Magnetorheological Landing Gear for UAVs – A conceptual design

M. Hari Prasad, K V Gangadharan

Abstract—Thedevelopment of Unmanned Air Vehicles (UAVs) for both military and civilian applicationslead the opportunites for the development of advanced technologies to improve their operational performance. Due to various mission requirements UAVs will carry different types of payloads which change the total all-up weight. The landing gears of the UAVs should be optimized to the changing weights and various sink speeds. Conventional landing gears are optimized for particular set of parameters and not efficient in all conditions. A novel solution to this problem is to implement a smart damping using magnetorheological (MR) fluids. This paper presents a design mtheodology that enable MR landing gear to be optimized, both interms of its damping and magnetic circuit performance using Magnetorheological Grease(MRG). The design approach focuses on the impact of landing phase of an UAV where large variations in the UAV mass, landing speed, sink speed makes MR shock absorber a potential solution. The usage of MRG in the present design overcomes the problem of sedimentation that exists in regular MR fluidswith long term usage.

Index Terms—Unmanned Air Vehicles (UAV),Aircraft landing gear, Electrorheological , Magnetorheological, semi-active damping, shock absorber, smart fluids, shock absorber, shimmy damper, adaptive impact absorption

◆

1 INTRODUCTION

The design of Aircraft Landing Gear, which is considered "the essential intermediary between the aeroplane and catastrophe", is one of the more fundamental aspects of aircraft design. Various designs and configurations are evolved during the course of development. The task of a landing gear designer is to define a reliable gear that meets all of the landing and take-off requirements. The aircraft landing gear consists of shock absorbers, retraction mechanism, steering, shimmy control, tires, wheels and brakes. This represents 3.5 to 7% of the gross weight and 2 to 4% of basic aircraft cost. To utilize the landing gear for its best performance, it is planned to modify the electrically tunable shock absorber and electrically operated brake system. The first part is to develop shock absorber and the second one is to develop a brake system.

Aircraft shock absorbers are designed as passive devices with characteristics satisfying the hardest expected landing impact conditions. However, in the majority of cases, the variation of real working conditions is below these critical levels and the passive shock absorber is too stiff to optimally perform the landing scenario. In contrast to passive systems this research is to develop an active adaptation of energy absorbing structural elements, where the system of sensors recognize the type of impact loading and activate energy absorbing components realizing a pre-design strategy of optimal impact energy dissipation. Present landing gear shock absorbers works on the principle of hydraulic fluid flow control using a metering pin to change the orifice dimension during landing operation. The design of landing gear is optimized for particular operational characteristics.

There is no control on the damping characteristics for different missions and operations which make the landing gear not to perform to its optimum characteristics.One of thesolutions for the above problem is to introduce an active control shock absorber to meet the various mission requirements. The active controllability can be achieved using controllable fluids such as Magenetorheological fluids (MRF), Electrorheological fluids (ERF) and Magnetorheological grease (MRG) etc. In order to influence the damping force at faster rate along with necessary control, Magnetorhrological dampers are candidate solution to achieve similar capabilities as stated preiviously.

Aircraft brakes absorb kinetic energy when brakes are applied. To take care of the energy absorption, sufficient force is to be generated by the brake pads on the discs. Presently these pads are actuated by caliper type brakes with hydraulic fluids and the required force is generated by the fluid pressure. In UAVs these brakes are actuated by an electromechanical actuator, to increase the fluid pressure. In order to eliminate these actuator and hydraulic braking system, it is planned to develop piezo based actuator which is able to deliver the required force and displacement of the brake pads.

The Unmanned Air Vehicles (UAV) are developed from few grams to few tonnes weight for different application and performance requirements. Smaller UAVs will be fitted with fixed landing gears made of metal or composite materials to take the landing loads. Medium weight class UAVs will have different types of landing gears from rubber shock absorbers to oleo-pneumatic type with retractable mechanisms. Most of the landing gears are adapted or fitted from the small manned aircrafts, due to their proven characteristics and clearance from the certification agencies.

