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UNSTEADY SEPARATED FLOW NEAR A FREE SURFACE

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ABSTRACT

Aim
The aim of the study is to determine the mechanisms by which vortex shedding from a circular cylinder is suppressed as it is moved closer to a free surface. This involves varying both the gap between the cylinder and the free surface and the Froude number of the flow. The fluid motion is predicted using a finite volume solver and compared with a number of previous experiments, particularly those of Sheridan *et al*. (1997).

Numerical Method
In order to model the free surface, which in practice is an interface between water and air, a two-dimensional multi-phase finite volume scheme was employed. This model essentially calculates the flow field for a single phase (with variable density and diffusivity) and determines the degree of mixing between the phases via the void or volume fraction. The scheme used was second-order accurate.

Results and Discussion

<u>Low Froude Number</u>
The different wake patterns as the cylinder is moved closer to the free surface are shown in Figure 1. The upper plot of each pair is for Fr = 0.0, the lower plot being for Fr = 0.20. The gap is denoted by the h^*, which is the gap normalised by the cylinder diameter.

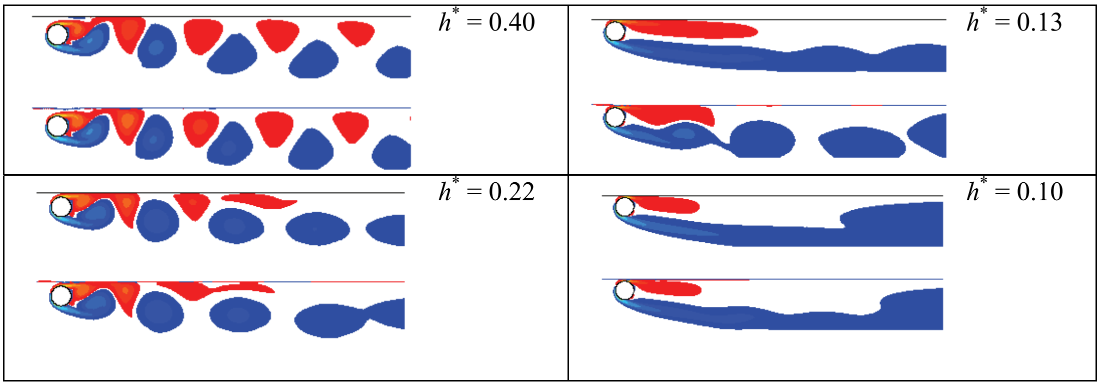

Figure 1 Vorticity fields for vortex shedding from a submerged cylinder for different gaps, h^*, and slip (Fr = 0.0) and free-surface condition (Fr = 0.2); flow from left to right.

The Strouhal number variation is shown in Figure 2 and compared with the observations of Angrilli *et al*. (1982). The Strouhal number increases slightly with decreasing gap before dropping off dramatically. Periodic shedding ceases altogether at approximately h^* = 0.13.

Higher Froude Number

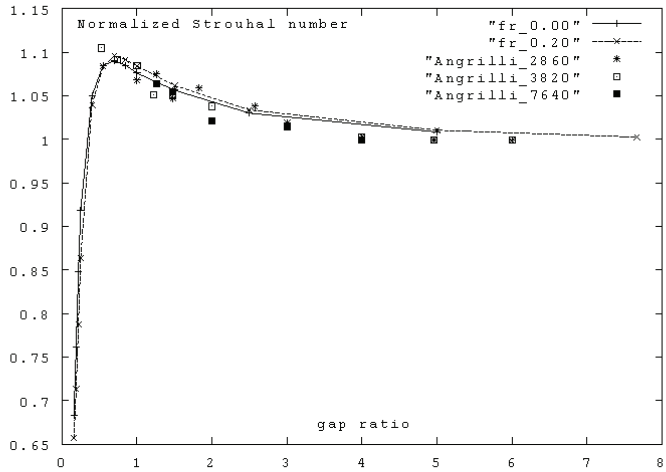

Fig.ure 2 Variation of predicted Strouhal number (normalised with respect to Strouhal number of the reference cylinder, i.e., St/St_0 with gap ratio, for both Fr=0.00 and Fr=0.20. The labels Angrill_2860, Angrill_3820 and Angrill_7640, in the Figure refer to the results of Angrilli et al. (1982) at three different Reynolds numbers namely (2860, 3820 and 7640).

At higher Froude numbers, the vortex shedding is suppressed at slightly larger gaps. In addition, the greater deflection of the free surface leads to some interesting effects, such as metastable states. The additional effects of surface deformation and secondary separation will be shown at higher Froude numbers to lead to more efficient annihilation of the vorticity shed from the cylinder surface closer to the free surface. The counter vorticity shed from the free surface and tracer particle paths are shown in Figure 3.

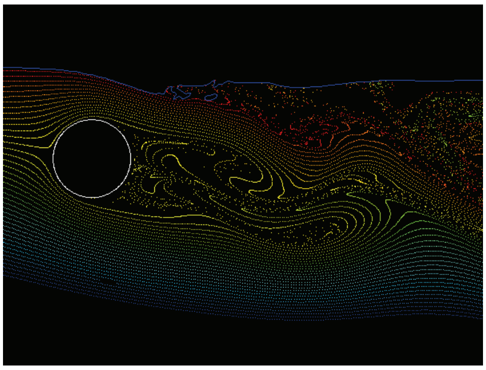

Figure 3 Flow field, from left to right, around a submerged cylinder at Froude number 0.60 and normalised gap h^* = 0.55. Left: Vorticity field; Right: Particle traces.

Proposed Mechanisms for Vortex Shedding Suppression
Detailed videos of the predicted flows will be shown at the symposium showing particle traces and vorticity fields. The mechanisms of vortex shedding suppression, *viz.* entrainment starvation, cross-annihilation due to free surface shedding, and vortex tearing, will be presented.

References
Angrilli, F., Bergamaschi, S. and Cossalter, V., *Journal of Fluids Engineering, Transactions of ASME*, **104** (December), 1982.
Sheridan, J., Lin, J.-C. and Rockwell, D., Flow over a cylinder close to a free surface, *J. Fluid Mechanics*, **330**, 1-30, 1997.