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Modeling and Simulation of Fighter Aircraft Refueling Probe Hydraulic System Using AMESim Software

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Abstract— This paper presents the work carried out in the modeling and simulation of fighter aircraft refueling probe hydraulic system with Advanced Modeling Environment for performing Simulations of engineering systems (AMESim) as the basic platform. Various component models like axial piston pump, accumulator, bootstrap reservoir and actuators along with the influence of engine speed are modeled and integrated in the AMESim. Air to air refueling consists in transferring fuel from one aircraft to another during flight. The inputs for simulation are; engine speed, refueling actuation command, flaperon command, rudder command and other flight control surface command which are obtained from tests conducted on hydraulic system test rig for a fighter aircraft. Simulation is carried out to identify the system behaviour.

Keywords— AMESim, Refueling, Fighter Aircraft, Axial Piston Pump, Flight Control Surface.

I. Introduction

Hydraulic system is a critical system of fighter aircraft. It utilizes the pressurized liquid to transmit energy from one place to another. The operation of landing gear, flaps, flight control surfaces, refuelling system and brakes is largely accomplished with hydraulic power systems. Air to air refueling is complex system of fighter aircraft. Two systems of aerial refuelling used by military aircraft i.e. Probe and Drogue, Flying booms. To achieve the necessary redundancy and reliability, the system may consist of several subsystems. All subsystems consists of a power generating device pump, reservoir, accumulator, heat exchanger, filtering system, etc. Preparing actual iron board of aircraft is costly affair, that's why it was decided to prepare model of hydraulic system in AMESim to try out various modifications whole aircraft is modeled in AMESim. Hydraulic systems have many advantages as power sources for operating various aircraft units. It has advantages of light weight, easy installation, simple inspection methods and minimum maintenance requirements. In general, prototype testing is an expensive tool for the design. In most cases of simulation of fighter aircraft hydraulic system, there is also a requirement of interfacing it with other modules e.g. flight control systems, models of sensors & actuators, aircraft dynamic models etc. which are integrated in the AMESim software. The paper is organized in different sections as follows, Section I contains the introduction of hydraulic system, Section II contain the modeling of hydraulic system, Section III contain the simulation of refueling probe hydraulic system, Section IV concludes research work.

II. Modeling of hydraulic system

The hydraulic system of an aircraft consists of a power pack e.g. pumps, accumulators etc., a distribution system e.g. the hydraulic fluid, pipe lines, hoses etc., and an actuation system e.g. actuators, motors etc. Normally, there are two or more systems for redundancy and the utilization is divided among different subsystems e.g. flight control system (FCS), landing gear system, nose wheel steering system, brake system etc. [1]. The present study, initially, focuses on the requirements of an aircraft flight control system only, which in the present case is assumed to consist of refueling system.

2.1 Modeling of hydraulic pump

There are two pumps modeled in the system. Pumps 1 and 2 are identical and are driven by the engine. All the pumps are pressure-controlled and have a non-linear pressure flow characteristics as a function of engine Revolutions per Minute (RPM) [1]. The hydraulic fluid flow rate varies with the change in engine RPM and hence the pump flow rate is also modeled as a function of the engine RPM at the time of simulation [1]. A swash plate variable displacement axial piston pump consists of piston, swash plate, valve plate, pressure compensated control, and swash plate control device (stroking piston). The components are modeled using hydraulic, mechanical, signal and control, and hydraulic component design library according to their functional requirements and working principles.