Present research is focused to develop a smart landing gear to meet the requirements of medium class UAV. The paper is focused on the design methodology for the development of

---

- *Research Scholar, Dept of Mechanical Engg., NITK, Surathkal, Karnataka, India, E-mail:manchoorhp@gmail.com*
- *Professor, Dept of Mechanical Engg., NITK, Surathkal, Karnataka, India E-mail: kvganga@gmail.com*

MRG based landing gear to meet the optimum requirements. The research is focused to control the damping characteristics through electrically controlled magnetic flux which inturn controls the flow characteristics of MRG. In addition to this the system also contains a pneumatic spring to support the UAV during parking and in the absence of electrical power.

2 MR LANDING GEARS

MR landing gears comprise more or less same modules in comparision to conventional oleo-pneumatic landing gear. The modifications being in the design of shock absorber strut. In MR landing gears the fluid used is basically a contorllable fluid. The control characteristics are altered by changing electromagnetic flux through the control of current as per the requirements. Studies revealed that 11.8% load reduction was achieved as a result of use of MRF in shock absorber[1]. Many research articles are appearing with different titles such as semi active control of landing gear, improved impact absorption of landing gear, active control of landing gear etc. Some of the research reported in open literature are discussed in subsequent paragraphs.

2.1 MR landing gear developments

Magnetorheological landing gear design and validation has been carriedout bymany institutes and organizations. One among them is ADLAND [2]. The design methodology for MR landing gear shock strut has has been illustred in [3]. The design methodology aimed at packaging, optimizing magnetic design and to produce desirable behavior for wide range of impact conditions unlike passive device. A 2DOF simulation studies were performed to simulate the exact drop test conditions. A widely adjustabale valve control ratio resulted in damping levels to accommodate large range impact conditions. The study helped is demonstrating the feasibility of an MR landing gear. The manufacture and testing was in the studies made by the same group [4]. It is emphasized that to validate the design, a quasi-steady MR valve function must beformulated analytically, without the need to update the yield stress and viscosity parameters. The study is performed at low velocities. There is a need to carryout the same with high velocities.

Landing gears are also designed for improved impact absorption [5]. Two technologies (piezoelectric and magnetorheological fluid)for adaptive landing gear have been stuied in which the piezoelectric valve can control the shock force and adapt the stiffness of shock absorber depending on several landing conditions. Scaling is required for developing a bigger shock absorber for large aircrafts.

Several numerical simulation studies for predicting the performance and control issues are studied [6]. Many prototypes are developed and validated for performance test byusing drop tests [7]. Dynamic loads and vibrations resulting from runway and taxiway unevenness are serious concerns for fatigue life. The experimental investigation reveals the feasibility of reducing loads by using active control gear. Such gear is effective in reducing the loads transmitted to the airframe. A non flying prototype of semi-active landing gear built by MR fluid shosck absorber for ageneral aviation aircraft was tested for performance [8]. The results revealed that with proper control the ground loads can be significantly reduced. Similar drop test studies were also carried by Zhu et.al [9]. The studies served to understand the MRF damper for aircraft landing gear application. Acomparaision of various MR fluids and their characteristics are describled for application of landing gears [10].

Many studies were conducted by in academic institutes and industries for the development of MRF based landing gear. Still it is not evident that any real usage of the MRF landing gear in commercial application. This is due to stringent reliability and certification issues. However the research continues to develop a smart and reliable system which meets the industry requirements. This will help realize the product in commercial market.

2.2 Properties for MRG

Magnetorheological grease (MRG) has been developed to overcome the settling of ferro particles in both ER/MR fluids. Due to settling, the performance of devices will degrade over aa period and not suitable for the devices used for long term application, such as aircraft landing gears. The synthesis and magneto mechanical properties of MR grease are brought out in [11]. The MR characteristics of MRG are similar to MRF. Some of the basic properties of MRG are tabulated in table 1.

