

Computational Analyses of Pressurization in Cryogenic Tanks

Vineet Ahuja¹, Ashvin Hosangadi², and Chun P. Lee³
Combustion Research and Flow Technology, Pipersville, PA 18947

and

Robert E. Field⁴ and Harry Ryan⁵
NASA Stennis Space Center, MS 39529, USA

A comprehensive numerical framework utilizing multi-element unstructured CFD and rigorous real fluid property routines has been developed to carry out analyses of propellant tank and delivery systems at NASA SSC. Traditionally CFD modeling of pressurization and mixing in cryogenic tanks has been difficult primarily because the fluids in the tank co-exist in different sub-critical and supercritical states with largely varying properties that have to be accurately accounted for in order to predict the correct mixing and phase change between the ullage and the propellant. For example, during tank pressurization under some circumstances, rapid mixing of relatively warm pressurant gas with cryogenic propellant can lead to rapid densification of the gas and loss of pressure in the tank. This phenomenon can cause serious problems during testing because of the resulting decrease in propellant flow rate. With proper physical models implemented, CFD can model the coupling between the propellant and pressurant including heat transfer and phase change effects and accurately capture the complex physics in the evolving flowfields. This holds the promise of allowing the specification of operational conditions and procedures that could minimize the undesirable mixing and heat transfer inherent in propellant tank operation.

In our modeling framework, we incorporated two different approaches to real fluids modeling: (a) the first approach is based on the HBMS model developed by Hirschfelder, Beuler, McGee and Sutton and (b) the second approach is based on a cubic equation of state developed by Soave, Redlich and Kwong (SRK). Both approaches cover fluid properties and property variation spanning sub-critical gas and liquid states as well as the supercritical states. Both models were rigorously tested and properties for common fluids such as oxygen, nitrogen, hydrogen etc were compared against NIST data in both the sub-critical as well as supercritical regimes.

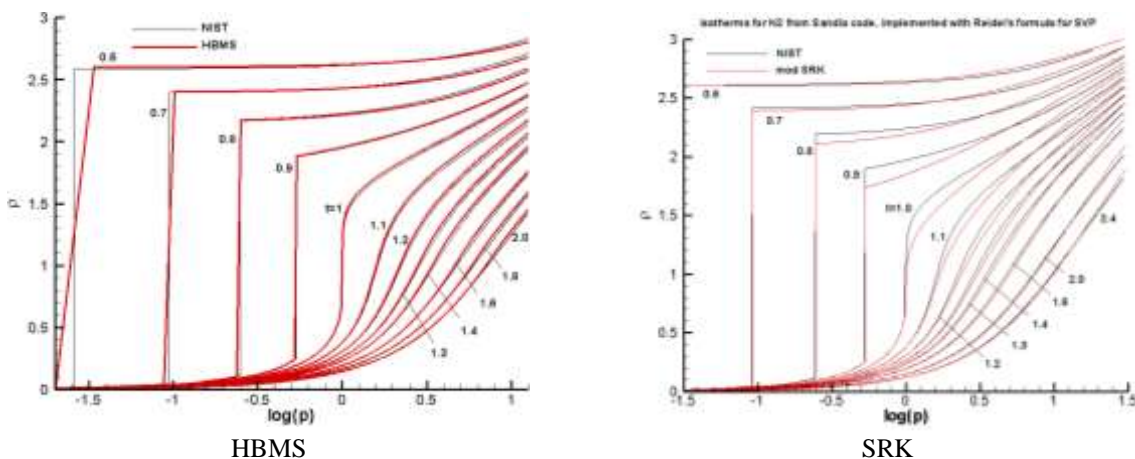


Figure 1. Comparisons of HBMS and SRK models for Real Fluids with NIST for oxygen in sub-critical and supercritical regimes. Temperature, pressure and density are normalized by critical quantities.

¹ Senior Research Scientist, 6210 Keller's Church Rd., and AIAA Senior Member.

² Principal Scientist, 6210 Keller's Church Rd., and AIAA Senior Member.

³ Research Scientist, 3313 Memorial Parkway South Suite 108, Huntsville, AL, 35801, and AIAA Member.

⁴ Aerospace Technologist, E&SD, Stennis Space Center, MS 39529-6000, and AIAA Member.

⁵ System Modeling and Analysis Group Lead, E&SD, Stennis Space Center, MS 39529-6000, and AIAA Member.

