

Free Surface Change During Free-Fall

The VOF capabilities in FLUENT 5 have been validated as part of a European project that focuses on the change in a liquid surface when the liquid is subjected to a sudden change in gravity. As part of the project, the numerical results were compared to experimental data obtained at the drop tower located at the ZARM Scientific Institute at the University of Bremen in Germany. Very good agreement was obtained for both normal and zero gravity conditions.

The ballistic phase of the launching of a space ship is characterized by a step reduction in gravity after the termination of the thruster firing. This transition is characterized by a sudden change in the value of the dimensionless Bond number, which is an indicator of the relative importance of gravitational and capillary forces. For a cylindrical container of liquid, it is defined as

$$Bo = \rho g r^2 / \sigma$$

where ρ is the liquid density, g is the mean apparent acceleration due to gravity, r is the container radius, and σ is the surface tension of the liquid. During the ballistic phase of a launch, the Bond number has a value greater than 150 before the end of thrust, and a value less than 10 afterwards.

Experiments designed to capture this transition were carried out in the drop tower of the ZARM Scientific Institute at the University of Bremen (Figure 1). This installation is a ground-based, short-duration microgravity laboratory. It is 146 m high, and through the use of vacuum pumps, can be evacuated to an internal



Figure 1: The ZARM Drop Tower at the University of Bremen

pressure of 10 Pa. Experiments are contained in a sealed capsule, which is dropped from a station near the top of the tower. The capsule is in free fall for about 4.74 seconds, during which time the contents of the capsule experience near weightlessness. Deceleration occurs in a bed of polystyrene beads at the bottom of the tower. The drop tower offers an economical alternative to scientists from around the world who wish to conduct microgravity research projects.

For the experiment described in this

example, a cylinder of radius r is filled with a liquid to an initial fill height, h . One liquid studied is DETRA, which, at room temperature, has properties similar to liquid hydrogen at 20°K. In particular, DETRA forms a wall contact angle of 5°. The other fluid studied is M3, which has very different properties, including a contact angle of 55°. Experiments with M3 were performed to ensure that the apparatus was working correctly, providing results that were indeed dependent on the fluid used.

At $t=0$ the free surface has an initial equilibrium shape influenced by the contact angle and gravity. Once the cylinder is

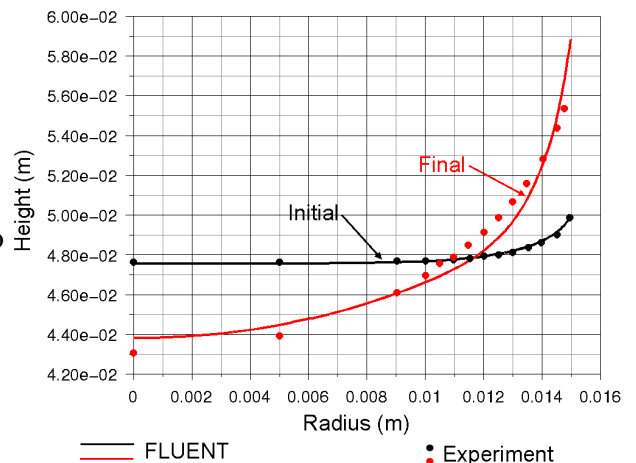


Figure 2: A comparison of experimental results and FLUENT predictions before and near the end of the fall for the fluid DETRA