TABLE 1
Typical Values of MRS fluid

Max. Yield Strength,τ_y	50-80kPa
Maximum field	Tested up to 1.2 T
Plastic viscosity, η	5-90Pa s
Operable Temp range	-65° -170°C
Response time	< milliseconds
Density	3-4 g/cm^3

2.3 MRF operation modes

The modes of operation of MR fluid devices are flow mode (fixed plate mode, valve mode), shear mode (clutch mode), squeeze mode (compression mode)and any combination of these three are stated in [12]. Diagrams of the three basic modes of operation are shown in Figure 1.

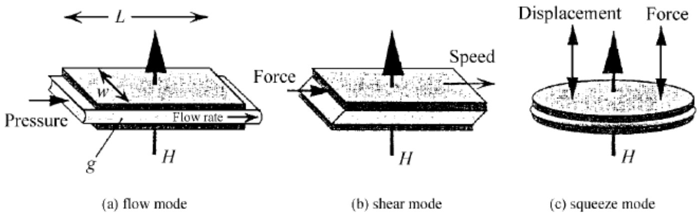


Fig. 1. Basic modes of operation of MR fluid devices

In flow mode, MR fluid is made to flow between static plates by a pressure drop and the flow resistance can be controlled by the magnetic field which runs normal to the flow direction. The flow mode is used in devices such as servo valves, dampers, shock absorbers and actuators. In the shear mode MR fluid is located between surfaces moving (sliding or rotating) in relation to each other with the magnetic field flowing orthogonally to the direction of motion of these shear surfaces. The characteristic of shear stress versus shear rate can be controlled by the magnetic field. Clutches, brakes, chucking and locking devices, dampers and structural composites work on the shear mode principle. In squeeze mode, the distance between the parallel pole plates changes, which causes a squeeze flow. In this mode relatively high forces can be achieved and this mode is suitable for damping of vibrations with low amplitudes and high dynamic forces.

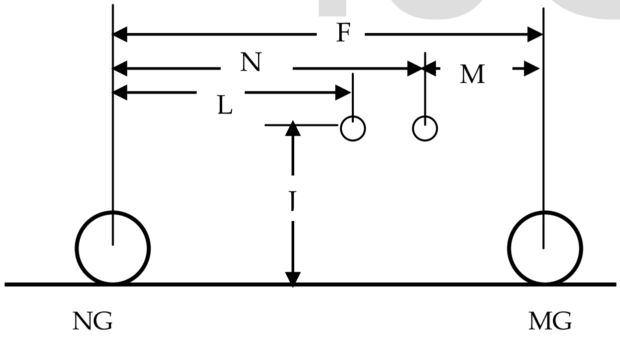
The present study is considered using the flow mode for the development of shock absorber for the landing gear.

3 LANDING GEAR DESIGN METHODOLOGY

3.1 Basic data of UAV

The data does not represent any typical existing UAV. The data considers typical parameters of some of the UAVs in a particular class.

The assumed data for the current studies are total mass of the UAV is 2000 Kg, Maximum Speed of aircraft on ground is 120 Km/hr and maximum vertical sink speed is 3.048 m/s and load factor 2-3. The landing gear geometrical arrangement is shown in Figure 2.



NG: *Nose Landing Gear* MG: *Main Landing Gear*

Fig. 2. Geometrical arrangement of Landing gear

F = 3.400 m, N = 3.088 m, M = 0.312 m, L = 2.863 m
J = 1.165 m

The loads on the gear struts are computed are as follws:

Max. Static Main gear load = 9080N
Max. Static Nose gear load = 3150N
Min Static Nose gear load = 1830N

3.2 Shock Absorber data

On the basis of previous assumptions, the necessary data for shock absorber sizing has been generated. The details of the same have given below. All the formule are considered from the regular landing gear design principles [13][14].

$$\text{Shock absorber travel } (S_s) = \frac{0.5\left[\frac{v_s^2}{gN_g}\right] - n_t S_t}{n_s} \qquad (1)$$

Neglecting tyre travel ($n_t S_t$) and substituting the previous data the shock absorber travel should be 0.2m.

