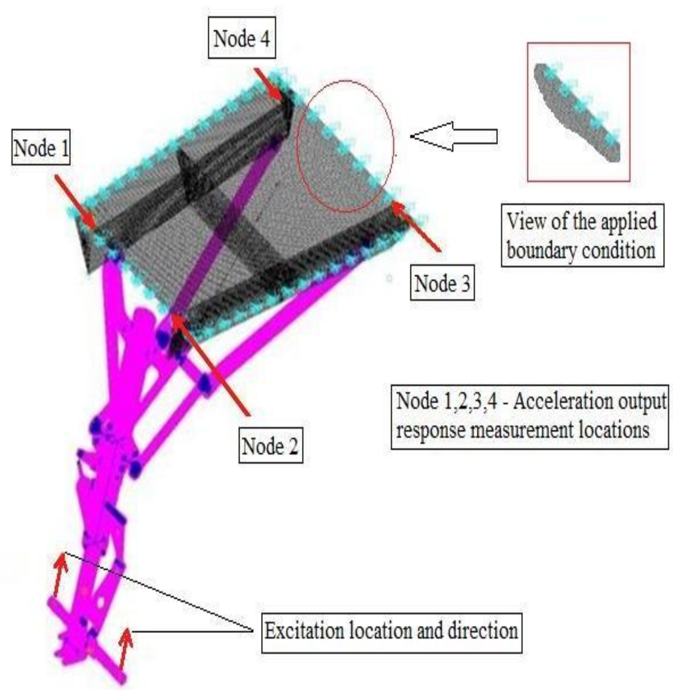

FIGURE 2. Finite Element Model of Landing gear with Floor Attachment

4. MODAL ANALYSIS

The finite element model of NLG with applied element properties, material properties and boundary conditions, exactly simulated mass properties was used to carry out the modal analysis[12, 13]. The modal behavior of the component level and assembly level of NLG was well understood by identifying the natural frequencies and mode shapes. This analysis was utilized for the consideration of design change to vary the stiffness of landing gear.

5.1 Modal Analysis Results – NLG with Fuselage Floor

The free vibration analysis or the modal analysis of the NLG with aircraft mass simulated fuselage floor is performed. The modes and the respective frequencies of the NLG that participate in building undue vibration of very high amplitude in the fuselage floor are spotted. The modal structural behavior needs design optimization to reduce the level of vibration that is considered getting transmitted to the fuselage floor.

5.2 Modal Analysis Results – Nose Gear Model with Fuselage Floor and added Stiffeners

The Strain energy values from the modal analysis results exactly identified the radius rod as the more sensitive location for the design change and improving the stiffness of the NLG. Considering the space availability for the design change, without doing the major modifications and disturbing the existing design, stiffeners are included in the radius rod to attain the required stiffness. Figure 3 shows the NLG with additionally introduced stiffeners.

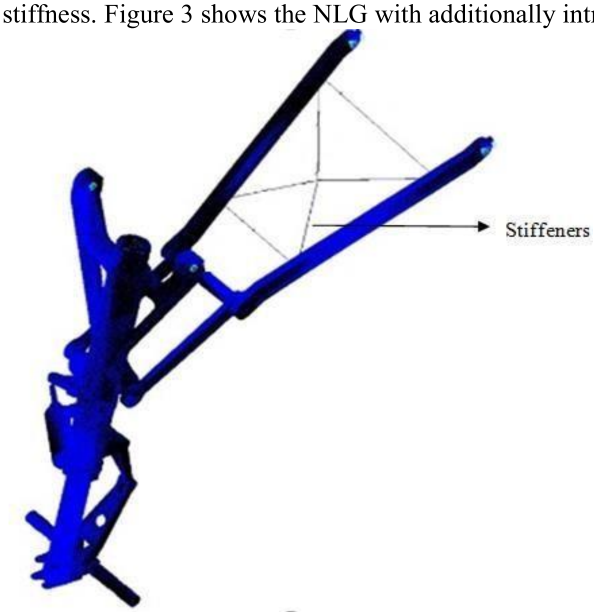

FIGURE 3. NLG with Additionally Introduced Stiffeners

The change in frequency values post addition of stiffeners reduces vibration amplitude in the fuselage floor. The frequency values are noted for lateral, fore and aft, torsion and pitching modes that can affect the floor vibration. The comparison of frequencies and mode shapes of the NLG assembly with fuselage floor before and after adding stiffeners in Figure 4 shows the drastic improvement in the pitching mode frequency value which is the main cause for the fuselage floor vibration.

