INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT

ISSN: 2278 – 0211 (Online)

Design, Modeling And Simulation Of Retractable Aircraft Landing Gear Hydraulic Actuator

YST Raju
Scientist-F, Combat Vehicles Research and Development Establishment (CVRDE-DRDO), Avadi, Chennai, India
Kothandaraman P
Scientist-F, Combat Vehicles Research and Development Establishment (CVRDE-DRDO), Avadi, Chennai, India
SH Gowtham Gudimella
Scientist-B, Combat Vehicles Research and Development Establishment (CVRDE-DRDO), Avadi, Chennai, India

Abstract:

Aircraft hydraulic systems are used to actuate flight control surfaces, thrust vectoring and reversing mechanisms, landing gear, cargo doors, and in some cases, weapon systems. The dynamic behavior of aircrafts in the air is largely influenced by the landing gear system for maneuverability to attain stability. The study of the hydraulic actuation system requires the identification of operating characteristics of each component.

This paper proposes an approach to model the hydraulic actuation system with MATLAB-Simulink by adopting component oriented modeling. The interconnection of these components will enable us to simulate, analyze and optimize the aircraft landing gear hydraulic actuation system. This method can greatly reduce the effort required for all kinds of hydraulic simulation test framework development and achieve higher productivity, better reusability, extend ability and maintainability. Interconnection between the subsystems is an issue, as it is surprisingly not a straightforward task in MATLAB/Simulink, despite the fact that each toolbox works well if used in standalone mode. The model is verified with the physical model of hydraulic actuator, actuated by micro electro-hydraulic components.

Key words: *Landing gear, Hydraulic Actuation System, Modeling, Simulation, mechatronics*

1.Introduction

Landing gears are crucial for the static as well as dynamic maneuverability and landing/takeoff operations. Inertial, friction and aero-drag loads are the major component loads on the landing gear system. Basic models of aircrafts as an engineering mockups are of fixed landing gear type which are not retractable. And most of the commercial aircrafts are of retractable type. These need a linear actuation system for retracting and deploying the landing gear struts. Different types of actuation systems based on hydraulic, pneumatic and electric principles are evident and in use for today's modern day air-crafts. Different types of arrangements are as shown below in Fig. 1:

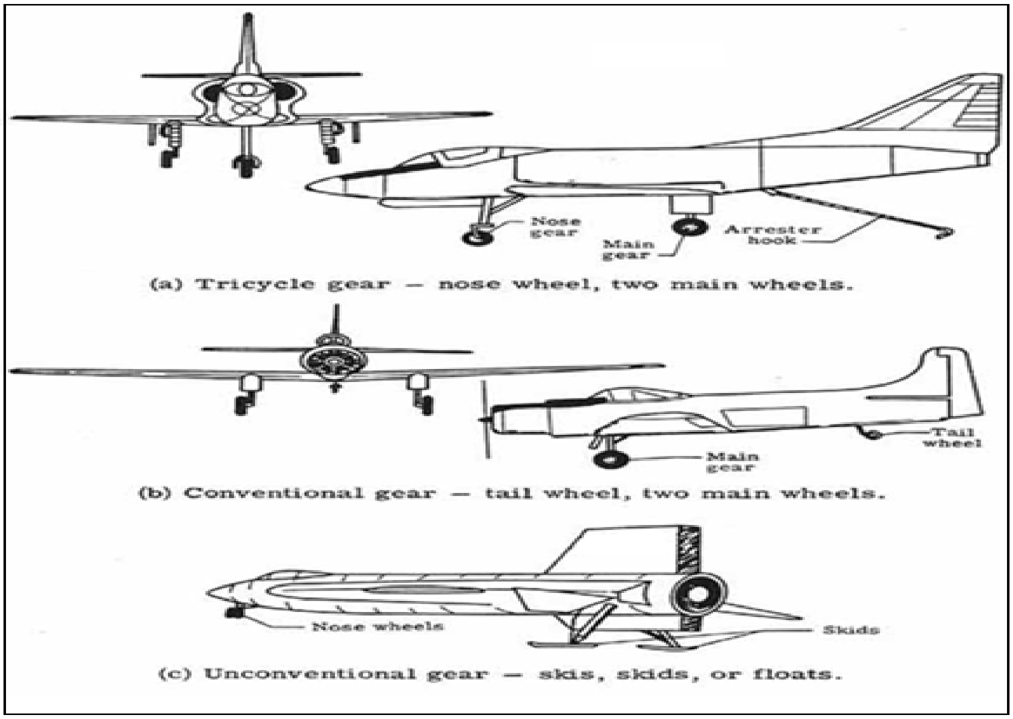

Figure 1: Different types of landing gears [1]

The tricycle arrangement (reverse of conventional landing gear or tail-dragger) has one wheel in the front, called the nose wheel, and two or more main wheels slightly aft of the center of gravity. Because of the ease of operating tricycle gear aircraft on the ground, the configuration is the most widely used on aircraft.

The tricycle gear has the following advantages over older landing gear:

- more stable in motion on the ground
- maintains the fuselage in a level position
- increases the pilot's visibility and control

- makes landing easier, especially in cross winds

Kinematics of Hydraulic actuation system forms an integrated part of the development of landing gear design. Conceptual understanding of the system has been important for modeling physical systems. In this paper, design, modeling and simulation of hydraulic actuator with physical model verification for the loading and simulated timing cycle are presented.

1.1.Simscape Programming Language

To model complex physical systems software Simscape, based on the Simulink platform, facilitates the modeling and simulation of physical systems with multiple domains. Mechatronics is the synergetic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and processes.

Simscape programming language, based on MATLAB object (component)-oriented language, was designed to create, develop and share, in the Simulink environment, areas of physics as well as components (mechanical, electromechanical, hydraulic...) while using a causal physical modeling approach.

2.Design And Development

A customized hydraulic actuation system for the actuating both retraction and extension requirements is essential for a retractable landing gear as shown in Fig. 2. This consists of precisely manufactured manifold block, assembled with cartridge valves, solenoid valves, pressure relief valves, non-return valves and hydraulic pipes & fittings. And a power pack of electric DC motor with hydraulic pump to be integrated with system along with hydraulic reservoir with suitable quantity of hydraulic oil. Electrical control unit to activate various operations is considered. An important consideration regarding the development of retractable hydraulic actuator needs to be a double acting hydraulic cylinder.

