SYSTEM DESIGN AND ANALYSIS OF MAIN LANDING GEAR STRUT (SHOCK ABSORBER)

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Abstract
The landing gear system is an integral part of an aircraft, which aids in manoeuvring, braking, shock absorption and acts as an undercarriage. This project focuses on the design and analysis of an oleo-pneumatic shock absorber strut for nose landing gear system for a light-weight aircraft having tri-cyclic configuration. The design is based on standard input values, such as sink speed, aircraft weight, load factor etc.., using an efficient single-orifice double-chamber shock absorption system. The geometrical parameters of the components of the strut were determined based on the loads and forces experienced during landing at various conditions and the equivalent volume and corresponding pressure values of the pneumatic column were computed after which numerical analysis was carried out. The graph curves were studied in order to analyse the efficiency of the system. Modelling was carried out based on the computed values, and the design was validated by finite element analysis in order to ensure compliance with the safety standards of the aviation industry.
Keywords: landing gear, shock absorption, Main Landing Gear, Nose Landing Gear, Centre of gravity, Safety Factor

I. INTRODUCTION

A. Introduction to Landing Gear

The landing gear is the interface of airplane to ground, so that all the ground loads are transmitted by it to the aircraft structure. The main functions of the landing gear are energy absorption at landing, braking, steering and taxi control. Without the landing gear, this energy wouldn't be dissipated and would impact the airframe, damaging it with time. The absorption of kinetic energy of moving bodies ranks among the important engineering in aviation. The deceleration of a machine in motion is often accompanied by shock loads that exceed the normal operating loads of the machine. Shock-absorbing devices are used to minimize the shock loads. Shock absorber is basically mechanical or hydraulic device designed to absorb and damp shock impulses. It does this by converting the kinetic energy of the shock into another form of energy (typically heat) which is then dissipated. In an air-craft it is used for absorbing the vertical kinetic energy of airplanes at the instant of landing. The landing gear system includes: Shock absorber; Extraction/retraction mechanism; Brakes; Wheel; Tires; Links and braces; The landing gear system is similar to a quarter-car arrangement in an automobile, and consists of 3 main components as in mass, spring and damper. The mass here is the mass of the aircraft. The spring is the gas and the fluid is the damper. The layout of the landing gears is decided by taking into account these parameters and consequently design carried out based on the requirements. The layout of the landing gear system determines the load transfer to the structure, ground stability and control.

B. Types of Landing gears based on arrangement

Tail wheel / conventional type landing gear
Tandem landing gear
Tricycle type landing gear
Fixed Landing gears
Retractable landing gears

C. Tricycle-Type Landing Gear

The most commonly used landing gear arrangement is the Tricycle-type arrangement. It is comprised of two main gears behind the centre of gravity of the aircraft and one nose gear arranged in a triangular fashion as in a tricycle and hence the name. The nose gear is used to steer the aircraft using a hydraulic system. The main gear on a tricycle-type landing gear arrangement is attached to the wing structure or the fuselage structure.

The number and location of wheels on the main gear vary. Many main gears have two or more wheels. Multiple wheels spread the weight of the aircraft over a larger area and hence reduce loads. They also provide a safety margin should any of the tires fail. Heavy aircraft may use four or more wheel assemblies on each main gear.

Tri-cyclic landing gears have a series of unquestioned advantages:

• Stability in braking;
• Steady touchdown with no risk of aerodynamic bounce;
• High pilot visibility during taxiing;
• Horizontal floor (occupants' comfort and easy freight loading);
• Low drag during take-off acceleration.

As far as the strut design is concerned, two solutions are mainly adopted: the telescopic and articulated leg. The telescopic version is lighter but requires higher ground clearance for light aircraft. Therefore, we chose telescopic type with tri-cyclic arrangement as it is the most efficient for light weight aircraft we are designing. We can also classify the types as retractable and fixed Landing gears.

A list of main requirements for an efficient and functional shock absorber follows:

• Damping characteristics should be different in compression and extension; the total orifice area can be changed by inserting check valves in some orifices or valves that throttle the orifices in one flow direction;
• for high landing vertical velocities, the shock absorber responds with high reaction forces due to oil viscosity; to attenuate the load transfer to the airplane structure, relief valves may be installed on the absorber, then flattening the reaction curve;

In selecting the type, due recognition must be given to the simplicity, reliability, maintainability, and relatively low cost of the solid-spring shock absorbers. On smaller utility aircraft, the weight penalty is usually negligible and the noted advantages far outweigh the penalties in such cases. There are two basic types of shock absorbers: those using a solid spring made of steel or rubber and those using a fluid spring with gas or oil, or a mixture of those two that is generally referred to as oleo-pneumatic. The gas is usually dry air or nitrogen. With the advent of heavier airplanes, faster speeds and greater wing loadings calls for the development of efficient shock absorbers. Shock absorbers evolved from a solid spring made of steel or rubber and those using a fluid spring with gas or oil, or a mixture of those two that is generally referred to as oleo-pneumatic.

