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Effect of wetting a wall on the impact of a liquid jet

A A Aganin and T S Guseva

Institute of Mechanics and Engineering - Subdivision of the Federal State Budgetary Institution of Science “Kazan Scientific Center of the Russian Academy of Sciences”, 2/31, Lobachevsky str., Kazan 420111 Russia

E-mail: ts.guseva@mail.ru

Abstract. The influence of a thin layer of water wetting a wall on the impact of a water jet is studied. The jet velocity is 250 m/s. The end of the jet is somewhat blunter than the hemispherical one. The thickness of the wetting layer is 4% of the jet radius so that the level of the pressure on the wall in the center of the impact area is approximately equal to that arising when hitting a dry wall. A numerical technique based on the approach without explicit separation of the interphase boundary is applied. The CUP-CUP method is used for integrating the Euler equations. An adaptive soroban-grid is utilized. It is shown that the presence of the wetting layer mainly manifests itself in a significant decrease of the pressure peaks realized in the narrow peripheral area of the impact zone on the wall.

1. Introduction

The problem of the high-speed impact of liquid mass (jet or drop) on a wall covered with a thin layer of liquid is important for many applications. Such impacts can occur during the operation of steam turbines, the flight of aircraft in rain conditions, the collapse of cavitation bubbles near the surfaces of bodies [1]. Jet impacts of cavitation nature are considered to be one of the main causes of the well-known phenomenon of cavitation destruction of body surfaces [1-3].

To date, the focus has been on studying the liquid impact on a dry wall (for example, [4, 5]). In the present work, the numerical investigation of the effect of wall wetting on the impact of a high-speed liquid jet is investigated. The case of a small thickness of the wetting layer is under consideration, in which the damping effect of the layer is relatively small. In particular, with such a thickness of the wetting layer, the level of the load on the wall in the center of the impact is comparable to what is realized when hitting a dry wall.

The important features of the considered jet impact on a wall are the shock waves arising in the liquid, their interaction with the free liquid surface leading to its large and rapid deformations, the high-speed lateral spreading of liquid with the possible formation of the smallest drops and bubbles [4]. All the features should be taken into account when choosing a method of numerical modeling. In this paper, we use the CIP-CUP (Constrained Interpolation Profile - Combined Unified Procedure) [6] method in combination with the approach without explicit treatment of the interphase boundary. The CIP-CUP method is quite effective in simulating the shock waves of moderate intensity and the contact boundaries with a large difference of the acoustic impedance (including boundaries of the gas-liquid type) [7]. Unstructured dynamically adaptive soroban-grids [8] are used to increase the efficiency of calculations.
2. Mathematical model

The impact of a high-speed jet of liquid (water) on a fixed flat rigid wall uniformly wetted with a thin layer of the same liquid is considered (Figure 1). The jet is surrounded by air under room conditions. The jet velocity is $V = 250 \text{ m/s}$, the wetting layer thickness is $d = 0.04R$ where $R$ is the jet radius, the undisturbed liquid pressure in the jet, the ambient air and the wetting layer is $p_0 = 1 \text{ bar}$.

![Figure 1. Schematic of the impact of the jet of the present work (a), the shape of the jet obtained in [9] by calculation of the collapse of a bubble near a wall by boundary element method (b) and the shape of the jet taken in [1] in the numerical simulation of the experiments on the impact of the jet on the surface of the liquid (c).](image)

The jet is supposed to be a cylindrical liquid column with a rounded end, the shape of which is described by the equation

$$z = \alpha \left( R - \sqrt{R^2 - r^2} \right)$$

where $r, z$ are the radial and axial cylindrical coordinates, $\alpha$ is a parameter determining the roundness of the shape. It is taken that $\alpha=0.25$ (Figure 1 a), which approximately corresponds to the ends of the jets in the works [9, 1] (Figure 1 b, c).

The influence of the thin liquid layer covering a wall on the impact of the jet is studied. For this purpose, a comparison is made with the case of impact on the dry wall.