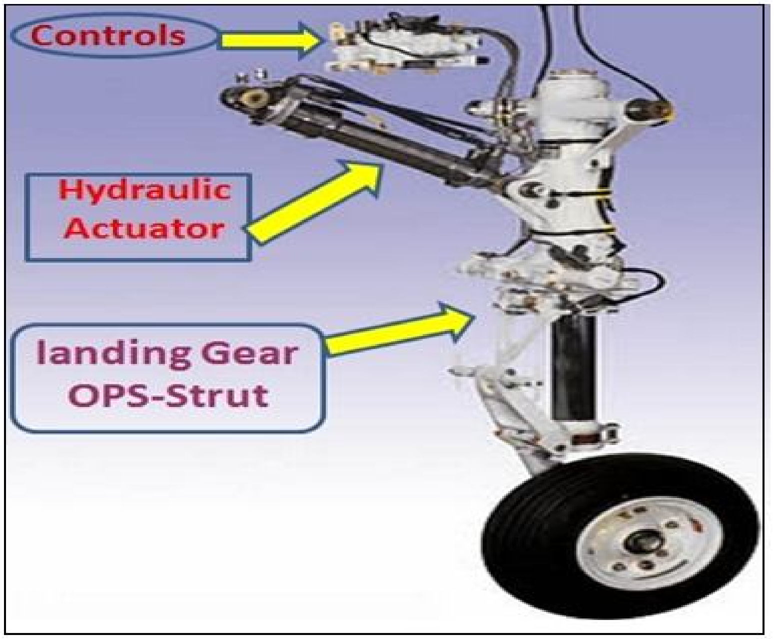

Figure 2: Landing Gear Model

Design of hydraulic actuator depends on the loading and timing cycle which signifies the operating pressure and flow rate. With the given requirement of load to be lifted, extension timing and retraction timings design of double acting hydraulic cylinder is done. With the supply of pressurized hydraulic fluid from the hydraulic reservoir with the electrical DC motor driven pump directed to actuate the hydraulic cylinders (linear actuators) which retract or deploy the landing gear.

System/Parameter	Requirement
Working Fluid	MIL-H-5606
Maximum System Supply Pressure (standard 3000 psi reference)	210 bar
Hydraulic Power Pack	DC Motor & Axial Piston Pump

Table 1: System Requirements-Hydraulic System

2.1.Hydraulic Cylinder

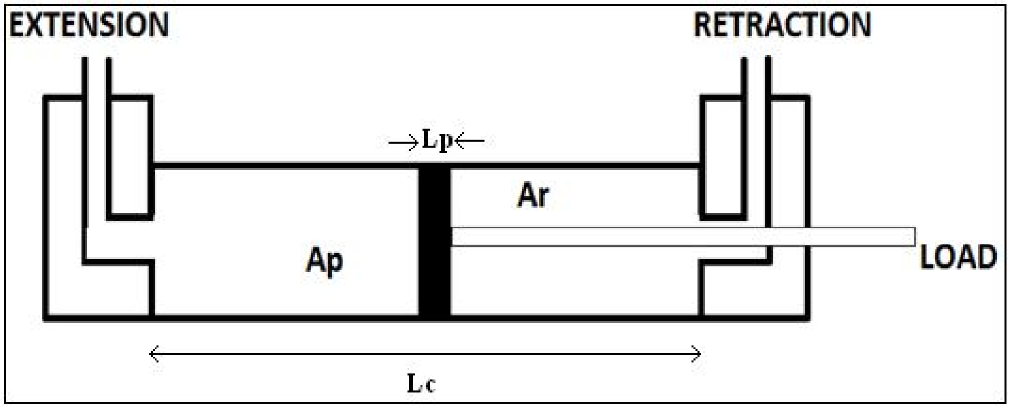

Figure 3: Schematic of hydraulic cylinder

Fig. 3 shows the configuration of hydraulic cylinder as per extension/retraction requirement.

Flow Rate is taken as 'Q'.

Retraction and extension timings are taken from Ref [2].

Time of Retraction-T_{ret} ~10 Seconds (1a)

Time of Extraction-T_{ext} ~15 Seconds (1b)

$$T_{ret} = \frac{(A_p - A_r) * X_{ret}}{Q} \quad (2a)$$

$$T_{ext} = \frac{A_p * X_{ext}}{Q} \quad (2b)$$

Where, X_{ret} and X_{ext} are retraction and extension displacements/strokes of the hydraulic cylinder piston respectively.

On simplification of (1) & (2), a relation between piston and rod diameter as $d_p = \sqrt{3} * d_r$ (3)

Where, d_p is diameter of piston and d_r is diameter of rod

Length of volume of cylinder $=L_v$; Length of total cylinder $=L_c$; Length of piston $=L_p$

And, $L_v = L_c - L_p$ (which could be taken as stroke) (4)

Full Cylinder Volume=>

$$CV_{ext} = \left(\frac{\pi}{4}\right).d_p^2.L_v$$

(5a)

$$CV_{ret} = \left(\frac{\pi}{4}\right).\left(\frac{2}{3}\right).d_p^2.L_v$$

(5b)

Flow rate=>

Retraction, R LPM = $\frac{\left[\left(\frac{\pi}{6}\right).d_p^2.L_v.10^{-9}\right]}{10} \frac{m^3}{\sec}$

Extension, E LPM = $\frac{\left[\left(\frac{\pi}{4}\right).d_p^2.L_v.10^{-9}\right]}{15} \frac{m^3}{\sec}$

And, actually both are equal that implies R=E= $\pi .d_p^2.L_v.10^{-6}\ LPM$

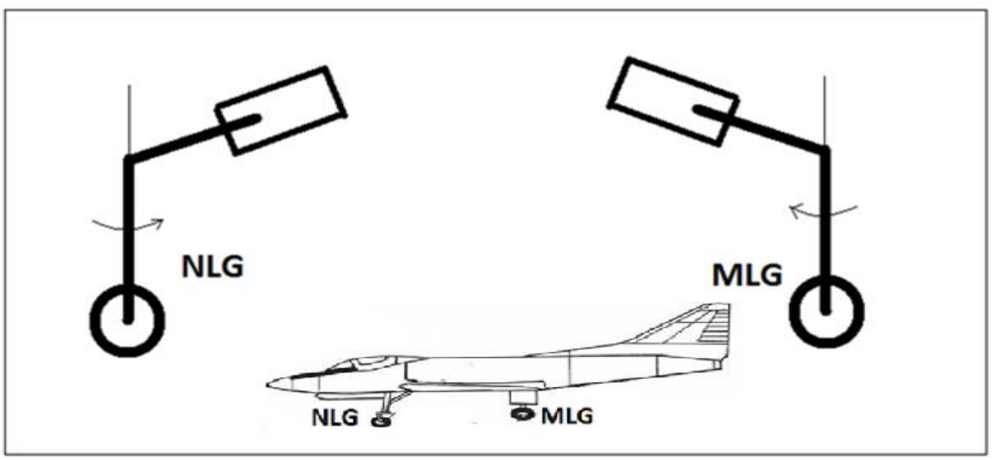

Figure 4: Direction of Retraction for NLG and MLG

Fig.4. shows the direction of NLG and MLG during extension and retraction. Table 2 below shows the effect of operational loads on nose and main landing gears. The drag load is calculated by taking the frontal area of strut.

