Performance evaluation of on-board hydraulic system for flight control actuator requirement based on modelling and simulation

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Abstract

This paper describes about the performance evaluation of on-board hydraulic system of an UAV designed for the supply of fluid power at required pressure and flow rate to flight control surface actuator and other system of UAV. The on-board hydraulic system generates power by constant pressure variable delivery hydraulic pump to deliver to various stake holder of the aircraft as and when demanded. The maximum flow generated by the pump is restricted to the RPM of the pump and its displacement. The engine RPM of the UAV varies at different phase of flight right from take-off to landing. Accordingly, the flow availability from the pump varies proportional to the rpm of the engine. A study has been carried out to assess the availability of the flow from the pump and the demand by flight control surface actuators of the UAV. The 1D simulation of on-board hydraulic system architecture is generated in Simcenter Amesim aerospace simulation suite. The requirement from various stake holder of hydraulic system at various phase of flight is generated and analysis has been carried out to see the on-board hydraulic system meet the requirement of the flight. The pressure drop due to sudden demand of flow from actuator and other system at different point of the hydraulic system circuit is analysed.

Introduction

On-board hydraulic system is a flight critical system of an air vehicle. Its main function is to provide hydraulic power at required pressure and flow rate to flight control surface actuators and other utility system of the vehicle. During the course of various phase of flight, the air vehicle needs different hydraulic flow to meet the requirement of various system. The take-off, landing and manoeuvring phases are the most important phases of the flight where the hydraulic power demand becomes critical as not only the flight control surface actuator but other system also demand hydraulic power simultaneously. As the air vehicle is built around a particular engine the availability of hydraulic power becomes a constraint. With the availability of hydraulic power at these phases of flight, the air vehicle has to complete the flight by meeting the demand of hydraulic power. The onboard hydraulic system is a complex system comprising of hydraulic pumps, the main source of power, along with a backup emergency hydraulic pump, reservoirs to store oil, accumulators to cater for excess demand and stabilise pressure fluctuation, filters, pipes/tube, various types of valves.

This paper focuses to arrive at a hydraulic system architecture model with flight control surface actuators and other utility system in 1D modelling software AmeSIM and analyse whether the system is capable to meet the energy demands of the system at various phase of flight. The power spectrum of the flight phase is derived based on the demands from the systems and compared with the available power from the engine. Also, a study is done to understand the effect of introducing an accumulator in the circuit. It is also studied to see the hammering effect on the suction line of the hydraulic system when there is a sudden high demand of the hydraulic flow. The continuation of the work as future study will be on the flow analysis of the on-board hydraulic system considering all the user systems with actual RPM of the engine to understand the functioning of the system in autonomous mode of the vehicle and also thermal analysis of hydraulic system to estimate the heat generation and fluid temperature rise during operation of hydraulic system.

Modelling Tool Capabilities

AmeSIM is a 1D modelling software which uses symbols to represent an individual component within a system which is either available from their standard libraries (hydraulic, pneumatic, electrical, mechanical etc.) or from user-defined libraries [2]. Amesim allows to build models from scratch and helps in realizing huge systems such as an aircraft hydraulic system and to carry out analysis for various data. This is the standard tool many in aerospace industry is using for modelling and simulation of aircraft system such as on-board hydraulic system.

On-Board Hydraulic system architecture design

The architecture of On-Board hydraulic system has been carried out based on SAE AS5440. It is derived based on the requirements of the various system and their operational demands to meet the requirement of the safe flight of the air vehicle. The air vehicle hydraulic system is a constant pressure variable flow system. It is a type II system as per SAE AS 5440A. There are two independent system operated by two main hydraulic pumps mounted on gear box. The flight control system and other utility system are powered by a common hydraulic pump. The flight control system line and other utility system line is isolated by a valve. Apart from that there are other LRUs to regulate the flow and maintain the pressure. The other hydraulic system components are reservoir, accumulator, filters, various types of valves etc

A schematic of the on-board hydraulic system has been arrived as shown in *Figure 1*. The flight control system actuators are tandem based and operated by direct drive valves. These actuators are hydraulically dual redundant i.e. both the systems are providing pressurized fluid to the actuator simultaneously.

