Modeling and Simulation of Command and Control System to Execute the Fuel Sequencing for Fighter Aircraft using AMESim

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Abstract: Eastern way of developing aircraft mainly focuses on mechanical based actuation fuel system components and auxiliary units. Fuel system uses pressurized fuel for its working. To model this type of system AMESim software (Advanced Modeling Environment for performing Simulations of engineering systems) is used as a basic platform. Tank volumetric design and data file generation is carried out using CATIA software for simulation requirement. Using available libraries mechanical components are created. Command and Control system which manages fuel flow within tanks and to the engine is integrated to the main fuel system. Jet Transducer is a controlling mechanical element modeled using signals and state chart also Hydro booster pump is created using thermal hydraulic library. The model of fuel system was simulated and analyzed for flow rates, tank pressure and % MAC variation with respect to time and fuel consumption. Ground testing results are used to compare results of simulation.

Index Terms **- AMESim, Data File, Jet Transducer, Hydro Booster Pump, MAC, Modeling.**

I. Introduction

There are two types of fuel system used in the aircraft, Eastern type and Western type. Western type of fuel system focuses on electric actuation of fuel system components. Eastern type of fuel system focuses on mechanical actuation of fuel system components. Studied aircraft is having eastern type of fuel system. Its fuel system use pressurized fuel to drive its components and auxiliary elements of fuel system. This type of system contains components like Jet Pump, Hydro Booster Pump, Jet Transducers, Flap Valves and NRVs. Complexity of fuel system increase from commercial aircraft to Fighter aircraft, in the case of fighter aircraft due limited space and irregular shapes of tank fuel system becomes more complex. This type of fuel system has high power to weight ratio because of less power conversion loss. Because of less moving parts low maintenance cost. There is least chance of catching fire within system as there is no use of electrical actuation. Because of electrical interference fuel system performance remains undamaged.

Conventionally for testing the performance of system prototype based testing was carried out to confirm the system performance. It takes lot of time and cost for prototype building and testing. With the wide application of computers, the computer simulation can be used for testing and analysis of system performance which saves time and cost. In the paper AMESim model of command and control is built to check the performance.

II. Motivation

Every aircraft has its life, after which it's sent for overhauling. During overhaul all parts of the aircraft are checked for their functionality one by one. In the testing if performance is not good then those parts are replaced with the new ones. It consumes lot of time to remove each and every part and test for its performance. To reduce this time simulated system results can be used to compare with testing results of actual system. During maintenance of such aircraft it is very difficult to find out the problems associated with the fuel system, as it is a complex network of pipe lines and interdependent systems. In order to troubleshoot the system easily it is better to have a simulated environment with which testing results can be compared. After manufacturing of the aircraft its fuel system is checked for its proper working. Along with testing calibration of different measuring devices also carried out, simulated environment helps in reducing the time of calibration as it has standard results as expected for the fuel system. For development of existing fuel system or new fuel system simulation acts as a base, on which different changes can be easily made.