Landing Gear	Retraction	Extension
Nose LG	Inertia Load - Drag Load	Inertia Load + Drag Load
Main LG	Inertia Load + Drag Load	Inertia Load - Drag Load

Table 2: Loads acting on the system during retraction and extension

Inertia Load =Weight of Strut +Wheel; Aircraft speed is 195 kmph for extension/retraction.

Drag Load = $\frac{1}{2}\rho.A.v^2$

Calculated as 299 N ('A' is frontal area of tire & strut~0.17m^2) which is ~30 kgf

(6)

With the given Cylinder Volume, $\pi.d_p^2.L_v.10^{-6}\,LPM$ and working out the L_v which is actually stroke with different diameters and LPM.

For different diameters of piston and flow rate strokes stroke lengths are computed to get idea of the system parameters.

Dp / LPM	20	25	30	35	40	45	50
0.3	238.63	152.72	106.06	77.92	59.65	47.13	38.18
0.6	477.27	305.45	212.12	155.84	119.31	94.27	76.36
0.9	715.90	458.18	318.18	233.76	178.97	141.41	114.54
1.2	954.54	610.90	424.24	311.68	238.63	188.55	152.72
1.5	1193.18	763.63	530.30	389.61	298.29	235.69	190.90

Table 3: Dependence of stroke length on flow and diameter of piston

From the above table 3, between 0.3 LPM and 0.6 LPM flow rate and diameter of piston as 40 mm we get a stroke of required 90.5 mm. For representative purpose stroke of higher order and commercially available hydraulic cylinders is considered in this paper. And stroke is taken as 100 mm for which flow rate is 0.503 LPM (~0.6 LPM accounting for any losses).

Considering d_p = 40mm which gives rod diameter as d_r =40/√3=23.094 mm hydraulic cylinder has been found to be appropriate for the application.

And L_v=100 mm Therefore, $L_c=L_p + L_v$, taking, L_p (Length of Piston) = 20 mm which gives L_c (Length of Cylinder) = 120 mm. Cylinder Material is taken as Aluminum alloy Al 2014-T6 whose yield stress is 275 MPa (σ_y). Taking Factor of Safety as 1.5 and burst pressure maximum is taken as 300 bar (p_c) even under extreme conditions with longitudinal joint efficiency as 80% (η=0.8) gives thickness as

$$t = \frac{p_c * FOS * d}{2 * \eta * \sigma_y} \quad (7)$$

Eq.7 gives thickness (t) as 4.09mm ~ 5 mm.

It is assumed that 0.503 LPM to each Landing gear (Total 1.515 LPM).

And a total flow rate of 2 LPM, along with extra auxiliaries of braking and with flow loss in pump as well as piping.

3.Simulation Of The Hydraulic System With Double-Acting Hydraulic Cylinder

Modeling of the hydraulic actuator with the power pack and control elements is a tedious task. Here an object/component oriented method is adopted to make the model in MATLAB-Simulink [3]. In MATLAB Simulink model is created to validate the piston stroke length and retraction as well as extension timings. Taking into consideration of pump parameters, simulated 4way-3position valves and simulated mass (landing gear strut) of 50 kgf (taken as sum of landing gear mass and drag load) and double acting hydraulic cylinder geometrical as well as operational parameters modeling is done. A typical block diagram of hydraulic actuation system in an aircraft is shown in Fig. 5. Fig. 5 as basis, we can discretize the system into a hydraulic reservoir with input of MIL-H-5606 fluid, power pack which provides the constant flow rate through the hydraulic pump which is being run by a DC electric motor (28V DC).

Apart from these components, important control block through which hydraulic cylinder can be controlled is a unique module.