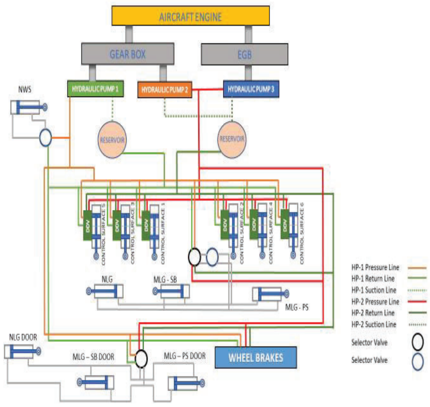

Figure 1: Preliminary on-board hydraulic system schematic for flight control surface

Tandem actuators comprise of two pistons connected to same rod hence dividing the actuator into 4 hydraulic chambers. The chambers have unequal area hence flow from each system during extension of the actuators will be different while during retraction, flow rate will be equal for both the systems.

Modelling of Hydraulic System Components

Each hydraulic system components are individually modelled in AmeSIM software and validated before integrating it to the system model. Constant pressure variable displacement pump (HYDVPD0) has been selected as the pump model from AmeSIM and it is to be connected to pressure compensator model (HYDCONPC0) along with pump control piston (HYDCONPIS0) to form the pump as shown in Figure 2 . The pressure compensator ensures the constant pressure characteristic of the hydraulic pump.

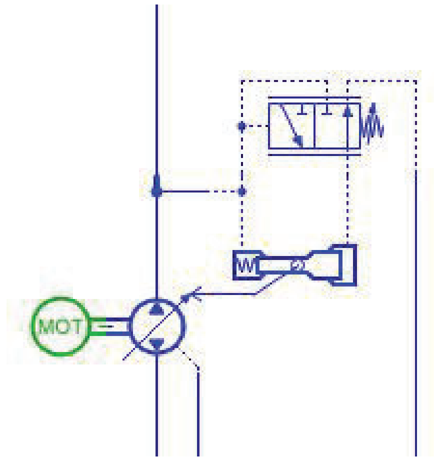

Figure 2: Pump model in AmeSIM

Flow rate is computed using the below equation:

$$Q = \frac{\boldsymbol{displacement} \times \boldsymbol{RPM}}{\mathbf{1000}}$$

where Q is pump flow rate,

The reservoir is modelled using various components from hydraulic component design (HCD) library, hydraulic library, pneumatic component design and 1D mechanical library to realise its functionality as shown in Figure 3. Reservoir fluid pressurization is done by a differential piston. A leakage component is also included in the reservoir model to simulate the internal leakage between the upper and lower chambers of the reservoir.

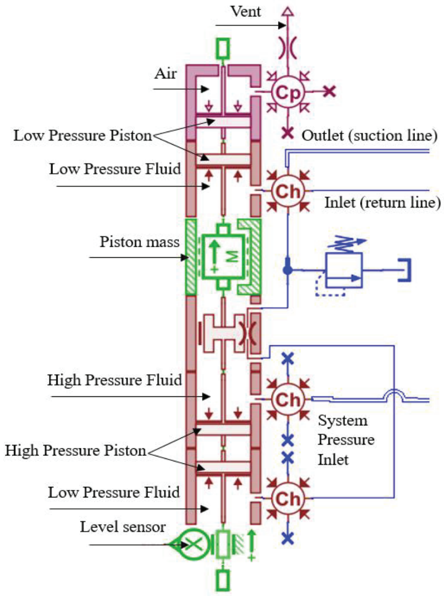

Figure 3: Bootstrap reservoir

Hydraulic System Modelling & Simulation

On-Board hydraulic system model is generated in AmeSim integrating all the components model. The control surface actuator model is integrated with the hydraulic system model in order to simulate the demand of the hydraulic flow during various phase of flight of the air vehicle. The model is used to study the performance of hydraulic system with six tandem actuators for the take-off, landing and manoeuvring phase of the flight. The AmeSim model of integrated hydraulic system is shown in Figure 4.

