Experimental Study of Surface Dynamics of a Liquid Jet

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Introduction

An interface between a liquid and a gas can exhibit various intricate shapes such as:

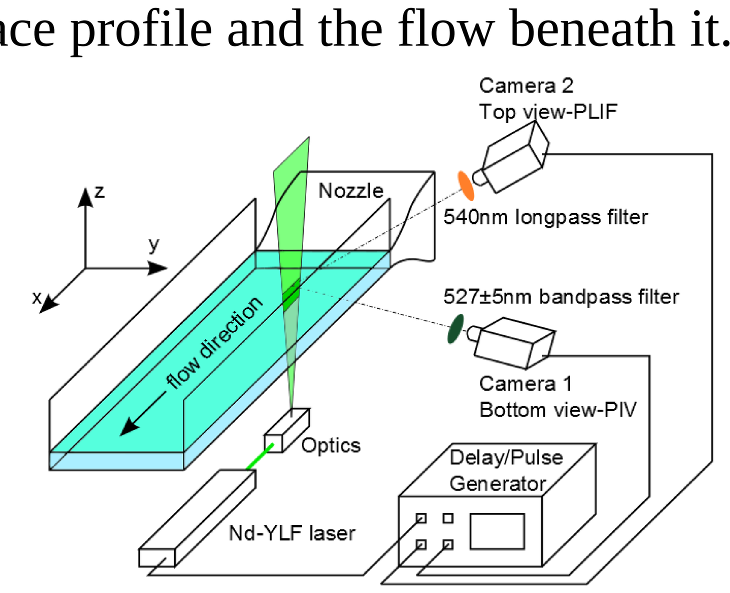
This has very important consequences on:

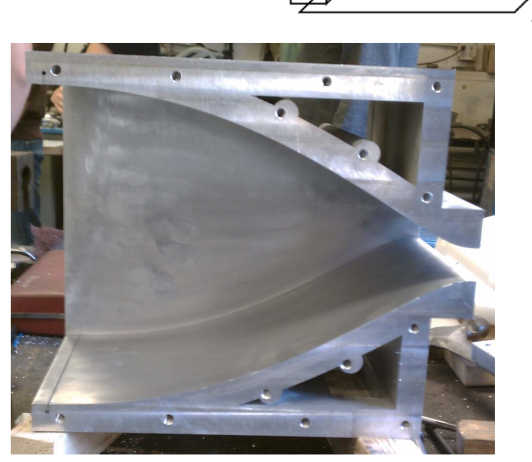
- Spray/Atomization
  - Fuel injection
  - Water jet breakup
- Aeration/Gas entrainment
  - Oxygen for aquatic life
  - Atmospheric CO_2 absorption by oceans
- Heat and mass transfer
  - Heat exchanger
  - Mixing process

An experimental approach is necessary to investigate such complex flows.

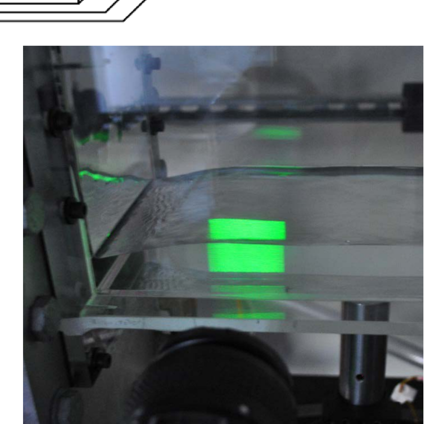
Experiment and Instrumentation

This research focusses on instabilities arising when the flow exits a wall. A 0.8” thick water jet flows from a contoured nozzle onto a transparent channel at velocities of 0 to 33 ft/s. A pulsed laser illuminates a cross section of the flow and two high speed cameras are simultaneously imaging the surface profile and the flow beneath it.





