Modeling of instabilities of oil containment systems by a vortex sheet method

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Floating booms with a catenary shape are the classical means of oil spill containment in the ocean or in rivers (Fig. 1). Due to the relative boom-water velocity U, oil is forced to accumulate in the boom's apex, as a gradually thickening slick; other equipments such as skimmers are then used to pick-up the oil. In the ocean, for optimum efficiency of the clean-up process, U should be as large as possible; various instabilities at the oil slick/water interface—both small and large scale—however, put a low practical limit to this velocity at about $U_{cr} \simeq 0.5$ m/s (see Grilli *et al.* (1996) (GHS) for details and literature review).

Experiments have shown that such instabilities are triggered by small scale shear instabilities at the oil/water interface, i.e., so-called Kelvin-Helmholtz (KH) instabilities (GHS) : beyond a critical value, the KH instability growth rate increases as a function of U and the density ratio $\varphi = \rho_o/\rho_w$ (with ρ_o the oil density and ρ_w the water density), and decreases with an increase in oil/water interfacial tension σ_{ow}. Increasing nonlinear effects, as interfacial KH waves develop and roll-up, are expected to reduce the instability growth rate to some extent, but only a numerical model can quantify these effects.

In this study, a vortex-sheet (VS) model of the fully nonlinear time evolution of KH instabilities at the interface between two fluids is developed and applied to the oil-water-boom system. To gain a better physical understanding of the effects of controlling parameters on nonlinear KH instabilities, we first restricted our scope to the simplified case of spatially-periodic two-dimensional KH instabilities. A periodic higher-order VS Boundary Element Model, combining the solution of Biot-Savart (BS) equation and a time evolution equation for the interfacial vorticity, was developed. Details of model development, implementation, and validation can be found in Grilli and Hu (1997). This model accurately predicts the fully-nonlinear growth rate of periodic interfacial KH instabilities, including situations where intense roll-up of interfacial VSs occurs (Fig. 2).

The application of this model to non-periodic cases is considered in the present study. Fig. 3 shows a sketch for the computational domain for an oil-water-boom system, in a vertical plane through the boom's apex. The central region is discretized by higher-order VSs and the semi-infinite regions before and beyond the boom, where the relative water velocity U is uniform, are represented by semi-infinite VSs over which BS's equations are analytically integrated. Fig. 4 shows a typical result obtained for a so-called headwave instability of the oil layer.

Details of the model equations, numerical implementation, and results will be presented and discussed at the workshop.

References

Grilli, S.T., Hu, Z. and Spaulding, M.L. Numerical Modeling of Oil Containment by a Boom. In *Proc.*

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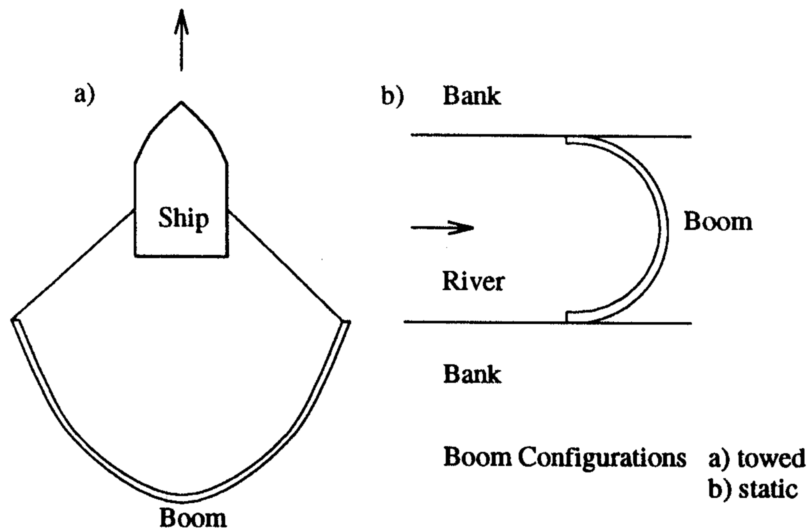

Figure 1: Floating booms used in oil containment systems : (a) towed boom in the ocean; (b) fixed boom across a river. Relative oil-water velocity is U.

