Numerical Analysis of Aircraft Nose Landing Gear using FEA

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Abstract
Landing gears, being one of the most significant subsystems of an aircraft are always subjected into investigations past many years to improvise its service and life. In this study, a retractable tricycle nose landing gear of a modest aircraft capable of carrying 30 passengers is designed using CATIA and then FEA is carried out to figure out the position and value of maximum stress and deformation. The designed model was further interpreted into a 3-part assembly consisting of the axle, shock strut made of Steel 300M and the trunnion formed using Aluminium- Al 7175. The FEA is carried out at the maximum take-off weight condition with maximum load on the gear yet at rest. Investigation is undertaken to reduce the value of maximum stress after obtaining the basic designed model simulation results. 4 modes were introduced one with material change and rest with design change and the results shows spectacular trends of limiting the maximum stress values. Thus, through this work, it can be concluded that smart modifications on the pre-existing landing gear models will generate surprising results with low maximum stress values which will always be welcomed by the aviation industry.

Keywords - *Tricycle nose landinggear, modification stress analysis*

I. INTRODUCTION

Aircraft landing gear supports the entire weight of an aircraft during landing and ground perations. Aircraftlanding gear supports the entire weight of an aircraft duringlanding and ground operations. They are ttached to primarystructural members of the aircraft. The type of gear dependson the aircraft design and its intended use. Most landing gearshave wheels to facilitate operation to and from hard surfaces,such as airport runways. Other gear feature skids for thispurpose, such as those found on helicopters, balloon gondolas, and in the tail area of some tail dragger aircraft. Aircraft thatoperate to an from frozen lakes and snowy areas may be equipped with landing gear that have skis. Aircraft thatoperate to and from the surface of water have pontoon-type landing gear. Regardless of the type of landing gear utilized, shock absorbing equipment, brakes, retraction mechanisms, controls, warning devices, cowling, fairings, and structural members necessary to attach the gear to the aircraft are considered part of the landing gear system.

Landing gear is one of the important parts of an aircraft; often referred to as undercarriage.Landing gear is a structure which is installed on the aircraft for the purpose to support the weight of the aircraft while it is on the ground and also allows the aircraft for smooth maneuver such as takeoff and landing. A similar system is used to allow the use of skis and wheels on aircraft that operate on both slippery, frozen surfaces and dry runways. Typically, the skis are retractable to allow use of the wheels when needed. The material included within the submissions include an overview of the various types of shock absorbers and the general equations pertinent to these designs, an in depth technical investigation of the oleo-pneumatic shock absorber, an analysis of multiple case studies, in addition to a discussion of future innovations. The landing gear's main function is to control the rate of compression/extension and to prevent further damage to itself as well as other parts of an aircraft when a load is applied. Loads can be either static or dynamic in both cases the structure must withstand applied loads and deformation and continue to do its purpose.

II. LANDING GEAR CONFIGURATION

Landing gears are attached to an aircraft in different locations based on the design requirement and need. Landing gears can be attached to the aircraft under the wings, in fuselage or in the point of intersection of the wing and fuselage. Listed below are the familiar landing gear configurations.

A. Single main,
B. Bicycle,
C. Tricycle,
D. Tail gear,
E. Quadricycle and
F. Multi-bogey landing gears.

A. Single Main Landing Gear

Single main is the elementary aircraft landing gear configuration. In this arrangement a huge landing gear located near to aircraft cg acts as the main gear and carries greater part of aircraft weight.

Also, a very modest gear is also present in this configuration. Though this arrangement favours in simple integrity and small weight, the instability in ground is a critical issue here. Auxiliary gears are equipped with these aircraft to prevent wing tipping.

B. Bicycle landing gear

In this landing gear configuration, two identical sized landing gears one forward and the other aft, almost equidistant from the aircraft cg are located. This is an expansion of the single main gear providing modesty and reduction in weight. However, ground instability is again a problem in this arrangement.

C. Tricycle landing gear

This is the broadly used configuration with two main wheels carrying majority of aircraft weight equally and positioned aft to the aircraft cg along with a nose landing gear located near the nose of the aircraft. In this configuration, the aircraft will be level on the ground as the nose and main landing gears are having almost same height and leading the floor to be flat. This arrangement provides directional stability and better view to the pilot during landing and lift off.

D. Tail gear configuration

In this configuration, two large gears carrying equal load are positioned forward and near to the aircraft cg and an auxiliary gear which is comparatively small is located below the tail. This is also called as a conventional landing gear. The ground stability is good as the aircraft has three gears. But the ground directional maneuverer is quite tough. Furthermore, as the auxiliary gear is much smaller than the main gear, the ground levelness is not there in these aircrafts.

