TEST AND VALIDATION OF PRESSURE FED ROCKET ENGINE TEST STANDS FEEDLINE SYSTEMS

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ABSTRACT:

Pressure fed rocket engine test stands have an important role for developing liquid fuel rocket engines (LRE). The major parts of a test stand are the propellant feedlines. They are responsible for delivering required amount of fuel to the rocket engine at desired pressure level. Feedlines consist of propellant tanks, valves, filters, flowmeters, orifices, pressure and temperature sensors. In this work, two pressure fed liquid rocket engine test stands' feedlines were modelled with Ecosimpro. Ecosimpro model has been validated with the experiments conducted using water. As a result, Ecosimpro simulations show good agreement with the test results. Created Ecosimpro model can be utilized to design and characterize new feedlines for future test stands.

1. INTRODUCTION

One of the most important rocket propulsion systems is liquid propellant propulsion system. Liquid propulsion systems have rocket engine that use oxidizer and fuel are liquid form and they produce thrust with transforming chemical energy of the propellants to kinetic energy. Unlike the other propulsion system types, liquid propulsion systems have subsystems like feedlines, pumps and pressurization tanks etc. that ensure rocket engine is fed with oxidizer and fuel at right condition.

Rocket engine static firing tests have great importance at developing phase of a rocket engine. Therefore, liquid propellant rocket engine test stands are designed and set. Test stands are formed from the combination of propellant tanks, pressurization systems and propellant feedline systems, which have mission of feeding the rocket engine with desired amount of propellants at specific pressure and temperature. Feedlines consist of propellant tanks, valves, filters, flowmeters, orifices, pressure and temperature sensors. The behavior of selected equipment for use in test stands should be known before the installation stage. For this reason, 1-D analysis programs like EcosimPro are used to simulate the propellant feedlines. EcosimPro is a validated worldwide used 1D analysis program. It has different libraries for different subjects. One of these libraries called Fluidapro is used for flow and rocket engine performance analysis.

In this work, feedlines of two different rocket engine test stands were modelled with EcosimPro. Models have been validated with experiments that used water as a working fluid. Generated EcosimPro model can be used for future test stand designs.

2. TEST SETUPS AND TESTS

Two different test stands for rocket engines that have different thrust levels, is designed and used in order to validate rocket engines at atmospheric conditions. They basically consist of subsystems like propellant filling system, pressurization system, data acquisition system and propellant feedline system. Among these subsystems, only propellant feedline system is modelled and simulated.

The first test stand called as TS1. Oxidizer and fuel feedlines of TS1 are simulated at the same EcosimPro model. 20 litres' propellant tanks are chosen for long test times. On fuel feedline, turbine type flowmeter is placed to get flowrate data. On the other hand, oxidizer side don't have any flowmeter because of compatibility issues. Common equipment for both feedlines are pneumatic actuated ball valves, orifices to eliminate the water-hammer pressure peaks, filters and cavitating venturis to ensure the flowrates are stable along the tests. In addition to these, there are several pressure sensors to measure the feedline pressure at different locations. P&ID of the TS1 is shown in Figure.1.

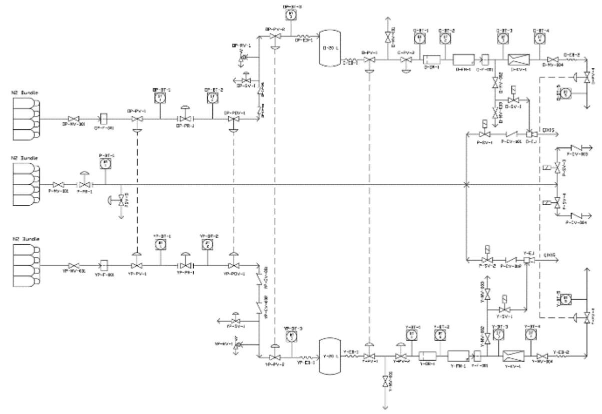

Figure 1 TS1 P&ID

The second test stand called as TS2. There are several difference between TS2 and TS1. The main difference is the feedline diameter due to required mass flow rates are higher for TS2. While 1/2" outside diameter piping is being used for TS1 feedlines, 1 1/2" outside diameter for TS2 feedlines. TS2's oxidizer and fuel feedlines have Coriolis flowmeter. P&ID of the TS2 is shown in Figure.2.

