Structural Analysis of Aircraft Landing Gear During Rough Landing

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Abstract—*Landing gear is the undercarriage of an aircraft or spacecraft, and is used in both takeoff and landing.. The landing gear shock absorber is an integral component of an aircraft's landing gear. The role of the shock absorber is to absorb and dissipate energy upon impact, such that the forces imposed on the aircraft's frame are tolerable. The shock absorber may be an independent element, or integrated with the landing gear strut. The aircraft may tend to land in a smooth manner or even in a rough manner. The landing gear components must be able to withstand the entire force. The objective of this project is to develop a landing gear which is suitable for rough landing too. The landing gear is modelled using solidworks and the modelled component is analyzed using Ansys to study its structural performance thereby replacing the material of the landing gear the same characters are studied in order to compare the result obtained by both the cases during the same landing conditions.*

Keywords—*Landing gear, shock absorber, loads, stresses, rebound chamber models*

I. INTRODUCTION

An aircraft landing gear shock absorber is a combination of mechanical structure, pneumatics and hydraulic damping used for transmitting impact loads. This project focuses energy based modelling of the shock absorber. A landing gear shock absorber model includes an aircraft mass with wing lift, shock absorber piston and cylinder structure, three hydraulic chambers representing the air chamber, hydraulic chamber, and rebound chamber, and tire. The design objective is to minimize ground reaction loads. The key design variables are centred on fixed or variable orifice definitions. [1]

II. THE DESIGN DECISION SITUATION

A. Context and Domain

The landing gear function is to absorb large amounts of energy in a controlled fashion, reducing the resulting loads on the remainder of the airplane. This project is aimed at this design problem. It is centred in the hydro-mechanical domain. [2]

B. System Description

The majority of landing gear shock struts are comprised of a piston and cylinder, pressurized by compressed nitrogen, using hydraulic fluid as the damping medium. The hydraulic chamber is normally separated from the air chamber by an orifice. This orifice may be fixed, or vary with stroke (that is, travel of the piston) or vary with pressure. Other arrangements are often employed, including dividing the air chamber into a low and high pressure volume to provide more complex (and tailor able) compression characteristics. An aircraft is supported entirely on air springs. Compression characteristics of the gas produce a pronounced non-linear spring rate, the slow, isothermal compression curve. During rapid stroking of the shock, hydraulic pressure due to viscous damping across the orifice becomes dominate, giving the strut the ability to react large dynamic loads. Often a second orifice and hydraulic chamber is used to meter the stroke velocity in the opposite (extending) direction.

C. The Design Decision

First step in design process is to decide about internal chamber arrangement and overall size of the piston/cylinder combination, followed by deciding pressure settings and damping characteristics. An efficient landing gear design balances the size and complexity of the landing gear with the load attenuation ability of the gear. This project will consider only a single landing gear, not a full aircraft. As such, aerodynamic effects, and body pitch and roll will not be explored. Also, other landing gear functions such as steering, braking, and retraction/extension for stowage will not be considered, other than how they may affect the mass of the components. [3]

III. OBJECTIVES DEVELOPMENT, MEANS AND FUNDAMENTAL

The overall fundamental objective is to maximize the landing gear performance. It is basically divided into four fundamental objectives [4]. The focus is on the energy absorption performance aspects

a) Minimize Landing Loads
b) Minimize Taxi Loads

c) Minimize Shock Absorber Volume, L x $\pi D^2/4$
d) Maximize Composite Reliability and Maintainability.

IV. SIMULATION SCENARIO

A. *Model Requirements*

1) "Fixed inputs" are those I intend to code into the model to represent physical features, but do not intend to explore for design [5]. These include:
   i) Tire characteristics (stiffness, stroke length)
   ii) Fluid characteristics (hydraulic oil)
2) "Design variables" are parameters (varied in comparative analysis). These :
   i) Stroke length, S, cm
   ii) Piston diameter, D, cm
   iii) Shock pressure, P, kPa
   iv) Shock volume, further divided into air volume, V_a, and fluid volume, V_f, cm*3
   v) Orifice characteristics, (units tbd)
3) "Variation variables" will be used to explore randomness or uncertainty in the model:
   i) Friction (piston to cylinder)
   ii) Gas compression characteristics (real gas or ideal gas).
4) "Usage variables" are parameters (varied to exercise the model in realistic usage scenarios). These will include:
   i) Aircraft mass: Only a proportional amount of mass will be applied to the model
   ii) Aircraft forward speed, m/sec
   iii) Vertical speed (landing cases only), m/sec
   iv) Bump profile (height as a function of distance).