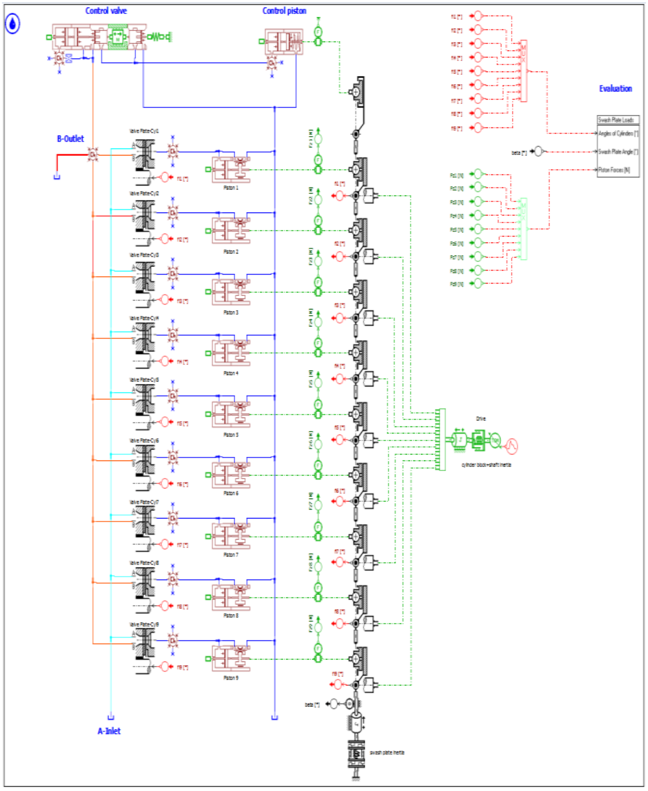

Figure 1: Nine axial piston pump

2.2 Modeling of bootstrap reservoir

AMESim model of bootstrap reservoir is modeled using mechanical, hydraulic, hydraulic component design and pneumatic component design library. Hydraulic piston is used to model low pressure chamber which stores hydraulic fluid. Pneumatic piston is used to model high pressure chamber (bootstrap chamber) which contains N_2 gas from accumulator. Sealing friction component from hydraulic component design library is used which considers dynamic friction force between piston and cylinder. Mass with friction and ideal end stops is used consider mass of piston and consider limits of displacement of the piston.

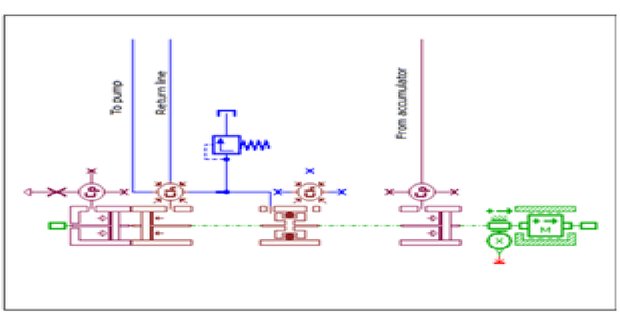

Figure 2: Bootstrap reservoir

2.3 Modeling of Accumulator

A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source against some dynamic force. The accumulator used in circuit is cylindrical type accumulator. Cylindrical accumulators consist of a cylinder and piston assembly. The piston separates the fluid and air/nitrogen chambers. For the particular gas and the accumulator, mR is constant

$$\frac{pV}{T} = \text{constant} \qquad (1)$$

When the change takes place over a long period of time, the temperature of the gas remains constant and such a change is called isothermal, resulting in the equation

$$P_1 v_1 = P_2 v_2 \qquad (2)$$

When the change occurs instantaneously, there is no time for heat transfer from the work to the environment. Such a change is called isentropic or reversible adiabatic and is given by [3]

$$P_1 {v_1}^{\gamma} = P_2 {v_2}^{\gamma} \qquad (3)$$

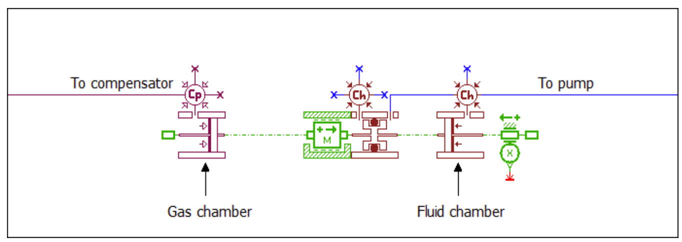

Figure 3: Piston accumulator

2.4 Modeling of hydraulic pipe lines and hose

The pipelines and hoses are considered the same for the purpose of modeling. The pressure drop in a pipe is calculated as given below [2]