D. Solid Spring type

These are majorly the steel coil springs and steel leaf spring type that are rarely used in present day aircraft since they weigh seven times more than the oleo-pneumatic type and are only about 60 percent efficient.

E. Oleo-Pneumatic type

Most of today's aircraft use oleo-pneumatic shock absorbers. They have the highest efficiencies of all shock absorber types and also have the best energy dissipation; i.e., unlike a coil spring that stores energy and then suddenly releases it, the oilis returned to its uncompressed state at a controlled rate. An oleo-pneumatic strut is an air–oil hydraulic shock absorber used on the landing gear of most large aircraft and many smaller ones. Oleo-pneumatic shock absorber is considered the safest and the most efficient modern shock absorption type with efficiencies up to 90%. This type of strut is currently the most advanced type being used in the aviation industry. This is most apt for our application and its design and working. Figure 1.1 compares the efficiencies and relative weights of the various shock absorber types.

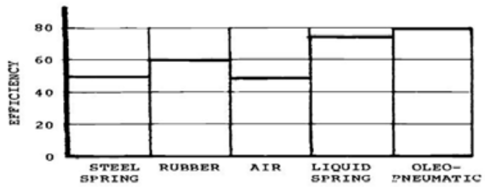


Fig 1.1: Shock absorber efficiency

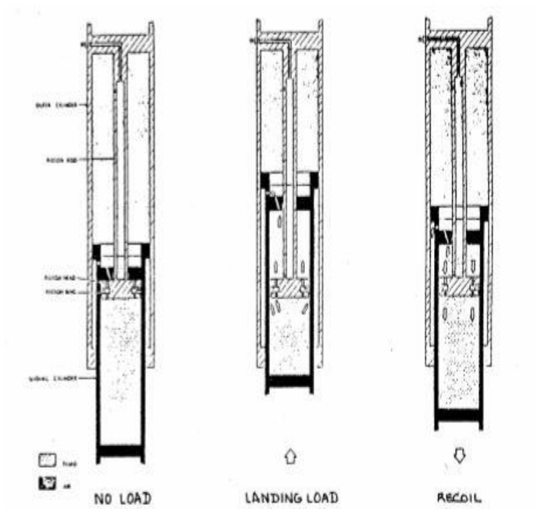


Fig 1.2: Oleo-Pneumatic strut

II. SHOCK ABSORBER STRUT

A requirement of all aircraft shock absorbers is that they absorb or dissipate the energy of descent or transient or vertical shocks without transferring them to the vehicle or aircraft structure. The general requirements of an oleo-pneumatic landing gear shock absorber strut are:

(i) Overall length must be as short as possible, owing to the space constraints given the fact that most airplanes used today are powered using jets hence much lesser ground clearance.

(ii)During compression, oil must be forced positively through the orifice so that the energy absorbed by the liquid in the upper chamber is distributed evenly.

(iii) During extension, oil must be forced positively by a piston through holes, giving what is called positive recoil control.

(iv) Suitable flap must be provided so that during motion in one direction oil can flow freely to damp motion in the other direction.

(v) Filling must be by some automatic levelling scheme such as a stack pipe and not by measurement of the amount of oil.

A. Working of the strut

This shock absorber is adapted to be placed between the sprung mass and the unsprung mass of a vehicle more particularly, between the landing gear and aircraft structure. In addition, it also acts as an undercarriage which supports the weight of the aircraft on the ground. When the aircraft is stationary on the ground, its weight is supported by the oil and compressed gasin the cylinder. During landing, or when the aircraft taxis over bumps, the piston slides up and down.

