WATER ENTRY OF A TWO-DIMENSIONAL BODY

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Slamming is of practical importance in several ship and offshore related problems. In order to make further progress in the theoretical solution of slamming it is important to be able to satisfy the exact non-linear free-surface conditions and at the same time properly describe the local flow at the intersection between the free surface and the body surface. The intersection problem respresents especially a challenge at a non-vertical body surface. This is a typical situation for the slamming problem.

We will concentrate on the impact between an initially calm free surface and a two-dimensional body of arbitrary cross-section. We will assume potential flow and that the air flow has no influence on the water flow. The latter means that we exclude a body with horizontal flat bottom or a small deadrise angle ($< \sim 2$ - $3°$). At the intersection between the free surface and the body surface a jet flow is created. As a first approximation the pressure is constant and equal to atmospheric pressure through the jet. This enable us to simplify the problem. We do that by defining an instantaneous fluid domain Ω that does not contain the whole jet flow. We represent the velocity potential ϕ for the flow inside the fluid domain Ω by Green's second identity. The surface S enclosing Ω consists of AB, CD, S_B, S_F and S_∞. S_∞ is a control surface far away from the body. AB is shown in Fig. 1. The angle between the body surface and AB is 90°, while the angle between AB and the free surface is close to 90°. The line AB is in an area where the jet starts and where the pressure can be approximated by atmospheric pressure. Assuming the body surface is symmetric about the z-axis, CD will be symmetric with AB about the z-axis. S_B is the wetted body surface below the points A and C. S_F is the free surface outside the points B and D and inside S_∞.

The problem is solved as an initial value problem where we set the velocity potential and the free surface elevation equal to zero at initial time. By using the kinematic and dynamic free surface condition we can follow how the free surface S_F moves and how the velocity potential changes on S_F. Far away from the body we represent the flow by a vertical dipole (Faltinsen (1977)). AB is determined by locating an area close to body where S_F is nearly parallel to S_B. This is an area where we can assume there is a jet flow. We can determine the velocity potential at AB by using Bernoulli's equation and that the pressure is equal to atmospheric pressure at AB. CD is handled in a similar way. At each time instant we solve an integral equation resulting from Green's second identity. On AB, CD and S_F the velocity potential ϕ is known and the normal velocity $\partial\phi/\partial n$ is unknown, while on S_B ϕ is unknown and $\partial\phi/\partial n$ is known. Details about the numerical procedure will be given.

We have extensively studied a wedge with $\alpha = 45°$ (see Fig. 1). Fig. 2 shows numerical simulations of free surface elevations during entry of the wedge. The wedge had a constant velocity $U_\infty = 12$ m/s. The figure shows the position of the wedge and the free surface at different time steps. Except for in the start process, the forms of the free surfaces are quite similar. In Fig. 3 we have selected a typical result and non-dimensionalized it by $U_\infty t$. We note that there is good agreement with both the similarity solution and the experimental results by Hughes (1972). Hughes' solution neglects the effect of gravity and is based on the principle of similarity. He finds the solution numerically by conformal mapping. The angle at which the free surface meets the wedge is 3.6° in Hughes solution. In our numerical solution we implicitly assume that the free surface never intersects the body surface.

Fig. 4 shows predictions of fluid velocities on the wedge surface. The velocities are relative to a body-fixed coordinate system. The agreement with Hughes solution is good except close to the jet area. The agreement between our numerical results and the experimental results is generally good. Hughes has also presented numerical results for the pressure distribution on the wedge surface. Our results agree well with Hughes' results except for a difference in the position where the maximum pressure occur close to the jet. An important reason to this difference is the differences in predicted velocities in this area (see Fig. 3). Greenhow (1987) has also tried to compare with Hughes' numerical solution. This was based on Vinje & Brevig's (1980) non-linear numerical method and a detailed description of the jet flow. His pressureresults showed poor agreement with Hughes' results. This indicate that a robust way of handling the flow at the intersection between the free surface and the body is essential.