The diameter of the shock absorber is given using the formula,

$$D_s = 0.041 + 0.0025\,(P_m)^{0.5} \qquad (2)$$

Where P_m is load on main landing gear in lbs and D_s will be inches. Considering the main landing gear load is about 1000x2.2 lbs, the diameter of the shock absorber is roundedoff to 0.050 m.

3.3 Load Estimation

The landing gear will have three different positions basing on the operation. The positions are (i) Static (ii) Extended (iii) Compressed. As per the industry standards the ratio of the positions for small aircrafts are assumed,

Static to extended - 2.1/1
Compressed to static - 1.9/1

Considering the above and maximum load on main landing gear 10000 N,

Static load - 10000 N
Load on fully extended condition - 4761.9 N
Load on fully compressed condition - 19000 N

On the basis of the above data, the pressure & volume requirements are,

Cylinder bore diameter - 0.050m
Area of Piston - 0.00196 m^2
Static pressure (P_2)= Static load/Area of piston
= 10000/0.00196 = 5001.3915 kPa

During fully compressed position, the piston in the pneumatic chamber will be moved to maximum position thereby fully compressing the air/nitrogen. The air volume at full compressed position is assumed to be 10% of fully extended position. Hence the volume in fully compressed position is,

V_3 = 0.1(Stroke x Piston Area)
= 0.1(0.2x0.00196)=0.392x10^{-4} m^3

Using 1.9/1 compression ratio,

Max. Pressrue in strut (P_3) = 1.9x p_2 = 9502. 64385 kPa

During fully extended condition the volume of air (V_1) is,

$$V_1 = V_3 + \text{Displacement}$$
$$= 0.392\text{x}10^{-4} + (0.2\text{x}0.00196)$$
$$= 4.312\text{x}10^{-4}\ \text{m}^3$$

To estimate the pressure at fully extended condition (p_1) we use the basic gas equations, i.e

$$P_1 V_1 = P_3 V_3$$

$$P_1 = P_3 V_3 / V_1$$

$$= 9502.64385\text{x}0.392\text{x}10^{-4}/4.312\text{x}10^{-4}$$
$$= 862.9852\text{kPa}$$

Similarly the Static volume(V_2) is $P_1 V_1/P_2 = 0.742\text{x}10^{-4}\ \text{m}^3$

The summary of the above data is presented in Table 2.

TABLE 2
Summary of shock absorber data

LG Position	Pressure (kPa)	Volume (m^3)	Stroke (m)
Extended	862.9852	$4.312\text{x}10^{-4}$	0
Static	5001.3915	$0.742\text{x}10^{-4}$	0.168
Compressed	9502. 64385	$0.392\text{x}10^{-4}$	0.2

4 SHOCK ABSORBER ARRANGEMENT

On the above estimated data, the shock absorber initial design was made. Majority of the shock absorbers designed using MR fluids in flow mode condition are with a moving piston along with electromagnetic coil in it. The MR fluid will flow through the annulus between piston and body of the cylinder. The disadvantage in these designs are, the electrical connection will also be moving along with the piston and the electrical connection will be difficult as the wires will be passing through a lengthy piston rod. Any sort of maintenance will not be that easy. To overcome such difficulties, a unique design was evolved. The arrangement is for ease of maintenance and electrically safe. The schematic arrangement of the major components are shown in Figure 3.

The basic elements are, pneumatic chamber in the top, fluid flow control module in the middle, MR fluid chamber at the bottom. The top and bottom chambers are integrated to the flow control module. The flow control module will hold all the electromagnetic coil and elements for the magnetic flux path. The top and bottom chambers are fabricated with non magnetic materials, so that the flux leakage will be minimized. The flow control module is manufactured with magnetic materials expcept the coil housing, coil cover and flow directing plates. All the items are properly machined with very close tolerances to maintain the geometric and positional requirements. The tyre is of standard aircraft quality to with stand the static and dynamic requirements.