3. Results

Figure 2 illustrates the features of the jet impact on the dry wall. At the beginning of the impact, a shock wave occurs travelling up the jet. Initially, the edge of this wave coincides with the boundary of the rapidly expanding area of contact between the jet and the wall, on the periphery of which the liquid pressure maximum is localized. Then the edge of the shock wave detaches from the wall and goes up the free surface of the jet, a high-speed lateral liquid spreading along the wall arises in the form of a thin film. The interaction of the shock wave with the jet surface leads to the formation of rarefaction waves. Focusing of some of those waves generated on the concave part of the jet boundary results in the appearance of a metastable zone in the vicinity of the jet surface. The metastable zone is then greatly increased, covering almost all the cross-section of the jet.
It can be seen that the pressure in the metastable zone of the jet, especially in the vicinity of the axis of symmetry, takes large negative values. In reality, this would lead to cavitation, which is not taken into account in the model of this paper. One may expect that the presence of the cavitation region will significantly influence on the subsequent dynamics of the liquid in the vicinity of the wall, therefore the subsequent process is not considered in this paper. The change of the load on the wall in the initial most intense stage of the jet impact is shown in Figure 2 b. It can be seen that in the center of the impact region the pressure decreases monotonically, whereas on the periphery of that region it first grows quite strongly, and then falls. The radial pressure distribution on the wall up to the moment $t_1$ is inhomogeneous. The inhomogeneity increases to the moment $t_4$, after which it decreases quite quickly.

Figure 3 illustrates the process of the impact of the jet on the wetted wall. In this case, two shock waves arise, the first of which propagates into the area of the jet, while the second one travels into the area of the layer. The edges of these waves are attached to the boundary of the rapidly expanding area of contact between the jet and the layer, where the liquid pressure maximum is localized. Soon the second shock wave reaches the wall, generating a third shock wave travelling upward. By the time $t_3$, the front of the reflected shock wave in the jet merges with the front of the first wave, and it merges with the front of the second wave in the wetting layer. The edges of the shock waves formed by the merging detach from the boundary of the jet-layer contact area and propagate along the surfaces of the jet and the layer, respectively. At the periphery of the jet-layer contact area, a thin splash of liquid is formed, which eventually becomes more pronounced (moments $t_9-t_{11}$). Then the process develops in many ways similar to the case of the dry wall. The interaction of the shock waves with the surfaces of
the jet and the layer leads to the formation of rarefaction waves. Focusing of some of those waves generated on the concave part of the jet boundary results to the appearance of a metastable zone in the vicinity of the jet surface. From then on, the metastable zone is greatly increased, covering the cross-section of the jet. The change of the load on the wall in the initial stage of the jet impact is shown in Figure 3 b. One can see that it is largely similar to the case of impact on the dry wall. The main difference is that the level of maximum pressure at the periphery of the impact area is now much lower. In addition, in the case of the wetted wall, the peripheral peaks decrease faster ($t > t_0$) due to the influence on the wall of the rarefaction wave coming from the layer surface.

![Figure 4](image_url)

**Figure 4.** The integral force of the jet action on the wall at the initial most intense stage in the cases of impact onto the dry (solid line) and wetted (dashed line) walls.

Figure 4 demonstrates the time dependences of the integral force of the jet action on the wall determined by the expression

$$F_w = \frac{2}{(p_{wh} - p_0)R^2} \int_0^{\infty} \left[ \max(p,0) - p_0 \right] dr$$

(2)

The initial stage is presented, where the action is most significant. It is seen that the influence of the wall wetting on the integral action is insignificant: the difference in the curves is mainly determined by the time delay caused by the passage of the shock wave incident on the wall through the wetting layer.

References

[1] Bourne N K 2005 On impacting liquid jets and drops onto polymethylmethacrylate targets *Proc. R. Soc. A.* 461 1129

[2] Kornfeld M, Suvorov L 1944 On the destructive action of cavitation *J. Appl. Phys.* 15 495

[3] Hawker N A, Ventikos Y 2012 Interaction of a strong shockwave with a gas bubble in a liquid medium: a numerical study *J. Fluid Mech.* 701 59

[4] Lesser M B, Field J E 1983 The impact of compressible liquids *Ann. Rev. Fluid Mech.* 15 97

[5] Rein M 1993 Phenomena of liquid drop impact on solid and liquid surfaces *Fluid dynamics Research* 12 61

[6] Yabe T, Wang P Y 1991 Unified numerical procedure for compressible and incompressible fluid *J. Phys. Soc. Japan* 60(7) 2105

[7] Yabe T, Xiao F, Utsumi T 2001 The constrained interpolation profile method for multiphase analysis *J. Comput. Phys.* 169(2) 556

[8] Takizawa K, Yabe T, Tsugawa Y, Tezduyar T E, Mizoe H 2007 Computation of free-surface flows and fluid-object interactions with the CIP method based on adaptive meshless Soroban grids *Comput. Mech.* 40 167

[9] Aganin A A, Ilgamov M A, Kosolapova L A, Malakhov V G 2016 Dynamics of a cavitation bubble near a solid wall *Thermophysics and Aeromechanics* 23(2) 211.