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Finite Element Simulation of Pressurized Fluid

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Abstract – *Simulation of pressurized fluid is generally needed over the areas of landing of re-entry vehicles, shock absorbers used in aircraft, space ship habitats etc. In this project work typical case of simulation of landing gear is carried out as it is considered to be one of the challenging problem faced by the liquid propulsion space centres. This will reduce huge cost spent on experiments/ prototype. In this paper, Finite Element Analysis (FEA) are performed in order to study the shock absorbility of working fluid used inside the landing gear system and to investigate the effect of fluid and air volume ratio with determination of orifice geometryr. Fluid simulation is carried out using SPH method using ABAQUS software.*

Key Words: Smoothed Particle Hydrodynamics (SPH) method, ABAQUS software, Shock Absorption of Fluid, Oleo Pneumatic Shock Absorber, orifice plate

1. INTRODUCTION

The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called Finite Element Method (FEM).

Simulation of pressurized fluid is generally needed over the areas of landing of re-entry vehicles, landing gear shock absorbers used in aircraft, space ship habitats etc. This will reduce huge cost spent on experiments/ prototype.

In this project work typical case of simulation of landing gear is carried out as it is considered to be one of the challenging problem faced by the research and space centres.

2. LANDING GEAR SHOCK ABSORBER

The landing gear shock absorber is an integral part of an aircraft's landing gear. The role of the shock absorber is to absorb and dissipate impact energy, such that the loads imposed on the aircraft's frame to a tolerable level.

These accelerations must be acceptable not only to structural components and also to other components contained within the aircraft (passengers, cargo, weapons, avionics etc).

The two main functions of efficient shock absorbers are the spring function and damping function.

Increased shock absorption became significant to accommodate the constantly increasing aircraft weights and sink speed rate.

According to the comparison of efficiency of different types of energy absorbers used the remaining solutions are not as efficient as oleo-pneumatic shock absorbers, they are in use because of low costs of production and low costs of maintenance.

In military and commercial aircraft where efficiency is the highest priority, mostly the oleo pneumatic shock absorbers are used to make up this factor.

Its role is to limit the impact loads by transmitting the lowest and most bearable acceleration level to the aircraft frame and other components contained within.

Fig -1: Landing Gear System

2.1 Oleo Pneumatic Shock Absorber

The oleo pneumatic shock absorber can only absorb vertical loads. Oleo pneumatic struts consist of a piston rod that moves up and down within a cylinder. The cylinder is fixed to the aircraft's structure and an axle is connected to the lower end of the piston rod. The cylinder is charged with gas (nitrogen is preferred as it is inert) and oil (mineral hydraulic oil).

The function of the gas is to support the weight of the aircraft at rest and acts as a spring to absorb the landing and taxiing loads. The oil is used to control the speed of compression and expansion, referred to as dampening of landing load and recoil action.

2.2 Objectives

The objective of study is to simulate landing gear shock absorber using SPH and to investigate parameters like

- Determination of orifice geometry

- Evaluation and determination of oleo-pneumatic volume ratio

3. FLUID SIMULATION

Simulation of air is done with the fluid cavity. Method adopted for the simulation of fluid: -
Smoothed Particle Hydrodynamics (SPH) Method

3.1 Smoothed Particle Hydrodynamics (SPH) Method

SPH is a numerical method that is part of the larger family of meshless (or mesh-free) methods. In smoothed particle hydrodynamics only a collection of points is necessary to represent a body and these nodes are commonly referred to as particles or pseudo-particles.

This method can use any of the materials available in Abaqus/Explicit (including user materials). SPH method works by dividing fluid into a set of discrete elements referred as particle(PC3D).

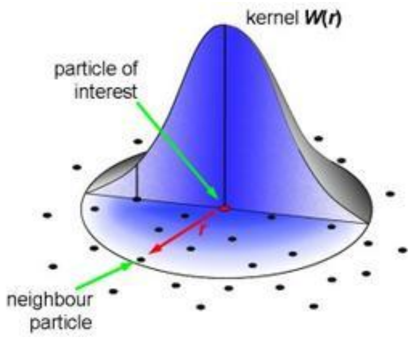

Fig-2: Fluid Representation in SPH method

These particles have spatial distance known as "smoothing length". Meshless method requires Equation of State(EOS). Can solve large deformation problems with high accuracy.

