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Circular hydraulic jumps affected by capillarity and external forces

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This work deals with modelling the axisymmetric spreading of a liquid film over a rigid surface. The liquid is supplied by a vertical jet impinging on the surface; it then flows radially in a supercritical regime, exhibiting a velocity exceeding the velocity of the gravity waves. Under certain conditions, the film thickness abruptly changes, forming a hydraulic jump and manifesting the transition to the subcritical flow regime. The work aims to establish the conditions of the hydraulic jump existence, accounting for the following factors that can prevent it.

First, we address the effect of an external force that accelerates the liquid. Large enough force keeps the flow supercritical everywhere; we have traced the transformation of the flow with a jump to this continuous regime while the force intensity increases. The flow undergoes several regime transformations and the values of the dimensionless parameters corresponding to the switch of the flow regime are found. The longitudinal component of gravity for the flow over a spherical cap [1] and centrifugal force [2] are considered as examples; the various reduced-order models based on depth-averaged thin-layer equations are examined for these problems.

Second, the effect of capillarity acting at the jump and at the periphery is considered. It has been shown [1] that the interplay between the accelerating force and the capillarity results in qualitatively different scenarios of the jump location behavior while the surface tension coefficient changes.

Then, we examine different ways of combining simplified models that describe two-dimensional flows, e.g., in the impingement region or inside the jump, with quasi-1D depth-averaged equations for the film. An attempt is made to keep the structure of the equations that allow the existence of jumps and admits accounting for capillarity while recovering complex velocity profile with the separation zones near the bottom and vortices at the jump near the free surface; in particular, the model that accounts for the mechanical energy evolution [3] is considered.

The published experimental and simulation data validate the results of the modelling.

Keywords: Hydraulic jump, surface tension, thin-film flows.

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