

Loci/STREAM Sharp Interface Model Validation of Cryogenic Propellant Tank Self- Pressurization

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This paper documents a model validation effort for the prediction of cryogenic propellant tank self-pressurization physics using the Loci/STREAM sharp interface CFD model developed at NASA MSFC. Cryogenic fluid management (CFM) applications for long duration spaceflight missions require accurate modeling of heat transfer and thermodynamics. Therefore, detailed validation of those physics is important to ensure simulation accuracy. In the past, the MSFC Propulsion Fluid Dynamics Branch has validated and used the Loci/STREAM Volume of Fluid (VOF) module extensively for propellant slosh applications, which are dominated by fluid motion. For cases where the interface gas/liquid interface is essentially static, the Loci/STREAM sharp interface was developed for more rapid and efficient CFM analysis. In the present study, Loci/STREAM sharp interface simulations were compared with the NASA K-site self-pressurization experiment of a flight weight, partially full, LH2 tank in normal gravity. This study investigated several parametric effects and made a number of important observations on the performance of the Loci/STREAM sharp interface method:

- First, a homogeneous model was derived to verify the CFD model. The homogeneous model assumes both gas and liquid phases are uniform and are at saturation temperature. The predicted pressure rise rates at 3.5 W/m^2 and 2.0 W/m^2 with a 49% fill level are all lower than the experimental measurement. This is expected due to the observed temperature stratification near the gas-liquid interface during testing.
- The k-w and k-e turbulence models predict comparable pressurization rates, which are much lower than the experiment measurement. On the other hand, the pressure values and pressurization rates from both models are almost the same as those of the homogeneous model. The current turbulence model is too diffusive and is not capable of capturing the thermal stratification in the liquid and ullage.
- When using the laminar flow model, the pressurization rate is found to be very close to the experimental value when a quasi-steady flow field is allowed to develop by continuously venting the tank prior to pressurization as was done during testing. On the other hand, without initial venting, the rate is not constant. Additionally, the development time to reach a quasi-steady flow field differed from the experiment due to the lack of turbulent mixing away from the gas-liquid interface that is expected in reality.

- Using the laminar flow model and appropriate initial conditioning, the pressurization rate is within 15% of the experimental value for 49% fill level at 3.5 W/m^2 and is within 18% for 2.0 W/m^2 heat loading.
- Using the laminar flow model and appropriate initial conditioning, the pressurization rate is within 18% of the experimental value for a 29% fill level and within 15% for an 83% fill level.