3.2 Fluid Cavity Definition

A fluid cavity interaction property defines the type of fluid occupying the cavity and the fluid properties. There is either a hydraulic fluid or a pneumatic fluid. Hydraulic fluids must include a fluid density; and they may include a fluid bulk modulus, thermal expansion coefficients, and other temperature-dependent data.

Pneumatic fluids must include an ideal gas molecular weight, and they may include a molar heat capacity. A fluid cavity interaction allows selecting and assigning properties to a liquid- or gas-filled fluid cavity in the model.

Fluid cavity selection includes a reference point and the surface that encloses the cavity. The fluid cavity interaction remains constant throughout all steps of an analysis.

The modeling of nitrogen gas filled chamber is done based on pneumatic fluid cavity definition and is shown in Fig-3.

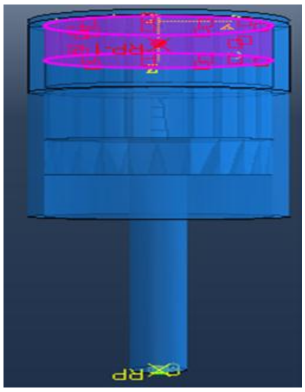

Fig-3: Fluid Cavity Definition

4. EXPLICIT DYNAMIC SCHEMES

The explicit dynamics procedure performs a large number of small time increments efficiently and in this study major part is shock absorption which may acts in milliseconds. An explicit central-difference time integration rule is used; each increment is relatively inexpensive (compared to the direct-integration dynamic analysis procedure available in Abaqus/Standard) because there is no solution for a set of simultaneous equations. The explicit central-difference operator satisfies the dynamic equilibrium equations at the beginning of the increment, t; the accelerations calculated at time t are used to advance the velocity solution to time T+$\frac{\Delta T}{2}$ and the displacement solution to time T+ΔT.

Dynamic simulation helps to predict the performance of a component or assembly. The results of this simulation will be more accurate compared to the hand calculations. These simulations help in handling large number of studies in short time.

The landing gear shock absorber performance is evaluated by a dynamic simulation of the landing and taxing. This takes into account, the hydraulic damping, air spring characteristics and friction effects and structural flexibility in landing gear. Using the computer models developed for this purpose, the shock absorber parameters are enhanced to maximize its efficiency and peak reaction behaviour. This helps in the preliminary estimation of the impact loads and taxi loads to arrive at the sizing of the landing gear elements for use in geometric modelling and kinematic analysis.

5. FINITE ELEMENT ANALYSIS

The basis for creating a simulation model of the oleo-pneumatic shock absorber are its principles of operation. The model needs to accurately represent the same physical phenomena as the real shock absorber. Oleo-pneumatic shock absorbers are highly efficient as they can absorb and remove vertical kinetic energy simultaneously.

5.1 Problem Description

From case study, the big problem with bungee or spring systems is that the return or recovery rate is very fast and has a rubber band or slingshot effect. The problem with compressed rubber wafers is just the opposite, sometimes the recovery is too slow or even worse the compression reaches its max and thus turns into a solid rather than continuing to work.

Although such a system is cost effective and therefore appropriate for general aviation aircraft, it offers relatively poor shock performance. The result is an aircraft that tends to bounce. The major failure of landing gear is mainly due to working fluid are poor shock performance, lack of hydraulic fluid. The objective is to study the effect of shock absorption of fluid and to calculate optimum fluid and air volume with orifice diameter.

Fig-4: Landing Gear Failure

5.2 Loads on Landing Gear

Total weight considered in case of a relaunch vehicle is 2000kg with 3g acceleration during landing
Therefore, Total Force, P = 58860N

In terms of landing gear configuration, the tricycle-nose wheel- layout is mainly used. Therefore, Total Force acting at front = $\frac{P}{2}$ = 29430N

Therefore, Pressure in Front, MPa= $\frac{P}{(2\times A)}$ = 2342MPa

This pressure is applied to the top of landing gear system and the corresponding shock absorption of fluid is analysed.

5.3 Design of Landing Gear

Oleo-pneumatic shock strut absorb energy by "pushing" a chamber of oil against a chamber of dry air or nitrogen and then compressing the gas and oil. Energy is dissipated by the oil being forced through one or more orifices and, after the initial impact; the rebound is controlled by the air pressure forcing the oil to flow back into its chamber through one or more recoil orifices. If oil flows back too quickly, the aircraft will bounce upward; if it flows back too slowly, the short wavelength bumps (found during taxiing) will not be adequately damped because the strut has not restored itself quickly enough to the static position.