B. *Assumptions and Simplifications*

1) Model rigid structure for the piston and cylinder, neglecting bending and expansion under load
2) Will model a single strut with 1-D motion
3) Neglect gas-fluid mixing
4) Assume constant fluid properties
5) Neglect high frequency dynamic behaviour.

C. *Critical Evaluation*

Certainly the basic structure of the physical phenomena of translating kinetic energy into stored energy and dissipated energy seems perfect for an energy-based modelling approach for HW #2. The uncertainty lies in not yet knowing what components and features in Dimple will support such a model [6]. The project concern is about modelling a pressure across an orifice.

While a fixed orifice is probably already available, to make the problem interesting and more realistic a means to model a variable orifice will have to be found or constructed [7]. The others fallout as required to make the system work.

If that proves to be too cumbersome, a fallback may be to specify more, perhaps making the strut size (stroke length and piston diameter) "givens" within which the rest of the study could proceed. That would also negate one of my measures of effectiveness (volume).

V. EXTERNAL MODELS

A. *Aircraft Model*

The aircraft model needed to be more than a simple mass in order to represent the transition from flying to being on the ground. [8] This was implemented by prescribing a wing lift decay function that gradually ramps the "weight" of the mass from 0 up to 9.81*Mass.

B. *Tire Model*

The tire can be adequately modelled as spring-damper arrangement, but real tires are generally not linear springs. The project is done by approximating the tire as three parallel spring-dampers. The springs have different free lengths so they become active at different deflections.

C. *Bump Model*

The landing simulations simply use the "Fixed" model from the library as the ground, but to enforce travel across a bump, an active bump was required. Many different profiles could be modelled; Sine functions are superimposed on a constant ground (flat) profile.

VI. INTERNAL LOADS

A. Shock Structure (Piston-Cylinder) Model

In the Stribeck friction model available in the Dymola library the friction is between the sliding mass and the "housing" which seems to be the unmoving reference frame (Earth).It is an approximation to attach the sliding friction mass to the cylinder. While the cylinder is moving down it generates a resistive force. [10] This is appropriate if the cylinder is moving relative to the piston, as when compressing the shock, but not appropriate when the cylinder is simply moving relative to the earth, as in the time shortly before landing. More work could be done to make the Stribeck friction between the cylinder and piston instead of cylinder and earth.

B. *Air Chamber Model*

The air chamber is a simple combination of a hydraulic chamber (to incorporate the correct net piston area) and a pneumatic chamber set to the air pre-charge pressure and volume. [11] There is no restriction between them as they are in direct fluid contact with each other.

C. Hydraulic Chamber Model

The hydraulic chamber model also utilizes a hydraulic chamber with the correct net piston area. [12] Flow into or out of this chamber must pass through metering orifice. A variable orifice is used in this model which allows it to be either a constant.

D. Rebound Chamber Model

The rebound chamber model is similar to the hydraulic chamber except that instead of a variable orifice, it uses two check valves. This allows different restriction into and out of the chamber. [13] This is necessary to avoid cavitations of the chamber on the strut compression stroke, but provide stiff restriction on the extension stroke. The rebound chambers usually have two distinct resistances, and could structure the model accordingly.

VII. LANDING GEAR DESIGN

The Landing Gear was modelled using Solidworks 2014 software with standard dimensions.

A. *Modelling in Solidworks.*

All the required dimensions for the Landing Gear were derived from various literature surveys. By using that dimensions, the parts of Landing Gear was modelled in Solidworks.

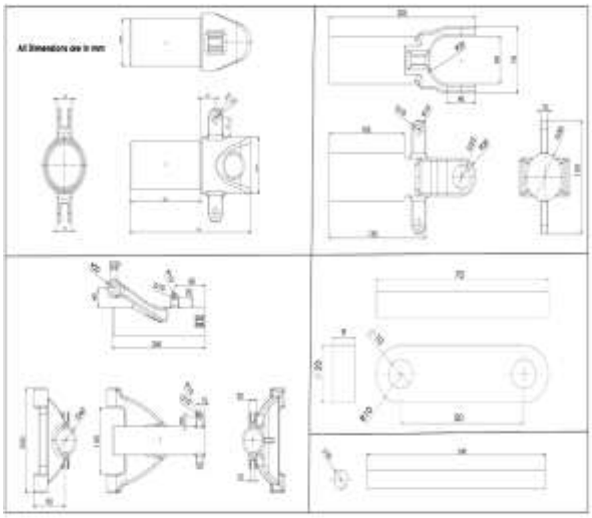

Fig.1 Parts modelled using solidworks

After all individual part file creation, assembly of all parts is done to create a single component. The assembled model of the landing gear is shown in fig.2. The three view diagram and isometric diagram of the model is shown.

