WATER EXIT OF SLENDER AND NON-SLENDER BODIES.

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Abstract

In a recent paper Greenhow (1987) looked at the wedge entry problem in some detail. For high enough constant entry speeds, the numerical results agreed well with solutions based on self-similarity of the flow which arises when gravity is neglected. For exit, however, gravity is essential: for example, an acceptable gravity-free solution would be that the fluid immediately loses contact with the wedge at all points, thereby leaving a triangular deformation in the free surface. Clearly this will not happen in practice. We also note that unlike the self-similar wedge entry problem, for exit there is a characteristic length scale from the initial condition (e.g. half the waterplane length ℓ , see figure 1) and hence a Froude number $F_r = U^2/\ell g$. The fact that entry is in no sense the time reversal of exit is further underlined by realising that the initial conditions for entry are not the final conditions for the exit problem we wish to solve, and vice-versa.

The author will present a number of wedge exit calculations based on the fully non-linear time-stepping method of Vinje and Brevig (1981); an example is given in fig 1. Forces and pressures will be examined, but it is not yet known if a pressure reversal across the free surface, leading to instability, can occur (as in the initially submerged cylinder exit case, see Greenhow 1988).

Unlike entry, where approximate but analytic added mass theories (including splash-up) are available, the exit problem does not appear to have been studied, since the gravity-free approximation is no longer available (as well as other difficulties outlined in Howison et al 1989). So far the only possibility seems to be Mackie's (1965) theory, based on time-dependent wavemaker theory, which assumes the body is slender so that the body boundary condition can be transferred to the centreline. Thus the linearised free surface elevation (including gravity) for wedge entry is given by:

$$\eta(x,t) = \frac{2}{\pi} \int_0^\infty \bar{\eta}(\lambda,t) \, \mathrm{Cos}\lambda x \, d\lambda$$

where $$\bar{\eta}(\lambda,t) = \frac{\varepsilon U^2}{\lambda(\lambda U^2+g)} \left[\mathrm{Cos}\left(\sqrt{\lambda g}\; t\right) - U\sqrt{\frac{\lambda}{g}}\,\mathrm{Sin}\left(\sqrt{\lambda g}\; t\right) - e^{-\lambda ut} \right]$$

For the exit problem we $(U < 0)$ have instead

$$\bar{\eta}(\lambda,t) = \varepsilon U^2 e^{-\lambda D} \left\{ \frac{\mathrm{Cos}\left(\sqrt{\lambda g}\; t\right) - e^{-\lambda Ut}}{\lambda(\lambda U^2 + g)} \right\}$$

$$- \frac{\varepsilon U e^{-\lambda D}\, \mathrm{Sin}\left(\sqrt{\lambda g}\; t\right)}{\lambda\left(\lambda U^2 + g\right)\sqrt{\lambda g}} \left\{ \lambda U^2 e^{\lambda D} + g\left(e^{\lambda D} - 1\right) \right\}$$

where D is the initial submergence depth and ε is the wedge half-angle (assumed small). From figure 1 we see that the linearisation of the free surface may not be too degrading; the satisfaction of the body boundary condition on $x = 0$ can however only be valid if ε is small. A major objective will be to compare these elevations with the numerical results to ascertain a range of F_r and ε where agreemnt is acceptable.

Some initial calculations have also been made with half-angles of 45° and 60°. As well as their intrinsic interest, these exit problems have important practical implications for ship slamming forces which are dependent on U^2 and hence correct calculation of U is important. This depends upon ship motions immediately preceding the slam; in particular the forces during bow emergence may affect the ship motion and hence U.

References

1) Greenhow M, (1987). "Wedge entry into initially calm water". **Appl. Ocean Res.,** Vol 9, pp 214-223.