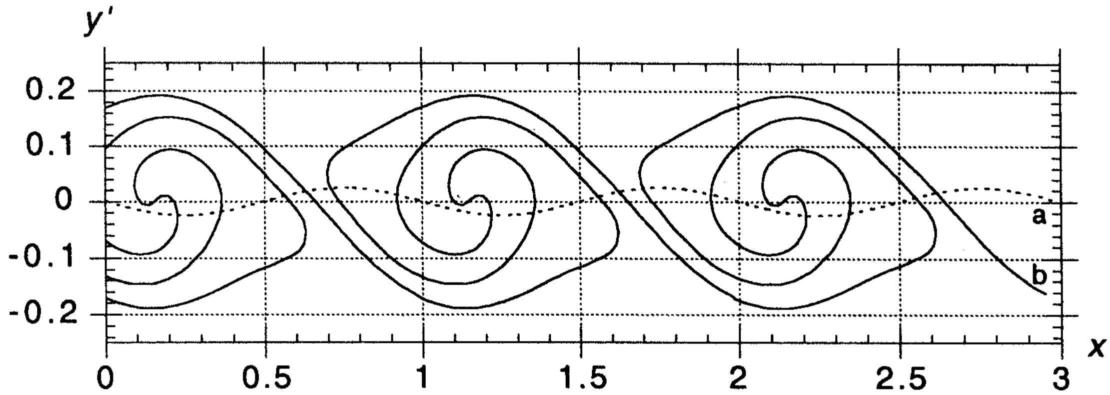

Figure 2: Typical computational result for the periodic KH instability at the interface between two fluids. a: initial sinusoidal perturbation; b: computational profile at some later time.

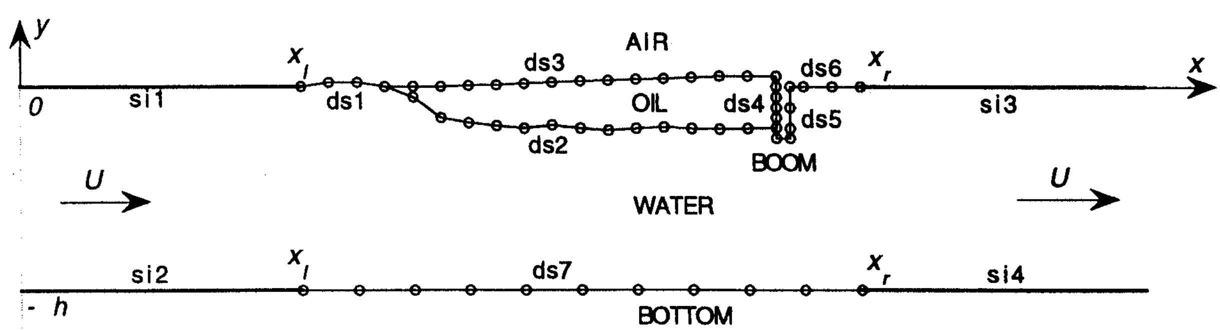

Figure 3: Sketch of computational domain for the non-periodic model. si : semi-infinite VSs; ds : discretized VSs.

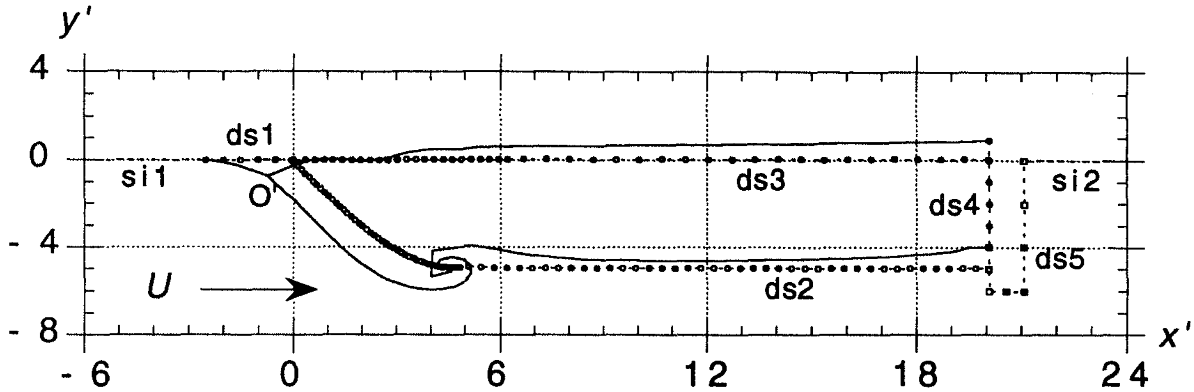

Figure 4: Typical computational result for the headwave instability of an oil slick contained by a boom (non-dimensional lengths have been used). (—o—) initial discretized oil slick shape; (——) computed oil slick shape at some later time.

19th Arctic and Marine Oil spill Prog. Tech. Seminar (AMOP), pps. 343-376. Environment Canada, 1996.

Grilli, S.T. and Hu, Z. A Higher-order Hypersingular Boundary Element Method for the Modeling of Vortex Sheet Dynamics. *Engineering Analysis with Boundary Elements* (accepted 10/97), 1997.