$$\Delta p = \frac{\rho f l v^2}{2d} \qquad (4)$$

2.5 Modeling of hydraulic actuator and servo valve

The actuator used for operation of hydraulic system is double acting balanced and unbalanced linear actuator. The AMESim model of balanced and unbalanced double acting linear actuator is modeled by hydraulic component design to simulate the hydraulic system of fighter aircraft. BAP 12 sub model of piston is used to model piston and rod with cylinder chamber volume. The mass with friction and end stops is used to give mass and displacement limits for the piston, which defines the stroke of the piston. To simulate the direction control valve, the standard component of 3 position 4 port servo-valve from hydraulic library is used.

Flow capacity across the valve is given

$$Q = Cq \times A \times \sqrt{\frac{2}{\rho} \times \Delta p} \qquad (5)$$

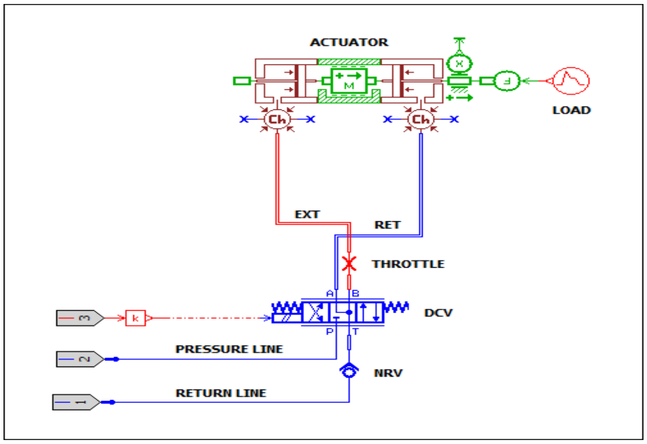

Figure 4: Valve and actuator

2.6 Modeling and integration of refueling probe hydraulic system

AMESim model refueling probe hydraulic system is modeled by integrating the models of swash plate axial piston pump, bootstrap reservoir, accumulator, actuator, direction control valve and other components from the hydraulic library like filter, pressure relief valve, and heat exchanger. Right hand system consists of control surface like refuelling, airbrake, slats, canard, stabilizer, air intake panel, ailerons, rudder, brake etc. This all control surfaces are modeled and integrated into one system with the help of super component. According to flight condition combination of control surface operation can be given with the help of transmitter and system will take it by receiver.