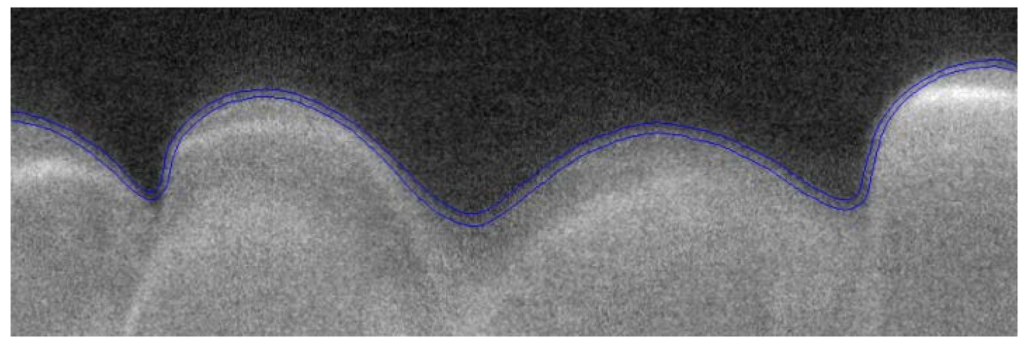
Machining of the nozzle out of aluminum.



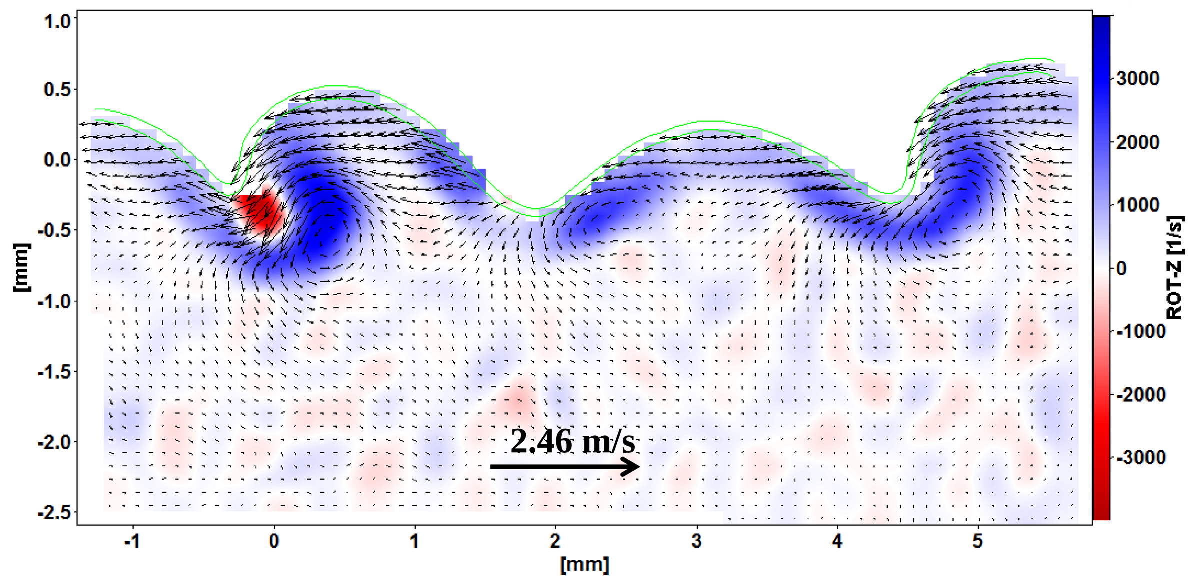
Jet exiting the nozzle, laser sheet is visible.

