Modeling Fluid Transient Phenomena in LRE Feedlines

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Fluid Transient Test Facility M3.5 at DLR for investigation of water hammer and priming in LRE feedline. Test fluids are water, ethanol, LN2 and LOx

Water Hammer

A Liquid Rocket Engine (LRE) is a complex pipe network in which each propellant must be delivered from the tank to the combustion chamber. Along its path, the fluid is conditioned by means of pumps, filters and several different valves. As in any fluid system, one of the most important fluid transient phenomenon to be taken into account is the water hammer [1]. It occurs upon a sudden change in flow velocity, induced e.g. by valve closing or pump trip. The prediction of the pressure peak and wave shape is a fundamental task for the safe design of the feedline subsystem. The pressure increase ΔP due to a change in flow velocity ΔV is given by the Joukowsky's equation (1), while the frequency *f* of the wave is derived from the acoustic of an open-closed pipe (2):

$$\Delta P = \rho c \Delta V \qquad (1)$$

$$f = \frac{c}{4L} \qquad (2)$$

where ρ is the fluid density, *c* is the speed of sound in the liquid and L is the distance tank-valve.

In LRE, the water hammer is of critical importance on the LOx side, due to its high values of density and speed of sound. Moreover, in case of cavitation, GOx will form, representing an ignition hazard as it can burn with the pipe wall when adiabatically compressed.

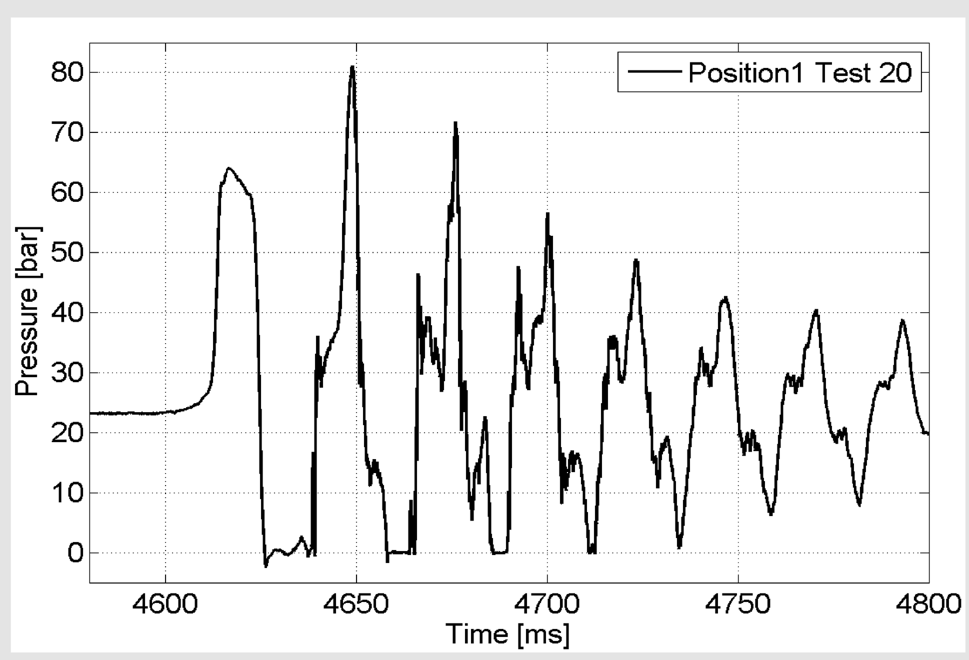
Modeling and Testing

Today, the design of the propulsion system includes the use of numerical tools. This necessitates validation as the models are simplifications of the complex physics at work. Testing of subsystems is therefore necessary to provide the data needed for the validation of these numerical tools.

At DLR a new test bench was built to investigate fluid transient phenomena in LRE mock-up feedlines. Test data are used to validate numerical simulations performed with EcosimPro/ESPSS, a ESA-developed tool for propulsion system design.