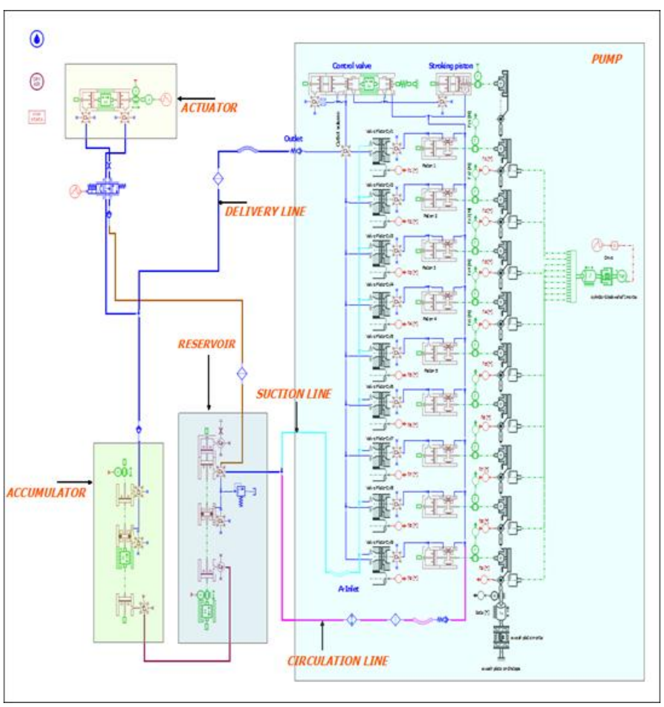

Figure 5: Modeling of refueling system

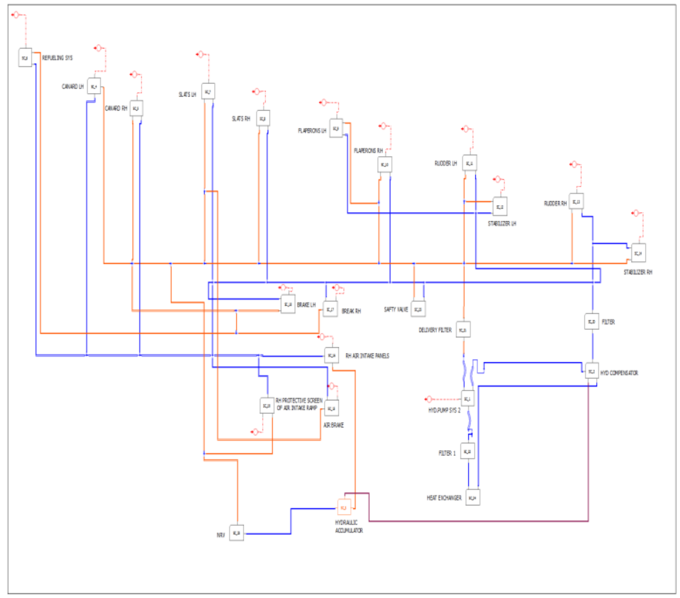

Figure 6: Hydraulic system

III. SIMULATION OF REFUELING SYSTEM

Simulation of various component of hydraulic system is done on AMESim software. A major aim of this simulation is to determine the pressure, flow, extension and retraction time of control surfaces for various operating conditions depending on requirement. To determine the system behaviour following case of refueling sytem was considered. The simulation of refueling hydraulic system is carried out in AMESim software for extension and retraction of the refueling. The total time for simulation is 15 seconds. The inputs for simulation of system are input signal for pump speed and valve rated current for opening of direction control valve. The parameters for simulation are pump speed and maximum swash plate angle.

Table 1: Simulation parameters

Start time	0 second
Final time	15 second
Time internal	0.001 second
Pump speed	4200 rpm
Swash plate angle	150
Flow resistance	12 bar for 50 lit/min

The input signal for pump is given in 3 stages, for first stage pump speed is 0. In second stage pump speed increases from 0 to 4200 rpm and third stage maximum pump speed of 4200 rpm is constant from 5.5 to 15 seconds. The pump speed signal is shown in the figure 7. The input signal for the direction control valve is 50 mA current since the valve rated current in model is set as 50 mA.

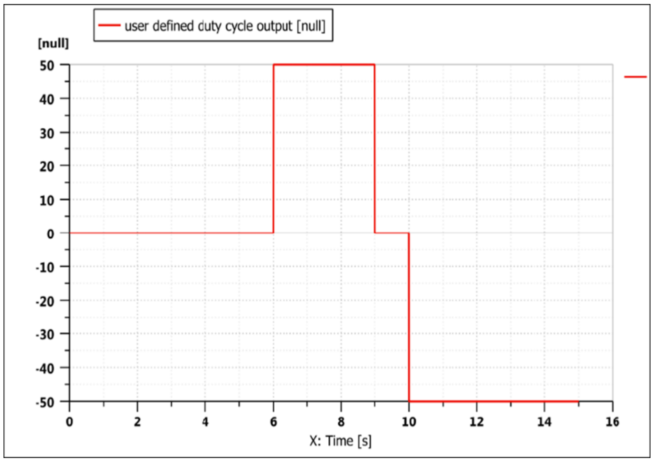

Figure 7: Valve signal

The discharge pressure of pump with respect to time is shown in figure 8. The discharge pressure drops below 280 bar at the time of extension (i.e. full opening of valve) and retraction (i.e. closing of valve).

