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SOLITARY WAVES ON A LIQUID FILM FLOWING ALONG A PERIODIC WALL

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Summary Experimental results are reported on the formation and characteristics of solitary waves on liquid films flowing along a periodically corrugated wall. The effect of the wall is manifested in the regularity of the resulting wavetrain and also in the shape of individual humps. At high Re, travelling waves recede in favor of a stationary three-dimensional structure, a phenomenon that has no counterpart in film flow along flat walls.

INTRODUCTION

Film flow along a wavy wall appears to have attracted relatively little attention, despite extensive engineering applications in process equipment aimed at enhancement of heat/mass transfer rates. Asymptotic and numerical studies beyond the limit of creeping flow (Bontozoglou & Papapolymerou 1997, Trifonov 1998, Malamataris & Bontozoglou 1999, Bontozoglou 2000, Wierschem, Scholle & Aksel 2002, Wierschem & Aksel 2003) indicate that significant interaction may occur between the corrugated wall and the free surface. A recent experimental study (Vlachogiannis & Bontozoglou 2002) revealed the establishment of a variety of flow regimes: A statically deformed free surface was observed at low Re, which forms the base flow and is the equivalent of Nusselt parabolic film along a flat wall. With increasing Re and/or inclination angle the base flow was observed to become unstable to traveling disturbances. The aim of the present work is to investigate experimentally the nonlinear evolution and the possible stationary forms of the free surface under these conditions.

EXPERIMENTAL SETUP

The wavy wall used in the experiments has orthogonal corrugations at right angles to the flow direction, with wavelength 12 mm (split into 6 mm of elevation and 6 mm of depression) and height 0.4 mm. Pure water and water-glycerol mixtures are tested at small inclination angles (1º-8º) and Reynolds numbers in the range $10<Re<400$ are used. A fluorescence imaging technique –combined with frame grabbing and image analysis software– is used to record the spatio-temporal evolution of the free surface.

RESULTS AND DISCUSSION

Following the technique of Alekseenko, Nakoryakov & Pokusaev (1985), we introduce at the channel inlet mass disturbances of large amplitude and low frequency. The evolution of the flow is depicted in Fig. 1, in the form of a time-series of the free surface elevation at a fixed downstream location. Each disturbance is observed to disintegrate into a series of waves of striking temporal regularity. Also shown in Fig. 1 is the time-series for flow under similar conditions but along a flat wall, which results in a less populated and more disordered wave train. The higher number and superior ordering of waves along the periodic wall may be interpreted in terms of the regular spatial triggering of each traveling disturbance by the wall corrugations.

For a wide range of Reynolds numbers, traveling disturbances evolve into two-dimensional solitary waves characterized by a steep front and a smooth tail. However, these solitary waves differ from their counterparts along a flat wall, because they are superposed on the base flow with the statically deformed free surface. An example is provided in Fig. 2, which plots instantaneous line profiles of the free surface at the center plane of the channel, along a window of view 90 mm in the flow direction. A solitary wave is observed traveling to the right, preceded by a capillary ripple and followed by a tail with distinct regular undulations. These undulations correspond exactly to the base flow, as is manifested by their appearance at the same absolute locations in the substrate before the solitary hump (lowest line). Of particular importance in the dynamics of the solitary wave is the interaction of the hump with successive crests of the static base flow. An instance of this interaction (which may be described as a weak coalescence) is evident in the upper line profile of Fig. 2.

At high Reynolds numbers a three-dimensional transition occurs, which does not appear in films along a flat wall and is characterized by the formation of a transverse series of depressions along the troughs of the periodic free surface. Surprisingly enough its role is stabilizing, as is indicated by the time-series presented in Fig. 3. More specifically, it is observed that with increasing Re solitary waves are drastically reduced in height and are eventually completely eliminated. It is interesting to note that this three-dimensional transition is a local effect. Thus, before it infects the entire flow field, the 3-D structure temporarily appears on the crests of solitary humps where Re is locally higher. This transient effect leads to the erosion of the crests observed in the upper curves of Fig. 3.