E. Quadri cycle landing gear

This landing gear system looks like a normal car wheel assembly with two wheels in the aft and two in the front of the aircraft cg providing high stability during ground and taxiing and are mainly preferred in bomber and huge cargo aircraft. But these aircraft have a negative effect if any rotation is needed during landing and lift off and so lengthy take off run is needed.

F. Multi-bogey landing gear

Larger aircraft need more landing gears for enhancing aircraft safety and so the number of landing gears also should be increased. Airbus A380 and Boeing 747 and similar giant aircrafts use multi-bogey landing gear where multiple gears are connected to the landing gear strut using a structural component called bogey providing amazing ground and taxiing stability. Anyhow, these landing gears are very expensive and complex.

III. METHODOLOGY

a. Literature review
b. Modeling of nose landing gear using CATIA V5
c. Structural Analysis of landing gear by using ANSYS software
d. Comparison of different model stress values.
f. Conclusion.

IV. DESIGNING OF THE NOSE LANDING GEAR FOR SMALL AIRCRAFT

When designing the landing gear fully or even designing its individual necessary components, there are plentiful things stuff to think about. There might have conflicting parameters were the industry want more stiffness and strength for the parts but doesn't appreciate an increase in component weight or the manufacturing cost.
The software used for design is CATIA V5 and the parts of the landing gear are modelled in the part design work bench individually and are assembled in the assembly workbench to form an integrated nose landing gear model. The part names, views and the material used for the respective part manufacturing of the nose landing gear for the small aircraft are listed below.

S.I NO	Nose landing gear Part names	Material used for part manufacturing
1	Trunnion	Aluminium Al 7175
2	Drag strut rod	Steel 300M
3	Drag strut brace	Steel 300M
4	Torque link	Steel 300M
5	Axle	Steel 300M
6	Towing fitting	Steel 300M
7	Actuator mounting plate	Steel 300M
8	Steering collar	Aluminium Al 7175
9	Upper steering actuator plate	Aluminium Al 7175
10	Lower steering actuator plate	Aluminium Al 7175
11	Shock strut (absorber)	Steel 300M
12	Steering actuator centre plate.	Aluminium Al 7175

Table 1; Nose landing gear parts of a small aircraft.

A. Complete Design model

The complete designed model as per the reference paper, of the nose landing gear for a small aircraft which can carry nearly 30 passengers is depicted below. As there is movement of parts in the landing gear assembly, kinematics is also included, and the designed model could represent a real time functionality.

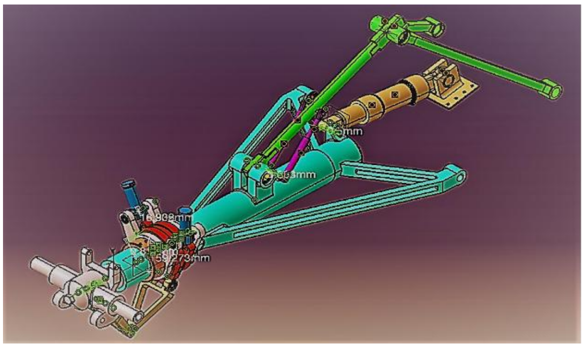

Fig 1. Modelled nose landing gear model

B. Simplified Model

Analysis is easy for simple models and is tough for complex or models with more parts. So, it is always simplifying the landing gear model in a smart engineering way by removing the parts which are not relevant to the analysis. Retraction mechanisms of the nose landing gear, for instance could be removed for simplification. A more decent model with only the most needed parts could be enough for conceptual analysis. This is similar to product-based design in a real world, where the simplified design model will be used foe analysis and investigation. However, the manufacturing-based design uses almost all the parts or sub-assemblies. The more simplified design model ready for the analysis is with 3 parts; trunnion, shock strut and axle.

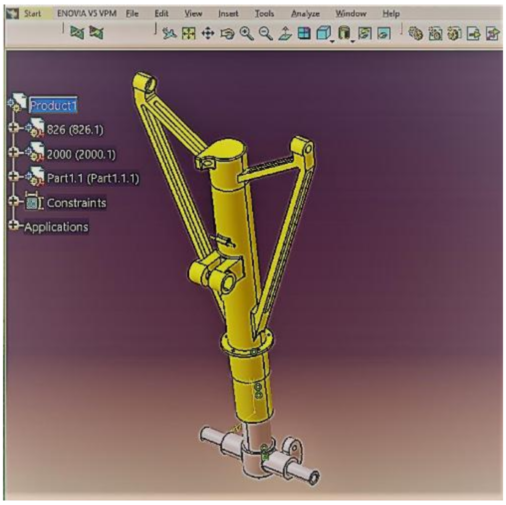

Fig 2. Simplified landing gear model, Model-0.

C. General Mathematical calculations and Assumption

There are two cases on which the action of the loads acting on an aircraft are varied.