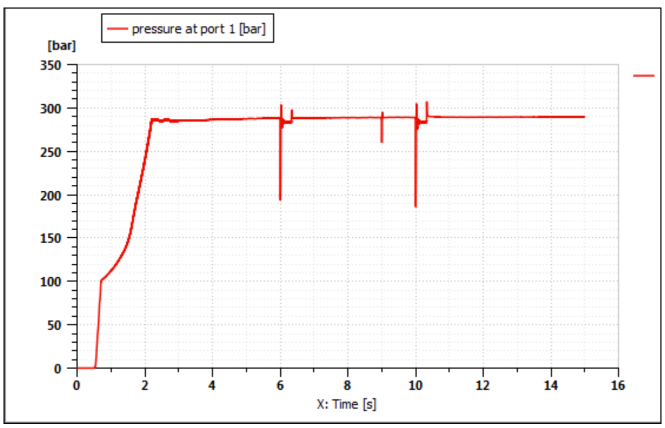

Figure 8: Discharge pressure

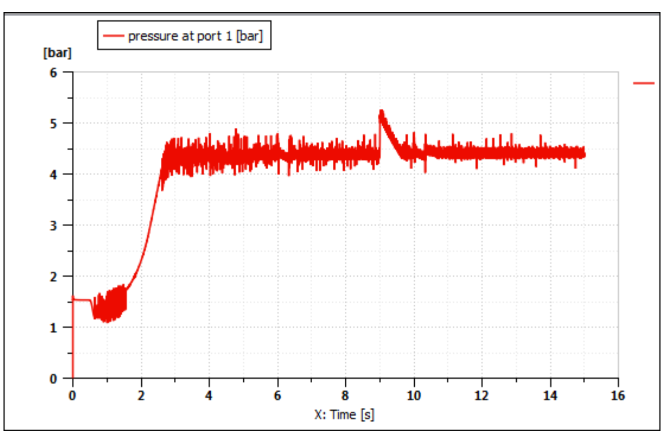

Figure 9: Suction pressure

The discharge flow of pump is shown in figure 10. The pump flow increases initially from 0.5 seconds to 3 seconds, in this period hydraulic fluid fills the accumulator. Once the accumulator is filled with hydraulic fluid, the pump flow increases for extension and retraction of the refuelling.

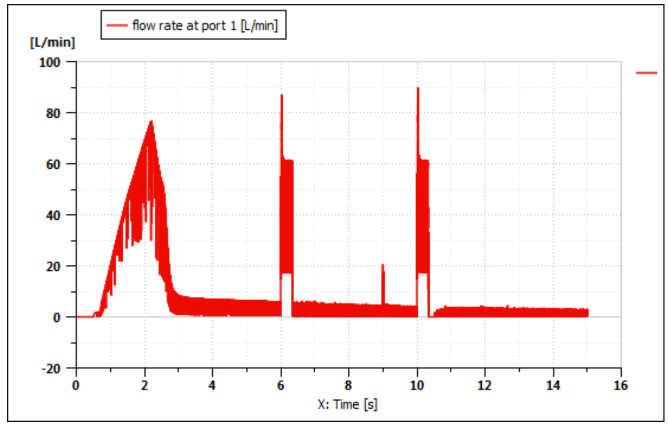

Figure 10: Pump delivery flow rate

The initial pressure of N_2 gas is 100 bar which increases up to 280 bar as hydraulic fluid from pump fills the accumulator which is at pressure 280 bar. The filter used in hydraulic system model is available in hydraulic library. The input parameter given to filter is table of flow rate vs. pressure taken from manufacturer's catalogue. The result of simulation of pressure drop with respect to time is shown in figure 11. The maximum pressure drop is between 4 to 5 bars during extension of refueling when flow rate pump increases.

