# NUMERICAL ANALYSIS OF NOSE LANDING GEAR SYSTEM

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**Abstract -** *An aircraft landing gear system must absorb the kinetic energy produced by a landing impact and excitations caused by the aircraft travelling over an uneven runway surface. This is the necessary requirement of a successfully designed landing system. The oleo-pneumatic shock is the most common type of shock absorber landing gear system used in aircrafts. It dissipates the kinetic energy produced by impacts arising when an airplane lands at high speed but also offers a comfortable ride to passengers when the airplane taxies at low speed. The objective of this project is to determine the stress behavior and the displacement of a nose gear of an aircraft during landing using structural finite element analysis. The nose gear was first modeled using computer-aided design software and then imported into finite element software. The external forces were determined analytically and the interactions between components were carefully modeled using contact analysis.*

**Key Words:**  Oleo pneumatic, Nose landing gear, Finite element analysis, Stress analysis, Normal modal analysis.

## 1. INTRODUCTION

The landing gear is that portion of the aircraft that supports the weight of the aircraft while it is on the ground. The landing gear contains components that are necessary for taking off and landing the aircraft safely. Some of these components are landing gear struts that absorb landing and taxing shocks; brakes that are used to stop the aircraft; nose wheel steering for steering the aircraft.

An aircraft landing gear system must absorb the kinetic energy produced by a landing impact and excitation caused by an aircraft travelling over an uneven runway surface. This is the necessary requirement of a successfully designed landing system. The oleo-pneumatic shock strut is the most common type of shock absorber landing gear system used in aircrafts. It dissipates the kinetic energy produced by impacts arising when an airplane lands at high speed but also offers a comfortable ride to passengers when the airplane taxies at low speed. The strut behaves in a strongly nonlinear manner, which influences the performance of the landing system. Investigations involving real-time feedback of the ground input to the landing system have shown that active control greatly reduces impact and fatigue loads experienced by the aircraft as well as vertical displacements. This is achieved by adjusting the system's stiffness and damping.

The landing gear is the interface of airplane to ground, so that all the ground loads are transmitted by it to an aircraft structure. There is a high influence of the landing gear on the local structure, which must be taken into account

in the initial design stage. The system must then have considerable mechanical resistance, which means in general that its mass is significant. Depending on aircraft category, this can range from 3 to 7% of the aircraft total mass.



Fig.1.1 Landing gear system.

The landing gear is necessary for the aircraft to take-off and land on a runway, to relocate itself on an airport and to support the weight of an aircraft when parked on the platform. Once landed, the landing gear is equipped with multiple systems to bring an aircraft to a safe stop. When the speed of the aircraft is reduced, the aircraft will land to the platform. When the aircraft is in flight, the landing gear will be retracted and the doors will be closed. This gives the aircraft better aerodynamic characteristics. When the aircraft is approaching the runway, the landing gear will be extended and locked.

The landing gear is the structure that supports an aircraft on the ground and allows it to taxing, take-off and land. In fact, landing gear design tends to have several interferences with the aircraft structural design.

The landing gear system includes:

1  Strut.
2  Shock absorber.
3  Extraction/retraction mechanism.
4  Brakes.
5  Wheel.
6  Tyre.

## 2. LITERATURE

The survey of literature devoted to the most commonly applied landing gear system, such as landing gears equipped with hydraulic-pneumatic shock absorbers. Reviewing the literature, in particular attention will be paid to the way in which the dynamic properties of wheel, shock absorber and

aircraft structures are taken into account, and to the way in which the loads due the landing impacts are calculated.

V. d. Neut et.al.[2] is a very extensive investigation in the field of symmetrical landing impact loads and is devoted in particular to the problem of defining critical loading cases for nose wheel landing gears. The tyre-shock absorber combination of the nose wheel landing gear is represented by a linear spring, but for the main wheel landing gear the shock absorber damping characteristics are represented by velocity squared damping forces. The unstrung mass is neglected while wheel and shock absorber spring characteristics are represented by linear springs. Further, the drop test interpretation problem of how to take into account static lift forces is already recognized.