Results - Instability Growth Mechanism

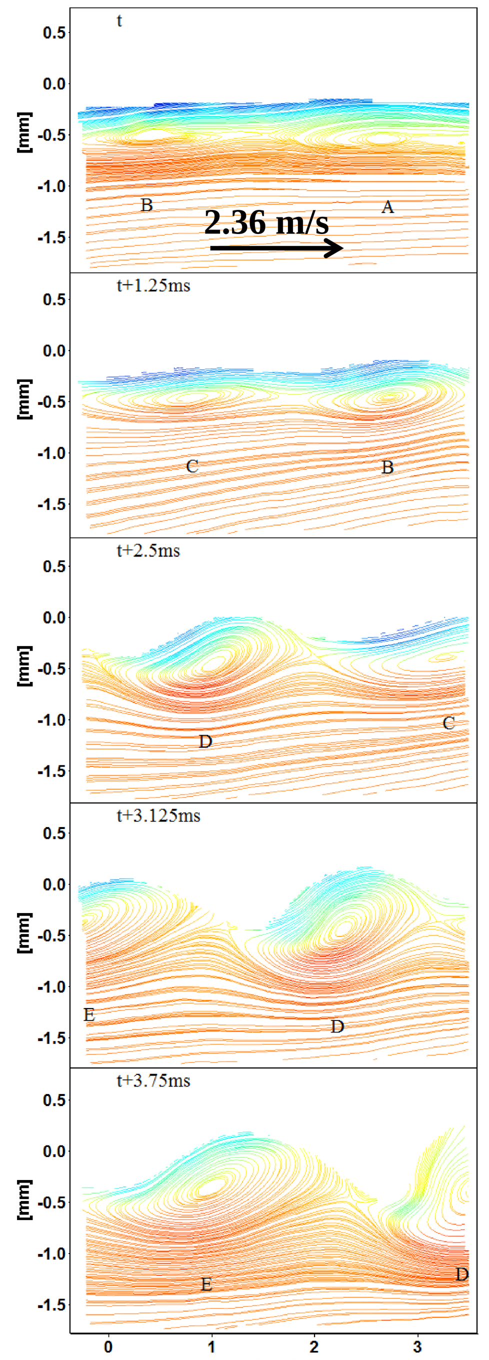
2D spanwise disturbances are visible on the surface of the jet. These are very small: (scale 1:1), thus high magnification optics are required.



Planar Laser Induced Fluorescence (PLIF) shows the surface profile. A Matlab® code automatically detects the interface location.



Particle Image Velocimetry (PIV) reveals the 2D velocity field below the surface. Surface profile from PLIF has been used to mask the image above the interface.

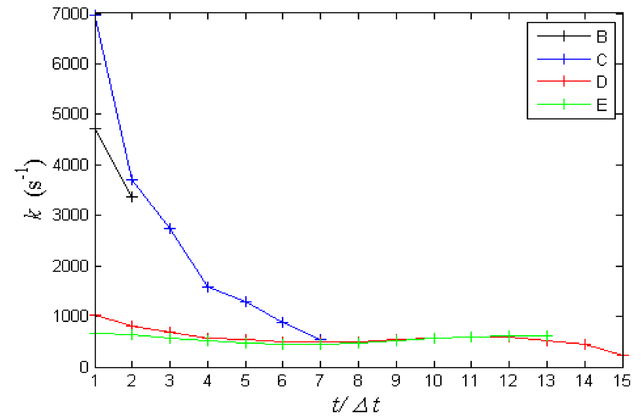


Time series of streamline plots showing the deformation of the surface by the vortexes.

The shear layer rolls up and forms a series of vortexes which deforms the surface.

- The first part is characterized by a quick growth (waves B and C).