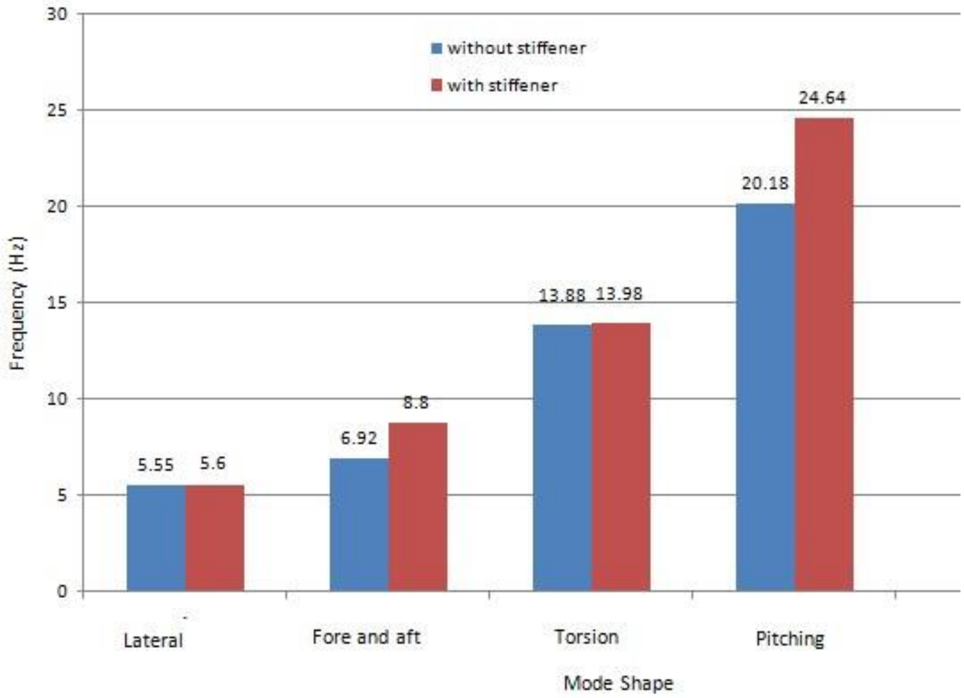

FIGURE 4. Comparisons of Modal Analysis Results

5. FREQUENCY RESPONSE ANALYSIS OF NLG

Frequency response analysis involves steady-state response of the NLG under a sinusoidal input signal is conducted. Frequency response [14, 15] is used to characterize the dynamic behavior NLG system and its components. The output spectrum of the assembly in terms of acceleration or displacement can be measured using frequency response analysis. Magnitude and phase are measured in terms of frequency at any locations and the results can beget compared in frequency response analysis.