1. When the aircraft is at rest carrying just the weight of it, that means, no drag force is acting on the landing gear.

2. When the aircraft is on motion, accelerating for lift-off or decelerating for landing, drag force which is nearly half of the weight of aircraft will act on the nose or main landing gear and this force could not be eliminated.

In the report, Stephen Fraser, says the weight values acting on the aircraft. It states the values of Take-off weight, Landing weight and empty weight of the aircraft.

- Take-off weight = 11600 Kg
- Landing weight = 11250 Kg
- Empty weight = 6880 Kg.

Static analysis is preferred in this project, as when aircraft touches the ground during landing, drag forces will also affect the landing gear and because of the landing gear motion, dynamic analysis is the right one to proceed there. However, aircraft with its maximum loading condition or the take-off weight condition is preferred for analysis with just the take-off weight acting on the landing gear.

- Take-off weight in terms of Newton,
  = (11600*9.81)
  = 113761.2 N.
- Also, nose landing gear carry nearly 12% of aircraft overall weight. So, the load acting on the nose landing gear = (113761.2) *(12/100)
  = 13651.344 N

Thus, static analysis of the aircraft landing gear can be done by loading the landing gear at the top and as well as at the bottom. If the loading is at top, which literally pictures the physical real time landing gear load transferring mechanism (transferring aircraft weight to the ground) and so a fixed support is applied at the aircraft wheel. If wheel is not selected for simplicity, fixed support should be provided at both of the axle ends. And if designer is applying the load at the wheel or at the axle representing the wheel, then fixed support is added on to the top. These two scenarios picture the same effect but in two ways.

The pattern of the analysis adopted here is, to find the value of maximum stress and its location. After finding out the location and value, incredible engineering approach in design is selected to reduce the value of stress. So, to find out the structural analysis of the basic model, named as model-0 is the first step in analysis.

V. ANALSIS OF THE NOSE LANDING GEAR

Basically, structural analysis of the nose landing gear model for small aircraft, named as model-0 need to be find out. After settling in selecting which software to use for analysis, this wonderful engineering hub is ready to take off. In this masterpiece, ANSYS is selected as the software for simulation and with the design load and respective boundary conditions, the following track is utilized for obtaining the results.

1. Select the analysis as static structural in ANSYS.
2. Import the designed model-0 into the modeller.

3. Select or update the materials used in the respective parts of the model and its material properties. Material properties of almost all materials are available in mat web. Aluminium-Al 7175 and Steel 300M are the materials selected for this landing gear parts.

4. Next step is to enter into the model workbench and setting up all the boundary conditions. As a preliminary step, material for the parts are updated first.

5.Next task is to provide satisfactory connection contacts in to the parts which are in contact to each other. The bodies which are in contact can be said like, the first one as a contact body and the other a target body and these are indicated in the modeller as red and blue colour of easy identification. General contacts types are Bonded, non-separation, Frictionless, Rough and Frictional and are selected according to the demand or contact type used.

6.Another important step is to apply the mesh to the model and as discussed earlier, element size is determined by the quality of the analysis and the allowable time. Mesh can be added in many ways and sizing is used here with an element size of 15mm.

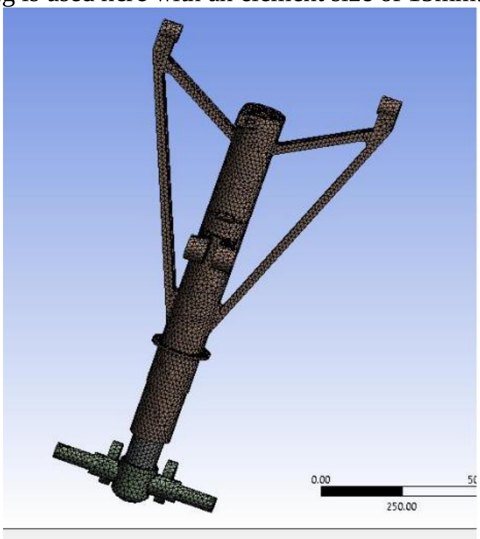

Fig 3. Meshed model-0.

7. After meshing, boundary conditions are applied, as fixed support on the trunnion top and frictionless support on the strut outer surface as below.

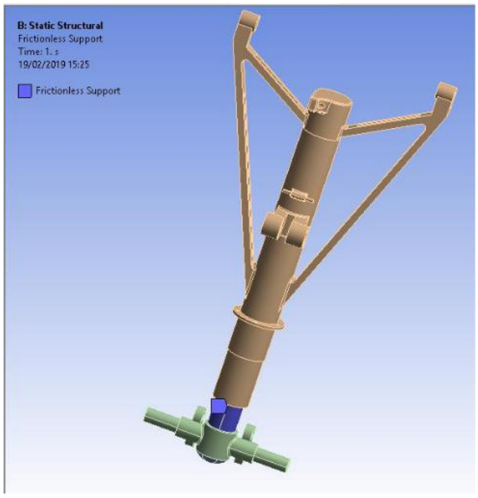

Fig 4. Frictionless support.

