Restraint of Liquid Jets by Surface Tension in Microgravity Modeled

Microgravity poses many challenges to the designer of spacecraft tanks. Chief among these are the lack of phase separation and the need to supply vapor-free liquid or liquid-free vapor to the spacecraft processes that require fluid. One of the principal problems of phase separation is the creation of liquid jets. A jet can be created by liquid filling, settling of the fluid to one end of the tank, or even closing a valve to stop the liquid flow. Anyone who has seen a fountain knows that jets occur in normal gravity also. However, in normal gravity, the gravity controls and restricts the jet flow. In microgravity, with gravity largely absent, jets must be contained by surface tension forces. Recent NASA experiments in microgravity (Tank Pressure Control Experiment, TPCE, and Vented Tank Pressure Experiment, VTRE) resulted in a wealth of data about jet behavior in microgravity. VTRE was surprising in that, although it contained a complex geometry of baffles and vanes, the limit on liquid inflow was the emergence of a liquid jet from the top of the vane structure. Clearly understanding the restraint of liquid jets by surface tension is key to managing fluids in low gravity.

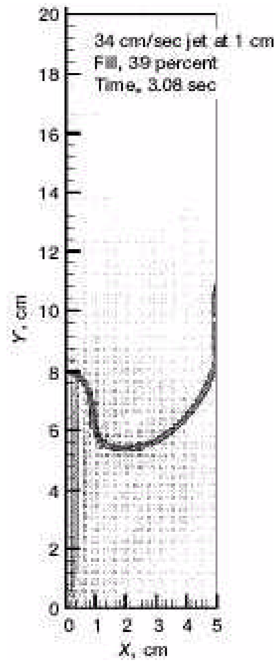
To model this phenomenon, we need a numerical method that can track the fluid motion and the surface tension forces. The fluid motion is modeled with the Navier-Stokes equation formulated for low-speed incompressible flows. The quantities of velocity and pressure are placed on a staggered grid, with velocity being tracked at cell faces and pressure at cell centers. The free surface is tracked via the introduction of a color function that tracks liquid as 1/2 and gas as -1/2. A phase model developed by Jacqmin (ref. 1) is used. This model converts the discrete surface tension force into a barrier function that peaks at the free surface and decays rapidly. Previous attempts at this formulation have been criticized for smearing the interface. However, by sharpening the phase function, double gridding the fluid function, and using a higher order solution for the fluid function, interface smearing is avoided. These equations can be rewritten as two coupled Poisson equations that also include the velocity. The method of solution is as follows: first, the phase equations are solved from this solution, a velocity field is generated, then a successive overrelaxation scheme is used to solve for a pressure field consistent with the velocity solution.

After the code was implemented in axisymmetric form and verified by several test cases, the drop tower runs of Aydelott (ref. 2) were modeled. The model handed the free-surface deformation quite nicely, even to the point of modeling geyser growth in the regime where the free surface was no longer restrained. A representative run is shown in the graph.

References

1. Jacqmin, D.: Calculation of Two-Phase Navier-Stokes Flows Using Phase-Field Modeling. J. Computational Physics, vol. 155, 1999, pp. 96-127.

2. Aydelott, J.C.: Modeling of Space Vehicle Propellant Mixing. NASA TP-2107, 1983.



Computer simulation of submerged liquid jet striking the free surface in microgravity. Jet of 34 cm/sec at 1 cm; fill, 39 percent; time, 3.08 sec; reference vector, 10 cm/sec.

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