CENTER FOR FLUID MECHANICS AND THE FLUIDS, THERMAL AND CHEMICAL PROCESSES GROUP OF THE DIVISION OF ENGINEERING SEMINAR SERIES

Tuesday, April 26, 2005, Barus & Holley, Room 190, 4:00pm

Professor Alexandra H. Techet, Massachusetts Institute of Technology, Center for Ocean Engineering

High Speed PIV of Breaking Waves on Both Sides of the Air-Water Interface

Wave breaking on the surface of the ocean results in significant transfer of mass, momentum, heat and energy across the air-sea interface. However, understanding the physics of these phenomena remains a challenge, as both the measurement and simulation of the relevant processes are highly complex. Recent numerical studies have begun to investigate the air-water coupling during the breaking process using level set methods (Hendrickson, 2004), but relatively few experimental studies have looked at flow on both sides of this interface. In order to more clearly understand the whole picture and to generate accurate models, experiments and simulations which consider the physics on both the air and water-side of the air-sea interface are necessary.

This talk presents experiments on small-scale, steep breaking waves forced by shoaling the waves up a ten degree slope to a level plateau. Breaking waves are generated by a computer controlled, paddle-type wave maker at one end of small (250cm long, 15.25 cm wide, 20.3 cm deep) acrylic tank. A beach is place at the far end of the tank to absorb reflections. The waves generated in this tank were smaller in scale than typical wave breaking experiments, in order to compare with numerical simulations by Hendrickson which were on the order of Reynolds number 10^3-10^4. Reynolds number in this case is defined as $\mathrm{Re} = \frac{\rho\sqrt{g\lambda^3}}{\mu}$, where ρ is the fluid density, μ is the fluid dynamic viscosity, g is the gravitational constant, and λ is the characteristic wavelength of the breaking wave. Reynolds numbers for the experiments presented here are between $9\mathrm{x}10^4$ and $2\mathrm{x}10^6$.

Qualitative and quantitative measurements were obtained through high-speed imaging techniques, including high speed PIV. While PIV seeding in the water was quite straight-forward, seeding in the air was quite complex. Air-seeding techniques such as atomized oil droplets are not appropriate in this study as the oil would negatively influence the surface tension significantly. Thus a water-soluble fog was used to seed the air, again no change in surface tension was recorded by addition of the fog. High speed video results show the formation of the vortex aft of the breaking wave and reveal strong counterclockwise vorticity in the air side of the interface. Conversely in the water, the majority of the vorticity has clockwise rotation for waves traveling from left to right. Figure 1 shows a snapshot of velocity (top) and vorticity (bottom) for a plunging breaker after the jet from the face of the wave has impacted the free surface and the air cavity has collapsed into smaller bubbles. Vector colors and length in the top plot represent magnitude of velocity from high (red) to low (blue). In the vorticity plot (below) the red represents clockwise vorticity and the blue counterclockwise vorticity. The red line shows a profile of the surface above which there is no water. Below this line is water except in a region of two-phase flow where air has been entrained due to the plunging jet.

This talk will present data from the experiments and discuss the experimental issues relating to measurements on the air-side of the air-sea interface. Challenges remain to refine air-side visualization method with improved seeding method and the implementation of a two-laser/two-camera setup with high-speed imaging capabilities. Data from wave probes and PIV measurements can then be used to quantify energy dissipation and transfer across air-water interface and the turbulent structures in the flow.

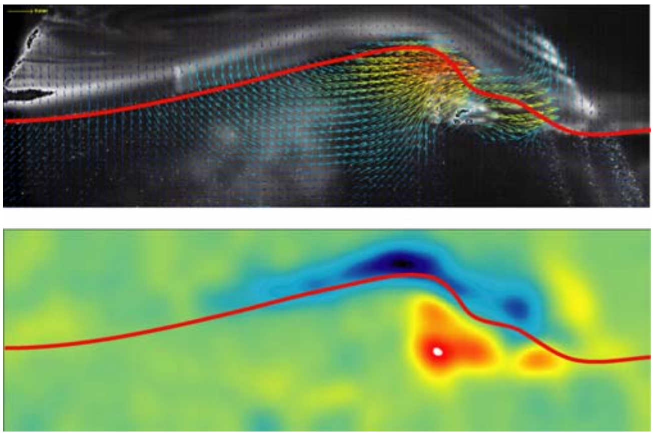

Figure 1: PIV measurements of the flow field, velocity (top) and vorticity (bottom), for a breaking wave just after the jet has plunged into the free-surface. The wave is moving from left to right. Red represents clockwise vorticity and blue counterclockwise vorticity in the lower plot.

References : K.L. Hendrickson, “Navier-Stokes Simulations of Steep Breaking Water Waves with a Coupled Air-Water Interface,” PhD Thesis, Massachusetts Institute of Technology, 2004.