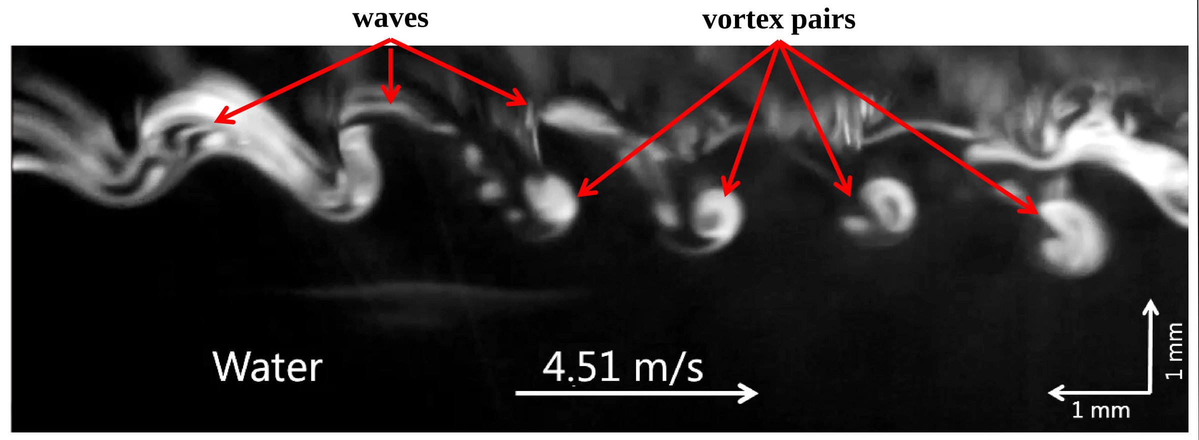
- The second part is defined by a constant growth rate (waves D and E). The waves and the vortexes are then coupled. This can sustain the waves for a long period.



Temporal growth rate of the waves showed on the left.

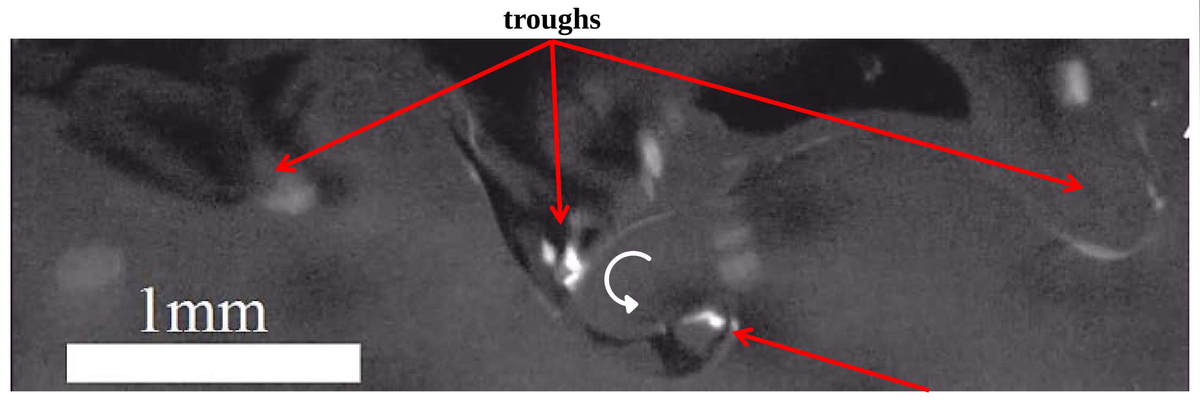
Results - Air Entrainment Mechanisms

For higher velocities, the waves collide. A counter-rotating vortex pair is injected in the flow from the closing troughs:



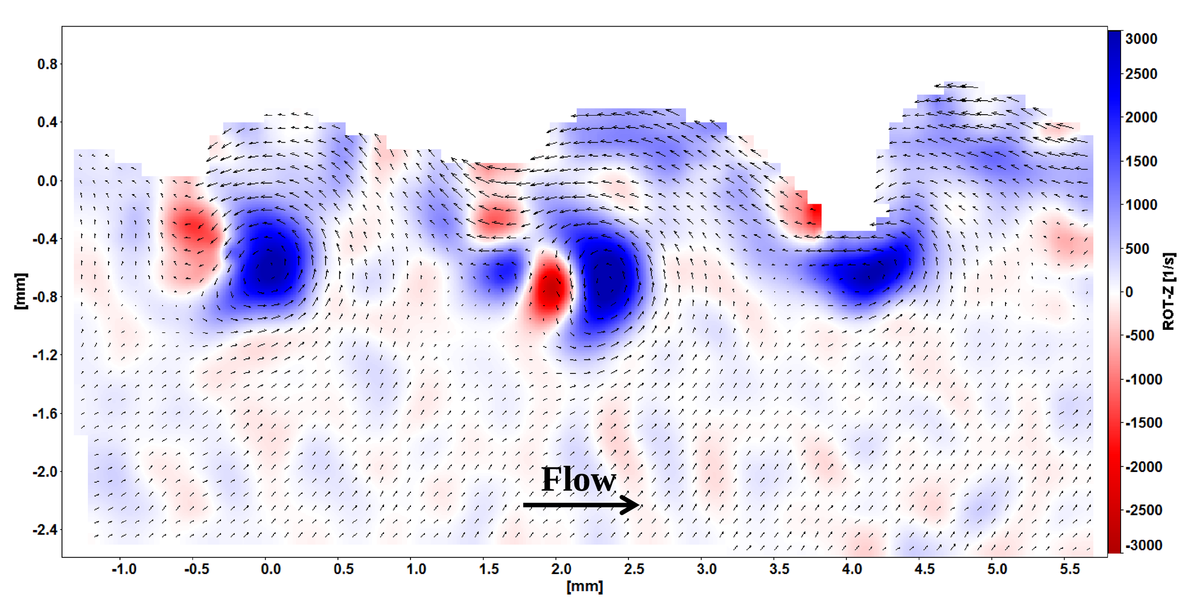
PLIF view with fluorescent dye in the surface layer.

The closing troughs can entrap an air bubble:

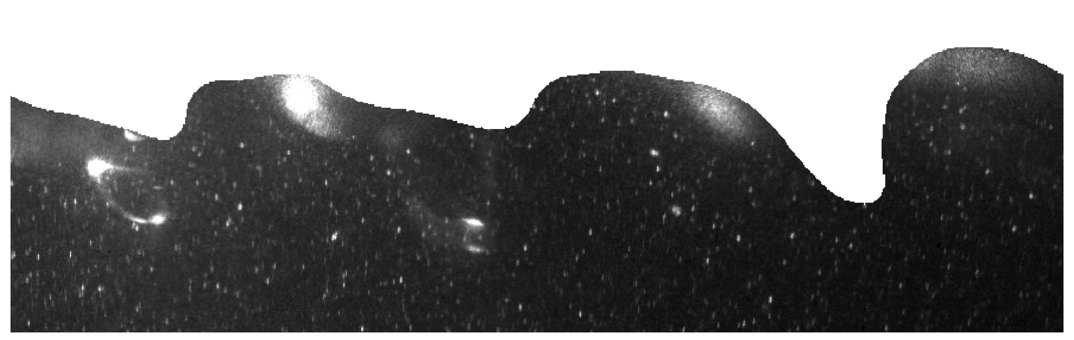


PLIF view showing a ligament of air about to breakup and releasing a bubble in the flow.

The bubbles are convected by the vortex pairs:



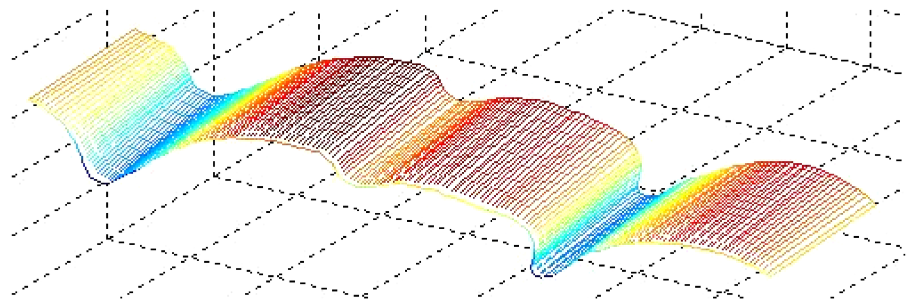
PIV view showing the vortex pairs (the red and blue blobs).



