Annular spread of a thin liquid film over a rotating disk

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Liquid jet impingement on a spinning disk is of vital importance in many engineering applications. Specifically, in semiconductor industries it is adopted for machining and cleaning the surface of silicium wafers. However, although the associated flow physics has been appreciated by many researchers in the special case of a stationary surface (for an overlook see e.g. [1]), radially spreading thin-film flow adjacent to a rotating disk has only been examined numerically for nozzle-like inlet conditions ([2]). In this contribution a thorough analytical/numerical investigation of the flow field generated by an impinging jet is presented, strictly based on first principles.

We consider a non-rotating circular jet carrying a volume flux $\tilde{Q}$ of a liquid with kinematic viscosity $\tilde{\nu}$. It shall impinge perpendicularly with cross-section-averaged velocity $\tilde{U}$ on the center of a disk which rotates with constant angular velocity $\tilde{\Omega}$ in a horizontal plane. The jet flow is assumed to be essentially inviscid. Thus, a boundary layer and, sufficiently far from the center, a thin viscous film forms above the disk. Employing asymptotic methods, the different flow regimes reflecting varying effects of viscous shear and centrifugal body force are elucidated. As a consequence of jet-forcing, the influence of gravity on the flow is seen to be negligibly small, which, most important for numerical reasons, in turn allows for a parabolic shallow-water approximation of the non-dimensionalized equations of motion.

As one crucial result of the analysis, the spread of the film appears to be primarily characterized solely by the Rossby number *Ro* of the problem if an appropriately defined reference radius $\tilde{R}$ is introduced, that is

$$Ro = \tilde{U}/(\tilde{\Omega}\tilde{R})\,, \quad \tilde{R} = \tilde{Q}^{2/3}/(4\pi^2\,\tilde{U}\tilde{\nu})^{1/3}\,.$$

Numerical solutions of the shallow-water equations have been obtained for a wide range of values of *Ro*. To this end, the inviscid inlet conditions were chosen to represent the practically important case of a parabolic velocity profile in the oncoming jet. Interestingly, if *Ro* exceeds a certain threshold, the radial distribution of the film thickness exhibits a maximum at a distinct radius while it tends to zero for large radii.

In addition, emphasis is put on the cases $Ro \to \infty$ and $Ro \to 0$. The latter one appears to be associated with a breakdown of the asymptotic structure of the flow, requiring a separate treatment. The corresponding limits of application of the theory presented are discussed.

References

[1] LIENHARD V, J. H. 1995 Liquid Jet Impingement. In *Ann. Rev. Heat Transfer* (ed. C.-L. Tien), Vol. VI, pp. 199–270. Begell House.

[2] RAHMAN, M. M. & FAGHRI, A. 1992 Numerical simulation of fluid flow and heat transfer in a liquid film over a rotating disk. *Int. J. Heat Mass Transfer* **35**, 1441–1453.