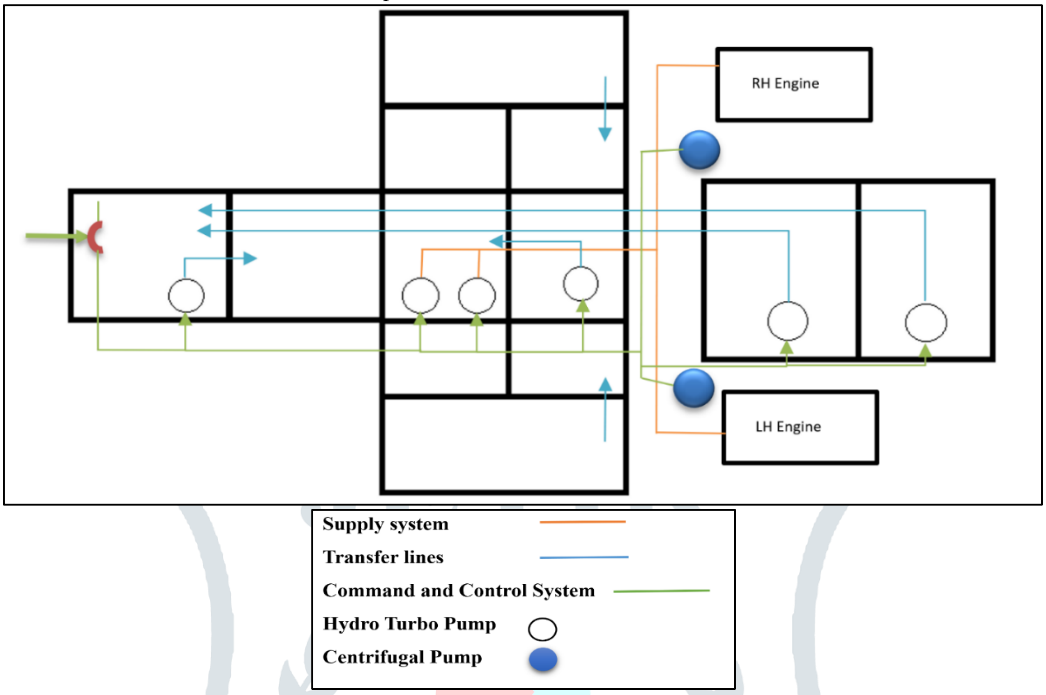
III. Software Preliminary Requirements

To model the system into the AMESim Preliminary Data Files which exhibits behavior of actual system are necessary. There are three files which represents behavior of the actual system which are Shape data file, Info data file and Step file. These files for each tank are prepared first. To prepare those files 3D tanks are modelled within CATIA, these tanks are located within CATIA at the same place as they are in actual system, while modeling these tanks into CATIA aircraft reference point is considered about this point tanks are located. These tanks are modeled individually and checked for their volumetric capacity of fuel, once volumetric capacities are matched with actual capacities of each tank, and then tank shapes are finalized.

Data file creation: In these file tank parameter of actual system are defined. For every tank changes in Centre of Gravity location of fuel, Volume left within the tank, Tank Reference Height and Tank Global Reference Height variation calculated with respect to fuel consumption. To calculate this parameters CATIA software is used, Data extraction process is automated using MACROS. Using technological data (inertia) data function related to the tank is extracted and written into the excel file. Data written into the excel file is in a specific order which includes x, y and z coordinates of center of gravity, reference height from global axis, reference height from local axis and volume of fuel present within tank. While generating these data unit and axis system used for generating data are important. All data written within data file is mentioned in the millimeters (mm) except volume of the fuel remained which is in the meter cube (m^3). Data generated by CATIA is in milli meter, it is necessary to convert these data into required form before entering it into the actual data file.

IV. System Layout

General layout of the studied system is shown in the following figure. Central tank has five sections, one of which supplies fuel to the engine. Other sections of Central tank supplies fuel to the central reserve section in order to avoid starvation of the main supply pumps to the engines. Front section of central tank receives fuel from front tank via Jet Pump which is coupled with HBP. Rear tank one and rear tank two supplies fuel to the front tank using HBP. Wing tanks are attached to the side sections of central tank, and supplies fuel to the central tank via Jet Pump.



In the layout different systems of fuel systems are shown, these are interconnected to each other and are interdependent. Fuel driving elements and fuel flow controlling elements are also shown into the layout. A particular sequence of consuming fuel from each tank is important to limit Centre of Gravity variation. To minimize this variation in lateral direction fuel from central tank is supplied to the engine. To control the longitudinal variation of Centre of Gravity sequence is important. An optimized sequence is the input from Onkar Waghmare, who carried out the research on the same fuel system to find out optimum fuel sequence. He used different sequence combinations to find out the optimum sequence for the system. Built the same system into the AMESim which works on the electrical actuation which allows easy implementation of sequence. Among different sequences one optimum sequence which gives least Centre of Gravity variation is used for the simulation. The sequence Partial front tank consumption, then rear tank 2, rear tank 1, complete consumption of front tank, partial central tank consumption, wing tank consumption and Central tank consumption is the fuel consumption is used for emptying tank.

V. AMESIM MODELING OF SYSTEM

Into the AMESim aircraft library is available which is used for the modeling of the system. As per the layout parts present within the library are studied and used for modeling the actual system. Driving element HBP and Controlling unit Jet Transducer is not available within aircraft library. These two are modelled first and checked for their functionality.