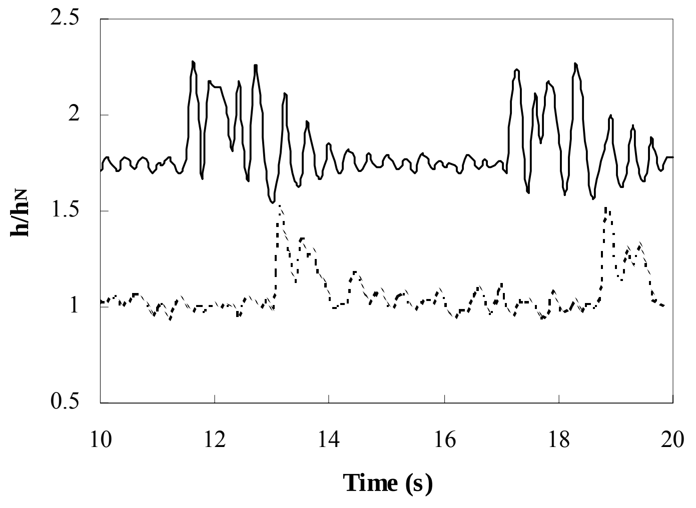

Figure 1: Time-series of free surface elevation at Re=50 and φ=3º, 480 mm downstream of the channel entrance: (—) corrugated wall, (---) flat wall.

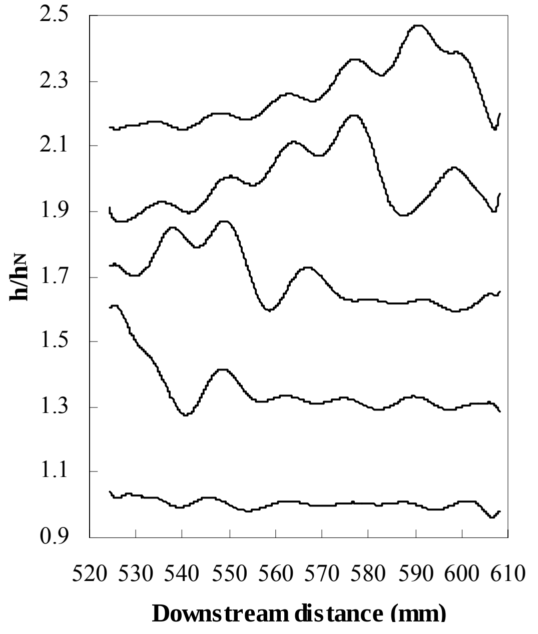

Figure 2: The line profile of a solitary wave traveling from left to right.

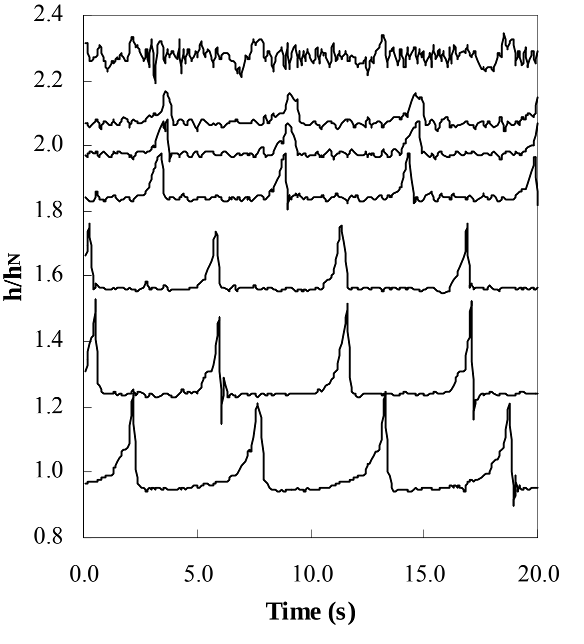

Figure 3: Time-series of free surface elevation at φ=1º, and Re=70, 96, 137, 182, 233, 280, 342 (from bottom to top).

CONCLUSIONS

The characteristics of solitary waves travelling along a wall with orthogonal corrugations are studied experimentally and are set in perspective with their counterparts over a flat wall. One effect of the presence of corrugations is the formation of a more ordered wave train. Solitary waves interact with the statically deformed free surface and thus manifest in their shape the periodicity of the wall. At high Re, a three-dimensional transition occurs, which apparently stabilizes the film and leads to the recession of travelling waves.

References

Alekseenko, S.V.,. Nakoryakov, V. Y and Pokusaev, B. G., *AIChE J.* **31**, 1446 (1985).

Bontozoglou, V. and Papapolymerou, G., *Int. J. Multiphase Flow*, **23**, 69-79 (1997).

Bontozoglou, V., *Computer Modeling Engng. Science*, **1**, 129-138 (2000).

Malamataris, N. A. and Bontozoglou, V., *J. Comp. Phys*., **154**, 372-392 (1999).

Trifonov, Yu. Ya., *Int. J. Multiphase Flow*, **24**, 1139-1161 (1998).

Vlachogiannis, M. and Bontozoglou, V., *J. Fluid Mech*., **457**, 133-156 (2002).

Wierschem, A. Scholle, M. and Aksel, N., *Exp. Fluids*, **33**, 429-442 (2002).

Wierschem, A. and Aksel, N., *Physica D*, **186**, 221-237 (2003).