We show a typical pressurization simulation, utilizing the above-mentioned framework, of a spherical propellant tank, containing liquid oxygen with approximately 10% ullage comprising of gaseous oxygen. The LOX and ullage GOX are maintained at pre-pressurization levels for the beginning of the simulation of 325 psia. The ullage temperature is initialized to 135.16 K and the liquid temperature is maintained at 90.18 K for the start of the simulations. Supercritical GOX (as an approximation to nitrogen) is fed in through the inlet duct at 294 K and a pressure of 8702 psia. The sequence of plots in Figure 2 shows the variation in temperature in the tank. In particular, we see initial mixing between the supercritical flow through the inlet duct and the ullage gas in the tank leading to the formation of a very well-defined central vortex. Consequently, the ullage gas both pressurizes and heats up and in turn leads to heat transfer and phase change with the liquid in the tank. The penetration of the supercritical jet on the surface of the liquid distorts the gas liquid interface leading to the rise of liquid in the middle of the tank. Subsequently, the liquid front hits the central plate with further pressurization. The liquid also starts rising along the walls of the tank as the temperature and the vapor pressure are lower along the walls than in the middle of the tank where the supercritical jet has mixed out with the ullage.

The density contours in Figure 3 clearly show the phase change processes and distortion of the gas liquid interface from the heat and mass transfer between the gas/liquid/supercritical flow. In this simulation the tank pressure changed from 325 psia to 7140 psia in 0.0632 seconds. In the final paper we will compare the pressurization profiles with lower fidelity system level codes.

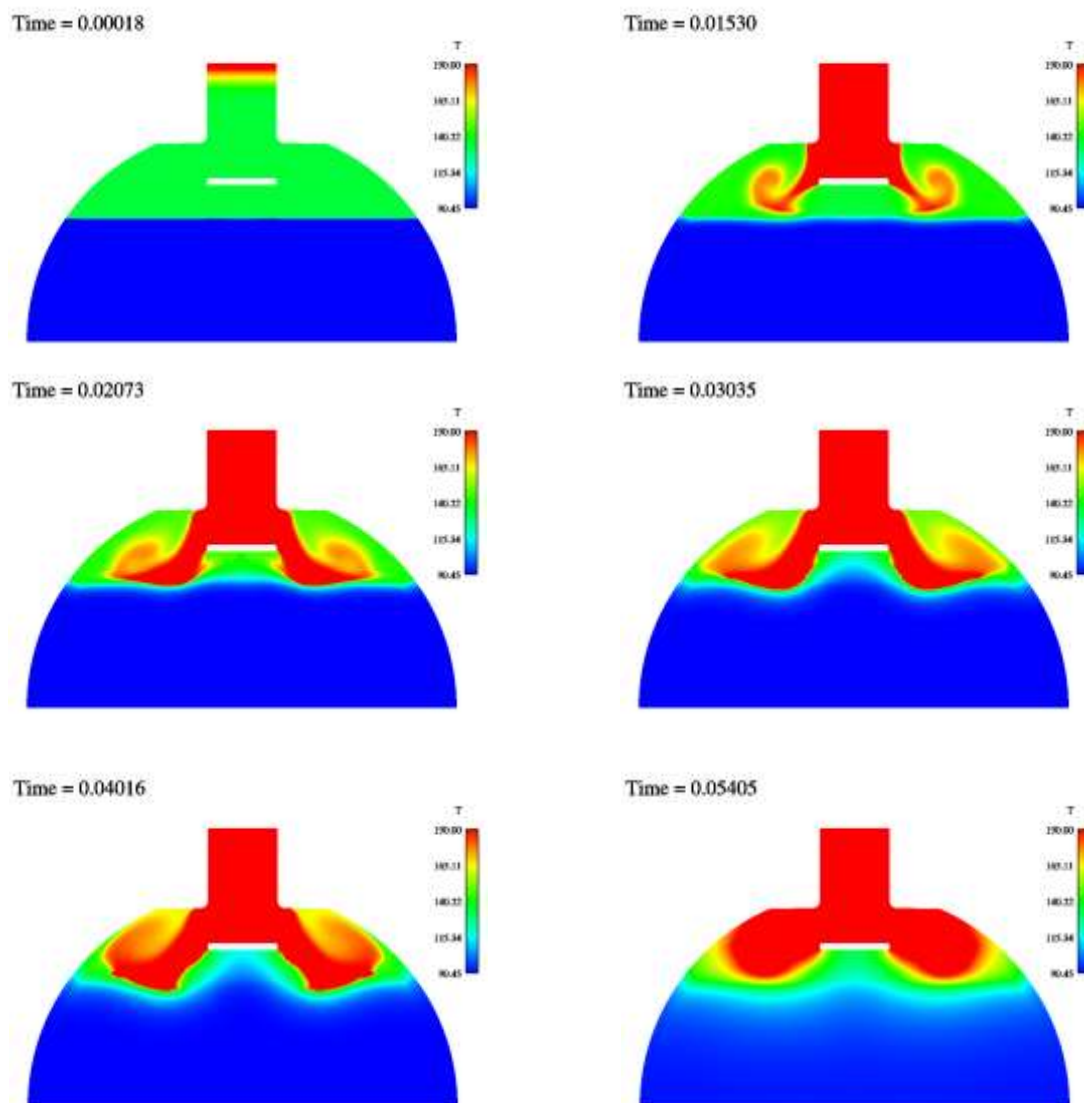


Figure 2. Variation of Temperature in the Tank during Pressurization.