Vaporous and gaseous cavitation

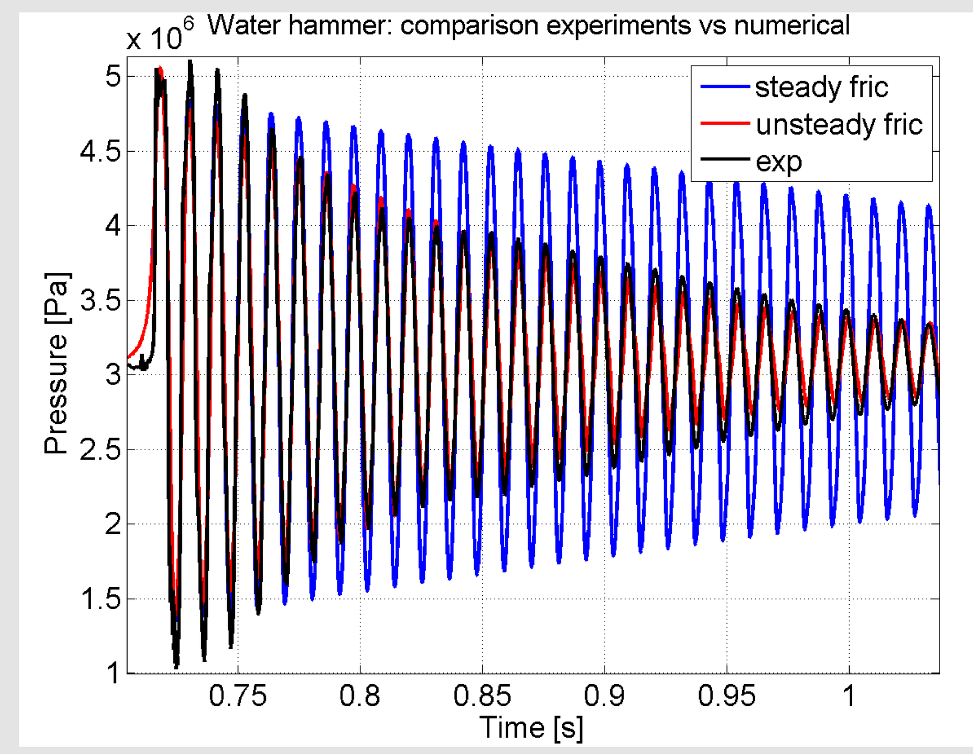
When the pressure drops below the saturation pressure of the liquid, cavitation occurs, with formation of vapour bubbles inside the liquid (vaporous cavitation).



If a dissolved gas is present (e.g. the pressurizing gas) this will desorb, a process known as gaseous cavitation. In this case, the flow is not only two-phase but also two-component. Modelling of such a complex flow is extremely difficult due to the lack of understanding of the physical behaviour. For example, the rate of desorption is not known and its value affects the final pressure value. Data from experiments aim to provide semi-empirical parameters to calibrate ad hoc submodels that will be implemented in the tool.

Unsteady friction

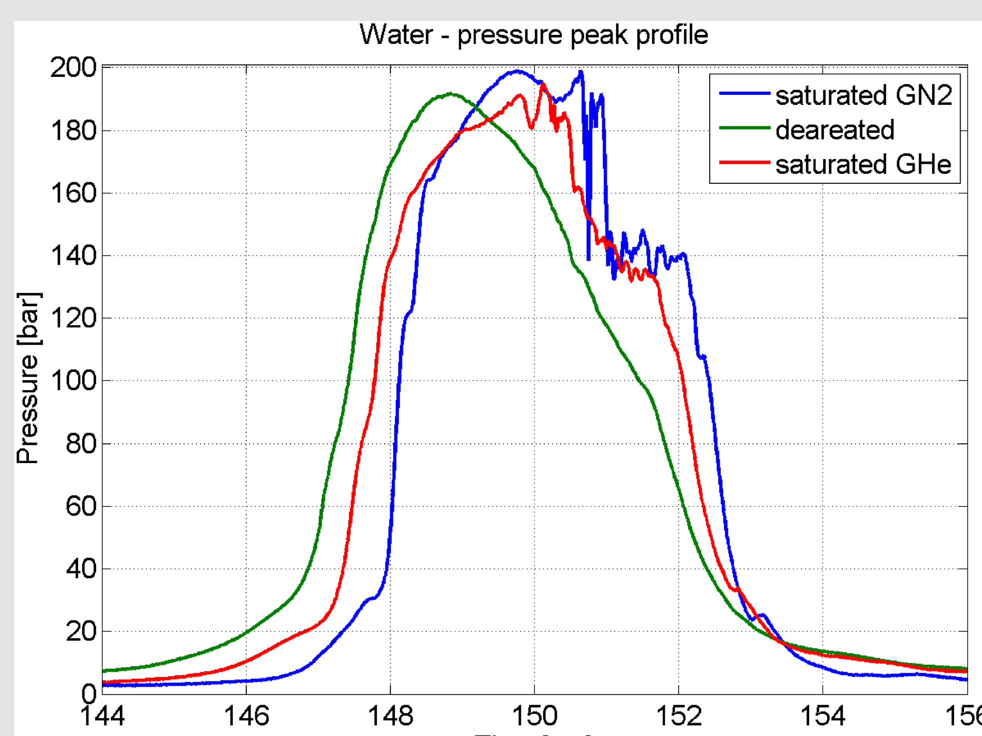
In transient conditions, the varying shear stress at the wall induces a greater friction. The wave is more damped and unsteady friction models need to be used