8.A bearing load is applied on the axle structure on both ends where wheel is joining. The physical load acting on the wheel is represented as the same load and is applied on the axle representing the same effect of the wheel. Bearing load is best suited here.than a normal load or pressure. Also, the weight of the inflated tires is ignored as it is very small compared to the aircraft load.

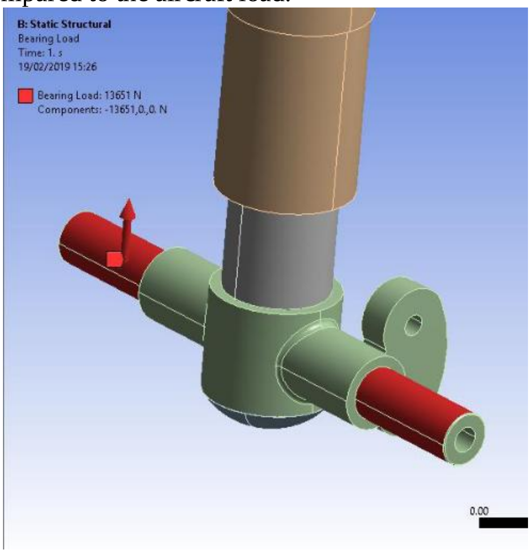

Fig 5. Bearing load on the axle.

9.Now it is the time to represent the shock absorber, and as described earlier, almost all modern aircrafts are equipped with advanced oleo-pneumatic shock absorbers and so likewise, the most simplified oleo-pneumatic shock strut is represented using water and air as the fluids. Water is denser than air and is subjected to present in the position in the strut and the air over the space on the top of the strut providing shock absorption by compressing the water and there by displacement mechanism to the system and shock absorption.

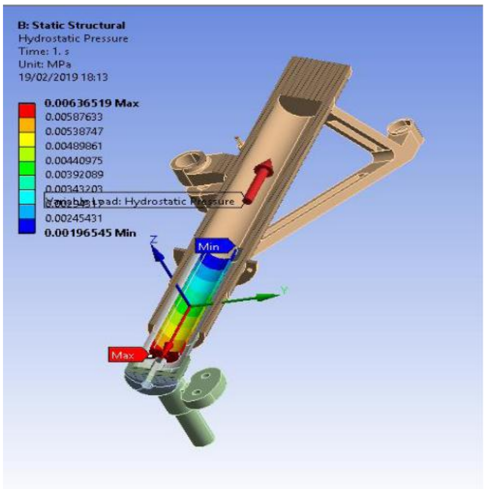

Fig .6 Hydrostatic force of water on to the strut structure.

Shock absorption mechanism can be represented as a damping system with a damping constant in advanced analysis scenarios. The hydrostatic water pressure is also added to improve more realistic effect. The air inside the trunnion is also exerting a force downward on to the water.

10.Thus, the loads and boundary conditions are added to the model-0 and now it is the time to run the analysis for solution. Total deformation and maximum value of stress and the location of maximum stress are the focus of this analysis. The results are shown below.

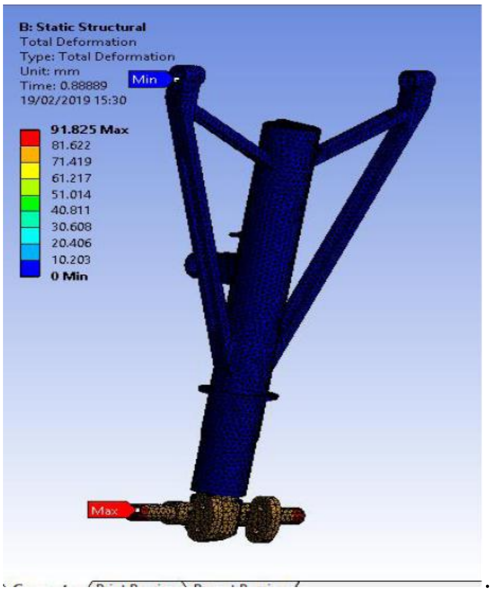

Fig 7. Total deformation for model-0.

The maximum value of stress is found to be 624. 4 Mpa and is acting near the bottom part of the trunnion. Now, different approaches should be adopted in order to reduce this maximum value of stress.