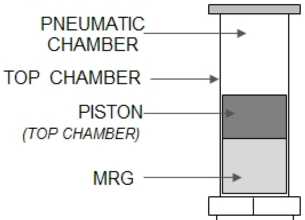


Fig. 3. Arrangement of Landing gear

The details of the various components are described subsequently.

4.1 Operating Principle

During touch down or landing condition, due to vertical descent and weight of the aircraft, the pistion rod will move inside pushing the MRG though the flow control module. The flow control module will regulate the flow of the MRG to the top chamber. As the flow of the fluid increases its volume in the top chamber, the piston in the top chamber will start compressing the gas inside the chamber and increases its pressure. The change in pressure also acts as a vertical force on the bottom piston. Once the gas is fully compressed, the movement of the pistons will be stopped. The pressure inside the top chamber is so high, that it is sufficient to float the UAV on the pneumatic pressure. As the gas is fully compressed, it will slowly expand and moves piston downward to a static position. Once fully compression is achieved, the magnetic flux will be switched off, so that the MRG will flow downward easily while the gas is in expansion condition. Thus the landing gear will settle in the static position. Once the takeoff is completed, air pressure pushes the pistion to the bottom positon, thus the piston in bottom chamber will also be pushed down to the fully extended condition. The power-on condition will be only during landing condition. The velocity of the compression stroke will be regulated to achieve the desired damping properties.

The solid model of shock absorber isshown in Figure 4. The model shows the internal arrangement of the pistions. However the flow control module is not clear about the arrangement of components. The details of flow control module have been described in subsequent Figure 5.

Fig. 4. Engineering model of landing gear

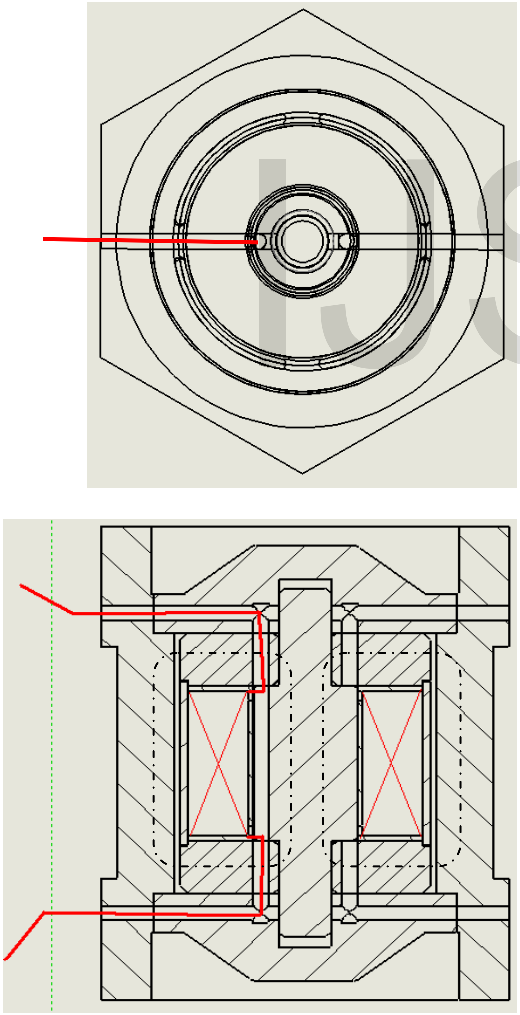


Fig. 5.Magnetic coil arrangement in flow control module

The flow control module comprises a magnetic coil wound on analuminium bobbin. The two ends of the coil wires are taken up through a cut in the shaft and through a flow diverting plate and through the body. The same is indicated through the red colour lines. The flux path is shown in dotted lines. The fluid flow will be between body and plates for magnetic flux return path. A cylindrical cover made up of aluminium cylinder is provided, so that the fluid will not come in contact with the coil at any time.