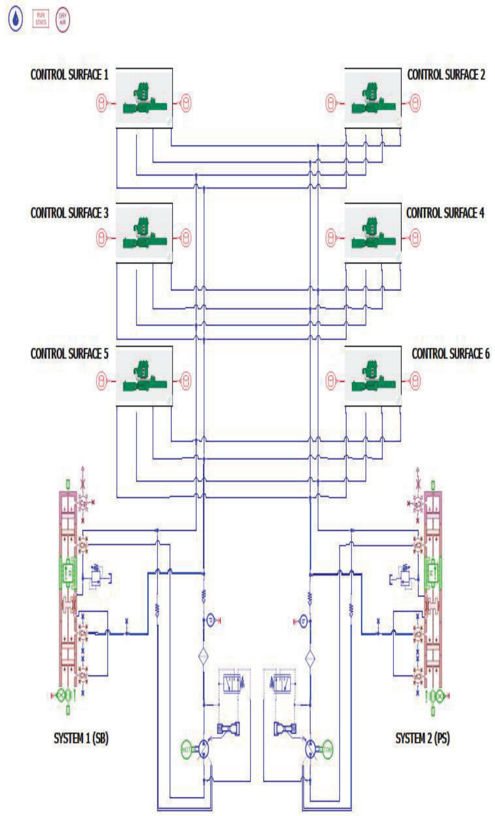

Figure 4: Integrated on-board hydraulic system model without accumulator

The model is used to study the performance of the on-board hydraulic system in various phase of flight. The input for the model is the demand of the hydraulic power for the movement of the control surface during take-off, manoeuvring and landing phase. It is observed that during the landing phase when the engine RPM is 70% and the available hydraulic power from the pump is proportionally less compared to the maximum flow available, the pressure drops significantly to meet the demand of the flow in the hydraulic circuit. In order to reduce the significant pressure drop an accumulator is added in the circuit of the hydraulic system model and simulation study carried out. It is observed that the pressure drop has been reduced significantly after introduction of the accumulator in the circuit. The drop in pressure with and without accumulator is shown in Figure 5.

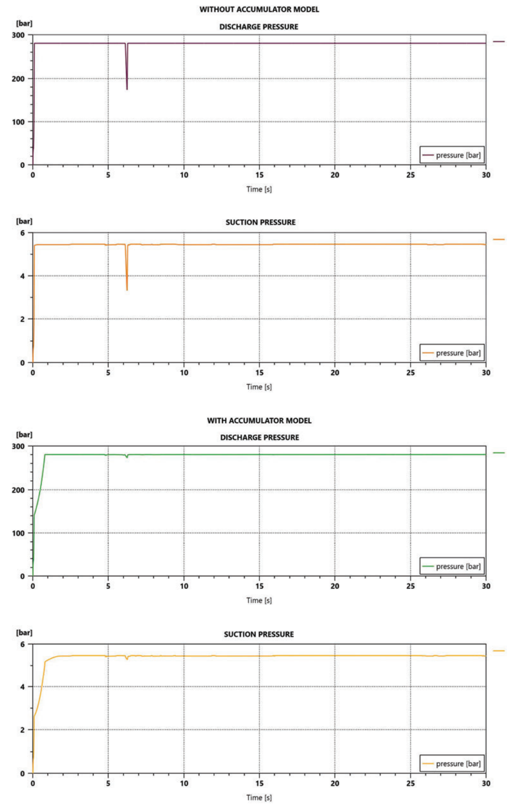

Figure 5: Pressure drop with and without accumulator

The integrated on-board hydraulic system model is shown in Figure 6. This model will be used for further analysis of the system to analyse the performance of the on-board hydraulic system for the various phase of flight.