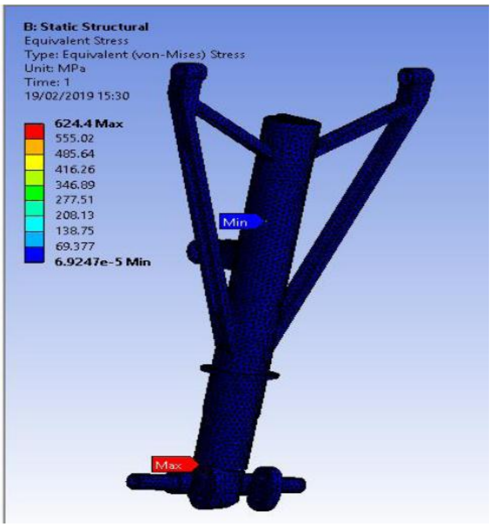

Fig.8. Stress results for model-0.

Common approach is to change the material or to do some modifications on to the model based on the limiting factors. In most cases, weight and cost are appaired to be the limiting factors. In this work, neither weight nor cost is considered as the limiting factor as this is more focused on conceptual design and analysis.

Further investigation to reduce the maximum value of stress is based on the 4 cases. In all the 4 cases the mesh size, value of loads, position of supports or the contact connections are kept constant. The 4 investigations are briefly explained here..

I. Changing the material by selecting any other material randomly and conducting the same analysis and there by investigating the new results. The new nose landing gear model can be named as, modified model-1.

II. Changing the design by varying the dimensions, keeping the materials same and following the analysis. This new modified model can be named as, modified model-2. This model-2 is having the same material as the default materials for model-0.

III.Changing the design by varying the dimension in a different way and following the analysis again with same material, model-0. This new modified model can be named as, modified model-3.

IV.Changing the preliminary design of model-0 slightly by varying any of its dimension values and following the analysis. This new modified model can be named as, modified model-4.

Thus basically 4 modifications are introduced for the investigation looking on to some positive side with expected favourable results.

1. Modified model, model-1

As said above model-1 is developed by just changing the material to a different one. All the dimensions and geometries are the same. Material selection can be done by advanced material selection software. Here random picking of material is done, and the value of the properties are added from mat web. The selected materials are High carbon steel and AK steel 301 austenitic Stainless steel which is cold worked and full hard.

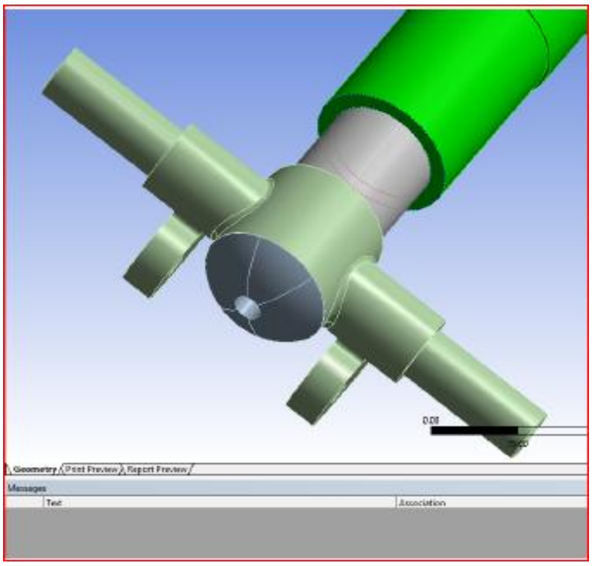

Fig 9. Updating the new materials to develop model-1.

2. Modified second model, model-2

The second nose landing gear model is developed by the modification of the model-0 by keeping the material same and changing the dimensions of the design. The changes adopted are as follows.

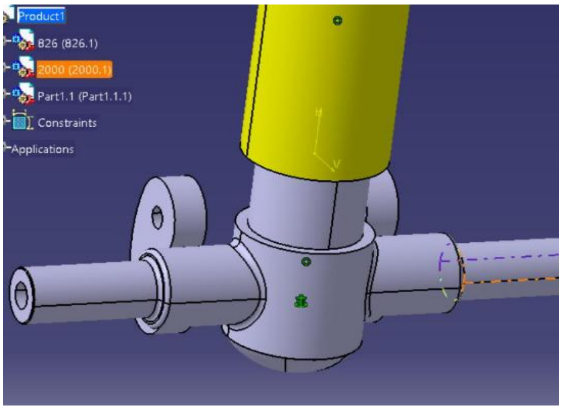

Fig 10. Model-2 for analysis.

After changing the dimensions of the diameter of trunnion inner surface and also providing few modifications on to the axle, model-2 is created. All the other parameters are kept same, and the analysis is carried out.

3. Modified model, model-3

Design modifications are done further to the model-0 to develop model-3 to inspect and identify whether these new design changes could bring more stress to drop down.