6.1 Outcome of Frequency Response Analysis Studies on NLG

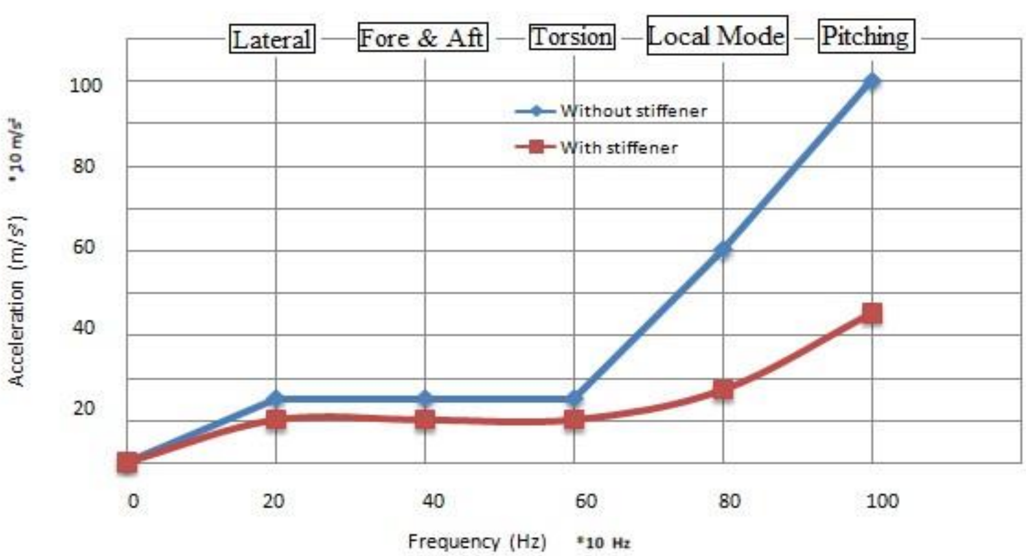

FIGURE 5. Acceleration Response Plot – Node 1

An input acceleration excitation of “11g” for the frequency range from 10 Hz to 1000Hz is applied at the spacer (Figure 4) in the Z-direction which is considered to be critical for fuselage floor vibration. From the frequency response analysis for the applied acceleration excitation level, the output acceleration and displacement response values for the frequencies ranging from 0 to 100Hz was plotted for the nodes in the fuselage floor. Acceleration value for all the dominant modes of NLG assembly with and without stiffener was obtained from the output acceleration response plots. It was identified form Figures 6 to 8 the acceleration values measured at nodes 1, 2, 3 and 4 clearly indicates that the maximum acceleration value reached for pitching mode. It is believed that main cause for floor vibration is by the pitching mode and the control of acceleration amplitude value largely defines the vibration transferred to the structure. Adding the stiffener in the NLG assembly is more effective in reducing acceleration value and in-fact reduces the floor vibration.

Table 2 clearly illustrates the percentage reduction in acceleration amplitude value for allthe dominant modes before and after adding the stiffener. More effect on percentage reduction is gained for pitching mode which is considered to be more effective in transferring the vibration from NLG to fuselage floor.