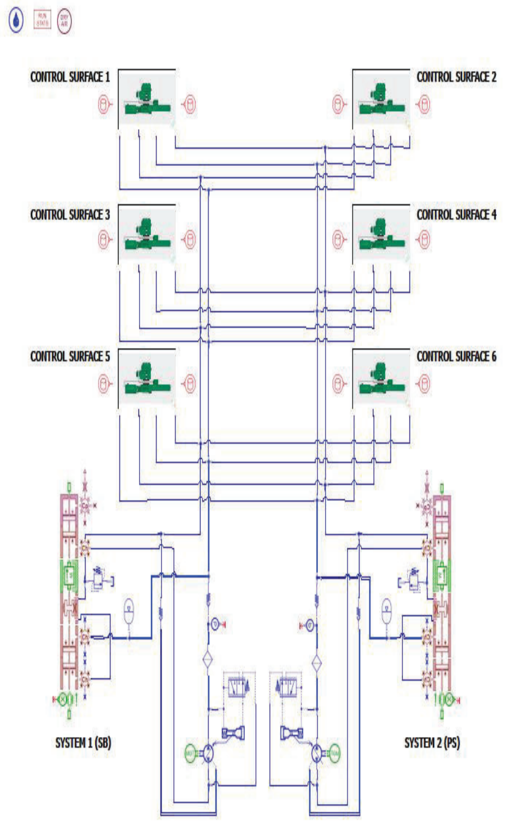

Figure 6: Integrated on-board hydraulic system model with accumulator

Performance evaluation of on-board hydraulic system

Take-off Phase

The study is carried out to check the performance of hydraulic system during take-off phase. The demand of the actuators in terms of degree is shown in Figure 7. The output is taken at an interval of 0.01 seconds. The flow required by each actuator is shown in Figure 8. The system 1 flow rate requirement is shown in Figure 9. It is also observed that the peak total flow rate is around 48 lpm as shown in Figure 9.

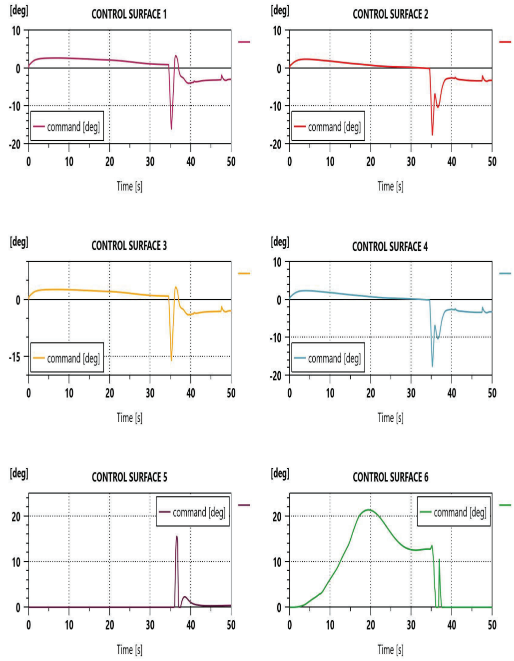

Figure 7: Input for control surface actuators for take-off phase

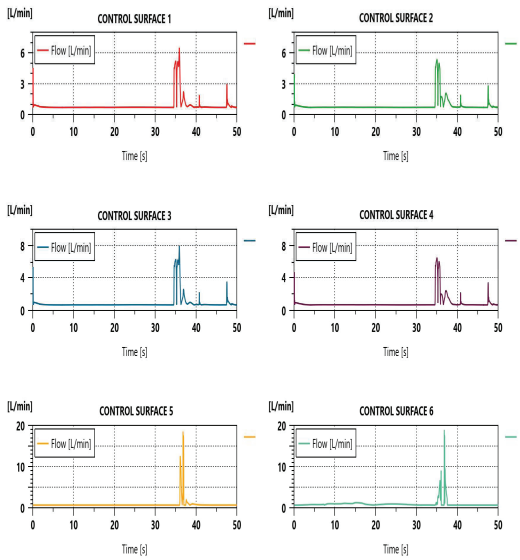

Figure 8: Control Surface flow rates

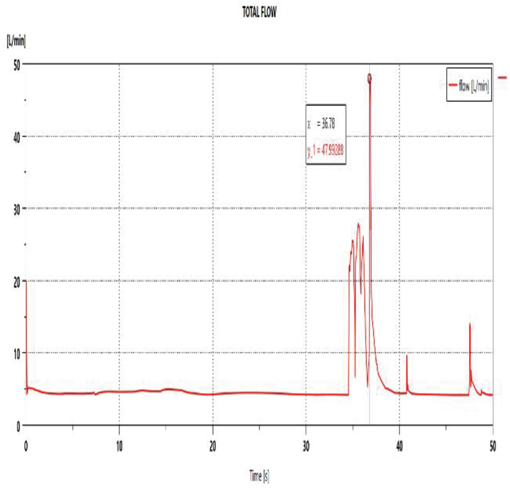

Figure 9: System 1 total flow rate requirement

Landing Phase

The simulation of the model was carried out for landing phase. The demand of the actuators in terms of degree is shown in Figure 10.