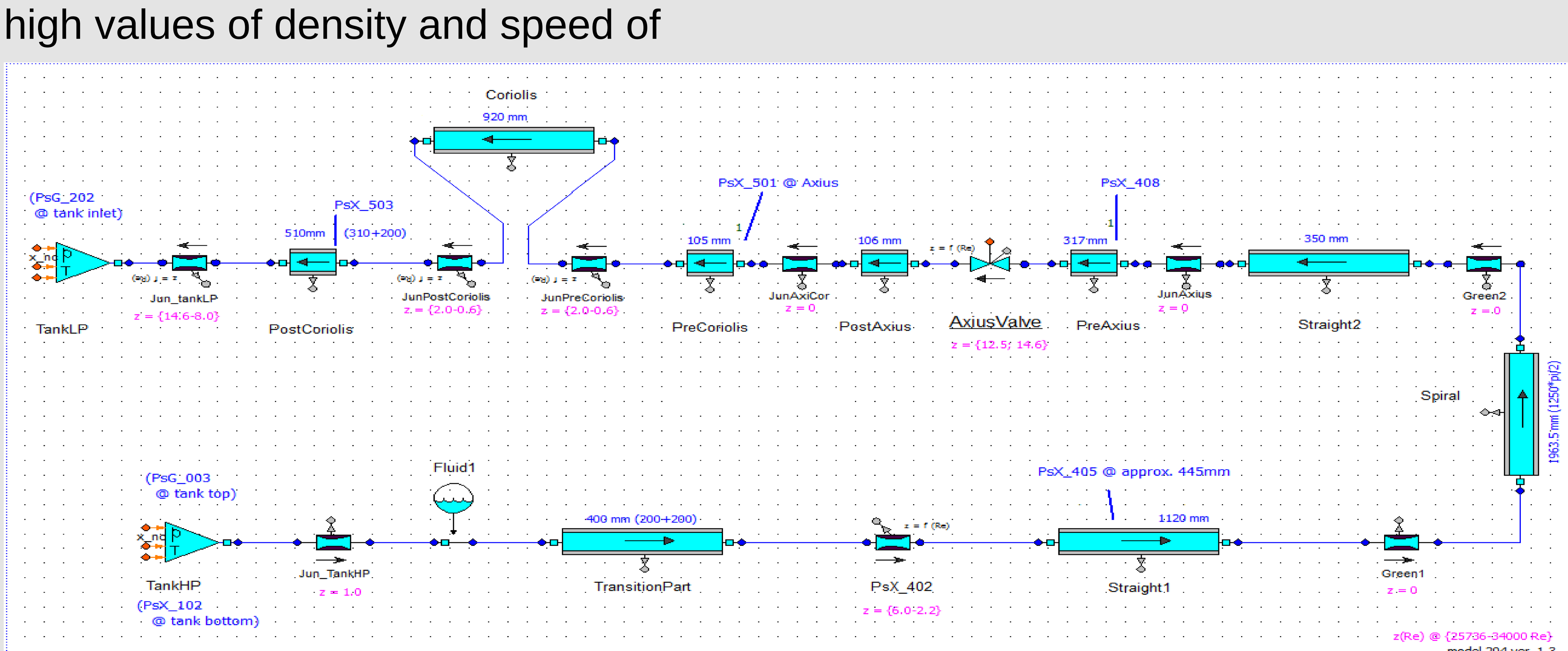
The most common model is Brunone's, where the unsteady friction depends on the convective and temporal derivative $(\frac{\partial V}{\partial x}, \frac{\partial V}{\partial t})$ of the velocity [2]. Again, experimental data are needed to calibrate empirical friction coefficient.

Priming

During the start-up of the propulsion system of a spacecraft, the filling of an evacuated pipeline, a process known as priming, can generate severe pressure peaks due to the slam (water hammer) of the propellant against a closed thruster valve.



In the case of priming, the desorption of the pressurizing gas from the propellant has an important effect on the wave characteristics [3]: pressure peak, frequency and wave attenuation are all affected by the released gas, as it changes the speed of sound and is cause of an additional cushion effect.



Numerical model of the test-bench with software EcosimPro®

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[2] Bergant, A., Simpson, A., and Vitkovsky, J., *Developments in Unsteady Pipe Flow Friction Modelling,*" J. Hydraul. Res., 2001, Vol.39, pp. 249–257.

[3] C.Bombardieri, T. Traudt, C.Manfletti, *Effect of the dissolved pressurizing gas on the pressure surge during the filling process of spacecraft feedlines*, 12th Pressure Surge Conference, Dublin, 18-20 Nov 2015