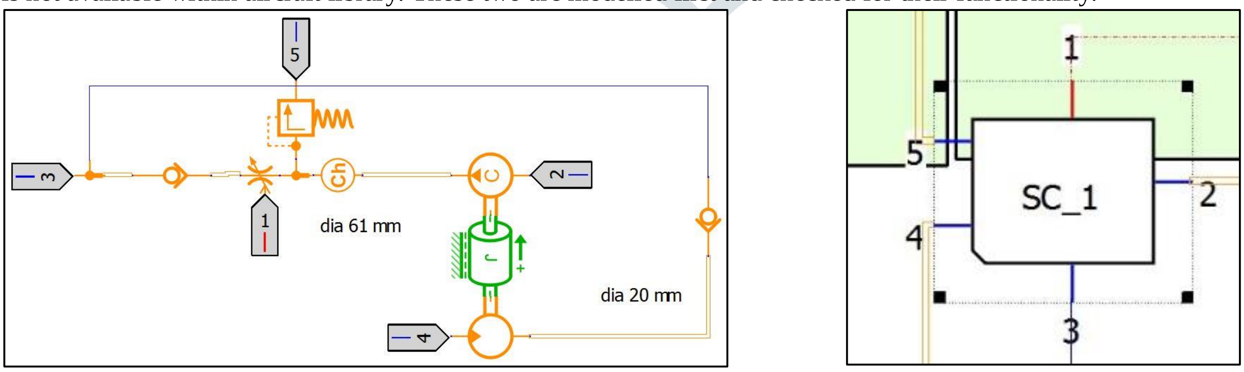
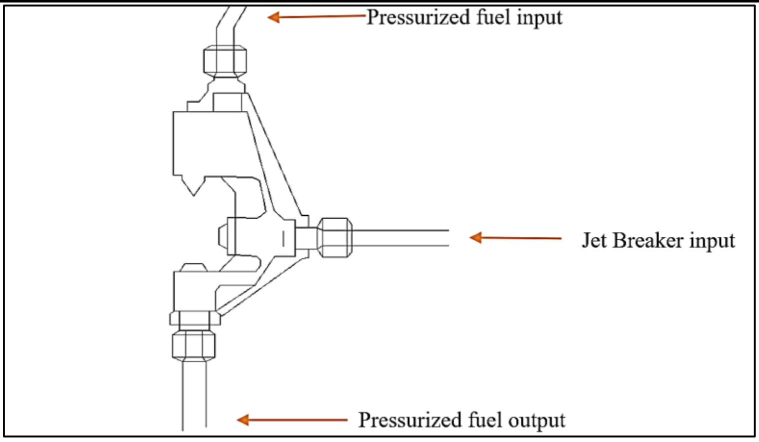


Fig HBP Modeled within AMESim

HBP is the pump uses pressurized fuel to turn turbine shaft which ultimately drives centrifugal pump. To create this pump within software hydraulic motor used which is attached to the centrifugal pump. The output flow rate for input pressurized fuel flow is checked with testing data available.

Jet transducer is a mechanical device, the height where it is located acts as triggering height. It has two inputs and one output. It turns ON or turns OFF the HBP or Wing Jet Pumps. Each Jet Transducer associated with a particular driving element. Once fuel goes down to the triggering height of jet transducer it turns ON the driving element. Once fuel within the other tank totally consumed then breaking Jet stops Jet Transducers working. Jet transducer is very complex element, forming its mathematical equation is very difficult. To model this element signal processing and Boolean used.



Jet Transducer Input and Output Ports

Following logic used for Jet Transducer modeling.