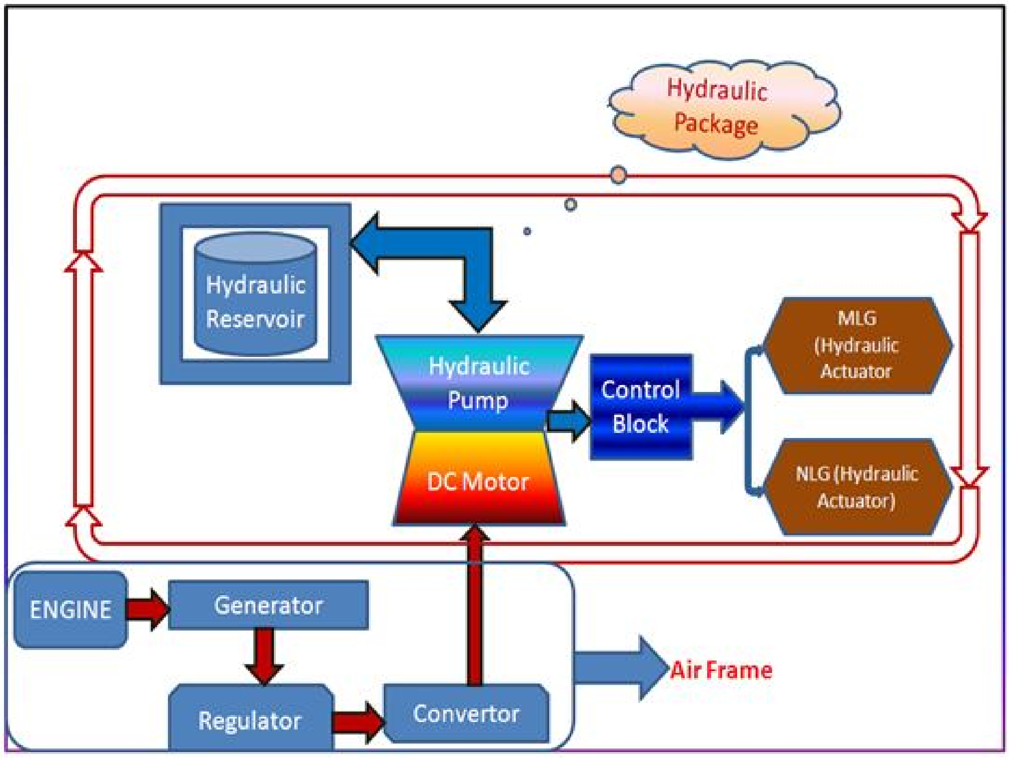

Figure 5: Typical block diagram of Hydraulic Actuation System in an aircraft

3.1.Harmonic Signal Analysis

The input signal amplitude to control valve is found by this analysis

3.1.1.<u>Simulink Operation Blocks</u>

- First component is hydraulic reservoir reference and fluid MIL-H-5606) as shown in Fig. 6a.
  - Hydraulic reference: This block represents a connection to atmosphere. It has one hydraulic conserving port. Connect to it hydraulic ports of other blocks that are considered directly connected to atmosphere.
- Second component is provision of ideal angular velocity source with a mechanical rotating reference (MRR) which needs to run a fixed displacement pump with specific volume per revolution of fluid (LPM) as shown in Fig. 6b.
  - Ideal Angular Velocity Source: The Ideal Angular Velocity Source block represents an ideal source of angular velocity that generates velocity differential at its terminals proportional to the input physical signal. The

source is ideal in a sense that it is assumed to be powerful enough to maintain specified velocity regardless of the torque exerted on the system.

- Pressure Relief Valve: This component represents a hydraulic pressure relief valve. The valve remains closed while pressure at the valve inlet is lower than the valve preset pressure. When the preset pressure is reached, the valve control member is forced off its seat, thus creating passage between inlet and outlet Some fluid is diverted to tank through this orifice, thus reducing pressure at the inlet.
- Mechanical Rotating Reference: This block represents a mechanical rotational reference point, i.e., a frame or a ground. Use it to connect mechanical rotational ports that are rigidly affixed to the frame (ground)
- Fixed-Displacement Pump: The Fixed-Displacement Pump block represents a positive, fixed-displacement pump of any type as a data-sheet-based model. The key parameters required for this block are pump displacement, volumetric and total efficiencies, nominal pressure, and angular velocity.

➢ Third component is control valve which is here taken as “4-way: 3-directional control valve”, a harmonic signal which actuates the valve and solver as shown in Fig. 6c.

- 4-way3-directional control valve: The 4-Way Directional Valve block represents a continuous 4-way directional valve. The fluid is pumped in the valve through the inlet line P and is distributed between two outside hydraulic lines A and B (usually connected to a double-acting actuator) and the return line T. The block has four hydraulic connections, corresponding to inlet port (P), actuator ports (A and B), and return port (T), and one physical signal port connection (S), which controls the spool position.

➢ Fourth component is a double-acting hydraulic cylinder with mechanical translational reference (MTR) as shown in Fig. 6d.

- Double-acting hydraulic cylinder: This block represents the model of the cylinder is built of the following building blocks: Translational Hydro-Mechanical Converter, Piston Chamber, Translational Hard Stop, and Ideal Translational Motion Sensor. The rod motion is limited with the mechanical Translational Hard Stop block.

- Fifth component is mass as well as support constraints (TS, TD) with an MTR, ITMS output measurement system and output scope along with input control signal reference as shown in Fig. 6e.
  - Ideal Translational Motion Sensor: The Ideal Translational Motion Sensor block represents a device that converts an across variable measured between two mechanical translational nodes into a control signal proportional to velocity or position. One can specify the initial position (offset) as a block parameter.

Miscellaneous components of the Simulink block for feasible simulation are as follows:

PS-Simulink Converter: converts a physical signal into a Simulink output signal

Solver Configuration: specifies global environment information for simulation and provides parameters for the solver that model needs before we can begin simulation.

Mechanical References: blocks represent a references point, or frame, for all mechanical translational and rotational ports.

The hydraulic actuator system modeling requires the interconnection of five systems as per Figure 6 are being assembled to obtain single Simulink model.

3.1.2.Input / Output Blocks

- Input Signal: The Signal Generator block (signal builder) harmonic waveform sine wave. The signal parameters can be expressed in Hertz (the default) or radians per second. It allows to create interchangeable groups of piecewise linear signal sources and use them in a model. For our model we choose the input signals that correspond to the amplitude. The sine wave block will be observed in the Scope (output).
- Output Signal: The Signal Parameters to be observed as the output values are the parameters that affect the output of the piston rod end of double acting hydraulic actuator, namely, the position and velocity. All blocks are simulated using the values as per the requirements with a simulated mass of 50 kg.
- Scope: This block displays cylinder rod velocity and extension/retraction timing

of the sequencing operation as shown in Fig. 6f.