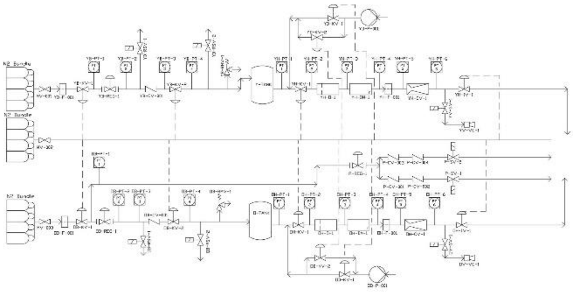

Figure 2. P&ID of TS2

Every feedline has unique cavitating venturi that provides different mass flow rates at specific inlet pressure. To validate the test setups before static firing tests, tests are conducted with water with equivalent mass flow rates. As a result of water tests, pressure of propellant tanks is determined.

3. ECOSIMPRO MODELS

Ecosimpro 1D models of test setups were prepared with Fluidapro library. There are lots of available flow components in Fluidapro. Feedline equipment as pipes, flexible hoses, orifices, valves and filters were modelled with available components in FLUIDAPRO library. Other equipment like turbine and coriolis flowmeters, needle valves and cavitating venturis (CVs) were simulated with combinations of different components in the library. For example, cavitating venturis (CVs) were simulated with four pipes that have constant, converging and diverging flow area. Details of feedline Ecosimpro models are shared below.

Working fluid definition is made with checkvalve component. It allows to define both hydraulic side and pneumatic side fluid. In this case, they are water and Nitrogen respectively.

Tank2Temp_2 component is used from the library. It is two port (top and bottom) tank component which can store two different fluids, water and Nitrogen. Parameters such as tank height, wetted perimeter, material, wall thickness, initial liquid and gas volumes are defined in the model.

Flexible Hoses are used at the exit of the propellant tanks and upstream of the thruster valve to make accurate loadcell measurements. They are modelled with pipe component that have friction coefficient multiplier to simulate additional pressure drop due to its inner corrugated form. Friction factor multiplier is determined as 4.5 from the water test results.

There are two types of flowmeters in the test setups. TS1 fuel line has a turbine type flowmeter and TS2 both feedlines have Coriolis type flowmeters. It is nonfunctional equipment in the simulation. The only reason modelling them is their pressure drops. To simulate the flowmeter pressure drop, junction component is used as orifice. Diameter of orifices are determined from water tests.

Valve components are used from the Fluidapro library. Derived flow areas from orifice diameters of valves of feedlines are used as an input parameter to the model component.

Fluidapro's filter component is used to model the filter. Input parameters of the model component is obtained from datasheets of the test setups' filters. The input parameters are reference liquid, pressure, temperature and respective pressure drop.

Cavitating venturis supply constant mass flow rate at a constant inlet pressure to the rocket engine. They are commonly used in static firing test setups and eliminate the oscillations based on combustion. The mass flow rate depends on inlet pressure, venturi throat diameter, density and vapour pressure of the liquid. General venturi geometry is given in Figure .3.

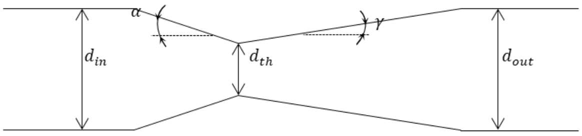

Figure 3. Cavitating venturi geometry

Since Fluidapro library does not have any cavitating venturi component, venturi model has been created with pipe component. Every part of cavitating venturi whose flow areas constant, converging and diverging shape were modeled with pipes separately. Developed four piped venturi model is shown in Figure 4.