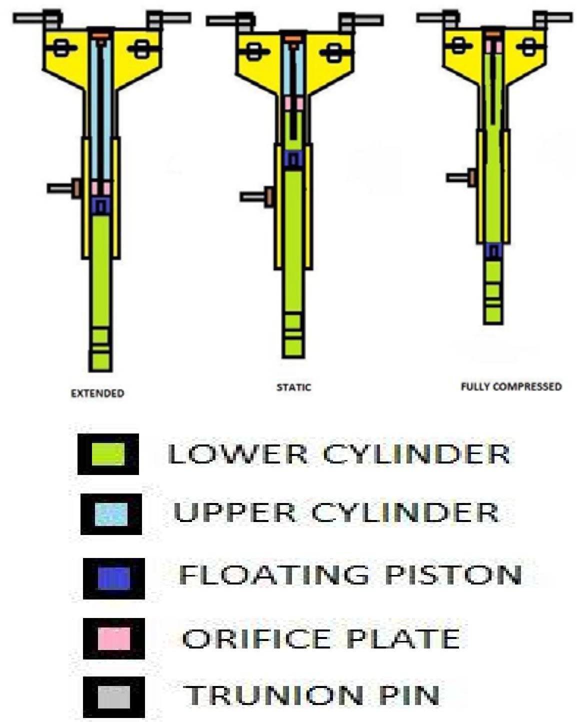


Fig 1.3: working of the strut

It compresses the gas, which acts as a spring, and forces oil through the orifice, which acts as a damper. The oleo-pneumatic shock absorber incorporates a pneumatic (gas) pressure chamber, a high gas pressure chamber and a hydraulic fluid (oil) pressure chamber. The oil chamber contains an orifice and metering pin; they control the rate of collapse of the low pressure gas chamber. Metering pins are designed so as to take a nearly constant load throughout the stroke of the shock absorber, even under transient loading conditions. Thereby to obtain maximum efficiency we need relatively small orifice at the beginning of the stroke, when the piston velocity is relatively slow; and during the middle part of the travel, a larger orifice is desirable and at the end of the travel a larger orifice is desirable. Figure shows the different positions of the strut.

During the landing of the aircraft, the load or force is applied to the lower end of the shock absorber or to the lug causing the piston to telescope into cylinder, as illustrated. As the piston moves upwardly into the chamber, it causes an increase in the oil pressure in the oil chamber. Fluid then flows from the high pressure chamber to the low pressure chamber through orifice in the piston. Now this oil begins to fill up the lower cylinder pushing the Floating Piston and thereby compressing the gas. During extension the high pressure air pushes the Floating Piston upwards and the fluid goes back to the upper cylinder via the orifice.

The figure below shows the position of the separating piston, sliding piston and the cylinder position during the condition of maximum load that is during landing, and extended condition when the flight is airborne or when the tires ceases to be in contact with the ground and static condition when the flight is stationary.

The inputs for the landing gear system calculations are the dimensions given in the figure and other parameters such as aircraft weight, sink speed, load factor etc. The aircraft is steered by the nose landing gear during taxiing and during take-off. But the loads acting are calculated with respect to the centre of gravity.

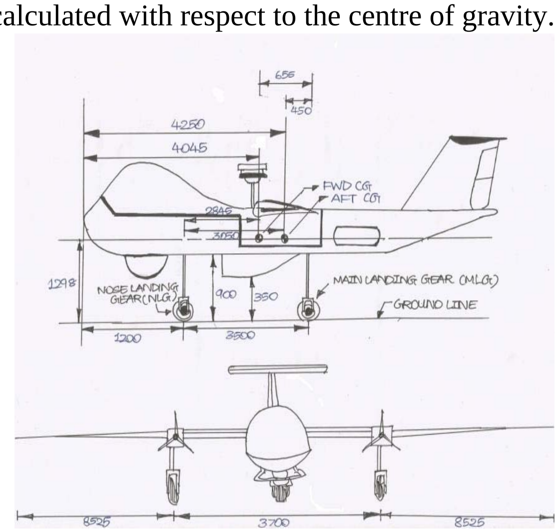


Fig 1.4: Specifications for the Mini aircraft

III. Calculations for Static Force

Table 1: Mass acting on the MLG

Position of CG	Static Force	Weight Applied
FWD CG	40834 N	2084 Kg
AFT CG	44917 N	2292 Kg

After calculating the forces, need to find out the stroke, diameters of upper and lower cylinder.

IV. Calculation of Stroke Ratios

Stroke ratios are based upon the different positions of the landing gear.

V. Calculation of Pressure and Volume Values

Table 2: Consolidated pressure values at various positions

S.No	MLG Position	Isothermal Pressure	Volume
1	Extended	10.76 bar	190*104 mm3
2	Static	25 bar	81.85*104 mm3
3	Compressed	74.24 bar	28.15*104 mm3

VI. Calculation of Forces and Design of Orifice

Table 3: Consolidated Force and metering pin values

S.No	MLG Position	Force at Isothermal (N)	Diameter of the Orifice (mm)
1	Extended	2672.94	15.04
2	Static	5512.95	12.65
3	Compressed	10023.55	10.64
4	Fully Compressed	17178.98	9.58

Therefore, by finding out the diameters of the orifice at various positions we will be able to arrive at the design of a metering pin and a subsequent metering pin that will facilitate the working of the same. ANALYSIS USING MATLAB and also preferred Load vs displacement characteristics for the strut.