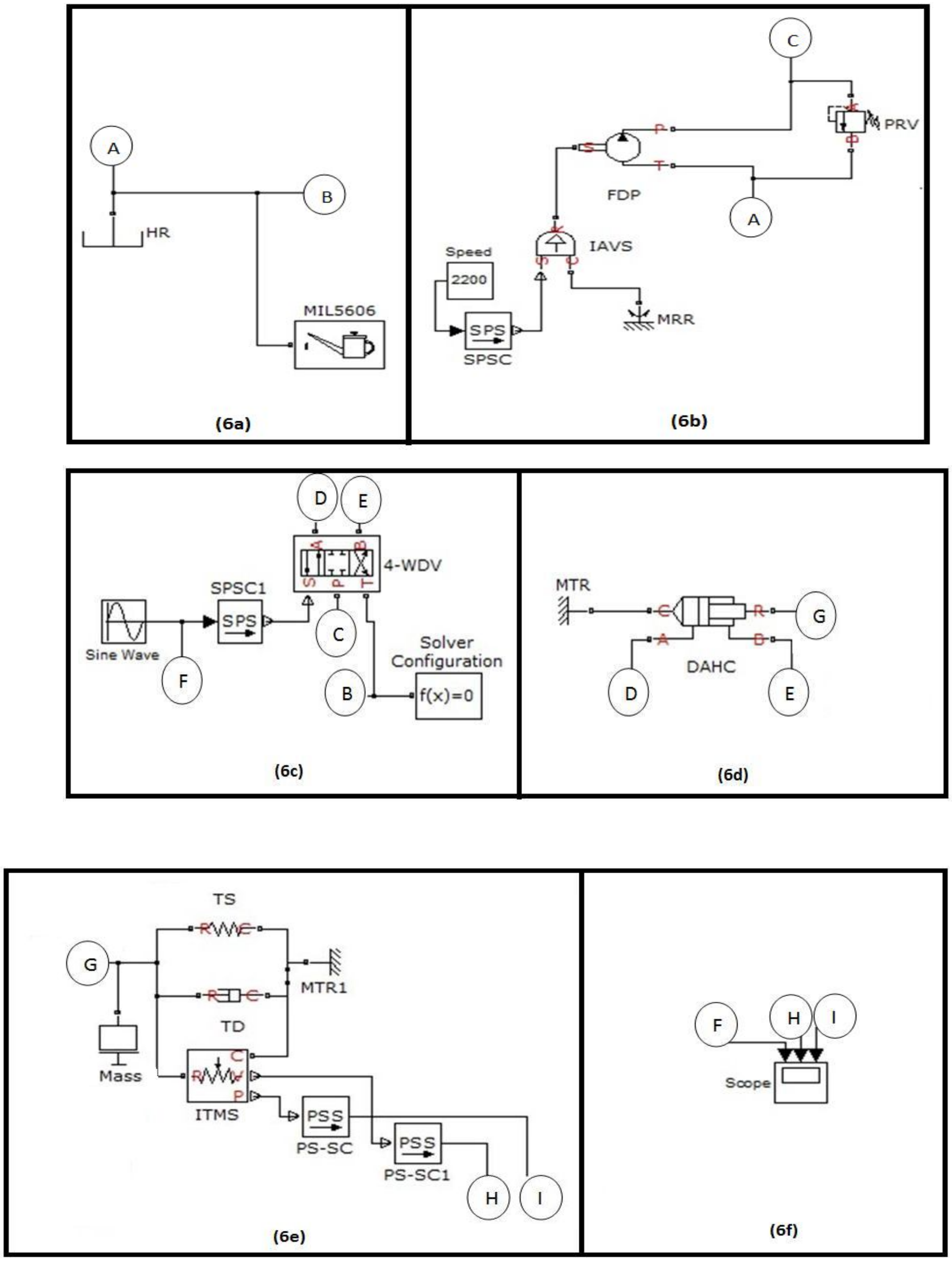

Figure 6: Components of Simulink Hydraulic Actuation System

The integration of different components as presented in Fig.6 into Simulink block as shown in Fig. 7.

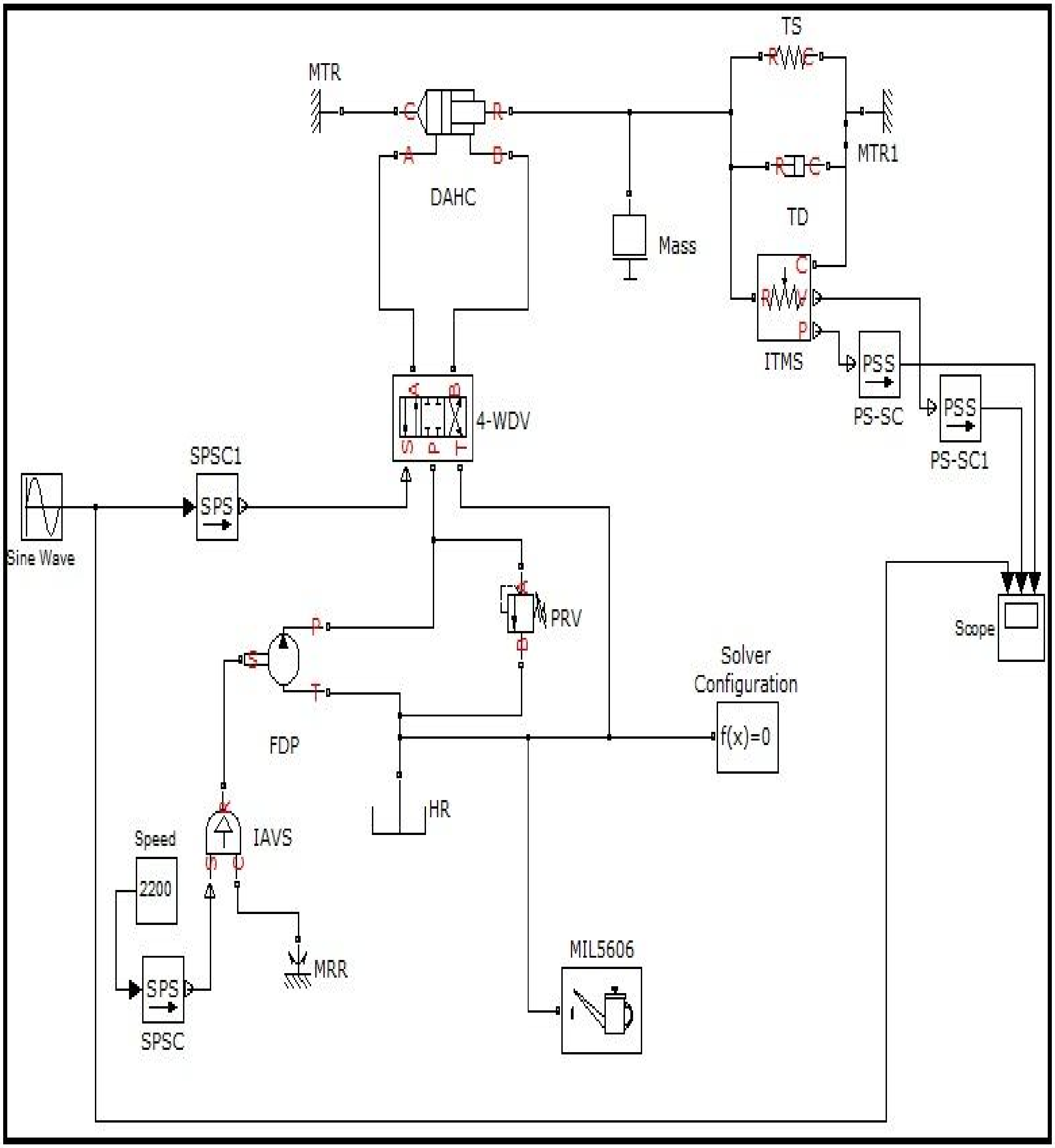

Figure 7: Simulation of double acting hydraulic cylinder for piston stroke validation

The simulation results are presented in the following Fig. 8 which shows input harmonic sine wave. Output velocity of piston as 6 mm/sec in extension, 9 mm/sec in retraction and displacement of piston rod end as 0.1 meters (100 mm) is observed from the Fig. 8.