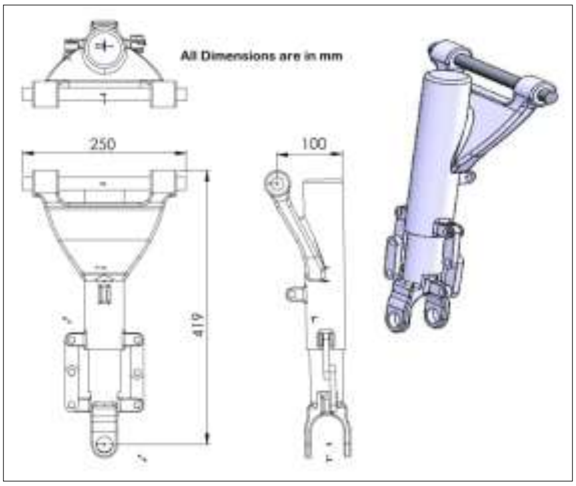

Fig.2 Assembled model of landing gear

VIII. NUMERICAL ANALYSIS

A. *FEA*:

Finite Element Analysis (FEA) uses numerical methods and algorithms to solve and analyse problems that involve analysis of structures or objects using computers.

B. *Outline Finite Element Analysis Process*

The three basic elements are

i) Pre-processor
ii) Solver
iii) Post-Processor

C. Material Selection

Materials selection for the Landing Gear is made using Ansys.. In general the landing gear is made of metal substrate which is a Titanium alloy Ti-6 Al – 4V. The SAE 1035 steel and 7075-76 aluminium alloy is replaced to improve the structural behaviour of the Landing Gear assembly. [14] The properties of these materials are listed in below table.1

D. *Geometry Creation*

In this process, geometry for the Landing Gear assembly is created. The Landing Gear and its components are modelled in SOLIDWORKS earlier which is a 3D model. The Landing Gear assembly has to be imported as an IGS file format to get a proper structure. The imported Landing Gear assembly model is as shown in figure.3.

TABLE I
MATERIAL PROPERTY

Property	**Ti-6Al – 4V**	**SAE 1035**	**7075-76 Al alloy**
Density	7.87 g/cm^3	4.43 g/cm^3	2.81 g/cm^3
Young's Modulus	196 GPa	113.8 GPa	71.7 GPa
Coeff. of Thermal Expansion	11.9 μC^{-1}	8.6 μC^{-1}	23.6 μC^{-1}
Reference Temperature	20°C	20°C	20°C
Poisson's Ratio	0.29	0.342	0.33
Tensile Yield Strength	550 MPa	880 MPa	503 MPa
Tensile Ultimate Strength	620 MPa	950 MPa	572 MPa

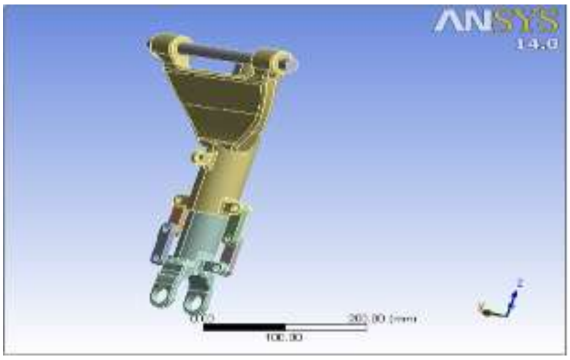

Fig. 3 Piston assembly

E. *Meshing*

Different meshing characteristics were used for the domain. In the simulations, the piston component surfaces were discretized with triangular mesh elements.

G. Boundary Condition

The problem is a structural analysis problem. The boundary condition for the problem is Force of 10 KN with the arm to be fixed.

H. Numerical Results

The structural behaviour of the Landing Gear has been studied for the above mentioned boundary conditions. The results obtained by these are shown in below. The Table.II shows the structural behaviour of the Landing Gear assembly. From the table it's clear that the SAE 1035 Steel material holds a very good structural property. The stress concentration over the SAE 1035 Steel is more than the Titanium alloy 6A1-4V and 7075-76 Aluminium alloy.