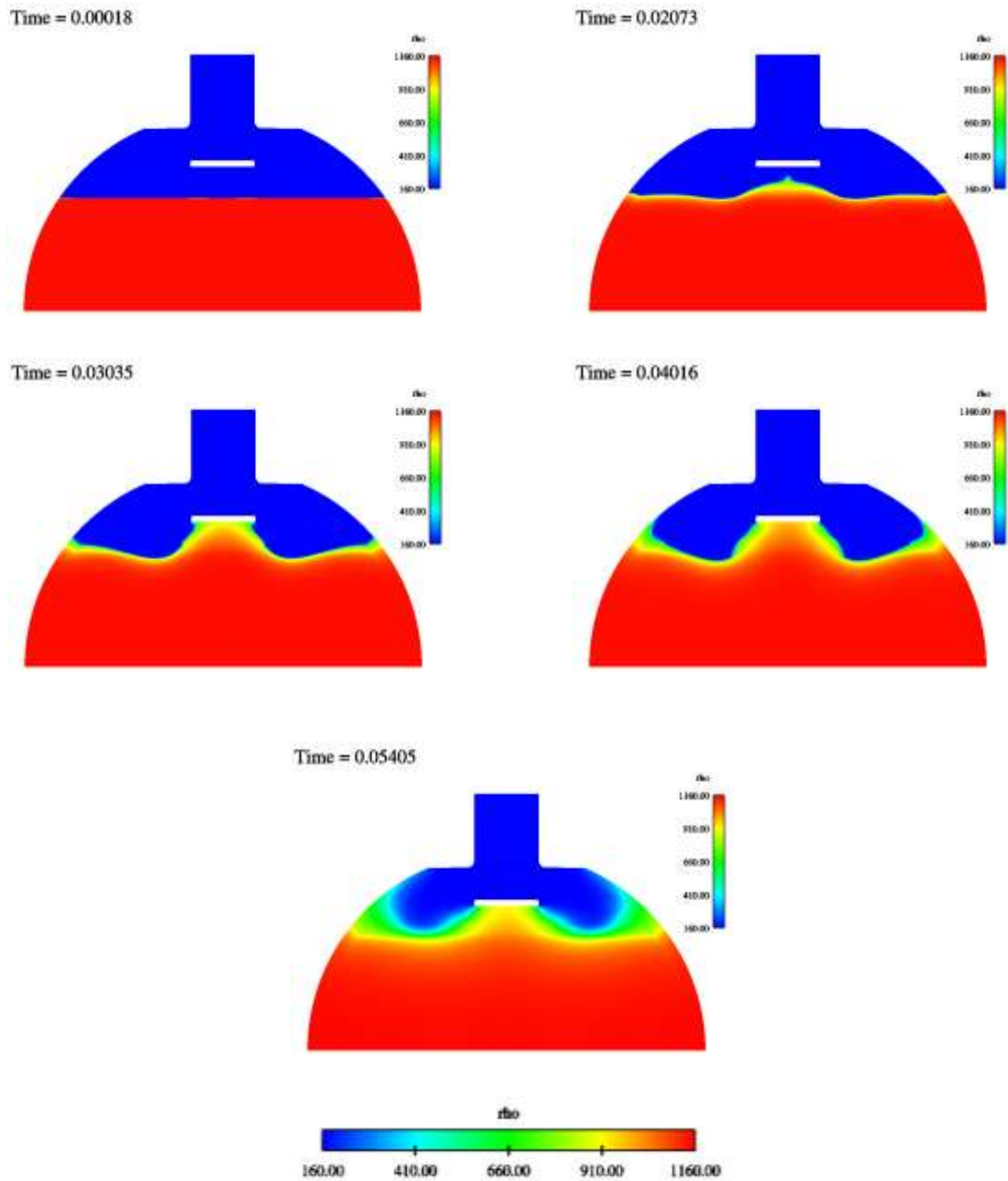


Figure 3. Variation of density in Tank during pressurization process.