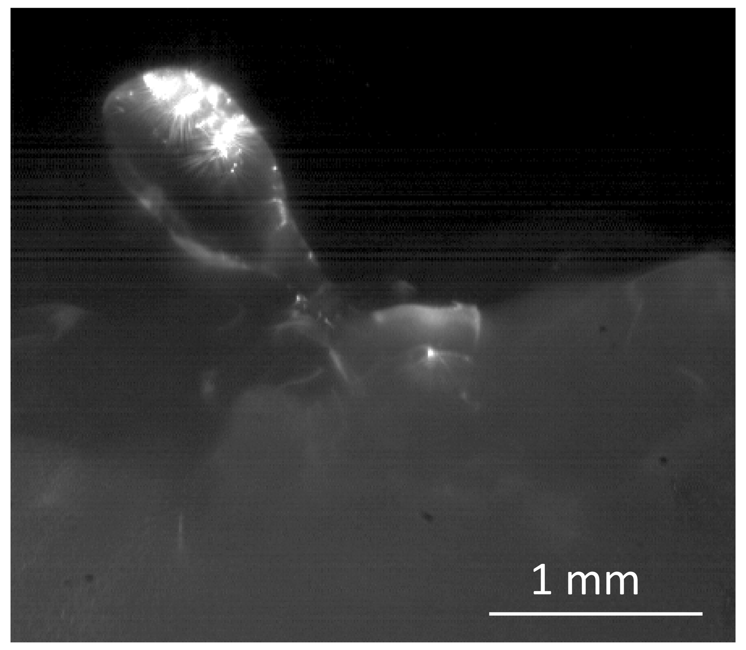
Raw image corresponding to the PIV image above. Air bubbles are visible where the vortex pairs are located.

Work In Progress

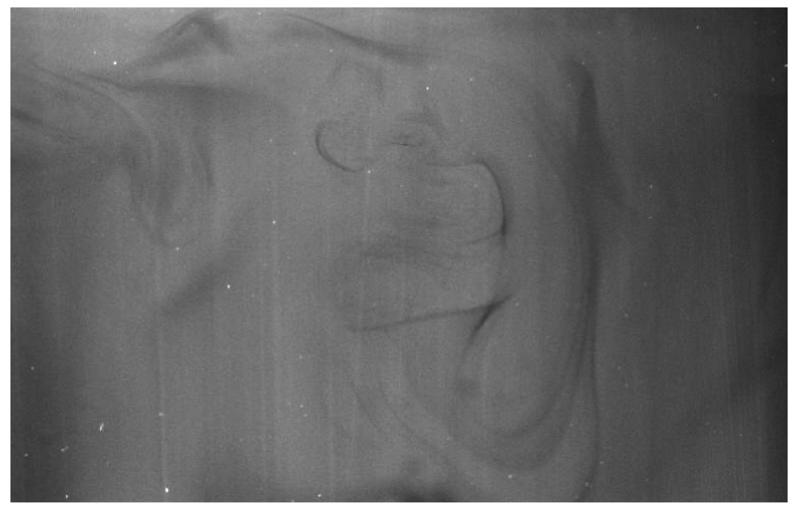
- 3D measurements:



- Primary breakup at higher velocity (10m/s):



- Direct mass transfer measurements: Dissolved oxygen is visible in dark by using a O_2 sensitive fluorescent dye:



Conclusion

Surface dynamics from initial disturbances to large amplitude deformations have been studied and characterized. Injection of vortex pairs has been observed for the first time. A new air entrapment mechanism in the trough of waves is also reported. The experiment offers the possibility to investigate primary breakup and other turbulent air entrainment mechanisms. Measurements of interphase gas transfer will be implemented in the near future. These results will help developing empirical correlations and validate high fidelity multiphase flow numerical simulations.