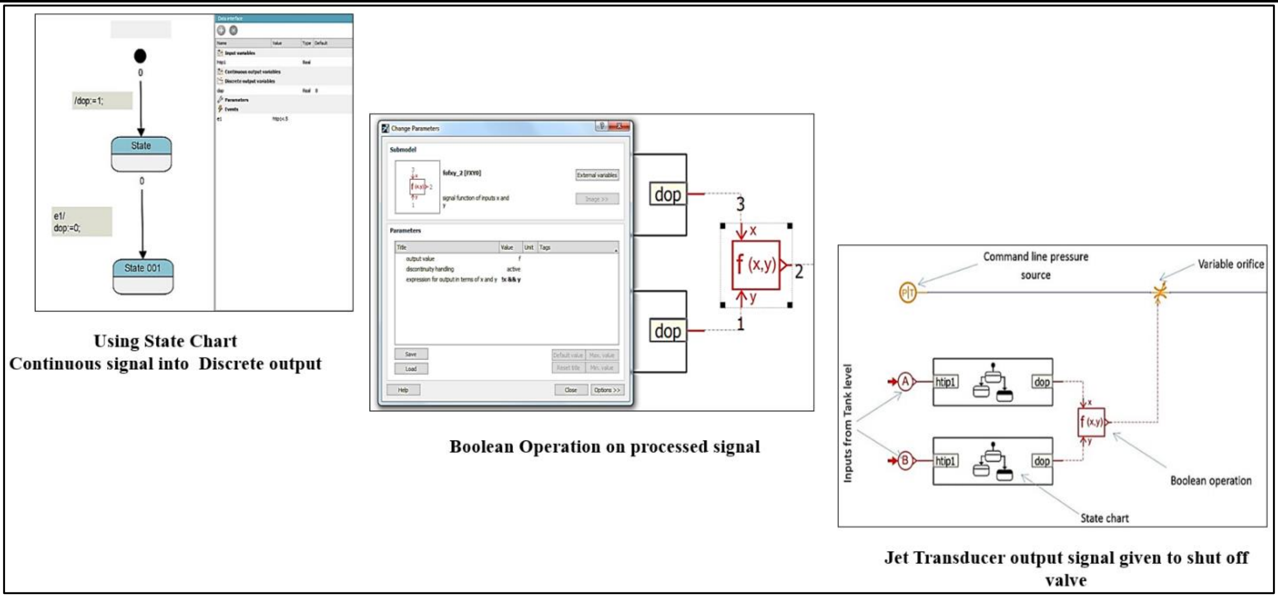
Condition Possible	Tank where Jet Transducer is located	Tank from where fuel is to be Transferred	Expected Output from the Jet Transducer
1	Tank full (Above level)	Tank full	Null
2	Tank full (Above level)	Tank empty	Null
3	Tank empty (Below level)	Tank full	On
4	Tank empty (Below level)	Tank empty	Null

Expected logical output can be received by using Boolean operation.

Above the Level	**1**
Below the Level	**0**

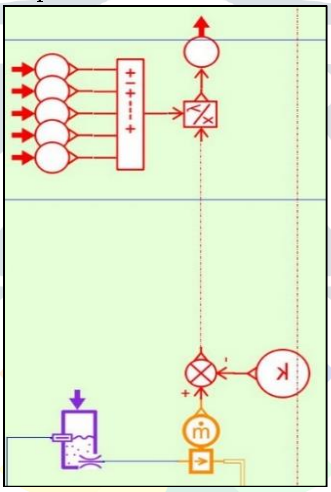
Event 1 (E1)	**Event 2 (E2)**	**Output Expected**	**Negation E1**	**E2**	**$\bar{E}$1 && E2**
1	**1**	**0**	**0**	**1**	**0**
1	**0**	**0**	**0**	**0**	**0**
0	**1**	**1**	**1**	**1**	**1**
0	**0**	**0**	**1**	**0**	**0**

Considering above requirement continuous signal is to be first converted into the discrete signal and then fed to the Boolean operator bock performs **E1 && E2** operation. Output of this bock given to the shut off valve which either turns ON or Turns OFF the fuel HBP or Jet Pump.



Jet Transducer Modeling Steps

Pressurized fuel is distributed evenly among the active elements which drives fuel, to achieve this fuel distribution unit is prepared. This unit checks active elements present at particular instant and then distribute tapped fuel among them equally.



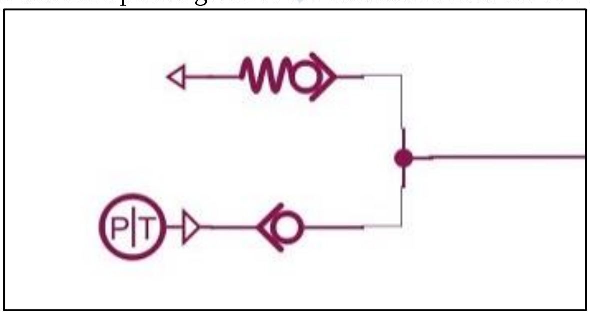
Fuel distribution unit

Flow rate signal from supply is subtracted by a fixed value which represents net fuel supply to the engine. The output signal represents tapped fuel from the supply line. This signal is given to the division block. Using transmitter and receiver from signal library active element discrete outputs are summed at summing block and given to the same division block. At division block tapped fuel signal gets divided into the number of active elements. The output of this division block transmitted to pressurization unit of each driving elements.

There are five fuel driving elements present within fuel system. During consumption for a particular sequence number of active element varies. Tapped fuel from the supply line is equally distributed among these active elements.

Vent Port

In the aircraft tank pressurization and venting both processes carried out by the same line. This is a three port valve has pressure source at port one, Vent at second port and third port is given to the centralised network of vent and pressurization.