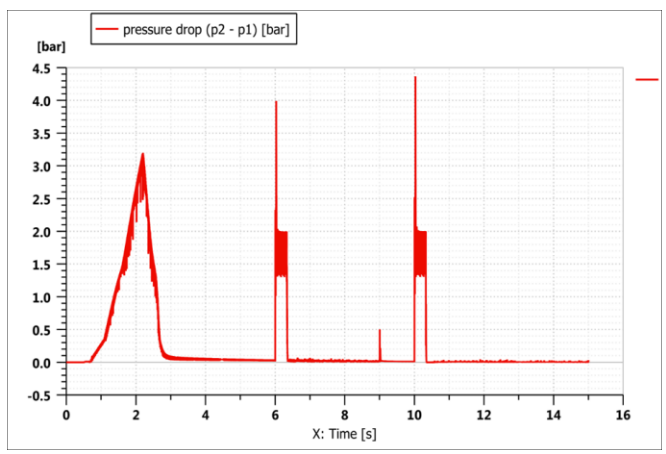

Figure 11: Filter pressure drop

The extension and retraction of refueling actuator is shown in figure 12. The extension of refueling starts at 6 seconds and the signal for retraction is starts at 10 seconds. The displacement of extension and retraction is 0.7 meter. The simulation result of displacement with respect to time is shown in figure 12.

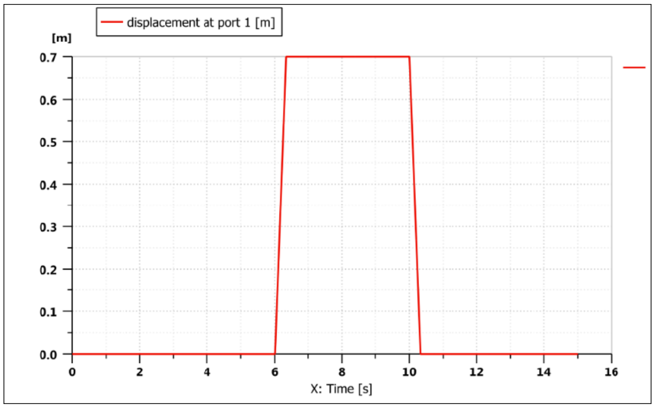

Figure 12: Extension and retraction of refueling actuator

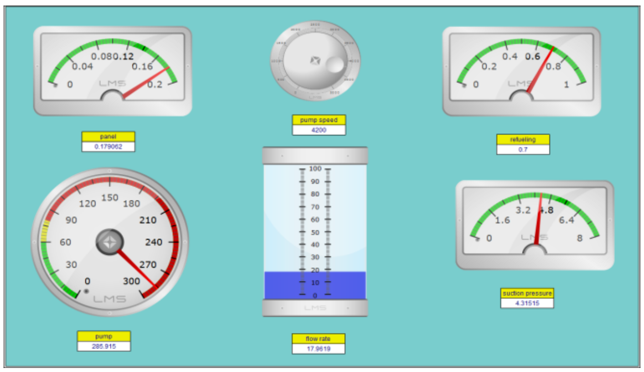

Figure 13: Dashbord for hydraulic system

IV. Conclusion

Modeling and simulation is done of hydraulic system components like hydraulic actuator, servo valve, piston chambers, and servo controllers by considering the system requirements, system characteristics, fluid flow properties and following conclusions are drawn. As per the simulation the extension and retraction of refueling probe is as per requirements. Pressure drop across the filter is within permissible limit. The simulation results give the pressures and pressure drops of the pumps and accumulator, flow rates, position of refueling system, actuator spool positions, acceleration and the accumulator gas volume. Dashboard gives the visualization of system for better understanding.

Nomenclatures

d: Pipe Diameter
f: Flow Friction Factor
Δp: Pressure Drop
l : Length of the Pipe
p : Accumulator Pressure
V : Accumulator Volume
Q: Servo Valve Flow Demand
Cq : Flow coeffienct
v : Velocity of Flow
ρ: Density of Fluid

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