With regard to the analytic approach to the problem in the USA, first of all the work of E. G. Keller [3] should be mentioned. This investigation formulates in an appropriate way the equations of motion of wheel and shock absorber, and calculates the vertical landing gear loads of a rigid aircraft. It is described how in an elastic structure the accelerations have to be calculated when the landing gear forces are known as a function of time.

Jerzy Malachowski[4] his research on the most effective methods of aircrafts' landing gears design as well as the evaluation of the gear's condition during utilization period and possibilities of extending its durability are the subject of numerous studies, including the ones by leading worldwide aviation companies and national scientific centers. It is indicated in these studies that numerical analysis of the strength of the construction elements of the examined aircraft's part (beside experimental research) is a necessary stage of proper methodology of aviation research, in particular in programming and reliability evaluation and development of methods of increasing durability in case of solutions already used in practice.

Yang Yang [5] he conducted project on FW-11 cooperated between Aviation Industry Corporation of China (AVIC) and Cranfield University. His group designed a new conceptual design and the target of it is to develop a flying wing commercial airliner. As a part of AVIC MSc program, the FW-11 project is constructed by three phases: conceptual design phase, preliminary design phase, and detail design phase. The author was involved in the conceptual design phase which was divided into three steps: derivation of requirements, design a conventional aircraft as baseline aircraft and design FW-11 comparing with the baseline aircraft. The main objective of this thesis was to build a set of diagnosis, prognosis and health management methods which are suitable for the aircraft landing gear extension and retraction control system. FMEA and FTA for the system were conducted. From the FHA, each of the catastrophic events of the landing gear extension/retraction control system was identified. The architecture of the rule-based expert system, the acquisition of comprehensive domain expert knowledge is in the most important factor.

Amit Goyal [7] he conducted this project in MSRIT School of Advanced Studies (SAS), INDIA. He present an approach for "Design Analysis; of a Nose Landing Gear of an Aircraft" made of advanced composites materials using advanced CAE tools and techniques. First of all, functional specification of the part has been specified. General principles of composite design were followed in arriving at suitable designs. In the design phase using the FEA tool ANSYS 5.7, starting form shape and wall construction, choosing a proper element type, loadings, constraints, materials and behavior modeling has been done. Various constants and lamination parameters were used to define the element.

## 3. METHODOLOGY

In this project, Finite Element analyses were used to determine the characteristics of the nose landing gear. All methodology principles and theories discussed were utilized to achieve the project's objectives. The combination of all the analysis results were used to develop virtual model created using FEM tools and the model was updated based on the correlation process. The literature review of the nose landing gear was carried out to obtain basic understanding of the project. Information like typical natural frequency values of nose landing gear, excitation sources and mode shape of nose landing gear were searched and reviewed. For the purpose of this study, the Landing gear was modeled using CATIAV5-R17 software according to the original size of structures. The model was then imported into Finite Element preprocessing software Hypermesh for the meshing analysis, 8 noded hexa element, 6 nodded penta elements and rigid elements were chosen to model the chassis. The model was then imported into Finite Element solver software MSC Nastran, Hyperview software is used for post processing the results.

## 4. FINITE ELEMENT METHOD

The Finite Element Method is a numerical approximation method, investing the behavior of complex structures by breaking them down into smaller pieces, simpler pieces and these smaller pieces are called finite elements. The elements are connected to each other at nodes. The finite element method is also known as the matrix method of structural analysis in the literature because it uses matrix algebra to solve the system of simultaneous equations and it is becoming the primary analysis tool for designers and analysts.

The finite element method is based on two concepts:

1. Transformation of the original problem into an equivalent integral formulation (weighted residual or variation).

2. Approximation of the field variable distributions and the geometry of the continuum domain in terms of a set of shape functions, which are locally, defined within small sub domains (finite elements) of the continuum domain.

