Gravity currents over concave slopes

M. E. Negretti[1]*, E. J. Hopfinger[1], J. B. Flor[1]

[1]LEGI, CNRS, UJF, BP 53, 38041 Grenoble Cedex 9, France

Gravity currents on slopes are frequent phenomena, examples of which are katabatic winds, avalanches, submarine turbidity currents. Often the boundary has varying slope angle but few studies have considered gravity currents on gradually varying slopes. Such changing slopes can be idealized by convex and/or concave boundaries. Numerical simulations of katabatic flows over convex boundaries by [3] have demonstrated the existence of the Goertler instability in the outer part of the current.

We present here experimental results of gravity currents on concave boundaries. Measurements have been performed using a 2D PIV measurement technique. The initial condition is a developed current on horizontal boundary which is continously supplied with a constant flow rate. The current then moves onto the concave slope of radius of curvature R. This situation, necessarily, gives rise to a transition from a stable current (large Richardson number) to a Kelvin-Helmholtz (KH) unstable current when the Richardson number falls below a critical value as the current accelerates on the slope.

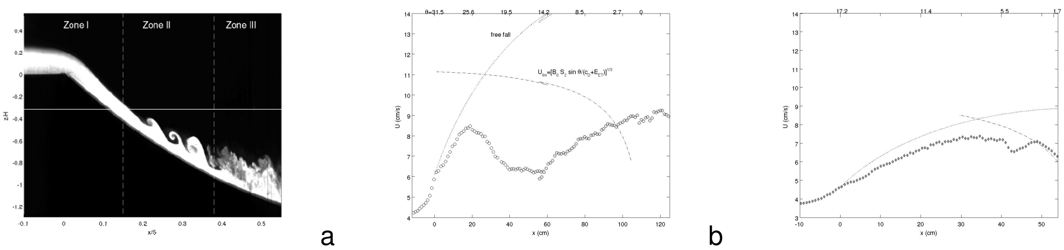
For large initial angles ($\theta_0 = 31°$ and $\theta_0 = 23°$), it is shown that, after the initial acceleration, the current velocity reaches a maximum, then decreases, reaccelerates and reaches a second maximum before the final decrease, possibly through an internal hydraulic jump, at the end of the concave slope. This behavior is independent on the flow curvature as demonstrated by the comparison to linearly sloping bottom. The variation in mean velocity depends on the mean slope angle. When the initial slope angle is small ($\theta_0 = 17°$), the flow accelerates until reaching a constant velocity which is predicted theoretically when the buoyancy force is balanced by bottom friction and entrainment.

The behaviour of the current is analysed with the similarity theory of the depth-averaged equations following closely the procedure of [2] but rewritten in cylindrical coordinates using a variable slope angle. The final expression for the velocity is

$$\frac{U^3}{B} = \frac{S_2 \sin\theta}{c_D + E(Ri)(1 + 0.5S_1 Ri) + T_A(1 + 0.5S_1 Ri) + 0.5S_1 h\frac{dRi}{Rd\theta}}$$

where $B = g'Uh$ is the buoyancy flux, $E = (1/U)d(Uh)/(Rd\theta)$ is the entrainment coefficient, $T_A = (h/U)dU/(Rd\theta)$ is an acceleration parameter, and $Ri = B/U^3 \cos\theta$ is the bulk Richardson number. The acceleration term, T_A, the change in Ri, the bottom friction and entrainment terms are determined from experiments.

Goertler instability is possible along the convex current streamlines when moving from the horizontal boundary onto the slope. However it is masked by the violent KH instability further downstream on the concave section.



a b c

Fig. 1: (a) Instantaneous picture (dye visualization) of an experiment of a gravity current down a concave slope showing the spatial development of the flow. Experimental velocity variation versus the downstream direction with an intial angle $\theta_0 = 31.5°$ (b) and $\theta_0 = 23°$ (c) compared to theoretical predictions.

References

[1] Floryan J.M. *AIAA Journal* **27(1)**:112-114, 1989.
[2] Turner J.S. *Buoyancy effects in fluids.* Cambridge University Press, 1973.
[3] Brun C & Chollet JP. *Congres Francais de Mecanique*, Marseille, June 1-4, 2009.

*corresponding author: maria-eletta.negretti@legi.cnrs.fr