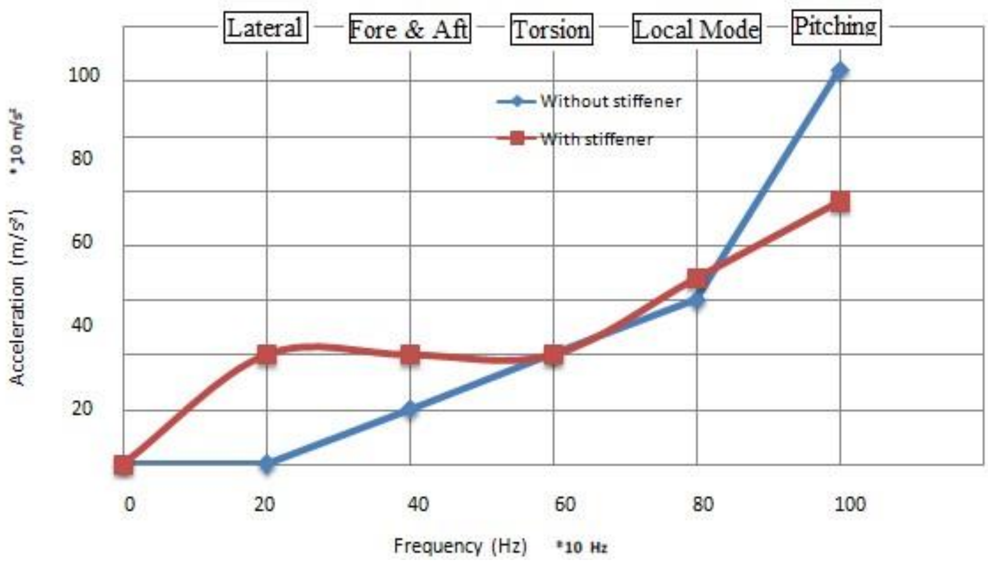

FIGURE 6. Acceleration Response Plot – Node 2

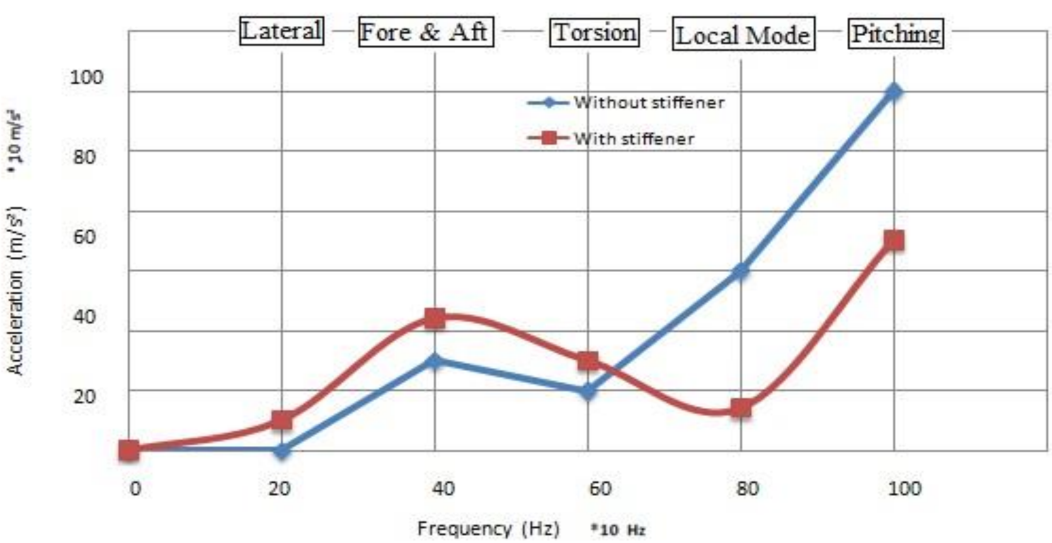

FIGURE 7. Acceleration Response Plot – Node 3

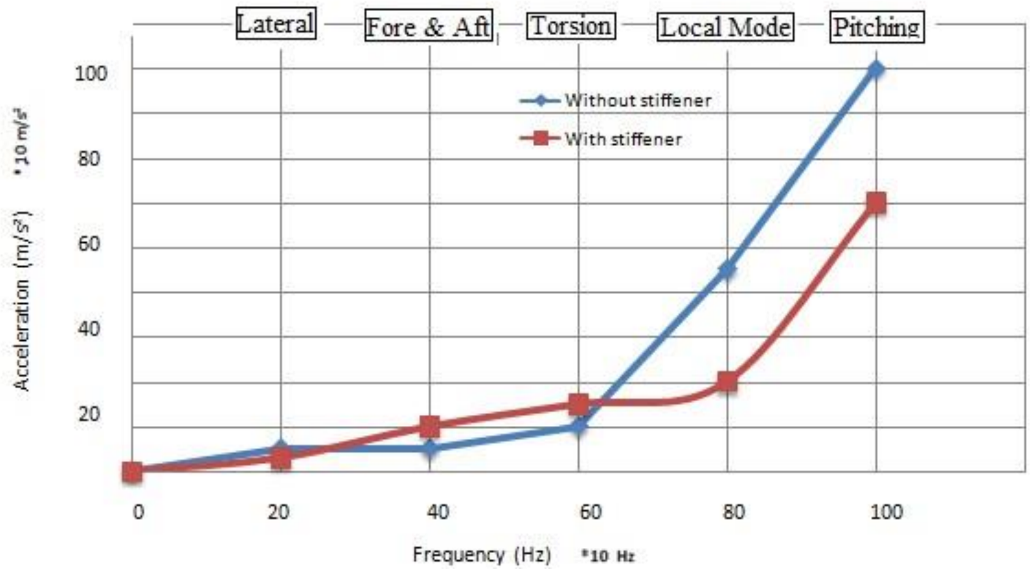

FIGURE 8. Acceleration Response Plot – Node 4

TABLE 2. Correlation of Maximum Acceleration Amplitude of Acceleration Response For Pitching Mode

Node Number	Maximum Amplitude of Acceleration for NLG with Fuselage Floor (g)	Maximum Amplitude of Acceleration for NLG with Fuselage Floor and Added Stiffeners (g)	% Reduction in the Amplitude of Acceleration Value
Node 1	37.5	27	28
Node 2	36.1	24	33
Node 3	52	30	42
Node 4	80	40	50

6. DESIGN OUTPUT

The effect of application of design modification in reducing the vibration is studied in this paper. Design optimization applied to the NLG by adding a stiffener contributed so much in controlling the level of amplitude of vibration transferred to the fuselage floor. The modal behavior is not affected due to the added stiffener but significant reduction in the acceleration amplitude of the predominant mode of the NLG that causes vibration was identified form the results obtained.

Further addition of stiffener does not affect the existing design and needs small modifications which could be done externally. Experimental validation is done by flight data analysis, measuring the acceleration values using the accelerometers kept at the locations where the acceleration response is taken theoretically using FEM.

7. CONCLUSION

The main focus of controlling the excessive vibration transferred from the NLG assembly to the fuselage floor was studied using FEA and achieved with the dynamic analysis results obtained in the form of natural frequencies, mode shapes and acceleration response plots. The modes of the NLG were obtained using modal analysis and the primary mode which causes vibration in the fuselage floor was identified by response analysis by measuring the acceleration amplitude. The exact solution to control the vibration was derived by adding a stiffener to the existing NLG assembly at critical location. The least design change with less cost and time duration by introducing a stiffener at critical location of the NLG assembly was greatly effective in dampening the vibration passes to the main structure to which it is attached. The random vibration and shock analysis can be carried out on NLG assembly for any further dynamic studies which may require additional design changes. Correlation of FE results with flight test data and ground vibration test data proves the accuracy of results.

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