Through the application of the element concept, the original problem of determining field variable distributions in a continuum domain is approximately transformed into a problem of determining the field variables at some discrete nodal positions within each element. This transformation results in a set of algebraic equations, for which numerical solution procedures are readily available.

Finite element analysis has been widely used in noise, vibration and harshness, (NVH) simulation especially in the fast growing automotive industries. Engineers were given the power and ability to predict and assess structure-borne noise in engine by high advanced computer software and hardware. Validation of the finite element model itself has become automated and more reliable. The finite element models are often correlated with experimental modal analysis results in order to achieve a high degree of confidence in the finite element analysis.

Basic steps in finite element method, they are:

1. Discretize.
2. Deriving governing equations for each element.
3. Assemble global governing equations.
4. Apply loads and boundary conditions.
5. Solve for primary unknowns.
6. Calculate derived variables.

## 5. DESIGN DETAILS

The physical component of Landing Gear was modelled by collecting various literature survey. These dimensional data was used to build CATIA part model by using CATIA V5R17.

CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault, at that time customer of the CAD/CAMCAD software to develop Dassault's Mirage fighter jet, then was adopted in the aerospace, automotive, shipbuilding, and other industries. Initially named CATI (Conception Assistive Tridimensionnelle Interactive — French for Interactive Aided Three-dimensional Design) — it was renamed CATIA in 1981, when Dassault created a subsidiary to develop and sell the software, and signed a non-exclusive distribution agreement with IBM.
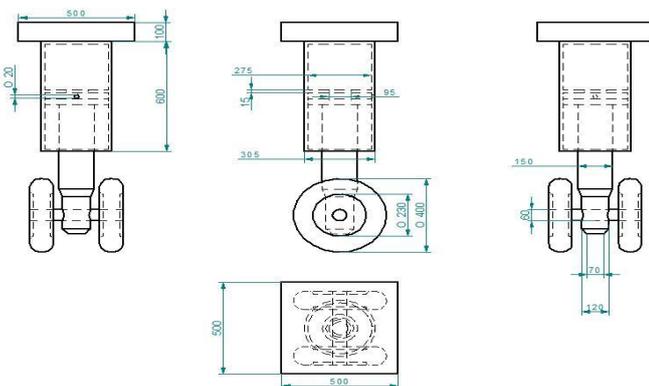

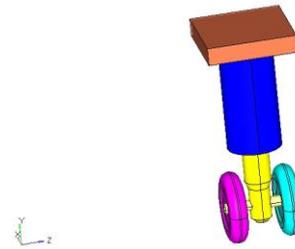
Fig.5.1 CATIA Model of nose landing gear system.



Fig.5.2 Isometric View of nose landing gear system.

### 5.1 CREATION OF FINITE ELEMENT MODEL:

After creation of CAD model in CATIAV5R17 to carry out further pre-processing process the CATIA model part was imported in Hypermesh during this process some geometric deviation will occur that needs to be corrected (geometric clean up) in Hypermesh. Nose landing gear system component modelled by using linear first-order (6-or 8-noded) elements. Solid elements are Hexahedral and Pentagon elements.

Meshing is done using Altair Hyperworksv10 pre-processor. There are three options in the "create mesh" sub-panel of Hypermesh. The switch allows one to choose from the interactive, automatic, and QI optimized selections. The interactive option is used to auto mesh multiple surfaces or elements with user-controlled parameters.

