

# ON A 3D COMPUTATIONAL MODEL OF FREE SURFACE FLOWS INCLUDING INTERNAL OBSTACLES

M. Pasandideh-Fard, M. Bussmann, S. Chandra and J. Mostaghimi

*Department of Mechanical and Industrial Engineering*

*University of Toronto, Toronto, Canada*

*<http://www.mie.utoronto.ca/labs/tsl/>*

## ABSTRACT

The impact of a water droplet on a stainless steel tube was studied using both numerical simulations and experiments. A 3D numerical model of Bussmann et al. [1] for free-surface flows (such as an impacting droplet) was extended to include internal obstacles (such as a solid tube) in the fluid computational domain. The results of the model were compared with experimental photographs for the impact of a 2 mm water droplet on two tube sizes: 3.18 mm (0.125 in) and 6.35 mm (0.25 in) O.D.; the impact velocity was 1 m/s and 1.2 m/s on the two tubes, respectively. The droplet impacting on the smaller tube size pinched off the tube surface. On the bigger tube size, however, surface tension effects arrested droplet downward flow on the tube surface; as a result, there was no droplet pinch off in this case. The good qualitative and quantitative agreement between the results of simulations and experimental photographs demonstrated the numerical model to be well suited for simulating free-surface flows over internal obstacles in general, and droplet spraying on tubes in particular.

## INTRODUCTION

The impact of an individual liquid droplet against a solid surface is an outcome of many spray applications. Most studies, both experimental and numerical, have considered the axisymmetric impact of a droplet against a flat solid surface, which may be considered two-dimensionally. Yet the solid surface geometry is often more complicated. For example, Hardalupas et al. [2] recently presented experimental results of the impact of droplets onto solid spheres of similar curvature, with application to the operation of fluidized beds. And while this is a geometry that can still be considered two-dimensionally, many others cannot. Yao et al. [3] presented results of the impact of water droplets onto the edge of heated thin steel strips, a geometry of interest during the reflooding phase of a nuclear reactor loss-of-coolant accident.

Of interest here is the impact of a droplet onto a cylindrical tube, to demonstrate the efficacy of a numerical technique presented previously [1]. Such a geometry is common in applications such as agricultural and medicinal sprays. Hung and Yao [4] presented experimental results of such a geometry, and

characterized the phenomenon according to the relative diameters of the tube and the droplet.

The numerical method presented here is an extension of a fixed-grid three-dimensional model presented previously [1]. Earlier simulations, of the impact of a droplet onto a flat incline and onto a sharp edge, could be defined along gridlines. Many geometries, like a cylindrical tube, cannot be handled in this way. The model has thus been extended to include the definition of internal obstacles within the grid, to accommodate such geometries. Results are presented of the 1 m/s and 1.2 m/s impacts of a 2 mm diameter water droplet onto tubes of two different diameters, and the results compared with photographs taken of corresponding impacts. The simulation results compare well with experiment, and demonstrate that the methodology is applicable to the simulation of such complex phenomena.

## EXPERIMENTAL METHOD

The experimental method is similar to that previously described by Chandra and Avedisian [5] and by Pasandideh-Fard et al. [6]. Single droplets are formed by slowly pumping distilled water through a hypodermic needle until the droplets detach under their own weight. Droplet diameter is uniformly 2 mm. The droplets fall onto a securely mounted horizontal stainless steel tube (either 3.18 mm (0.125 in) or 6.35 mm (0.25 in) O.D.) polished with 600-grit emery paper. The distance between the needle tip and the point of impact is set to yield the 1 m/s and 1.2 m/s impact velocities. A single 35 mm photograph is taken of any one instant during an impact, as determined by a set time delay between droplet release and the illumination provided by a strobe of 8  $\mu$ s duration. The photographs of any particular instant from one droplet to the next are sufficiently repeatable that a complete impact sequence may be reconstructed from individual photographs of different droplets.

## NUMERICAL METHOD

**Fluid Flow.** Fluid flow in an impacting droplet was modeled using a finite difference solution of the Navier-Stokes equations in a 3D Cartesian coordinate system assuming laminar, incompressible flow. The