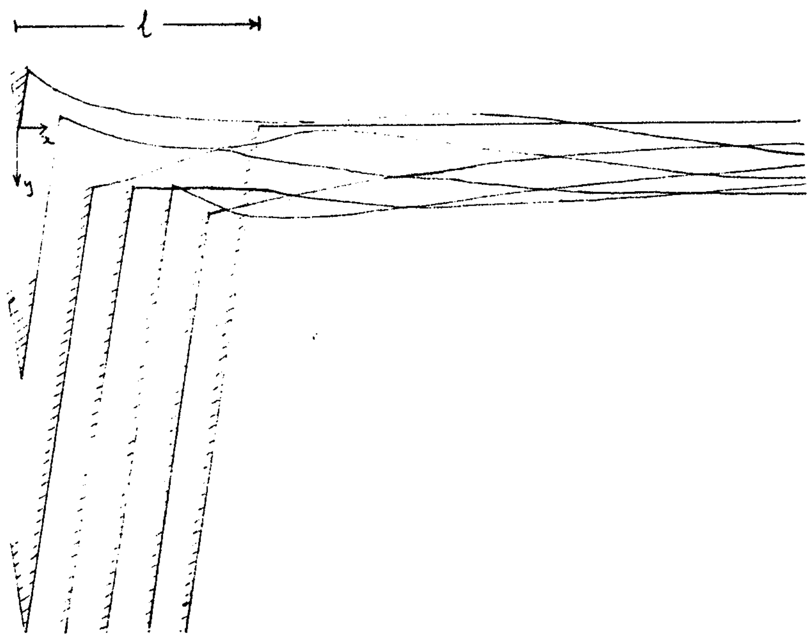
2) Greenhow M, (1988). "Water entry and exit of a horizontal circular cylinder". **Appl. Ocean Res.,** Vol 10, pp 191-198.

3) Howison S D, Ockendon J R and Wilson S K, (1989). "A note on incompressible water entry problems at small deadrise angles". Submitted for publication.

4) Mackie A G, (1965). "Gravity effects in the water entry problem". **J. Aust. Math. Soc.,** Vol 5, pp 427-433.

5) Vinje T and Brevig P, (1981). "Nonlinear ship motions". **N.S.F.I. Report No R-112.81,** Trondheim, Norway.

Fig 1: Wedge exit from initially calm water $\varepsilon = 9°$, $F_r = 1.07$.



DISCUSSION

Miloh: A comment: our approach is not a three-dimensional extension of the method of Kaplan & Silbert [1], since we include the so-called 'wetting correction', which we found to be very important when we compared our analysis with the experimental data of Moghisi & Squire [2] (our paper is due to appear in *Appl. Ocean Res.*). The factor of $\frac{1}{2}$ which appears in the energy formulation (as compared with the momentum approach) depends on the interpretation of the kinetic energy computed.

Greenhow: I agree with your comment, of course — I may have pointed to the wrong diagram in my lecture, i.e. one without the free-surface correction that you used. The two-dimensional cylinder, with this correction, is treated in [3].

Miloh: It is quite common to apply the boundary condition $\phi = 0$ on the free surface at very early stages of water impact (following the classical works of von Karman, Sedov, Wagner etc.). How early is 'early' and what is the range of validity of this useful approximation?

Greenhow: For the cases of wedge entry treated by me, the approximation is good if

$$t \leq \frac{U}{2g},$$

i.e. gravity is then unimportant (except that the jets fall as parabolas).

Wu: When a body enters water at high speed, the water cannot be treated as incompressible. What happens when the body leaves the water at high speed?

Greenhow: If the body is deeply submerged, cavitation is a possibility. If it is near the surface, ventilation from the surface into the regions of low pressure can occur, which may cause Rayleigh-Taylor breaking due to pressure inversion; see Reference 2).

References

[1] P. Kaplan & M.N. Silbert, 'Impact forces on platform horizontal members in the splash zone', *Proc. 8th Offshore Technology Conf.*, Houston, Paper OTC 2498, Vol. 1 (1976) 749–758.

[2] M. Moghisi & P.T. Squire, 'An experimental investigation of the initial force of impact on a sphere striking a liquid surface', *J. Fluid Mech.* **108** (1981) 133–146.

[3] M. Greenhow & Y. Li, 'Added masses for circular cylinders near or penetrating fluid boundaries — review, extension and application to water-entry, -exit and slamming', *Ocean Engng.* **14** (1987) 325–348.