Here global element size 2mm is maintained and the minimum edge length is 0.5mm.
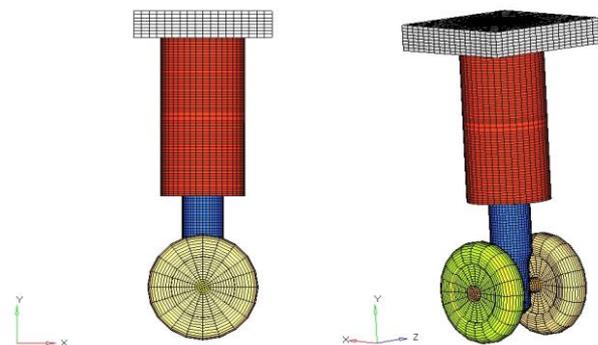


Fig.5.2 Finite Element Model of an Landing Gear system.

### 5.1.1 MESHING PARAMETERS:

Table 5.1 Landing Gear System Finite Element Model Data.

| Meshing Size | Type Of Mesh | Type Of Element Used | Number Of Nodes | Number Of Elements |
|---|---|---|---|---|
| Fine mesh(10mm) | solid | Hexa, penta | 319358 | 289486 |
| Tetra mesh (15mm) | solid | Tetra | 21821 | 83054 |
| Average mesh (20mm) | solid | Hexa, penta | 44065 | 36191 |

## 5.1.2 ELEMENT QUALITY PARAMETERS:

For accurate results and numerical stability, elements should be cleared for the quality criteria mentioned.

Table 5.2 Quality Criteria for 3 Dimensional Elements.

| PARTICULAR | UPPER LIMIT | PARTICULAR | UPPER LIMIT |
|---|---|---|---|
| Warpage | 30 degree | Length* | 0.5mm |
| Aspect | 5mm | Jacobian | 0.6 |
| Skew | 60 degree | Tria min angle | 30 degree |
| Quad min angle | 45 degree | Tria max angle | 120 degree |
| Quad max angle | 135 degree | | |

*length may vary from component to component.

### 5.1.3  MATERIAL PROPERTIES:

Material details of nose landing gear system.

| Components | Material | Young's Modulus [E] N/mm² | Poissoin's Ratio [Nu] | Density [Rho] Tonne/mm³ | Mass [M] Tonne |
|---|---|---|---|---|---|
| wheels | Rubber | 70 | 0.45 | 6.5E-9 | 6.9E-2 |
| piston | Steel | 2.47E5 | 0.29 | 7.86E-9 | 11.16E-2 |
| Upper mass | Aluminium | 7.17E4 | 0.33 | 2.82E-9 | 7.05E-2 |
| Wheel hub | Magnesium | 4.48E3 | 0.35 | 1.8E-9 | 2.0E-3 |
| Cylinder | Aluminium | 7.17E4 | 0.33 | 2.82E-9 | 2.948E-2 |
| Piston rod | Steel | 2.47E5 | 0.29 | 7.86E-9 | 11.16E-2 |

Table 5.3 Material Properties of nose landing Gear system.

## 5.2 BOUNDARY CONDITIONS:

Finite element analysis was carried out to evaluate the static analysis and dynamic behavior such as eigen values and eigen vectors. To execute the finite element analysis, different boundary conditions were used depending up on the nature of result to be evaluated.

### 5.2.1 BOUNDARY CONDITIONS FOR STATIC AND DYNAMIC ANALYSIS:

The analysis was carried out to predict the mode shapes and first few natural frequencies of nose landing gear system. The mode shapes required for the study of dynamic behaviour, were generally the lower mode shapes of the structure.
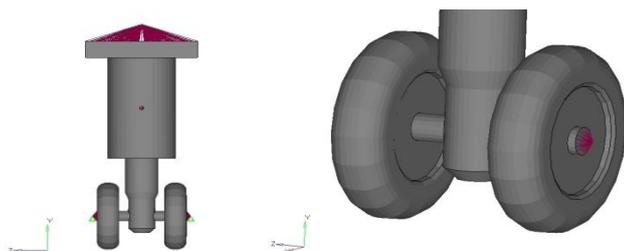


Fixed in All Degree of freedom.
Fig.5.5 Finite Element Model of nose landing gear system with Boundary Conditions.