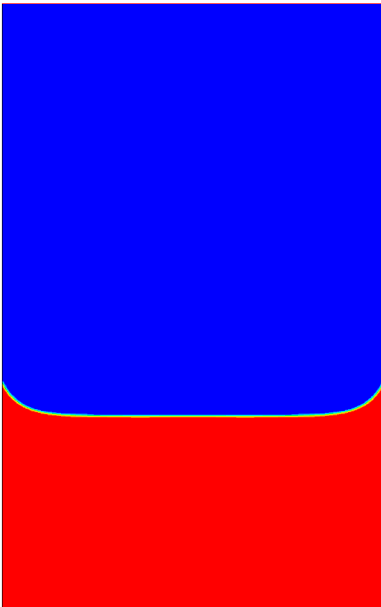


Figure 3: The free surface of the fluid DETRA before the drop

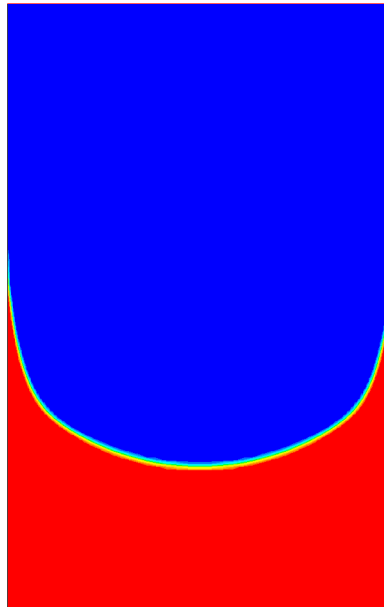


Figure 4: The free surface of the fluid DETRA after 4.6 seconds of free-fall

dropped, there is a sudden change in gravity, and a high speed camera monitors the change in the liquid surface during the fall.

Simulations were carried out using FLUENT 5.5. A very simple hex mesh of approximately 5000 cells was created using GAMBIT 1.3. For each liquid, the first step was to obtain the initial equilibrium surface shape, using the contact angle and standard gravitational force as boundary conditions. The gravitational acceleration was then abruptly changed to 0, and the shape of the free surface was monitored during a transient simulation.

Profiles of the free surface are shown before the drop and after 4.6 seconds of weightlessness for the fluid DETRA in Figure 2. Before the drop (when g is maximum), the FLUENT results are in excellent agreement with the data. After the drop (when g is minimum), the agreement is not quite as good. This is very likely due to the fact that the only

driving force for the second case is the wall adhesion angle. Slight differences between the true fluid value and that imposed in the CFD model can bring about a significant difference in the resultant surface profiles.

In Figure 3, the shape of the free surface before the drop is shown for the fluid DETRA. Both gravity and the wall adhesion angle work to govern the shape of the surface. In Figure 4, the shape of the free surface after the drop (but before deceleration) is shown for the same fluid. For this calculation, the surface shape is determined by the wall adhesion angle only.

The experiment and simulation were repeated for another fluid with different properties. For this fluid, M3, the agreement between the FLUENT predictions and data is very good

before and after the drop (Figure 5). The improved agreement during weightlessness may be due to the fact that the wall adhesion angle is larger for this fluid, and slight discrepancies between the true fluid value and that used in the simulation may not cause as much of a differential in the resultant surface profiles.

To summarize, the VOF model in FLUENT 5, which includes surface tension and wall adhesion effects, has been validated against experimental data. Measurements were made of the surface profiles of two liquids subjected to a sudden drop in gravity (to a near-zero value). To simulate this sudden change to weightlessness in FLUENT, a step reduction in gravity was specified. Very good or excellent agreement was found for both fluids at two times: before the drop and 4.6 seconds after the drop. Discrepancies in the results may be due to slight differences in the contact angles of the actual fluids and those specified in the simulations.

*Courtesy of
ZARM Scientific Institute
<http://www.zarm.uni-bremen.de>*

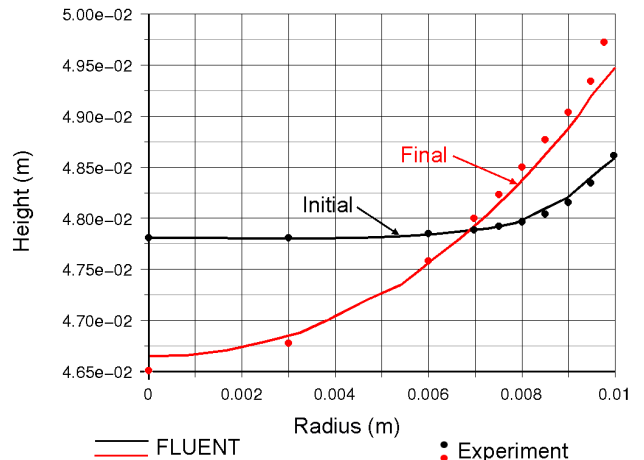


Figure 5: A comparison of experimental results and FLUENT predictions before and near the end of the fall for the fluid M3