The designer selects an initial static position, based on similar aircraft and/or experience, and then modifies this position as the design progresses.

Two compression ratios are normally considered: fully extended to static and static to fully compressed. For a small aircraft or one in which the variation in floor height with aircraft or relaunch vehicle weight is important, the following ratios would be satisfactory:

Static to extended -2. 1 /1
Compressed to static -1.9/l

Hence, in this case we considered a launch vehicle with 2000kg during landing. Therefore, the static to compression ratio opted is 1/1.9. Total weight considered in case of a relaunch vehicle is 2000kg with 3g acceleration during landing

Therefore, Total Force, P=58860N

Total Force acting at front = $\frac{P}{2}$ =2943

Assume 1500psi (10.34MPa) static pressure

Static to compression-1/1.9

Pressure= $\frac{10.34}{1.9}$

Piston Area= $\frac{\text{Max Load}}{\text{Pressure}}$ = 84mm

Based on principles of landing gear design diameter of piston rod, $D_r = \frac{Dp}{\sqrt{3}}$= 48mm

Therefore, Diameter of Piston = 84mm

Piston Area = 5541.7mm^2

Total Load = 10.34×5541.7 = 57301.178N

Force acting at the front =29430N

MOS = $\frac{57301.178}{29430} - 1$

= 0.947057289>0, hence it is under safe.

Hoop stress = $\frac{Pr}{T}$ = 124.08N/mm^2

Longitudinal stress = $\frac{Pr}{2T}$ = 62.04N/mm^2

Yield Strength of Aluminium T7075-T6 = 480MPa

Ultimate Tensile Strength of Aluminium

T7075-T6 = 540MPa

MOS = $\frac{124.08}{480}$ = 2.868

Shell Deformation, ɠ = $\frac{PR^2}{ET}\times (1-\mu/2)$ = 0.0606mm

Since the amount of shell deformation is very less i.e. 60.6 microns it concludes that there is no leakage of working fluid based on the design criteria.

5.4 Property Specification

Details regarding the material properties are presented in Table 1

Table -1: Material Properties of Shock Absorber

Properties	Cylinder (T7075-T6 (Aluminum Alloy)	Fluid (Hydraulic Oil 5606H)
Young's Modulus (MPa)	71705	
Poisson's Ratio,µ	0.33	
Density,ρ(Ton/mm^3)	3.32e-09	8.82e-10
Eos,mm/s		1.49e06
Gruneisen Ratio,Gamma		10
Viscosity,Pa.s		1.214e-08

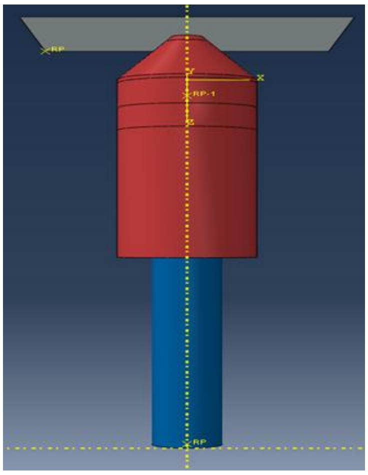

Fig -5: SPH Model of Landing Gear Shock Absorber

5.5 Modelling

The oleo pneumatic shock absorber comprises several key parts that dynamically interact to absorb the landing energy of aircraft. Typical Oleo pneumatic shock absorbers contain: Cylinder, Piston (Piston rod, Piston head), Working Fluids (Gas, Liquid). Dimension of Shock Absorber is shown in Table 2.

Table -2: Dimensions of Shock Absorber

Diameter of outer cylinder	90mm
Diameter of inner cylinder	84mm
Piston rod diameter	48mm
Piston Diameter	82mm
Stroke length	260mm

5.6 Loading and Boundary Conditions

The tank is subjected to acceleration due to gravity (g) in downward direction and a pressure of 2341.96MPa at the top of cylinder.

Two rigid surfaces are created as reference level. It is restrained in U1 and U2 at the end of outer cylinder and fixed at end of piston.

An input load for the shock loading of the landing gear is given as time response in step.

5.7 Mesh Generation

The model is provided with mid fine mesh with approximate size of 10. The element used for water and cylinder is C3D8R: An 8-node linear brick, reduced integration, hourglass control and the fluid is converted to particle.