## 5.3 POST-PROCESSING:

### 5.3.1 LINEAR STATIC ANALYSIS RESULTS FOR FINE MESH SIZE 10mm:

**Stress and displacement contours for load in y direction:**

The stress and displacement contours have been obtained for the load cases mentioned above, following figures shows the Stress and displacement contours for load case. The Figure shows the Displacement contour for the first load case.

It is found that maximum displacement occurs at the wheel hub which can be visualized from the red colored portion indicating maximum value as shown in the figure below.

### 5.3.1.1 LOAD CASE 1 EMPTY WEIGHT OF AIRCRAFT (10.5KN):
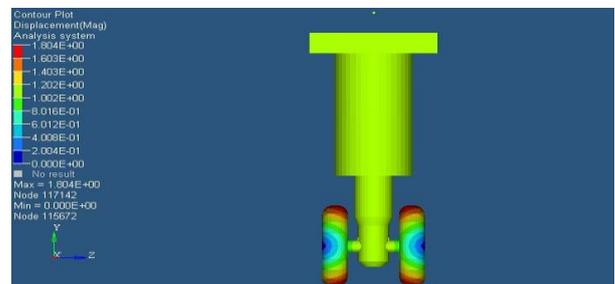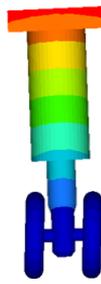


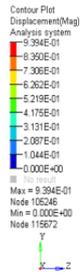**Displacement contour for load case-I**
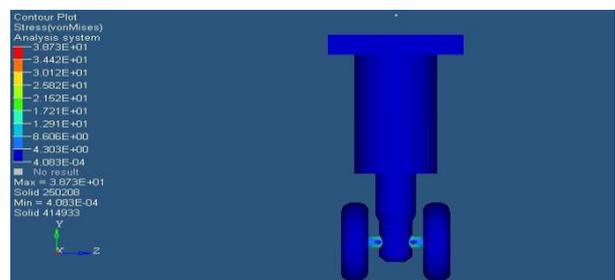


**Stress contour for load case-I**
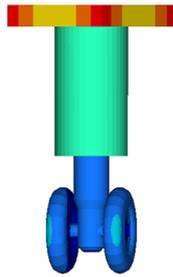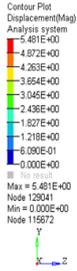
### 5.3.2 NORMAL MODAL ANALYSIS-RESULTS:

The natural frequencies obtained from the finite element modal analysis are tabulated below. Here the frequency range of interest of an Landing gear system is between 0 to 300Hz.
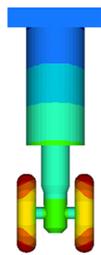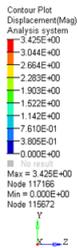


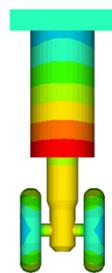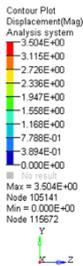First mode shape of Landing gear system.

Second mode shape of Landing gear system.



Third mode shape of Landing gear system.



Fourth mode shape of Landing gear system.



Fifth mode shape of Landing gear system.

## 6. RESULTS OF LINEAR STATIC ANALYSIS:

As the material is ductile, maximum. Distortion energy theory (Von mises theory) is considered for determining the criterion for failure. Taking a factor of safety of 2.0, the allowable stress for the material is 205 MPa, based on Y.S of 410 MPa.