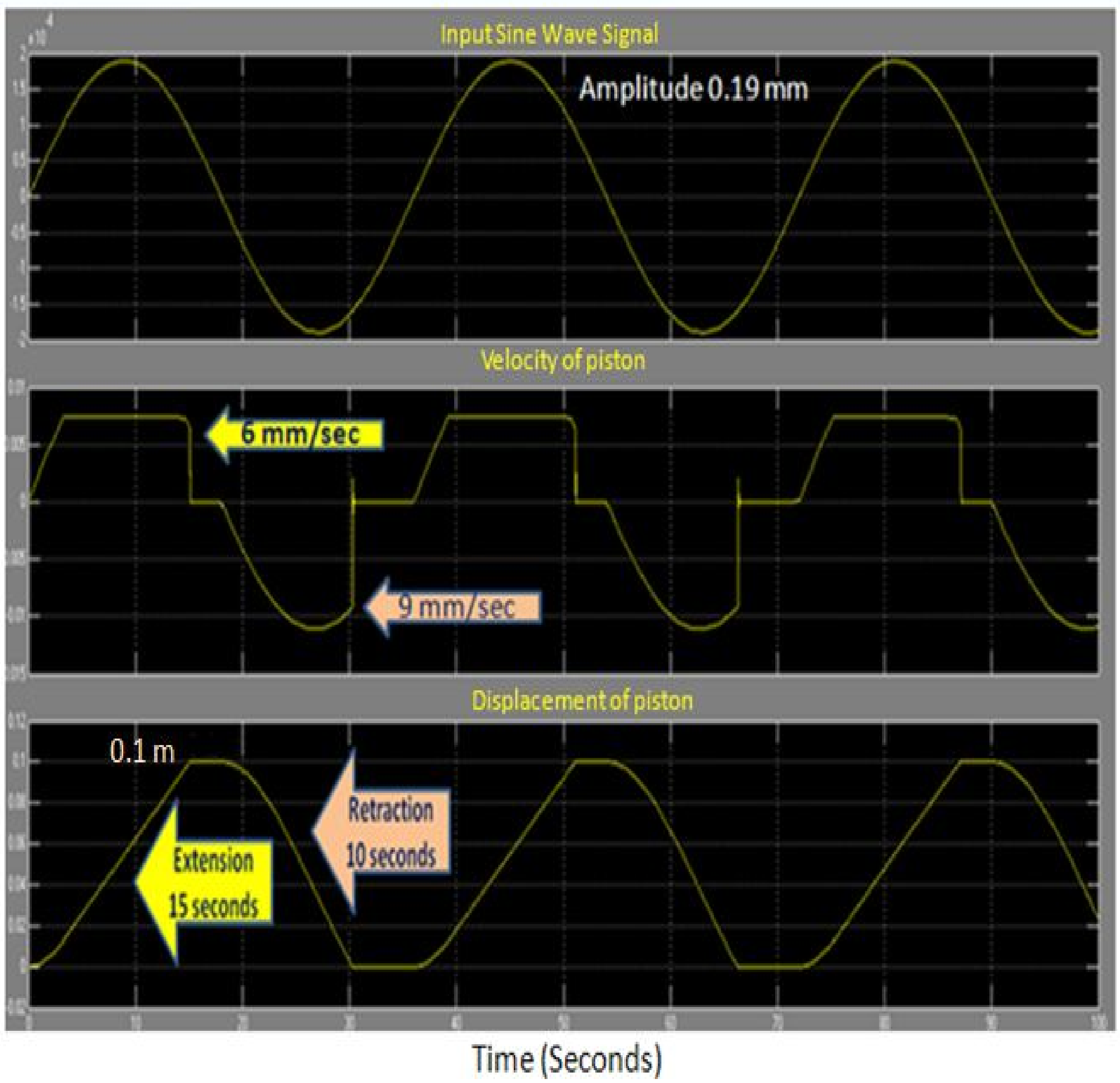

Figure 8: Simulation Results for (15 s) extension and (10 s) retraction with sinusoidal input control signal

Results are found to be in well agreement with the requirement of piston stroke displacement of 100 mm (0.1 m) in 10 seconds for retraction and 15 seconds for extension.

3.1.3.<u>Step Input To Control Valve</u>

Having obtained the desired characteristics of the hydraulic actuator and real time amplitude of the signal to actuate the control valve simulink block/component (6c) is modified as step input from sinusoidal (harmonic input). Results are in well agreement with the required retraction and extension timings. Circuit and model remains same as shown in section 3.1, only change is step input signal in (6c).

3.1.4.Input Blocks

Step input to actuate control valve is as shown in Fig. 9.

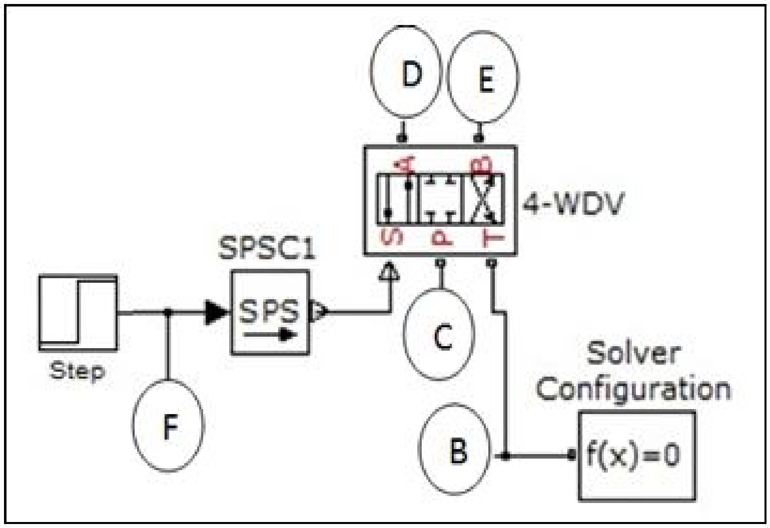

Figure 9: Step Input signal with reference to Figure (6c)

The simulation results are presented here which shows step input, output velocity and position of piston rod end as 0.1 meters (100 mm).