TABLE II
STRUCTURAL BEHAVIOUR

Case	**Material**	**Deformation (mm)**	**Stress (MPa)**	**Strain**
1	Ti- 6Al-4V	1.7734	232.03	0.0021
2	7075-76 Al	2.8162	232.7	0.0033
3	SAE 1035	1.0318	235.05	0.0012

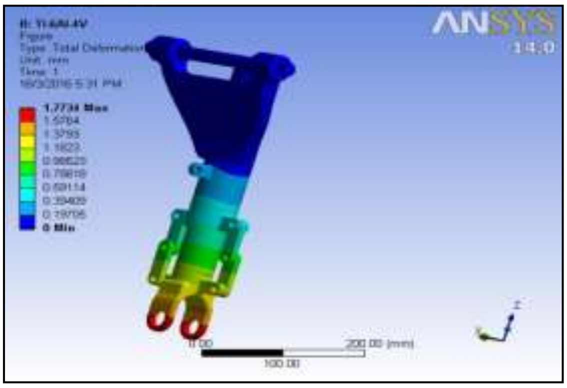

Fig. 4 Deformation for case-1

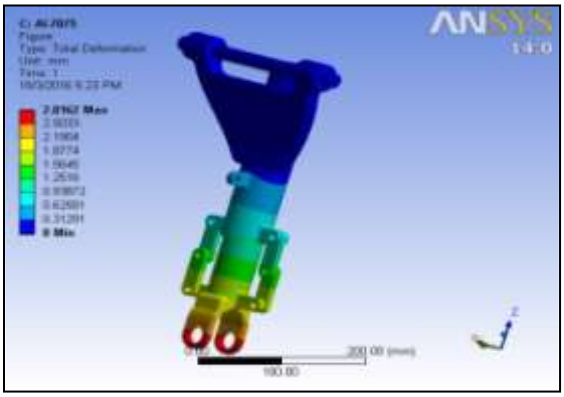

Fig. 5 Deformation for case-2

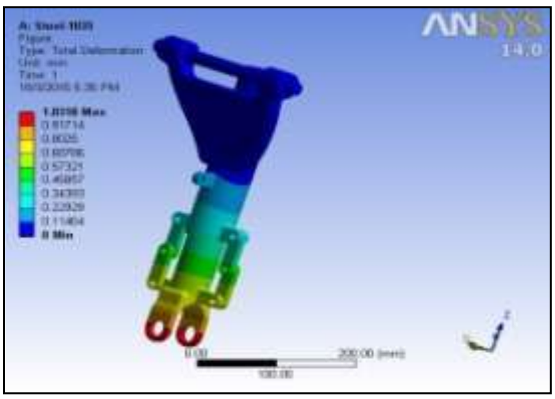

Fig. 6 Deformation for case-3

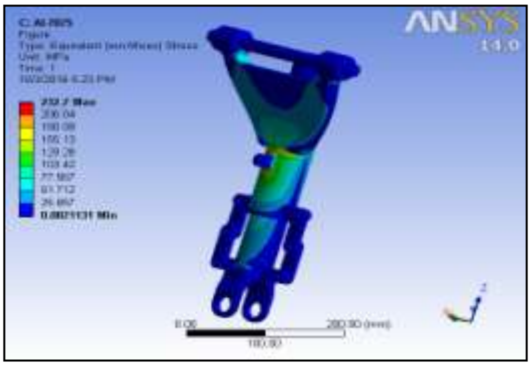

Fig. 7 Stress for case-1

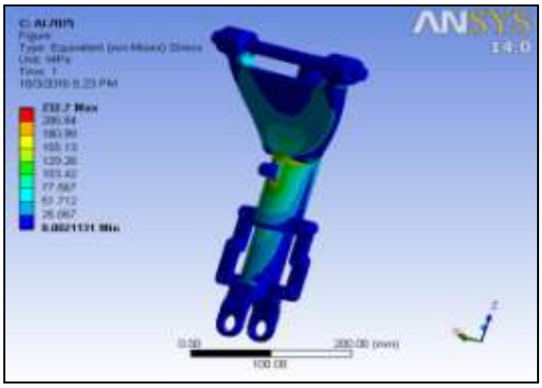

Fig . 8 Stress for case-2

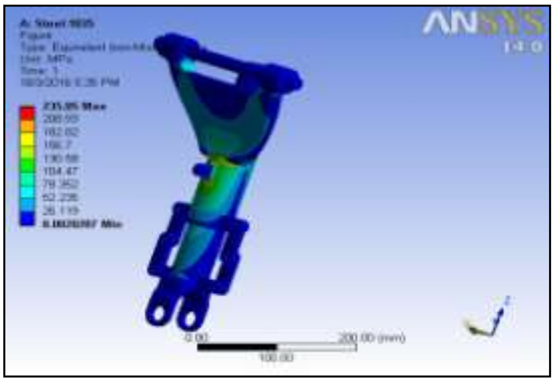

Fig. 9 Stress for case-3

From figure 4,5 and 6 the values of deformation for three cases were observed. The deformation contour clearly shows that the deforamtion is high for the aluminium alloy when compared to other two materials. The SAE 1035 holds a less deformation even blow that of titanium. So interms of deformation the SAE 1035 holds a better performance than the other two materials. From figures 7,8 and 9 the value of stresses are determined. The stress concentarion over the SAE 1035 is higher than the other cases.

The SAE 1035 holds a higher yield value than the other materials. So the higher stress doesn't affect the SAE 1035, so interms of stress concentation over the model its recommended to us SAE 1035 material.

From figures 10,11 and 12 the value of strain are observed. Since the stress is directly proportional to strain the performance of the strain also will be better for the SAE 1035 material. So in terms of all structural paramters the SAE 1035 material holds a good performance.