Vent Port Modeled Within AMESim

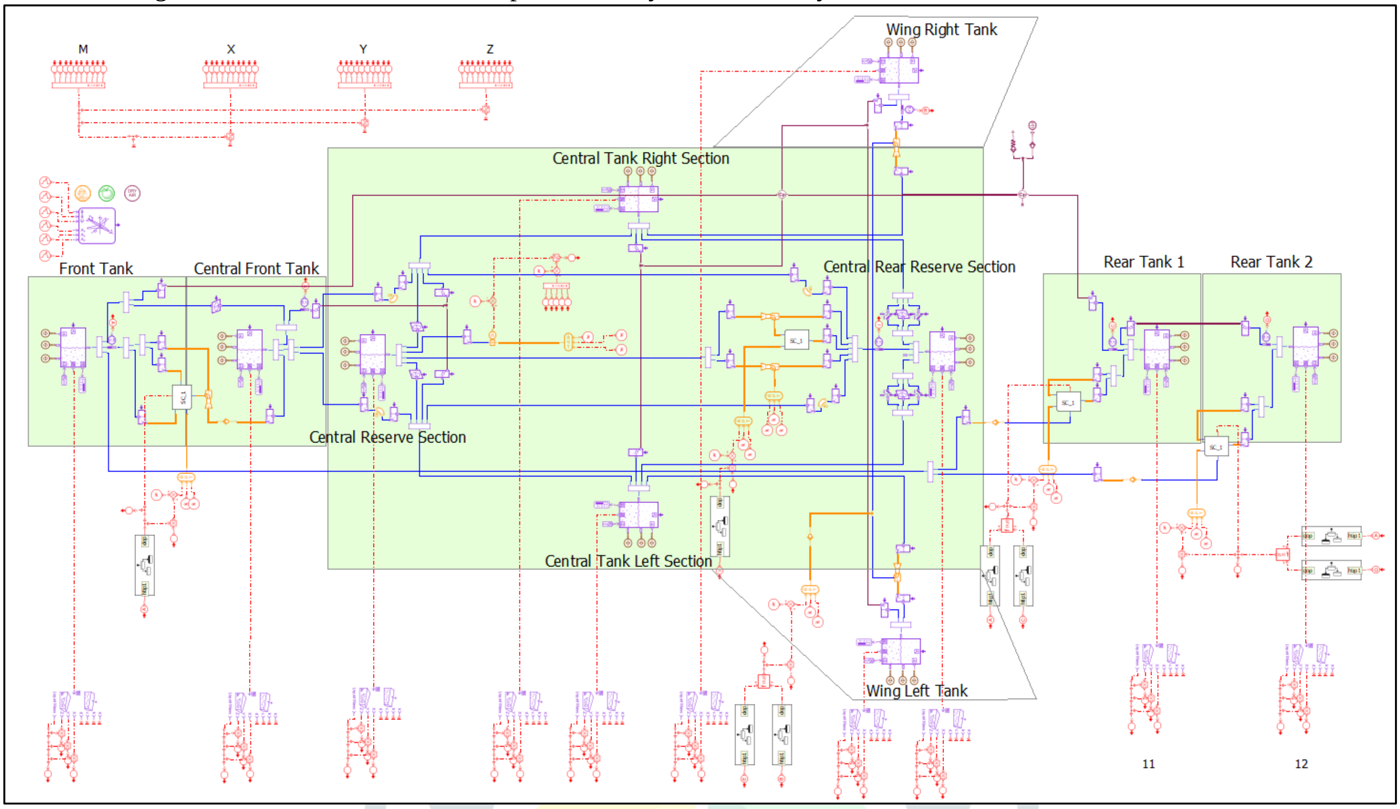
To model this port pressure source is used which pressurizes the line, to maintain this pressure within the line exit port has spring operated non return valve set for particular cracking pressure which is to be maintained within tanks. This spring operated valve opens to the atmosphere, as pressure within tanks increases this valve opens and trapped air escaped to the atmosphere, this situation occurs during refueling. During consumption accumulation fuel within a tank might occurs, which compresses trapped air results in pressure rise into the tank. Otherwise there is no reason for rising pressure within tank.