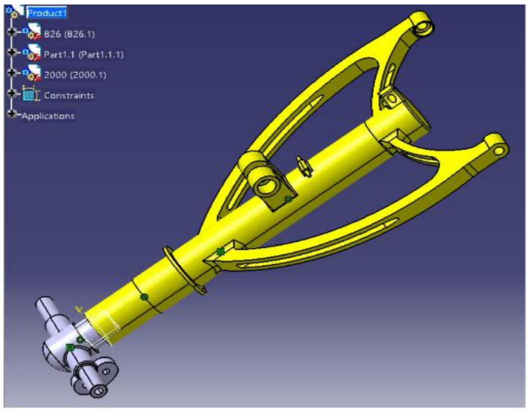

Fig.11. Model 3 Creatd

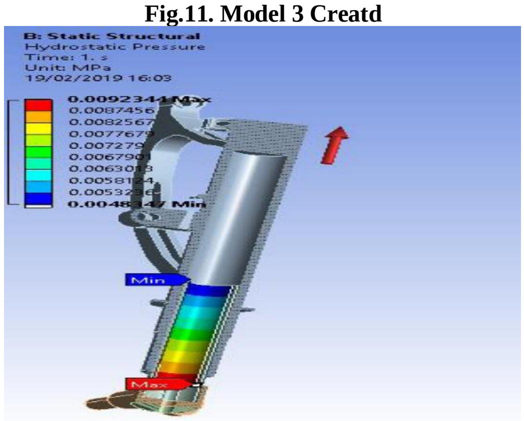

Fig 12. Hydrostatic pressure applied on model-3.

4. Modified model, model-4

The final model, model-4 is also developed by changing the design of the model-0. The new model-4 is shown below. Here the trunnion structure is further changed, and slight deign variations are also provided for axle and strut. The investigation will hopefully represent how far the stress vary with the design alterations.

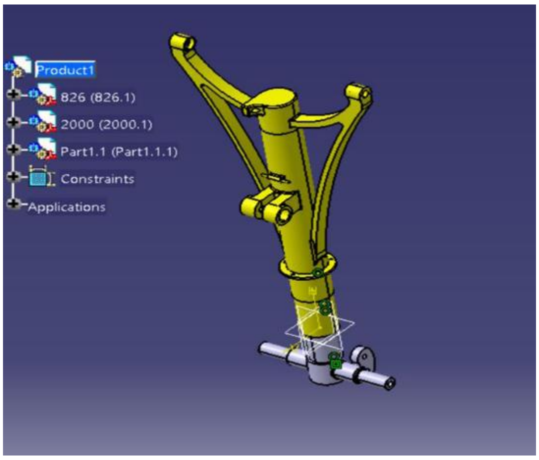

Fig 13. Modified model, model-4.

Thus, a total of 4 new investigation is conducted to analyse the stress behaviour. 1 by changing the martial and its properties and the other 3 by changing the design slightly. Now the stress results of all the modified models are compared with that of model-0 and then the investigation results are gathered.

VI .ANALYSIS RESULTS

The post-processor results of structural analysis of the 4 modified models are as follows; The results are shown as the values of stress and deflection obtained from the analysis.

1. Results of modified nose landing gear model-1

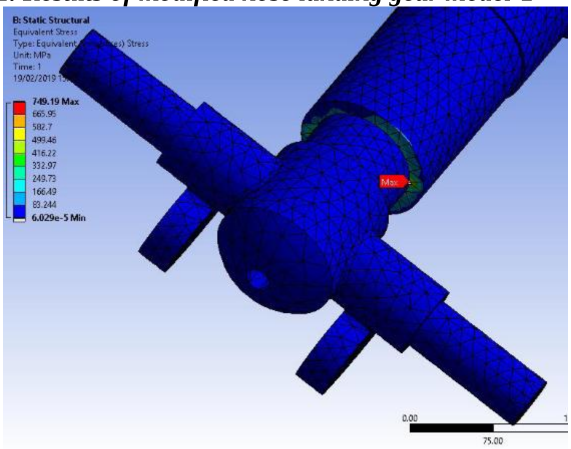

Fig 14. Stress results of modified model-1.

The results states that, when randomly changed the material, the stress and deformation values also varied dramatically. The value of deflection of model-1 is reduced, where as the value of maximum stress is increased which is not a positive result.

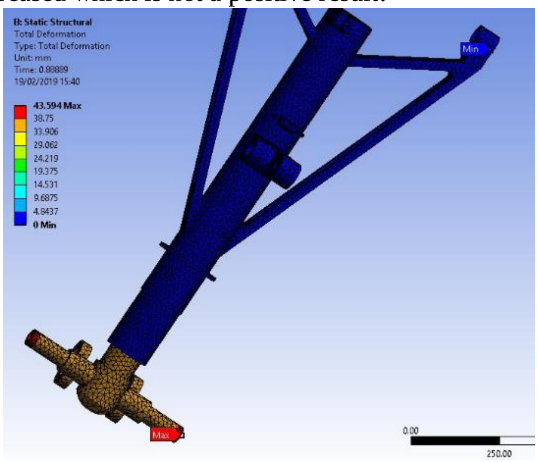

Fig *15.Defrmation of model 1*

2. Results of modified nose gear model-2

The stress and deformation results of model-2 is as follows. A small change in the design is considered and applied to the model-0 and the results are as follows..