For piston rod is R3D4: A 4-node 3-D bilinear rigid quadrilateral. The mesh model is shown in Fig. 6.

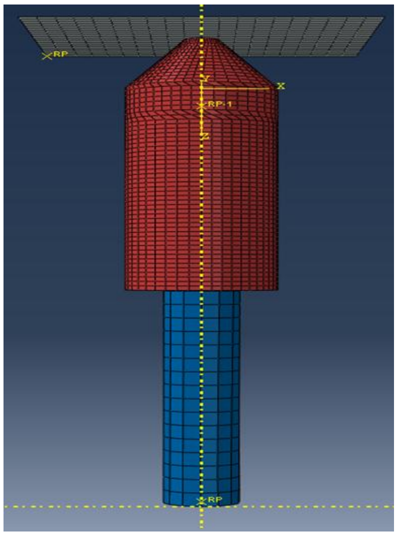

Fig-6: Meshed Model SPH model

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6. ANALYSIS AND RESULTS

6.1 General

In this project the simulation of landing gear is carried out. It includes the effect of fluid damping, shock absorption of fluid and to calculate optimum fluid and air volume with orifice diameter and comparison of shock absorbility using SPH method.

6.2 Analysis of Landing Gear Shock Absorber

From amplitude time response for the input load, the shock effect is given with an input load of 29430N.

6.2.1 Determination of Orifice Diameter

Fixing the diameter of orifice and analysis of its effect in shock absorption is a major factor. The model is analysed with varying radius of orifice i.e. 2.5mm, 5mm, 7.5mm, 10mm, 12.5mm, 15mm.

From the analysis carried out shock absorption is more for radius 10mm and it is comparable with d/D ratio=0.23 [7]. With further increase in diameter shock absorption percentage is decreasing.

Chart 1 represents the effect of orifice (rad-10mm) in landing gear simulation

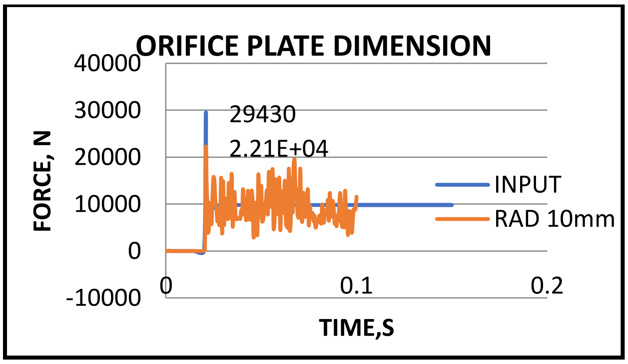

Chart 1: Effect of orifice (rad-10mm) in shock absorption of landing gear simulation

Shock absorption effect on radius-2.5mm, 5mm, 7.5mm, 10mm, 12.5mm, and 15mm is shown in chart 2

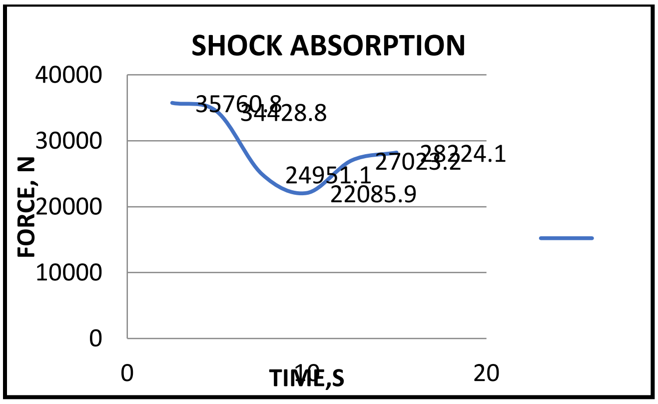

Chart 2: Effect of orifice (radius) in shock absorption

6.2.2 Evaluation and determination of Oleo- Pneumatic Volume

In this present study with the orifice radius fixed 10mm the ratio of oleo-pneumatic volume considered are 1:1, 2:1, 3:1, 4:1, and 5:1. Since orifice is considered for as the major components which controls fluid flow, increased pneumatic volume ratio are omitted from the study which leads to simulation errors.