VI. APPROACH OF MODELING

After modeling these two elements layout is formed within AMESim. Modeling starts with Central tank as it receives fuel from all tanks. Then individual tanks Front tank, Rear tank one, Rear Tank two are attached and at the end wing tanks are attached. In other approach of modeling of system pressurization of within individual tank creates problems like discontinuity. To avoid these discontinuity individual vent are provided for each tank, in final modification all tank vents are connected to each other using pneumatic vent line. After setting all parameters of each element, integration of sub systems and placing of different units at their place system is simulated in simulation mode.

During simulation if the system simulation fails can be troubleshoot using performance analyser. In this tab number of variables handled during simulations are shown. If there is problem with any one of the component then variables required for that elements rises drastically. If for a particular element cumulative contribution of variables handling graph becomes stiff suddenly then it represents a problem associated with it.

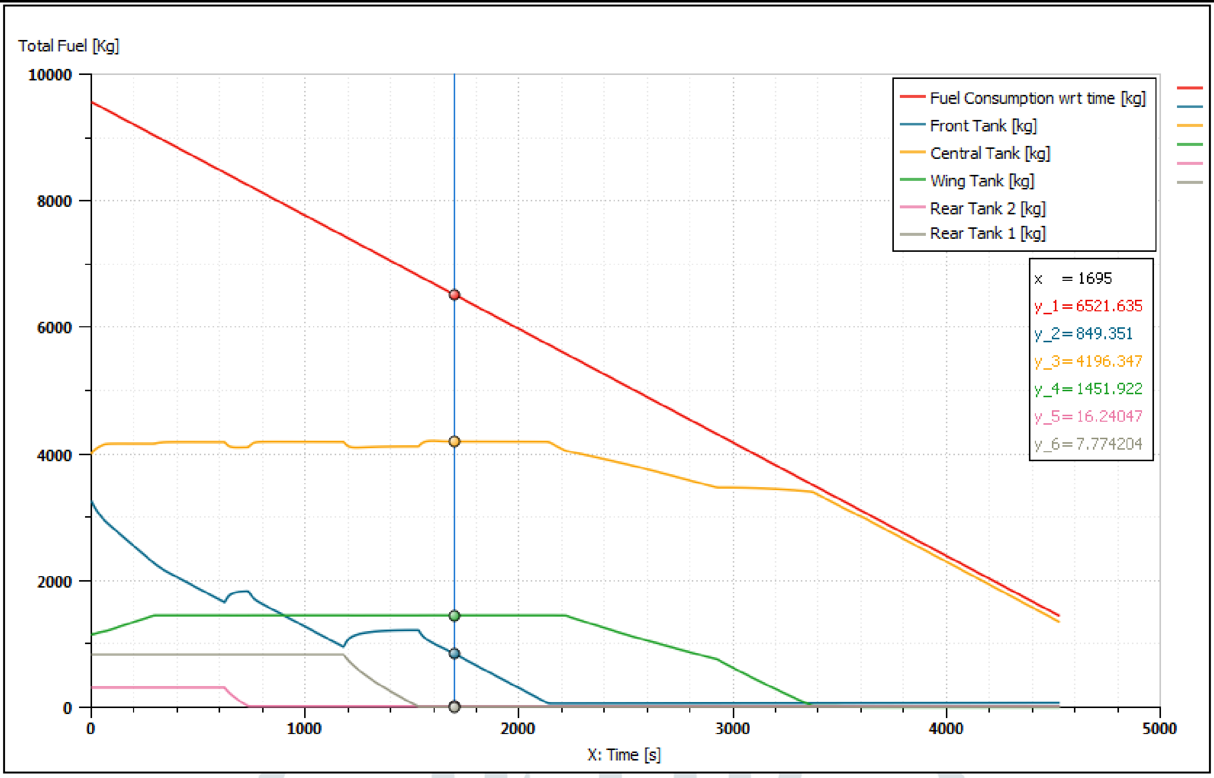
Following figure shows layout of the system modelled within AMESim. It includes centralized Vent and Pressurization line, super component of HBP created in order to reduce complexity of layout, Jet Transducers located at their places, interconnecting links between tanks and interdependent subsystems of fuel system.