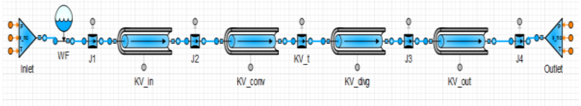

Figure 4. Four piped venturi model

In Ecosimpro models, only propellant feedlines were modelled. Therefore, propellant tanks inlet pressure values defined as boundary condition from tests. Both oxidizer and fuel feedline are simulated at same Ecosimpro model for TS1 test setup. Unlike the TS1 model, two separate Ecosimpro model were created for each feeline. Developed Ecosimpro model schemes are shown in Figure 5., 6 and 7.

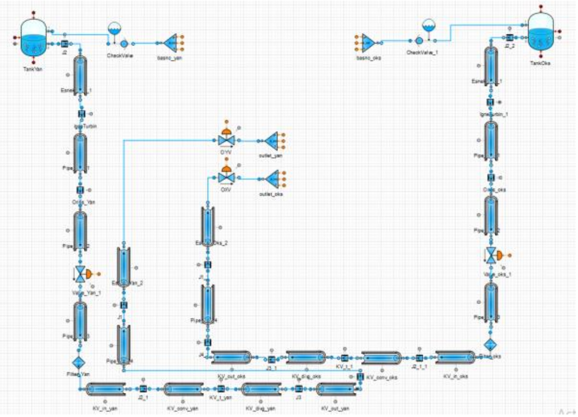

Figure 5. TS1 Ecosimpro model

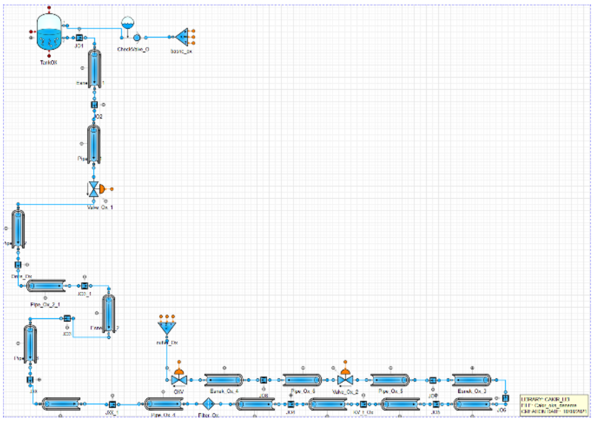

Figure 6. TS2 oxidizer feedline Ecosimpro model

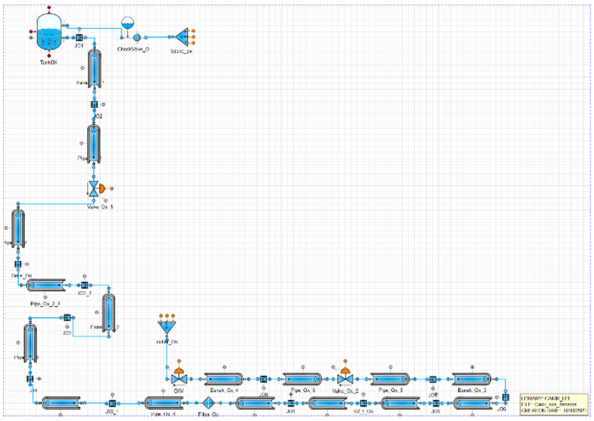

Figure 7. TS2 fuel feedline Ecosimpro model

4. RESULTS

First of all, cavitating venturi performances were determined by comparing inlet pressure and mass flow rate values for different outlet pressures. Thus, the effect of outlet pressure to the cavitation and mass flow rate could be observed. After the point that cavitation is lost, mass flow rate becomes lower. Ecosimpro cavitating venturi model results of TS1's oxidizer and fuel feedline are given in Fig. 8 and Fig. 9. Analyses have been made at constant cavitating venturi inlet pressures 26.40 barA and 24.66 barA for oxidizer and fuel feedline respectively.