Hence concluded that in order to have proper functioning of both oleo and pneumatic chamber, the volume of oleo chamber should be greater than or orifice plate should be within oleo chamber. The most effective shock absorption, gravity stabilization is obtained for the ratio of 2:1(oleo-pneumatic)

Chart 3 represents the simulation of landing gear shock absorber using SPH method with orifice radius 10mm and oleo: pneumatic ratio 2:1

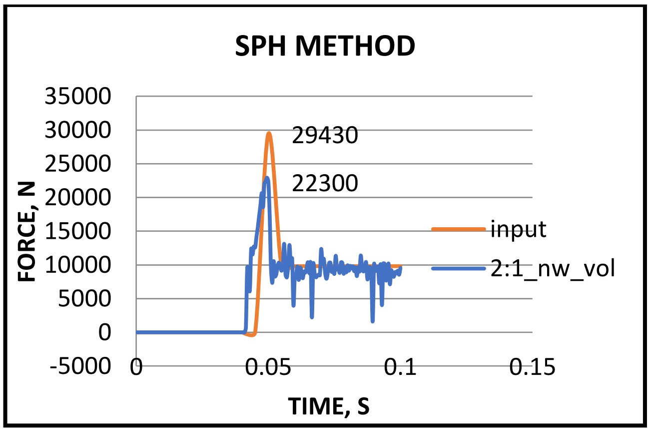

Chart 3: Simulation of landing gear shock absorber using SPH method

From the graph the percentage of reduction of shock load is about 24.2% and it offers gravity stabilization upto 0.04s

Fig-7 shows displacement of fluid in simulation of shock absorber

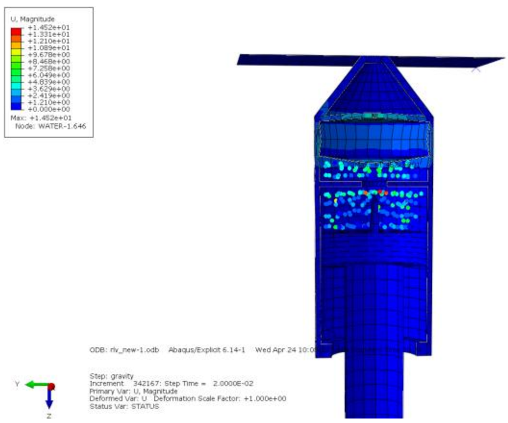

Fig-7: Displacement of Fluid in Simulation of Shock Absorber

Chart 4 represents the comparison of shock absorption using SPH method with input data.

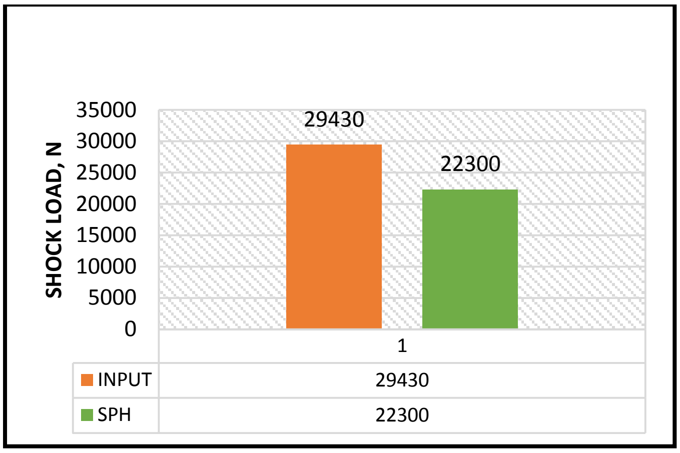

Chart 4 Comparison of Shock Absorption using SPH method with Input Data

From the graph we can conclude that SPH offers shock absorption about 24.2% more than input shock load

7. CONCLUSIONS

The following conclusions were drawn from the study,

- In the present study, simulation of landing gear shock absorber is done
- Shock absorption of fluid is carried out using SPH method
- From the comparison of SPH method and input shock load, SPH offers shock absorption about 24.2 % and CPU run time required is less compared to grid based method.
- Two parameters like determination of orifice radius for the simulation analysis and evaluation and determination of oleo-pneumatic volume is also analysed.
- It is concluded that orifice with radius 10mm offered more absorption of shock.
- In order to have proper functioning of both oleo and pneumatic chamber, the volume of oleo chamber should be greater than or orifice plate should be within oleo chamber and volume ratio 2:1 showed good results compared to input data.
- The amount of shell deformation is very less i.e. about 60.6 microns it concludes that there is no leakage of working fluid based on the design criteria.

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