VII. PART MODELLING

A. Creo Parametric

Creo Parametric 2.0 is the software that was used in modelling the individual components in the shock absorber strut assembly. Upper cylinder; Lower cylinder; Top cap; Floating piston.

VIII. ASSIGNING OF MATERIAL PROPERTIES

The material properties are an important parameter which is one of the main inputs for the analysis.

Assigning material properties is considered to be of prime importance for the sake of analysis. The analysis of the designed model in the following manner by using FEM and MATLAB.

SL. NO	COMPONENT	MATERIAL	MODULUS OF ELASTICITY (GPA)	ULTIMATE TENSILE STRENGTH (MPA)	YIELD STRENGTH (MPA)	POISSON'S RATIO	DENSITY (KG/M3)
1.	Upper Cylinder	Steel (4340)	210	1450	1300	0.3	8085
2.	Lower Cylinder	Steel (4340)	210	1450	1300	0.3	8085
3.	Metering Pin Cap	Steel (4340)	210	1450	1300	0.3	8085
4.	Floating Piston	Aluminium (7175 – T6)	71.5	595	530	0.3	2.7

Table 4 : Material Properties of Components

IX. FINITE ELEMENT ANALYSIS

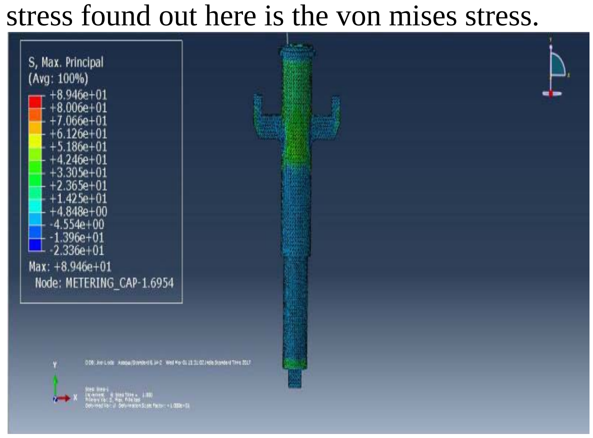
The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variation methods from the calculus of variations to solve the problem by minimizing an associated error function. A typical work out of the method involves (1) dividing the domain of the problem into a collection of sub-domains, with each sub-domain represented by a set of element equations to the original problem, followed by (2) systematically recombining all sets of element equations into a global system of equations for the final calculation. Then Analysis using FEA software ABAQUS, MESHING, Nature of meshing, Shell Meshing, Solid Meshing and Loading conditions and constraints.

X. RESULTS

The two main components of the shock absorber strut have been analysed in COSMOS. The analysis was carried out as a static analysis with discussed boundary conditions. It can be inferred that the maximum displacement in the strut occurs when the shock absorber is loaded both horizontally and vertically.

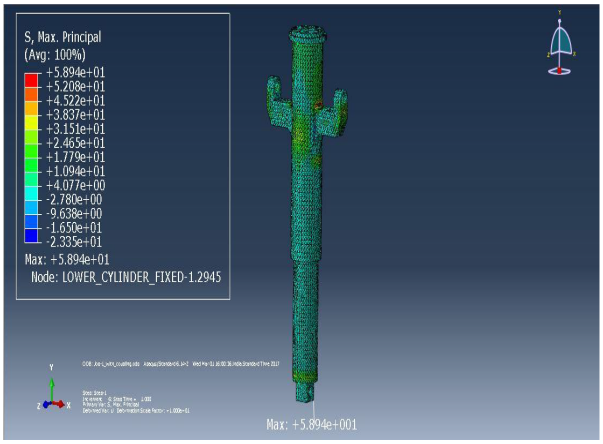
A. Factor of safety

The factor of safety for a load also known as safety factor is a term describing the structural capacity of a system beyond the expected loads or actual loads. In the calculation of stress, the stress found out here is the von mises stress.