It is concluded that, the maximum stress of 163MPa (for both of above load cases, over the entire landing gear assembly) is well within the allowable limit.
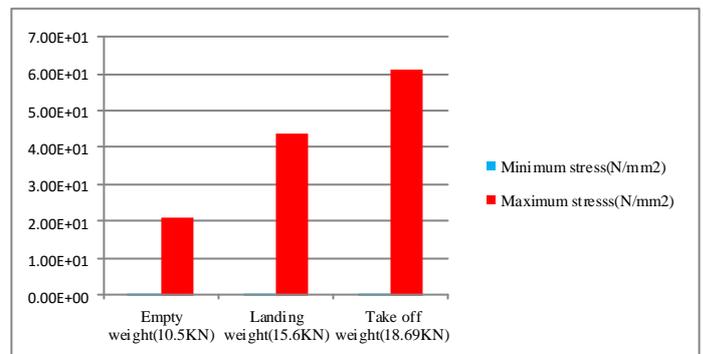
### 6.1.1 Graphs of stress v/s loading condition for nose landing gear model.
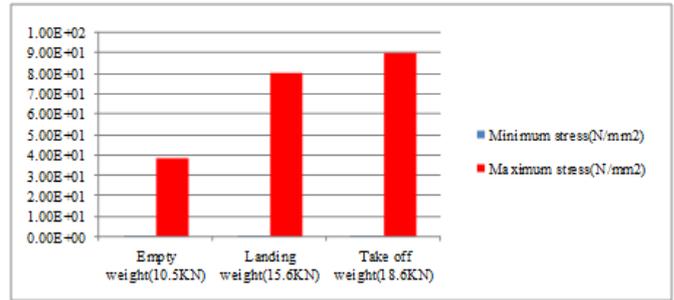


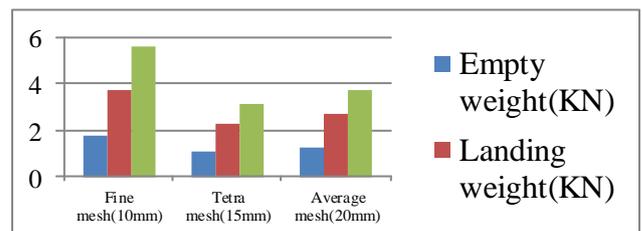Graph 6.1 - Stress v/s Load in fine mesh (10mm) model.
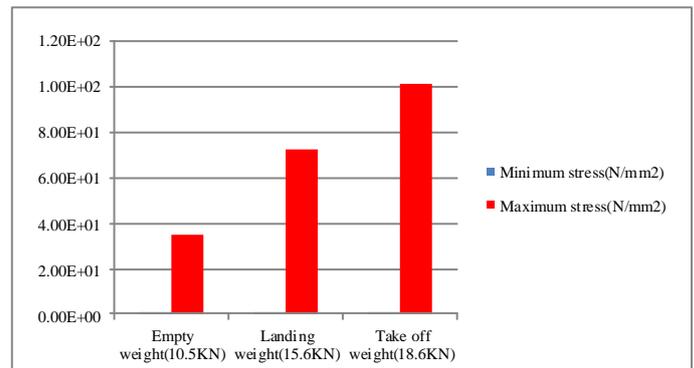


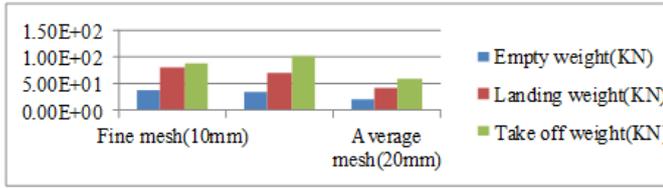Graph 6.2 - Stress v/s Load in Tetra mesh (15mm) model.



Graph 6.3 - Stress v/s Load in Average mesh (20 mm) model.

### 6.1.2 Graphs of Displacement v/s varying Meshing size for nose landing gear model.
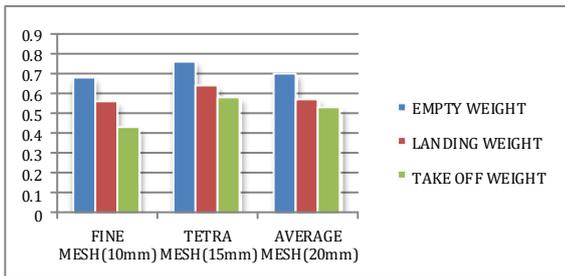


Graph 6.7- Displacement (mm) v/s varying mesh size.

