THE INITIAL DEVELOPMENT OF A JET

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There is a long history of experimental and theoretical studies of the interaction between a solid body and a fluid with a free surface. One outstanding, and occasionally dramatic, feature of the fluid/body interaction is that of jet formation. As examples of this, a ship moving at forward speed can carry with it a large bow splash, and the impact of a wave on a tidal barrage (or any form of sea defence) may cause a large jet of water to rise vertically. These jets are of some practical importance as they may affect the stability of a vessel or cause wear and damage to a barrage.

At the present time the effect of these jets is assessed by either scale model experiments or, more commonly, numerical simulations of the flow. For the details of various numerical schemes and an extensive source of references see Greenhow (1993). Any numerical scheme that attempts to follow the evolution of such a jet caused by a body being moved impulsively into the fluid must address the question of what spatial resolution is needed to accurately model the jet. The thickness of a jet forming on an undisturbed free surface is initially zero and subsequently increases. The accuracy and efficiency of the numerical calculation of such a flow may be improved if the order of magnitude of this jet thickness is known *a priori*; a discussion of this issue can be found in Greenhow (1987). It is worth pointing out that for wedge entry problems, which are commonly used to model ship-slamming, the flow is intrinsically self-similar so that the temporal evolution of jet thickness is known *a priori.* However, the resolution of the spatial structure of the jet still poses considerable difficulty. Recent work on this type of flow can be found in Cointe & Armand 1987, Cointe 1989 and Howison, Ockendon & Wilson 1991.

This work studies the small time evolution of a jet which is formed when a vertical plate is accelerated into a stationary fluid of finite depth with a free surface and gravitational restoring force. It is clear that this model problem is related to the initial motion of a slender ship accelerating from rest, where the flow, in a place transverse to the motion, is that of a plate moving into a stationary body of fluid with a free surface. This particular jet problem has been studied experimentally by Greenhow & Lin (1983) in the context of wavemakers and ship-slamming, and with particular reference to jet formation by Yong & Chwang (1992). An interesting, although unpublished theoretical study of this problem was carried out by Peregrine in 1972 who developed a solution that was valid except in a neighbourhood of the free-surface/plate intersection where a singularity developed.

Essentially the same analysis although with a greater variety of plate motions was carried out by Chwang (1983). A method of avoiding the above-mentioned singularity was devised by Roberts (1987) who treated a transient wavemaker problem by an expansion in wavemaker amplitude. A train of very short-wavelength dispersive waves was found near to the moving boundary. This study was extended by Joo, Schultz & Messiter (1990) to include capillary effects and it was shown that the prescription of a contact angle between the wavemaker and fluid could supress the short-wavelength wiggles found by Roberts. One feature of the solutions of Roberts and Joo *et al.* that is of some note is the free-surface slope at the contact point jumps to a finite value in infinitesimally small time. Most recently this problem has been studied by Frankel (1990) in the context of a slightly compressible fluid. However, in the limit of zero compressibility the singularity that was found by Peregrine reappears at the free surface/plate intersection.

We now readdress the basic problem of a plate accelerating into a fluid at rest with a free surface by using matched asymptotic expansions to construct a uniformly valid small-time solution which holds for arbitrary parameter values. The anlaysis of a surface-piercing plate impulsively moved into a fluid with constant velocity requires a more sophisticated asymptotic theory. We take as a starting point the Euler equations for incompressible inviscid flow and construct an asymptotic solution to these with the time (t) as small parameter. In this particular problem the flow is irrotational and we could work with a velocity potential from the outset. We choose not to do this for two reasons. In physical variables we feel there is rather more insight into the pressure and velocity field which causes the jet. Furthermore, for a slightly compressible fluid which is rapidly accelerated such as water-hammer problems, there is the possibility of a curved shock front being formed. By Crocco's theorem this would generate vorticity and we would then be forced to return to the Euler equations as the irrotationality is lost. The basic outer solution contains a non-uniformity, which manifests itself as a singularity at the free-surface/plate intersection, and is caused by the neglect of the fluid inertia near to the plate. On rescaling to a region near to the plate it is necessary to solve the full nonlinear free-surface flow problem. However, the boundary conditions are rather simpler than the original ones and a simple exact solution can be found which represents a thin jet of fluid rising uniformly up the plate. The spatial structure of the flow in this region is found by further considering higher-order terms in this inner region. We conclude by surveying other free-surface flow problems of possible practical importance which can be treated by the methods presented here.