Layout of actual system modeled within AMESim

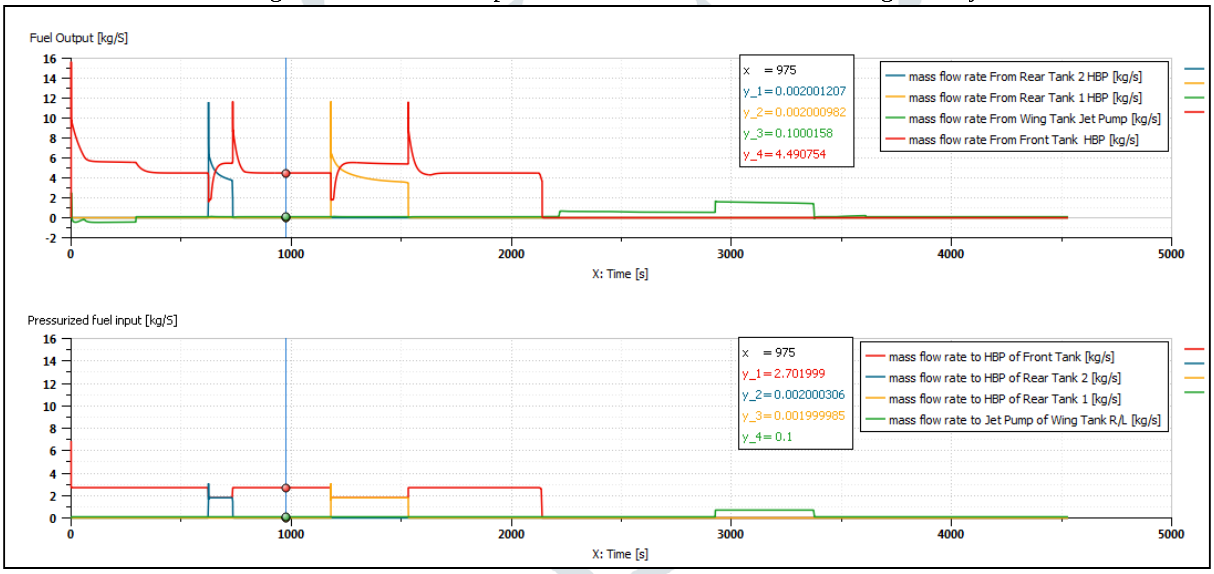
VII. RESULT

At the end of simulation volume of fuel present in each tank is plotted with respect to time, the red line shows total fuel volume left within whole fuel system at particular instant. The slope of this line represents flow rate given to the engines. In the following result it is a straight line because there is constant fuel supply given to the engine.



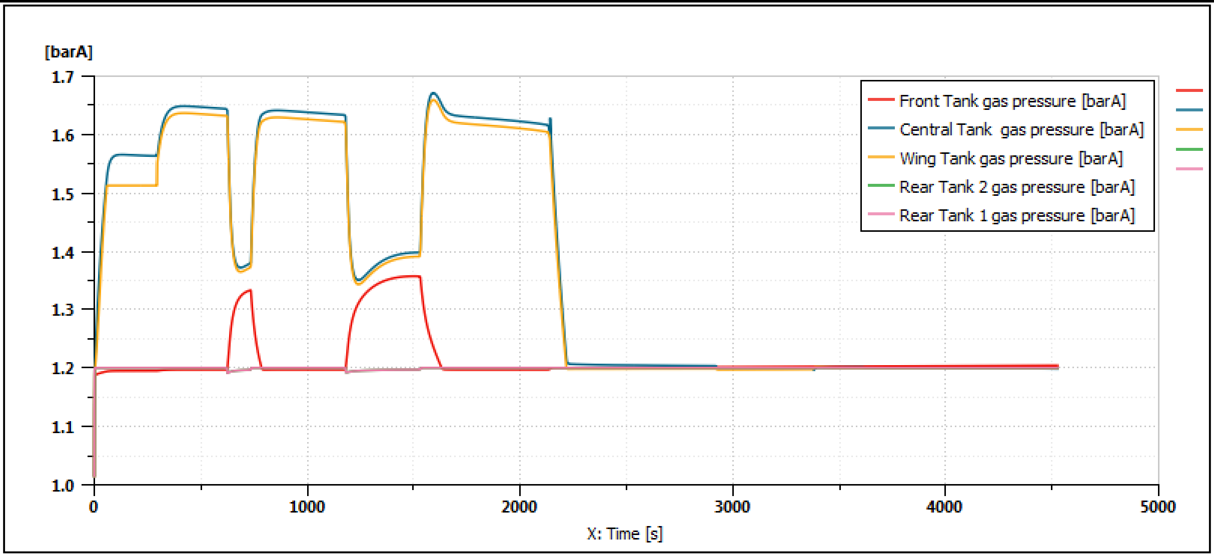
Total Fuel Consumption from Fuel System and Individual Tank

Following plot shows pressurized fuel signaling to the driving elements and output from the driving elements with respect to time. Due to sudden actuation of driving elements there is a peak at initial, afterwards decreases gradually.