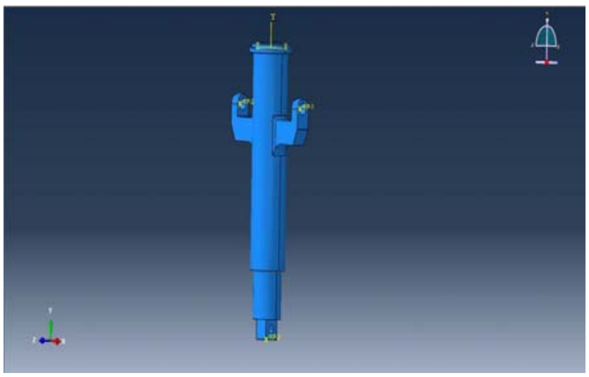


Static – condition 1 – Pressure- Reaction – Max Principal Stress. Case I: For Static - Pressure; FOS = (1450 * 106)/ (980 * 106) = 3.2; FOS = 1.5 CASE II: For Static – Load from Bottom; FOS= 1450/979 = 2.58; FOS=1.5

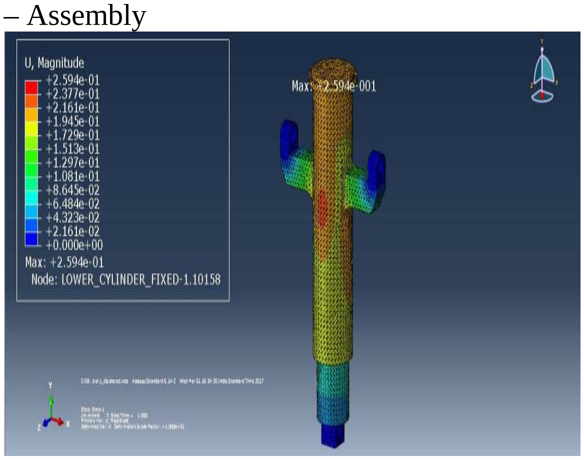
CASE III: For Compressed Pressure (WORST); FOS= 1450/2870 = 1.95; FOS=0.5



Static – condition 2 – Load from Bottom – Max Principal Stress

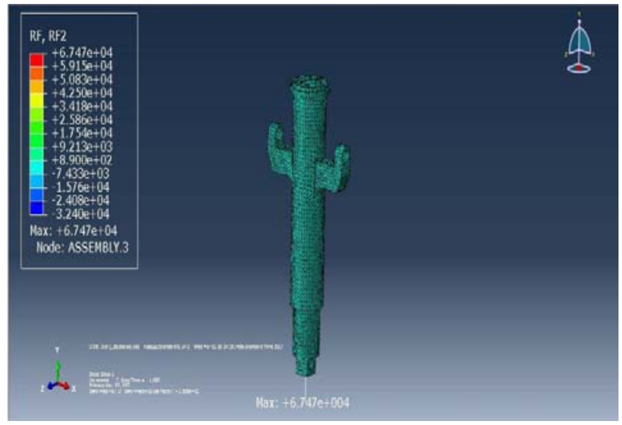


Compressed – condition 3 – Pressure- Reaction – Assembly



Compressed – condition 3 – Pressure- Reaction – Displacement

The above FOS signals a positive approach to the design and also seems to escape from failure. The results obtained for stress, strain and displacement have been observed to be well within the limits and hence they seem to satisfy the conditions of loading at the worst case. Hence the Design is safe.



Compressed – condition 3 – Pressure- Reaction – Reaction Force Diagram

XI. Tabulation of Results – FEA Results

Loading Condition	Maximum Displacement (mm)	Maximum Stress (N/m2)
For Static – Pressure	0.08690	9.80*108
For Static – Load from Bottom	0.08690	9.79*108
For Compressed - Pressure	0.2594	28.7*108

XII. CONCLUSION AND DISCUSSIONS

The results of the study also indicated that landing gear stability could be improved by longer wheel axle, smaller wheel mass and lower aircraft velocity. The nose wheel tricycle gear has been the preferred configuration for UAV. It leads to a nearly level fuselage when the aircraft is on the ground, important for payload safety. The most attractive feature of this type of undercarriages is the improved stability during braking and ground maneuvers. Under normal landing attitude, the relative location of the main assembly to the aircraft cg produces a nose-down pitching moment upon touchdown. This moment helps to reduce the angle of attack of the aircraft and thus the lift generated by the wing. In addition, the braking forces, which act behind the aircraft e.g., have a stabilizing effect and thus enable the external pilot to make full use of the brakes. These factors all contribute to a shorter landing field length requirement. While the shock absorber stroke is not a function of the aircraft weight, nevertheless it is vital to increase the size of the stroke to lower the landing load factors and thereby minimizing the structure weight due to landing loads. To accommodate this requirement, larger-section tires can be utilized. However, the penalty for this solution is the increase in aircraft weight and therefore reduced payload that would be too costly for UAVs.

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