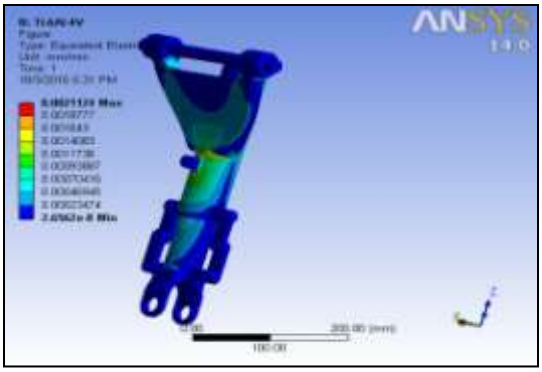

Fig. 10 Strain for case -1

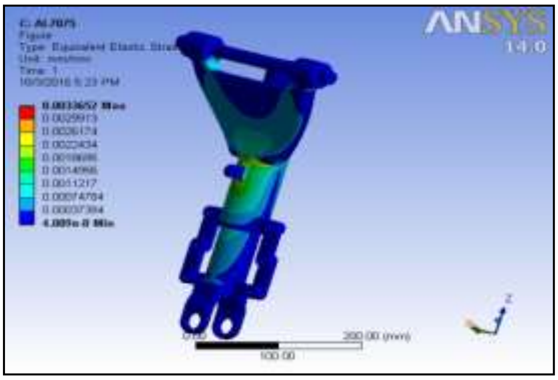

Fig. 11 Strain for case -2

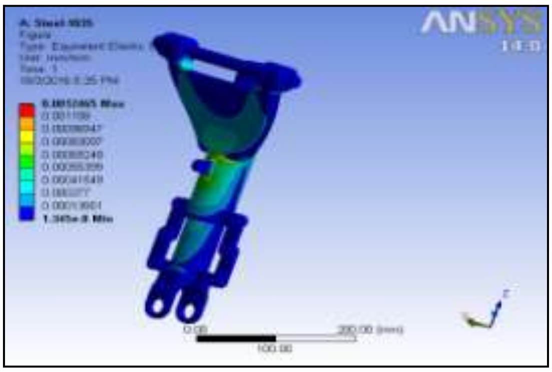

Fig.12 Strain for case-3

IX. CONCLUSION

The landing gear is modeled and assembled using SOLIDWORKS. The assembled CAD model has been considered to perform structural analysis by finite element approach using the ANSYS package. In general the accuracy of the solution depends on the mesh quality. Each component has been checked for its mesh quality to ensure the solution accuracy. Also before the meshing process model has been simplified. After these processes the structural analysis has been carried for the landing gear assembly for three different materials Titanium alloy 6A1-4V, 7075-76 Aluminum alloy and SAE 1035 Steel. The results show that the SAE 1035 steel holds a good performance when compared to other materials. The result has been compared on the basis of the parameters like deformation, stress and strain. The SAE 1035 steel has a less deformation when compared to other materials; around 35 % of the deformation has been reduced when compared. So the implementation of this material would help to avoid the landing gear damage and also it can have a better life than the other materials due to its less damage**.**

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