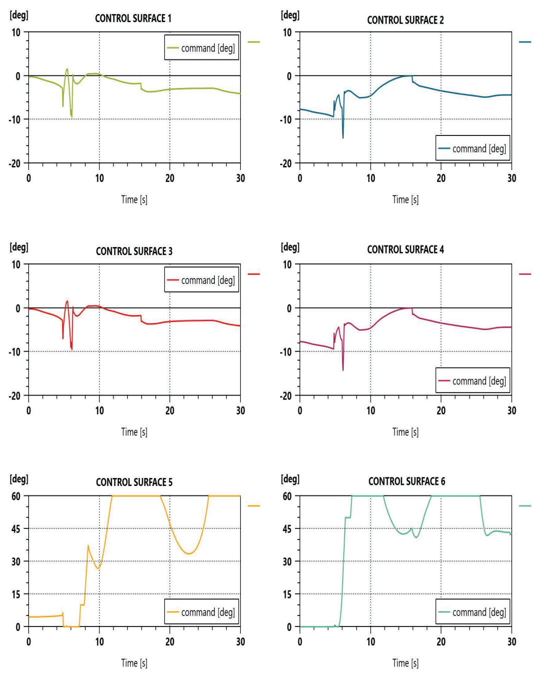

Figure 10: Control surface input for landing phase

The output is taken at an interval of 0.01 seconds. The flow required by each actuator is shown in Figure 11.

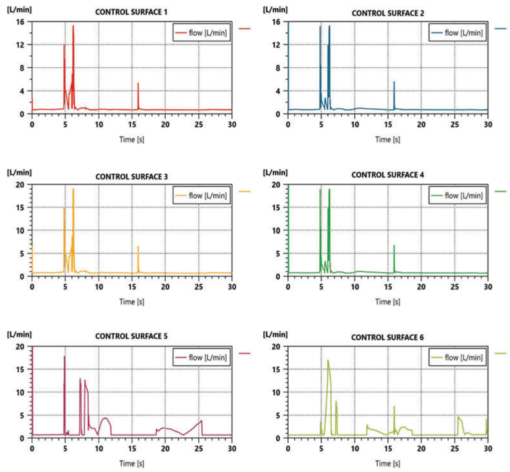

Figure 11: Actuator flow during landing phase

The system 1 flow rate requirement is shown in Figure 12. It is also observed that the peak total flow rate is around 84 lpm as shown in Figure 12.

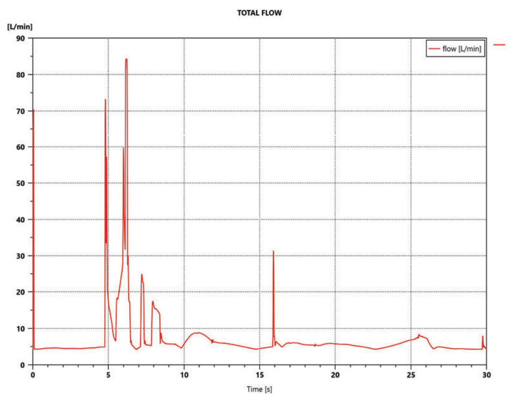

Figure 12: System 1 Total flow

It is also clear that accumulator assists the pump to cater to the demand during landing when the demand exceeds the pump capability as shown in Figure 13. It can be observed that accumulator gets charged once the demand reduces and can be met by the pump alone as indicated by the negative flow in the plot.

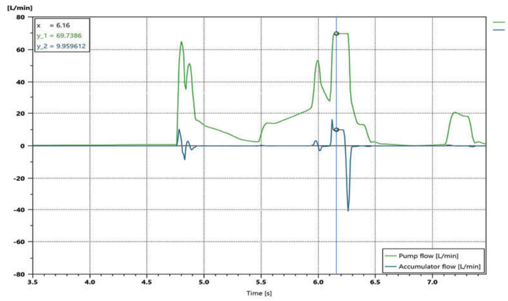

Figure 13: Accumulator flow and pump flow curve during landing

Conclusion

In this paper, each element of on-board hydraulic system is modelled and analysed. The related models are integrated and the overall system simulation model is arrived in AmeSIM software. With the developed on-board hydraulic system model, a take-off and landing phase of the flight has been analysed based on the requirement of flight control surface actuators and other utility system. The developed hydraulic system model meets the requirement and verify the specification of the components selected.

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