EXPERIMENTAL INVESTIGATION OF KELVIN-HELMHOLTZ INSTABILITY IN A CONFINED RECTANGULAR GEOMETRY, WITH TURBULENCE.

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Abstract We have experimentally investigated the development of Kelvin-Helmholtz vortices on each side of a tape moving at high speed at the free surface of a rectangular pool of water. Depending on the boundary conditions, a recirculation of the flow can occur at the bottom of the tank or along the tape lateral sides, with formation of vortices and turbulence. Depending on the geometry of the tank, a transition from a 3D to a 2D flow is observed that can lead to relatively well organized Bénard Von Karman streets without the classical forcing of the wake behind an obstacle. The selection of vortex spacing is in agreement with a theory developed by Rosenhead for point street vortices in the complex plane.

KELVIN-HELMHOLTZ INSTABILITY IN A CONFINED GEOMETRY

Kelvin–Helmholtz instability (KHI) can occur when there is velocity shear in a single continuous fluid or a velocity difference across the interface between two fluids. For example, when the wind blows over water, waves are generated at the free surface; this is a manifestation of this instability. In the case of the interface between two fluids, if the surface tension is high enough, the instability will only lead to waves; if the surface tension is small enough or if we are in the case of a shear in a single continuous fluid, the waves can develop into vortices.

This instability has been widely investigated since it has been first characterized by Kelvin [1] and Helmhlotz [2], but only few experiments have been conducted in confined geometry. Though, the behavior can be very different: in an infinite bi-dimensional flow, the vortices can grow with no end, in a confined one, it is limited by the dimensions of the flow. Some studies in circular geometry are available [3], but nothing has been done in a rectangular geometry.

We have investigated experimentally the behavior of KHI in a confined rectangular geometry. To do so, we used a tank of water with a tape moving at high speed on its surface (see **Figure 1**): some of the water is dragged by the tape, some is recirculating in the other direction, an instability can occur with the shear between these two flows.

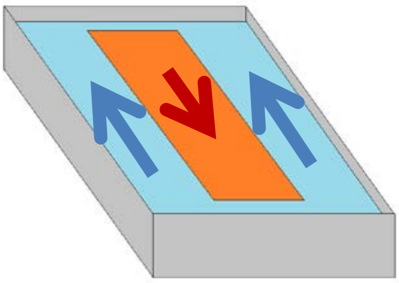

Figure 1. Sketch of the experimental setup: a belt (orange) moves at the surface of a water tank (blue). Some of the water is dragged (red arrow) inducing recirculation (blue arrows).

OBSERVATIONS

In our geometry, at slow velocities, for a tape speed V<<100mm/s, we observed that all the surface of the tank is dragged by the belt and the recirculation flows at the bottom. It does not leads to KHI. At higher velocities, for a tape speed V>>100mm/s, there is a transition to another pattern: the surface stops to be dragged and the recirculation occurs along the tape lateral sides, here we observe KHI with formation of vortices and turbulence [4].

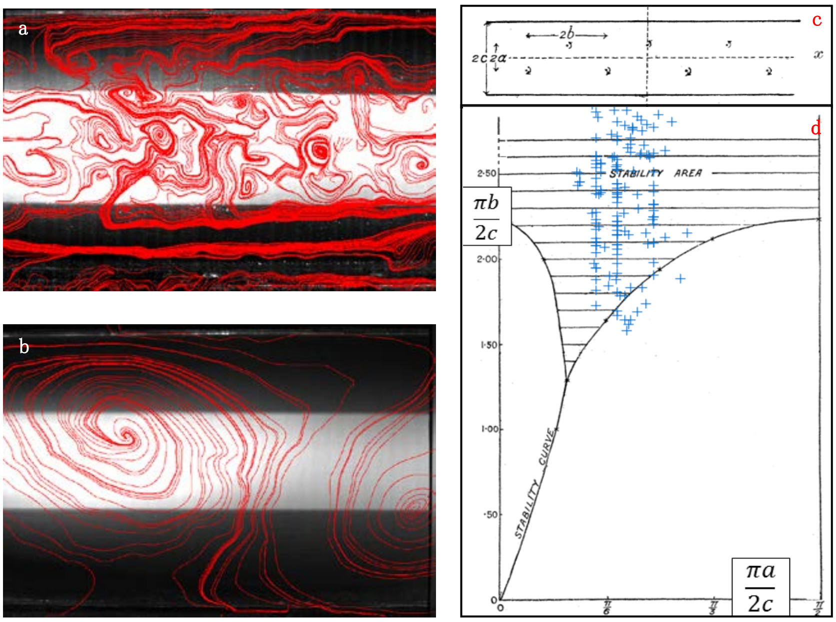

Figure 2. Left :View of a portion of the flow in a horizontal plane under the belt (in white). The top and the bottom of the pictures correspond to the lateral walls. Streamlines are ine red. **a -** 3D flow. **b -** 2D flow, with big stable vortices. Right : **c -** geometry of the Rosenhead-like vortex street, definition of a, b and c used in the graph below. **d -** Stability graph of the vortex street, depending on a, b and c. The hatched zone is where Rosenhead predicts stable streets. The blue points give our vortex street characteristics. We see that our experimental results are compatible with the theory.

Depending on the geometry of the tank, the KHI can lead to stable or unstable vortices. A transition between a two-dimensional and a three-dimensional flow is observed:

- When the depth of the water is higher than an experimental value h_e (around 45mm), we observe small unstable vortices appearing and disappearing constantly in the flow, as can be seen in Figure 2a. The flow is mainly tri-dimensional. **Figure 2a**
- When the depth of the liquid is lower than h_e we observe a transition to a mainly 2D flow. Here, the vortices are stable and grow until they lead to a relatively well organized vortex street confined between the two lateral walls. **Figure 2b**
- However, if the tape is larger than an experimental critical value, we do not observe any stable vortices anymore, irrespectively of the depth of water.

The behavior of the vortex street and more precisely, the selection of vortex spacing is in agreement with the theory developed by Von Karman in 1912 for point vortices streets in an infinite geometry [5] and completed in 1929 by Rosenhead for a street confined between two walls [6]. See **Figure 2c & 2d**. We thus generated a Bénard-Von Karman Street without the help of a classical wake behind an obstacle.

Further investigations are expected. We are currently trying to understand how to characterize the 2D-3D transition. Improved modeling including the 3D cyclone structure of the vortices, as well as direct numerical simulations are also under way.

References

[1]Lord Kelvin, "Hydrokinetic solutions and observations". *Philosophical Magazine* 42: 362–377. (1871)

[2] Hermann von Helmholtz. "Über discontinuierliche Flüssigkeits".*Mon. Königlichen Preus. Akademie Wiss. Berlin* ***23****: 215–228* (1868).

[3] M. Rabaud and Y. Couder, « A shear flow instability in a circular geometry », J. Fluid Mech. 136, 291-319 (1983)

[4] P. Boniface, L. Lebon, L. Limat, M. Receveur, F. Bouillet, "Kelvin-Helmholtz instability in a confined geometry", Bull. of the American Phys. Soc., 65th Annual Meeting of the APS Division of Fluid Dynamics, Vol. 57, Number 17, November 18–20, 2012; San Diego, California (2013).

[5] Th. V. Karman. "über den Mechanismus des wiederstandes, den ein bewegter korper in einer flüssigkeit erfahrt", Gött. Nachr. p. 547 (1912)

[6] L. Rosenhead, " The Karman Street of Vortices in a Channel of Finite Breadth", Phil. Trans. R. Soc. Lond. A 228, 275-329 (1929).