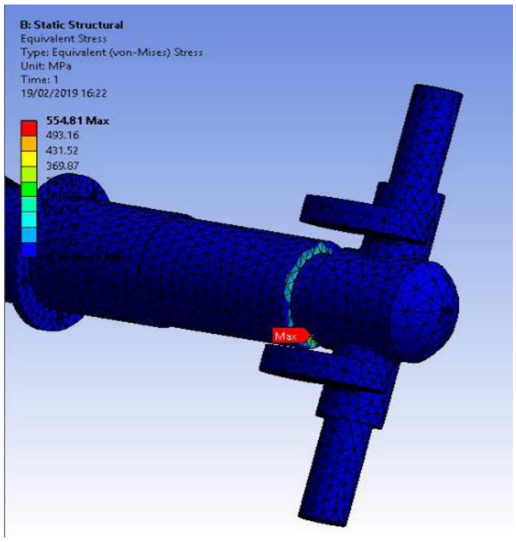

Fig 15. Stress values of model-2.

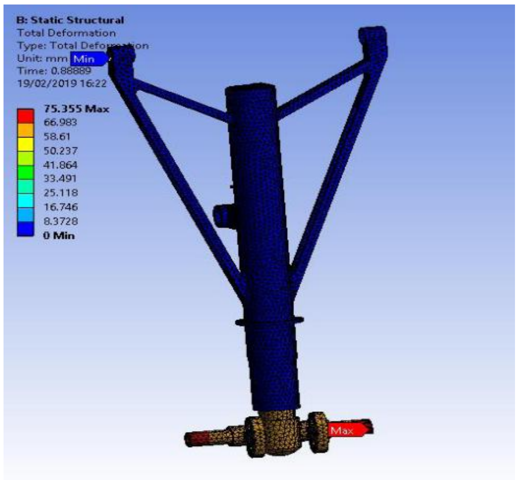

Fig.16. Deformation values of model-2.

The value of maximum stress is lowered in this care. Also, the deformation is reduced slightly representing a positive analysis outcome.

3. Results of modified nose landing gear model-3

Model-3 is impressive when it displayed the stress and deflection results. The value of maximum stress is found to be 177.61 Mpa, which was spectacular and so when the design is varied slightly, maximum value of stress drops down to nearly more than 70 % of the initial value of stress of model-0. The deformation is also reduced indicating the manufactures a more demanding design to use for the nose landing gear for small aircrafts.

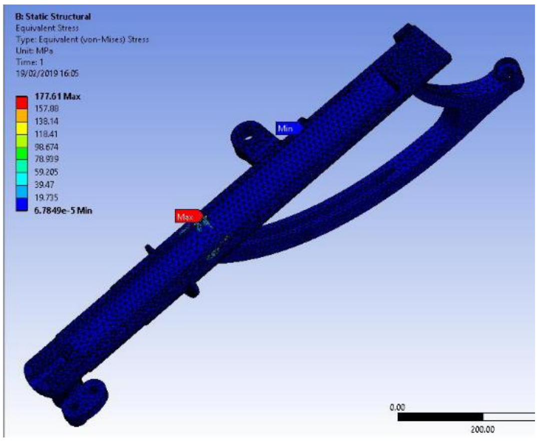

Fig.17. Model-3 with its stress value.

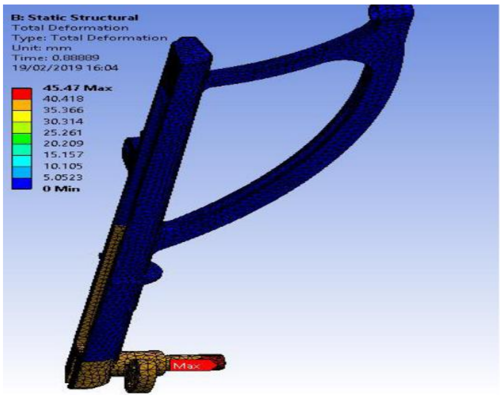

Fig.18. Model-3 deformation value.

4. Results of modified nose landing gear model-4

The stress analysis of the model-4 is also admirable as model-4 also got the value of stress similar to model-3.