By fixing the other assembly on both sides of the flow control module the total assembly will be free from any leakages.All parts are fabricated with suitable materials. The machined components before assembly are shown in Figure 6.

Fig. 6. Machined parts for landing gear assembly

5 CONCLUSION

The study gave an insight in to the design process for developing a smart landing gear using MRG controllable fluid. The design being novel and unique will give more benefits for practical implementation. However simulation and experimental results need to be carriedouton the above design for various loads and configurations. Further studies have to be conducted to conclude the results. This will help the researchers to design, develop and evaluate the “Adaptive Landing Gear ” or “Smart Landing Gear for UAVs”.

ACKNOWLEDGMENT

The authors are indebted to Shri P Srikumar, Outstanding Scientist and Director, ADE for his continued guidance, support and according permission for publishing paper. We record our grateful thanks to Dr ACR Pillai (Rtd), Group Director, ADE and KG Rammanohar, Group Director for their unstinted support and guidance.

REFERENCES

[1] ZhingniewSkorupka, “Magnetorelogical fluids as method for active controlling of landing gear shock absorber characteristic”, *Transaction of the Institute of Aviation* No.207,Warszwa.

[2] Adaptive Landing Gears for Improved Impact absorptioin (ADLAND), *Project No.IST-FP6-2002-Aero 1-502793-STREP*, EU Research project.

[3] D C Batteerbee, N D Sims, R Stanway and ZbigniewWolejsza, “Magnetorheological Landing Gear, Part 1: Design Methodology”, *Dept of Mech. Engg., The University of Sheffield*, Sheffield, S1 3JD, UK

[4] D C Batteerbee, N D Sims, R Stanway and ZbigniewWolejsza, “Magnetorheological Landing Gear, Part 2: Validation using Experimental Data”, *Dept of Mech.Engg,, The University of Sheffield*, Sheffield, S1 3JD, UK

[5] G. Mikulowski, “Advaned Landing Gears for Improved Impact Absorption”, 11th*International Conference on New Actuators*, Bremen, Germany, 8-11 June 2008.

[6] Gian Luca Ghiringhelli, StefaniaGualdi, “Evaluation of Landing gear semi-active control system for complete aircraft landing”.

[7] William E Howell, et. al, “F-106B Airplane Active Control landing Gear Drop Test Performance”, NASA Technical Memorandum 102741, 1990.

[8] Gian Luca Ghiringhelli, “testing of a semi-active landing gear control for a general aviation aircraft”, Poloitechnico di Miland, Italy.

[9] Zhu et.al, “Experimental Research on Aircraft Landing Gear Drop Test Based on MRF Damper”, *Procedia Engineering* 15(2011)4712-4717

[10] M. Hari Prasad, K V Gangadharan, “Research Trends in Controllable Fluids for Landig Gear Applications”, *International Journal of Scientific & Engineering Research*,Volume 5, Issue 7, July-2014

[11] M. Hari Prasad, K V Gangadharan,”Synthesis and Magneto Mechanical Properties of MR Grease”,*International Journal of Engineering Research &Technology(IJERT)*, Vol 3 Issue 5, May 2014.

[12] Bolter, R. and Janocha, H.Design rules for MR fuid actuators in different working modes. In *Proceedings of theSPIE Conference of the International Society for Optical Engineers (Ed. L. P. Davis)*, 1997, Vol. 3045, pp. 148–159(SPIE, Washington).

[13] Norman S.Currey, *Aircraft Landing Gear Design*: Principles and Practices, AIAA Education Series (1988)

[14] LadislaoPazmany, *Landin gear design for Light Aircraft*, Primary Aircraft Corporation, San Diego, Calif (1986)