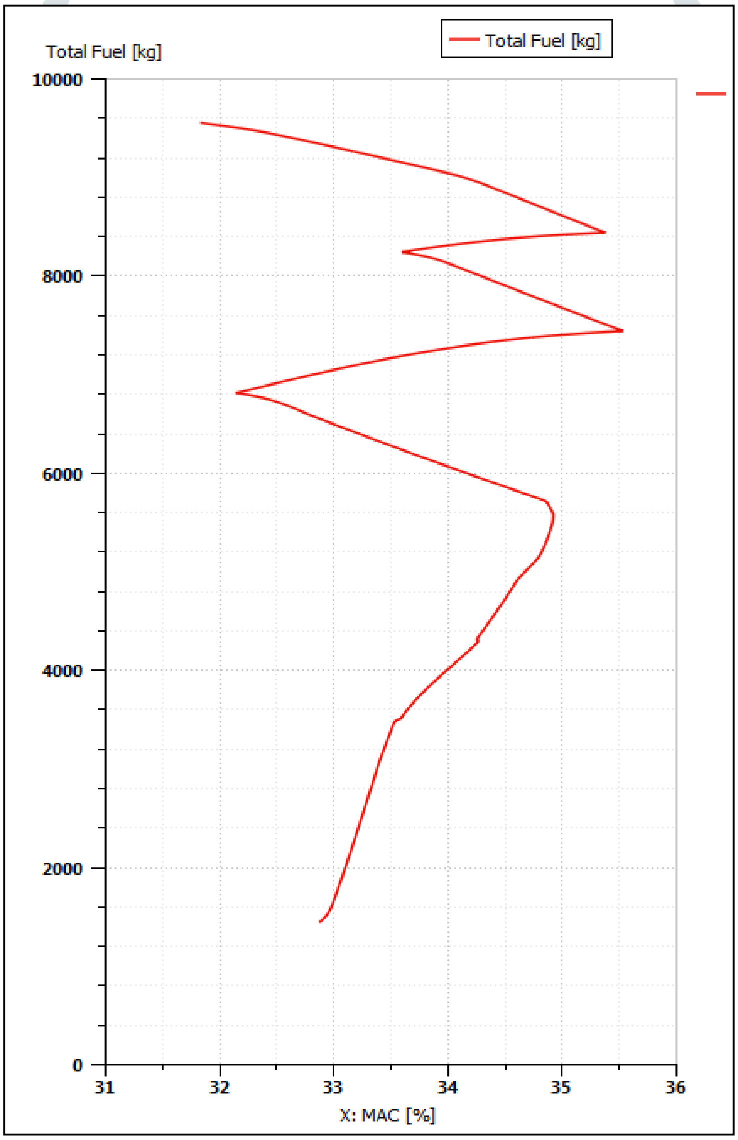
Pressurized Fuel Input Signal Flow Rate and Fuel Output Flow Rate

Following plot shows pressure variation within each tank with respect to time. Pressure increases due to accumulation of fuel within tank which compresses gas present above the fuel. Accumulation of fuel causes because of high flow rate of fuel driving elements present within fuel transfer lines. If pressure within tank increases above than that of cracking pressure then it relieves pressure to the atmosphere.



Pressure Variation within Different Tanks

Following plot represents %MAC Mean Aerodynamic Chord Variation with respect to Fuel Consumption. MAC variation occurs because of variation of Centre of Gravity.



Fuel Consumption Vs %MAC Variation

VIII. CONCLUSION

a. AMESim model of fuel system prepared replicates the actual system behaviour.

b. Pressure variation in each tank can be seen varying, this is because of accumulation of fuel within tank. Centralized vent and Pressurization system maintains overall pressure same in all tanks.

c. At the end of simulation large fuel remains within the all tanks of aircraft, to collect this fuel in the aircraft scavenging system is available. In the simulated environment scavenging system is not implemented. This problem of software further limits use of sortie conditions (Pitch Movement of Aircraft).

d. Complete model developed within AMESim allows easy changes in the system model, addition or removal of component, checking behaviour of system at extreme conditions. Warning appears during simulation if the pressure or temperature goes down or goes up by threshold value which is not expected.

e. The fuel system modeled within AMESim software can be used during troubleshooting for easy localization of fault.

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