Figure 10a shows the extension actuation. And Figure 10b shows the retraction actuation.

These results show the ideal representation of the hydraulic actuation model with typical real time values. Actual experimental values are always in proximity to these values.

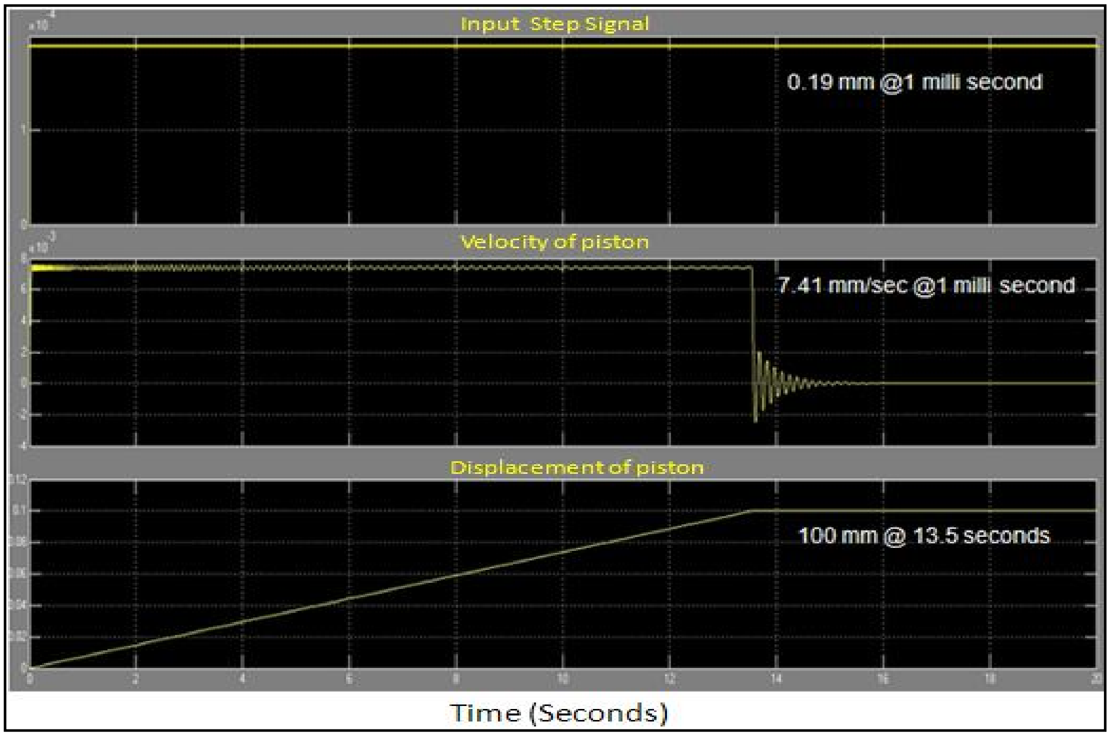

Figure 10a: Simulation Results for (≤15 s) extension with step input control signal

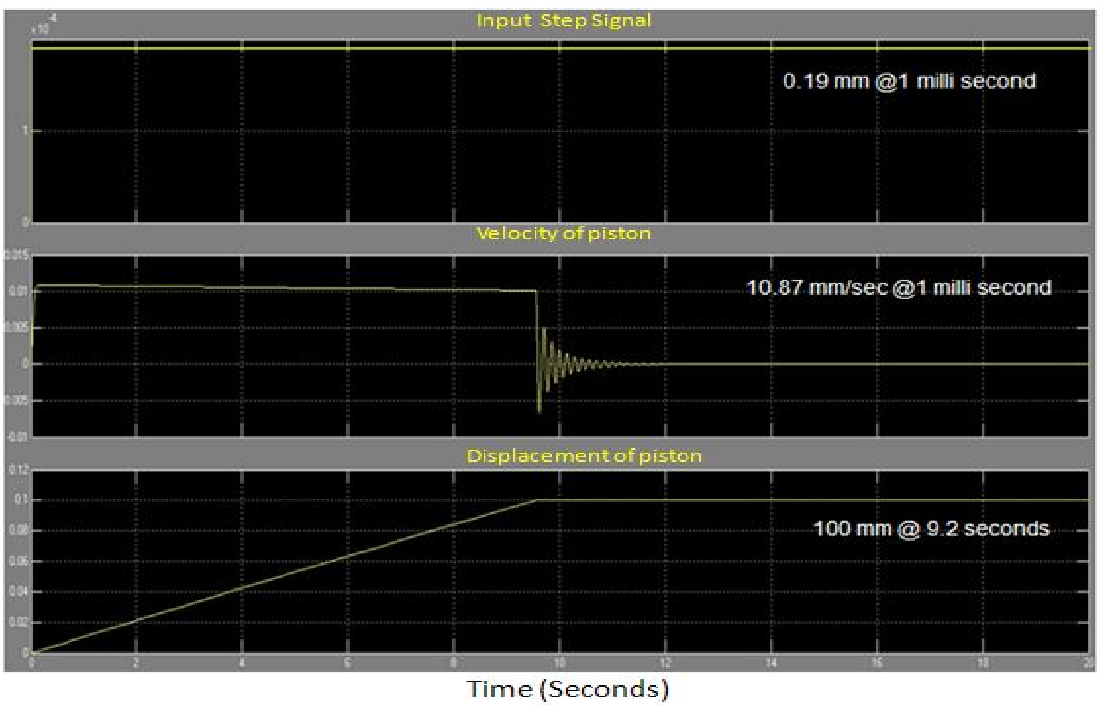

Figure 10b: Simulation Results for (≤10 s) retraction with step input control signal

4.Validation With Physical Model- Experimental Setup

The results obtained from simulation of physical model in virtual environment are biased to some mathematical models and numerical approximations while solving any ODE's (Ordinary Differential Equation's). For the same reason a physical model setup and performing the suitable experiments to meet the requirements. These results can always be corroborated with the vast set of simulated results from which the relevant adoptable sets can be taken.