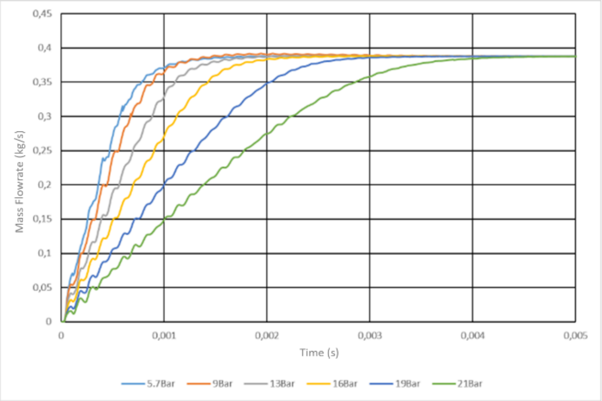

Figure 8. TS1 oxidizer feedline cavitating venturi mass flowrates at different outlet pressures

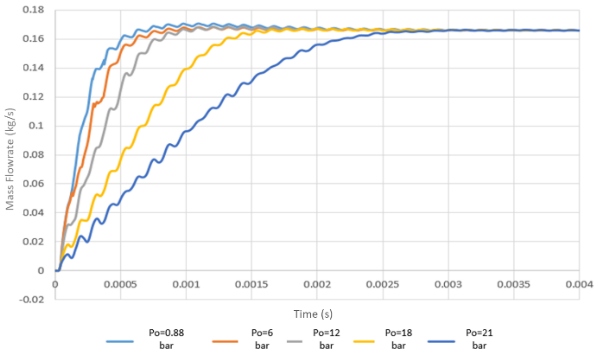

Figure 9. TS1 fuel feedline cavitating venturi mass flowrates at different outlet pressures

TS2's cavitating venturi model results are given in Fig. 10 and Fig. 11 for oxidizer and fuel side respectively. A detailed comparison of Ecosimpro model results is shown in Table 1.

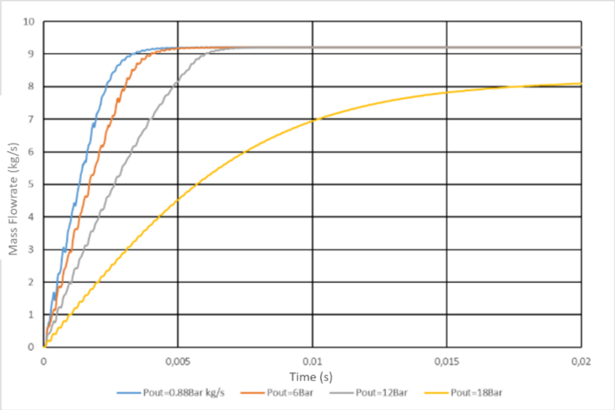

Figure 10. TS2 oxidizer feedline cavitating venturi mass flowrates at different outlet pressures

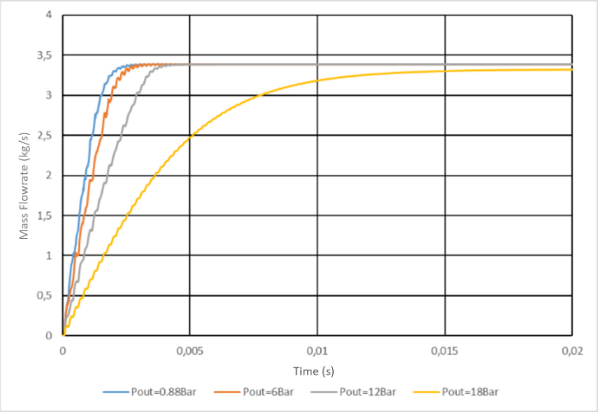

Figure 11. TS2 fuel feedline cavitating venturi mass flowrates at different outlet pressures

