Experimental and theoretical evidence for a new instability in film flow along periodic corrugations

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ABSTRACT

Film flow along periodic, sinusoidal corrugations is studied experimentally in an inclined channel by taking time-series of the free surface elevation with conductance probes [1], and theoretically by a long-wave model based on the weighted-residual boundary integral method [2]. The question asked is the possible modification of the primary instability by the replacement of the flat wall by a corrugated one.

With increasing Re, a new instability appears, which is unique to corrugated walls and consists of temporal oscillations around the steady flow. This instability manifests at all inclinations tested (5-40^{o}), and its onset roughly coincides with the onset of long-wave traveling disturbances. The oscillation has a high (10-20 Hz) and well-defined frequency, and a slowly modulated amplitude. It extends throughout the entire channel, and is exactly out of phase at consecutive crests/troughs. Thus, it appears to be an absolute instability.

Numerical solution of the long-wave model for a domain with many corrugation cycles predicts transition to a time-periodic oscillation, which is in synchrony throughout the computational domain and whose frequency agrees with the data. Though the predicted oscillation amplitude is constant, it exhibits a strong, increasing dependence on Re, as is also observed in the experiments. Thus, it is argued that theory and experiment describe the same phenomenon.

The stability threshold is compared to the classical result for a flat wall. Experiment and theory indicate that, for the wall parameters tested (wavelength 12 mm, amplitude 2 mm), corrugations postpone the instability to higher Re and the deviation intensifies with increasing inclination. However, the agreement between experiment and theory is here only qualitative. Experiments with a corrugated wall consisting of symmetric steps (with the same wavelength and amplitude as above) show that the stabilization of steady flow depends significantly on the shape of the corrugations.

Long, traveling waves beyond the primary threshold are studied experimentally by introducing low-frequency inlet disturbances. These waves develop a main hump preceded by precursor ripples, and resemble roughly solitary waves along a flat wall. The main difference is that the temporal oscillation is superposed along the entire traveling profile, and its amplitude attains very high values in front of the main hump. Thus, the corrugated wall appears to affect the unstable dynamics through the oscillatory instability. It is noted that a strong effect of the wall in the unstable dynamics has been previously reported [3], though the data acquisition rate was in that case too low to permit detection of the oscillation.

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[1] M. Vlachogiannis, A. Samandas, V. Leontidis, V. Bontozoglou, Effect of channel width on the primary instability of inclined film flow, Phys. Fluids, **22,** 012106 (2010)

[2] A. Oron, C. Heining, Weighted-residual integral boundary-layer model for the nonlinear dynamics of thin liquid films falling on an undulating vertical wall, Phys. Fluids **20,** 082102 (2008)

[3] K. Argyriadi, M. Vlachogiannis, and V. Bontozoglou, Experimental study of inclined film flow along periodic corrugations: The effect of wall steepness, Phys. Fluids **18**, 012102 (2006).