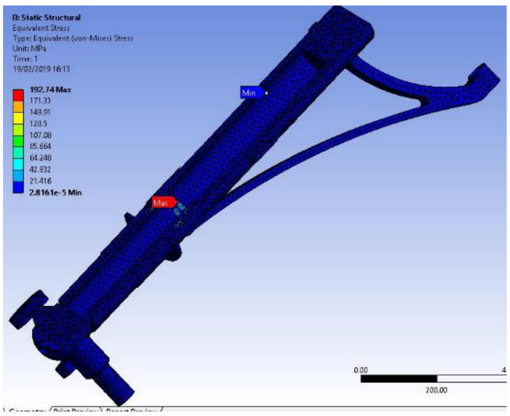

fig.19. Model-4 stress result.

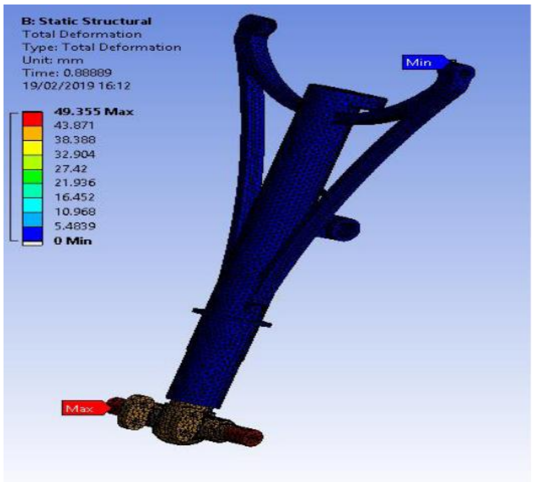

fig.20. Model-4 deformation results.

The model-4 is also a similar design variant to the fundamental model-0. However, model-4 also came up with a surprising result and thus the investigation of the analysis seems to be promising. Comparison of the values of maximum stress and deformation is shown below.

No	Model	Maximum deformation in mm	Maximum Stress value in Mpa.
1	Model-0	91. 825	624.4
2	Model-1	43.594	749.19
3	Model-2	75. 355	554.81
4	Model-3	45. 47	117.61
5	Model-4	49. 355	192.74

Table 2; Comparison of stress and deformation of all models.

VII. DISCUSSION

From all the structural analysis conducted using the 5 models, the behaviour of the stress is identified and it is clear that in all scenarios the stress and deformation keeps varying and in most cases the value of maximum stress and maximum deformation values are reduced when compared to the basic model-0. The material type and the proper design of parts are very relevant to the analysis as the stress value will be less for some designs and also the deformation is limited representing a clearer idea that the life and the utility period of the nose landing gear model could be improved. The limiting factors are not added to make the analysis simple. Practically, cost, weight and quality or precision of the results are the limiting factors.

The analysis can be further improved, or the reality of the analysis can be boosted in many ways for improved approximated results.

• Mesh size could again be reduced, to get a better result.

• Representation of entire landing gear assembly on analysis gives the full behaviour of the stress and an idea of the load transfer, stress and deformation of entire landing gear parts could be identified.

• Nose landing analysis could be conducted when the aircraft lands and touches the ground as it is one of the most critical time to cause failure of the component.

• Other loads such as tire weight could be added if tire is nor preferred for analysis.

• Advanced shock absorption mechanism could be designed and then the analysis will be more similar to the practical life scenarios.

• Material selection software can be employed to find out the material with more strength and so the stress could be reduced.

• Finally, improved designs need to be obtained for design with proper part dimension and necessary details to design.

In a general outlook, time, cost and precision of results determines the usage and removal of improvements in results. Furthermore, as quality always takes more time, there should be a mutual understanding between the result quality and allowable time to complete the analysis.

VIII. CONCLUSION

The study focusses mainly on the application of FEA in reducing the maximum stress value of the nose landing gear of a tiny passenger aircraft capable of carrying 30 passengers. The investigation is conducted by designing the landing gear model using CATIA and then carrying out the FEA analysis using ANSYS. The nose landing gear type selected was a tricycle, retractable gear having dual tires. The complex nose landing gear is simplified into a 3-parts assembly having an axle, shock strut and a trunnion structure. Maximum take-off load of about 11600 kg is considered to act on all the landing gears where as about 12% of this load is applied into the nose landing gear model foe analysis. The results of the simulation provided the location and value of maximum stress and deformation. With this backup values, the preliminary model is modified with 1 material change approach and 3 design alteration approach and a total of 4 modified models were generated. The modified models on analysis using the same mesh, loads, contacts and boundary conditions shows that modifications bring out surprising results with desired limiting for the value of maximum stress. Thus, this investigation strongly states that, smart re-modifications in the design of systems which need further improvements in any of its variables, generates spectacular results as illustrated in this nose landing gear FEA study which almost came up with desired results in most of the modified models.

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