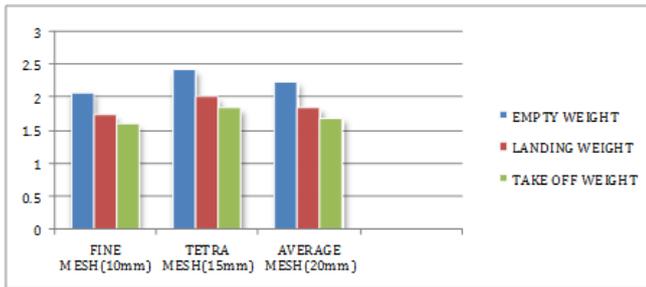### 6.1.3 Graphs of Stress v/s varying Meshing size for nose landing gear model.



Graph - 6.8 Stress (N/mm$^2$) v/s varying mesh size.

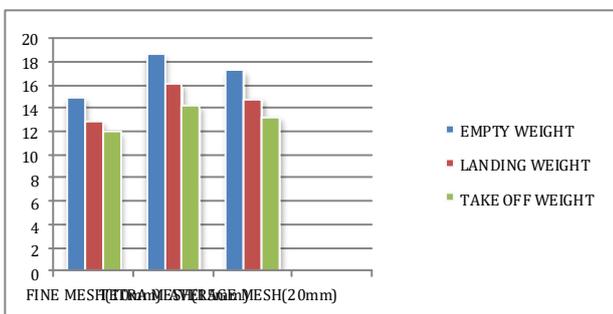### 6.1.4 GRAPHS OF FREQUENCY V/S MESH SIZE FOR NOSE LANDING GEAR MODEL.



Graph 6.11 Frequency v/s mesh size in first modal shape.



Graph 6.12 Frequency v/s mesh size in second modal shape.



Graph 6.13 Frequency v/s mesh size in third modal shape.

From the modal analysis graph it is observed that tetra mesh results are greatly reduces when compare with average mesh and fine mesh. Hence it is recommended that to avoid the tetrahedral elements for dynamic analysis.

## CONCLUSION

This analysis demonstrated several important factors in analysing a nose landing gear. First, the function of the nose landing gears must be understood. A CAD model of nose landing gear was designed and discretized in to finite element mesh using HYPERMESH. Design loads were applied through RBE3 connection in respective directions. Static and Normal Modal analysis were conducted in MSC NASTRAN.

In static analysis the obtained stresses are much lesser than the allowable stresses of the material. The obtained magnitudes of maximum stress are less than the yield stress and ultimate stress so we conclude that material in elastic limit and not yet started yielding and initial crack. FE analysis will allow them to make design alterations prior to manufacturing and testing, which in turn can save them time and money. This analysis can be performed on the Twin Otter nose landing gear to predict failure. Future research can be implemented from this analysis, such as incorporating the tyre into the analysis, performing non-linear and dynamics stress analysis at the time the tyre contacts with the runway until the aircraft stop, and performing physical testing for validation purposes.

In normal modal analysis predict the dynamic characteristic of nose landing gear system such as the natural frequency and mode shape. Basically, natural frequency and mode shape are important parameters in design. That is because damage can be occurred if the nose landing gear is excited at the natural frequency during operation. As conclusion, this project has achieved its core objectives. The dynamic characteristic such as the natural frequencies and mode shapes of the nose landing gear was determined analytically. The result indicating that the FE model shows a good correlation with the experimental model for the mode shape but not for the natural frequencies. The FE model presented an average of 10% higher frequencies than the nose landing gear. This fact is due to the perfection of the model and the imperfection of the real structure. For instance, in the FE model the welds are perfect but in reality these can have defects that lead to a smaller structural stiffness.

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## BIOGRAPHIES

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