Table 1. Cavitating venturi model mass flow rates comparison

C. Venturi	***Experimental Mass Flowrate (kg/s)***	***Ecosimpro Model (kg/s)***	***% Error***
TS1 Ox	*0.368*	*0.360*	*2.17*
TS1 Fuel	*0.144*	*0.152*	*5.55*
TS2 Ox	*8.9*	*9.2*	*3.37*
TS2 Fuel	*3.45*	*3.38*	*2.02*

After the cavitating venturi model was set, the Ecosimpro model is given in Fig.5 was simulated. The comparison of Ecosimpo TS1 simulation result and water tests are given below.

Table 2. Results of TS1 Ecosimpro Model and Experiments

Parameter	*Ox Feedline Experimental*	*Ox Feedline Simulation*	*% Error*	*Fuel Feedline Experimental*	*Fuel Feedline Simulation*	*% Error*
Tank Pressure (BarA)	*31.49*	*31.52*	*0.09*	*31.90*	*31.93*	*0.09*
Orifice Inlet Pressure (BarA)	*30.94*	*30.87*	*0.23*	*25.94*	*26.16*	*0.85*
Orifice Outlet Pressure (BarA)	*30.38*	*30.05*	*1.08*	*25.85*	*26.03*	*0.70*
CV Inlet Pressure (BarA)	*26.40*	*26.48*	*0.30*	*24.66*	*24.53*	*0.53*
CV Outlet Pressure (BarA)	*5.77*	*5.70*	*1.21*	*4.15*	*4.12*	*0.72*
Mass Flowrate (g/s)	*368.9*	*359.8*	*2.17*	*144*	*152*	*5.55*

Pressure values at different locations both Ecosimpro simulation and experiments are quite similar to each other. The maximum error percentage at pressure values is 1.21%. Reason of this difference can be explained by neglecting tee connections of sensors at Ecosimpro model. On the other hand, mass flow rate differences are 2.17% and 5.55% for oxidizer and fuel feedlines, respectively. Graphs of TS1 feedlines pressures at specific locations are given in Fig.12 and Fig.13.

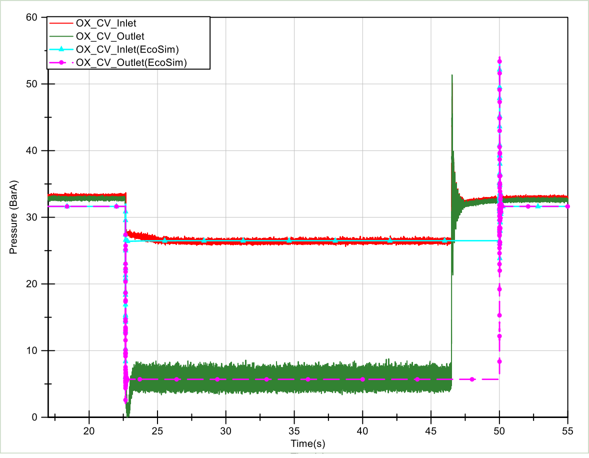

Figure 12. TS1 oxidizer pressure comparison

Results of TS2's feedline simulations also match with each other. It is given in Table 3. The maximum error percentage at pressure values is 3.05%. Except this value, other error percentages are below 1.20%. Reason of this difference can be explained by neglecting tee sensor connections at Ecosimpro model. On the other hand, mass flow rate differences are 3.37% and 2.02% for oxidizer and fuel feedlines, respectively. Graphs of TS2 feedlines mass flowrates comparisons are given in Fig.14 and Fig.15.