Power pack which consists of Reservoir, DC electric motor, intermediate gear box which steps down the speed from 7200 rpm to 2200 rpm for running hydraulic pump is being setup is shown in Fig. 11. And a control valve, piping along with accessories is incorporated. A double acting hydraulic cylinder is connected to the control valve by taking into consideration of support and end conditions along with load at rod end. Experimental setup is being as shown in Fig. 12.

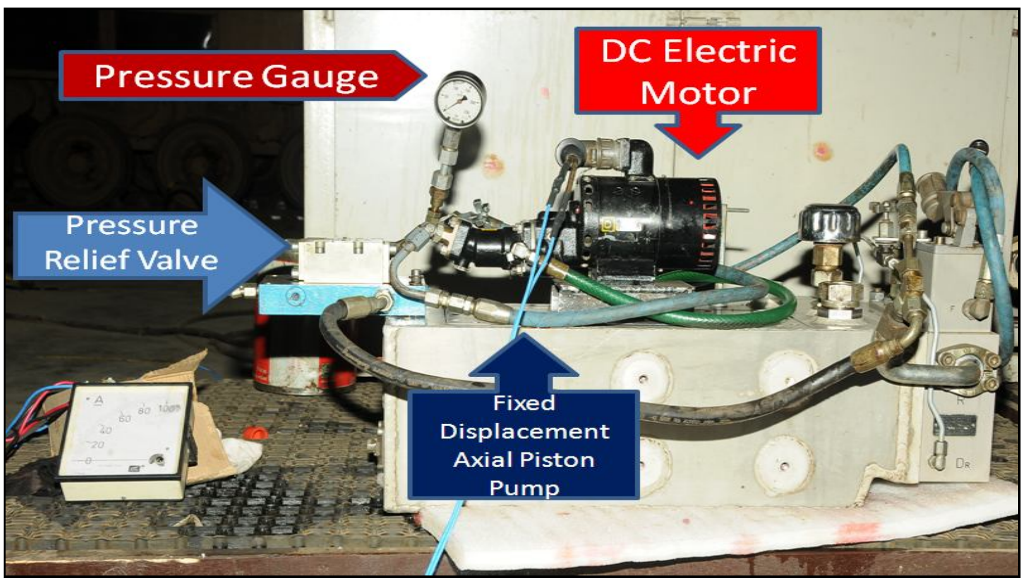

Figure 11: Power Pack and Hydraulic Reservoir Setup with Pressure Relief Valve

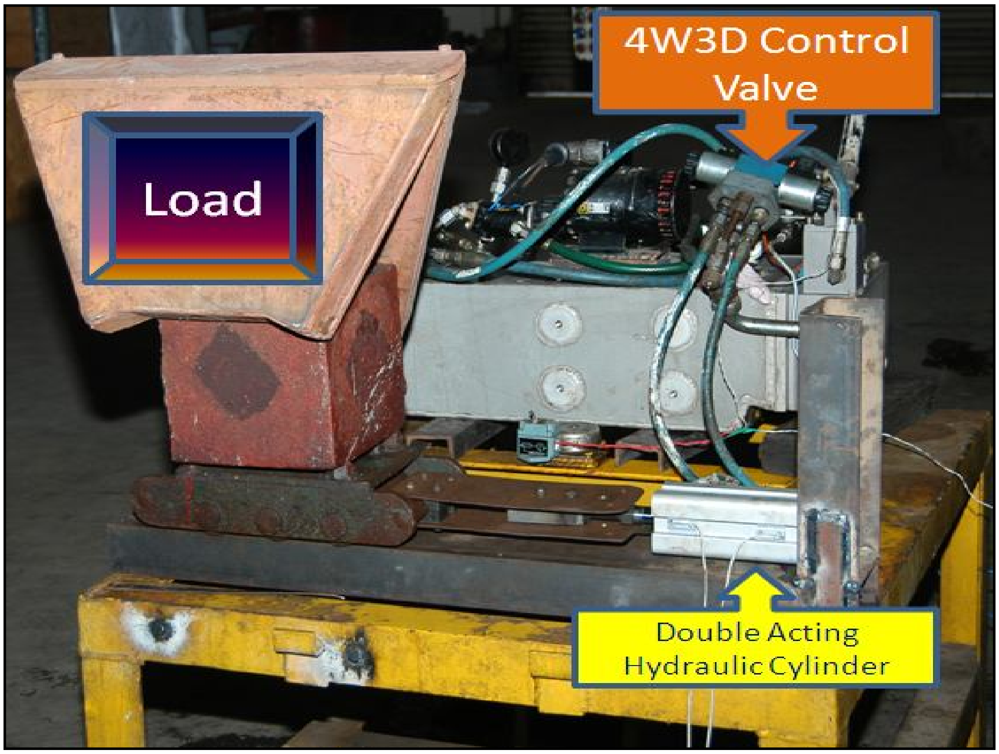

Figure 12: Hydraulic Actuator with Directional Control Valve and Load

S.No.	Current (A)	Voltage (V)	Pressure (bar)	Flow rate (LPM)	Load (kg)	Extension Timing (Seconds)	Retraction Timing (Seconds)
1	24	28	50	0.6	50	13.9	9.5
2	25	28	51	0.625	50	13.7	9.4
3	24	28	50	0.6	50	13.9	9.5

Table 4: Experimental Loading and Extension/retraction Timing results

Experimental loading and timing simulation cycles are corroborated with the model created in MATLAB Simulink and results are found to be in reasonable agreement, slight deviations are due to hydraulic cylinder packing drag friction.

5.Conclusion

Design of the hydraulic actuator using basic design principles is done. Modeling of aircraft landing gear hydraulic actuator requires, one hand, the study of the system and the identification of operating characteristics of each system component, and on the other hand, the mastery of Simulink language modeling by adopting a component- oriented method. The interconnection of these components will enable us to establish a model for the aircraft landing gear hydraulic actuator.

This model consists of blocks modeled with adjustable parameters. This fact, it allows us analyze and optimize the system parameters. The simulation shows dynamic parameters of involved in the aircraft landing gear hydraulic actuator system with simulated loading and timing cycle. The model is verified with the physical model of hydraulic actuator actuated by micro electro-hydraulic components along with power pack which is created as an experimental setup.

6.Reference

1. http://www.history.nasa.gov/SP-367/chapt2.htm
2. H.G. Conway, 1958, Landing Gear Design, Royal Aeronautical society-Chapman & Hall Ltd. London
3. User's Guide, MATLAB Simulink, 2012 by The Math Works, Inc