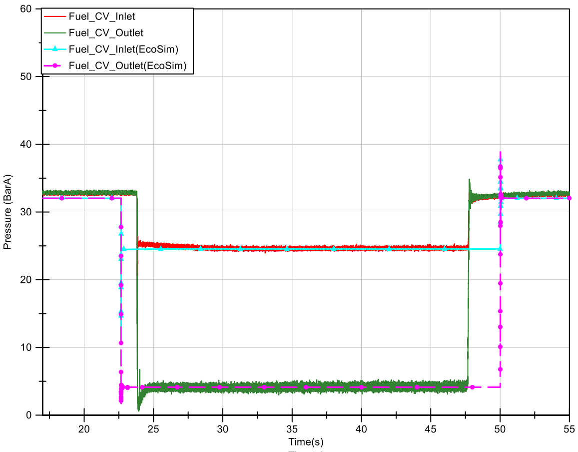

Figure 13. TS1 oxidizer pressure comparison

Table 3. Results of TS2 Ecosimpro Model and Experiments

Parameter	*Ox Feedline Experimental*	*Ox Feedline Simulation*	*% Error*	*Fuel Feedline Experimental*	*Fuel Feedline Simulation*	*% Error*
Tank Pressure (BarA)	*30.98*	*31.08*	*0.32*	*27.36*	*27.35*	*0.04*
Orifice Inlet Pressure (BarA)	*30.98*	*31.08*	*0.32*	*26.92*	*27.16*	*0.89*
Orifice Outlet Pressure (BarA)	*28.94*	*28.79*	*0.52*	*26.71*	*26.81*	*0.37*
CV Inlet Pressure (BarA)	*23.96*	*23.77*	*0.79*	*25.94*	*25.95*	*0.04*
CV Outlet Pressure (BarA)	*4.91*	*4.76*	*3.05*	*8.33*	*8.23*	*1.20*
Mass Flowrate (kg/s)	*8.91*	*9.20*	*3.37*	*3.45*	*3.38*	*2.02*

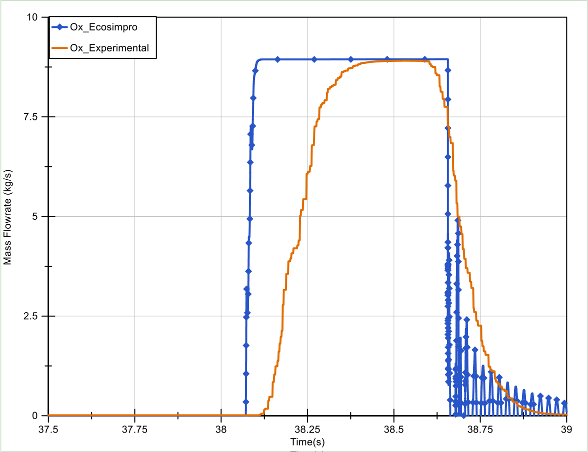

Figure 14. TS2 oxidizer feedline mass flowrate comparison

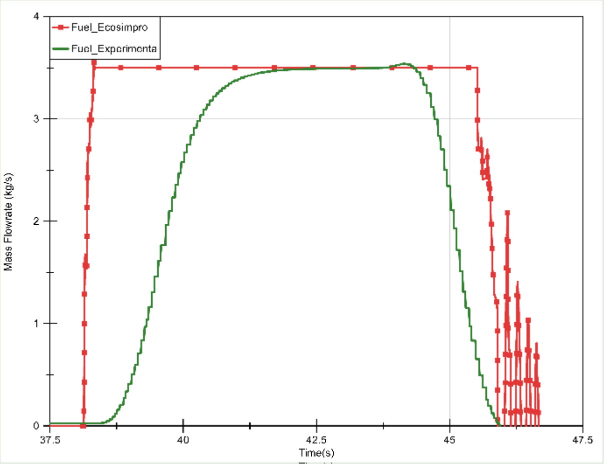

Figure 15. TS2 fuel feedline mass flowrate comparison

5. CONCLUSION

In conclusion, developed Ecosimpro simulation results have good agreement with test results. Maximum error percentages are below 3% for the pressure values. Although the mass flowrate values are also similar to the test results, it can be improved for further studies.

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