We have also tried our numerical method for smaller α-values. At the moment we feel that we have been successful in simulating results for $\alpha = 15°$. The smaller the α-value is, the stronger the jet flow is, and the more difficult it is to follow numerically the flow in time. Our method is not restricted to wedges. In the future we will study ship sections typical for high-speed vessels. We also hope to be able to predict wave impact against the wet deck of catamarans and SES. However this will require that we are able to simulate impact for quite small α-values ($\sim 3°$). We hope to be able to present results for this case at the workshop.

References

Hughes, O.F., 1972, Solution of the wedge entry problem by numerical conformal mapping, J. Fluid Mech, 56, 1 : 173-92.

Faltinsen, O., 1977, Numerical solutions of transient nonlinear free-surface motion outside or inside moving bodies, Proceedings Second Int. Conf. Num. Ship Hydro., Univ of California, Berkeley.

Greenhow, M., 1987, Wedge entry into initially calm water, Applied Ocean Research, 9, 214-23.

Vinje, T., Brevig, P., 1980, Nonlinear two-dimensional ship motions, Proc. 3rd Int Conf. Num. Ship Hydro, Paris, June, pp. 257-66.

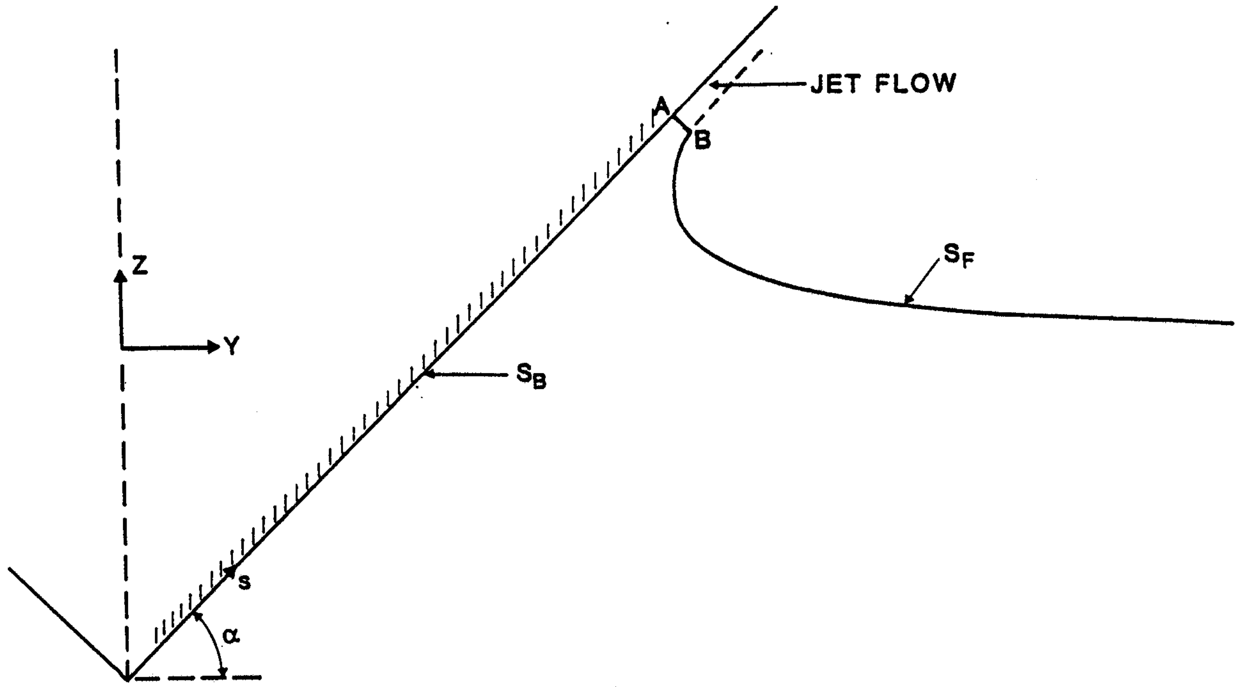

Fig. 1 Definitions of coordinate system and control surfaces used in numerical solution of the wedge entry problem.

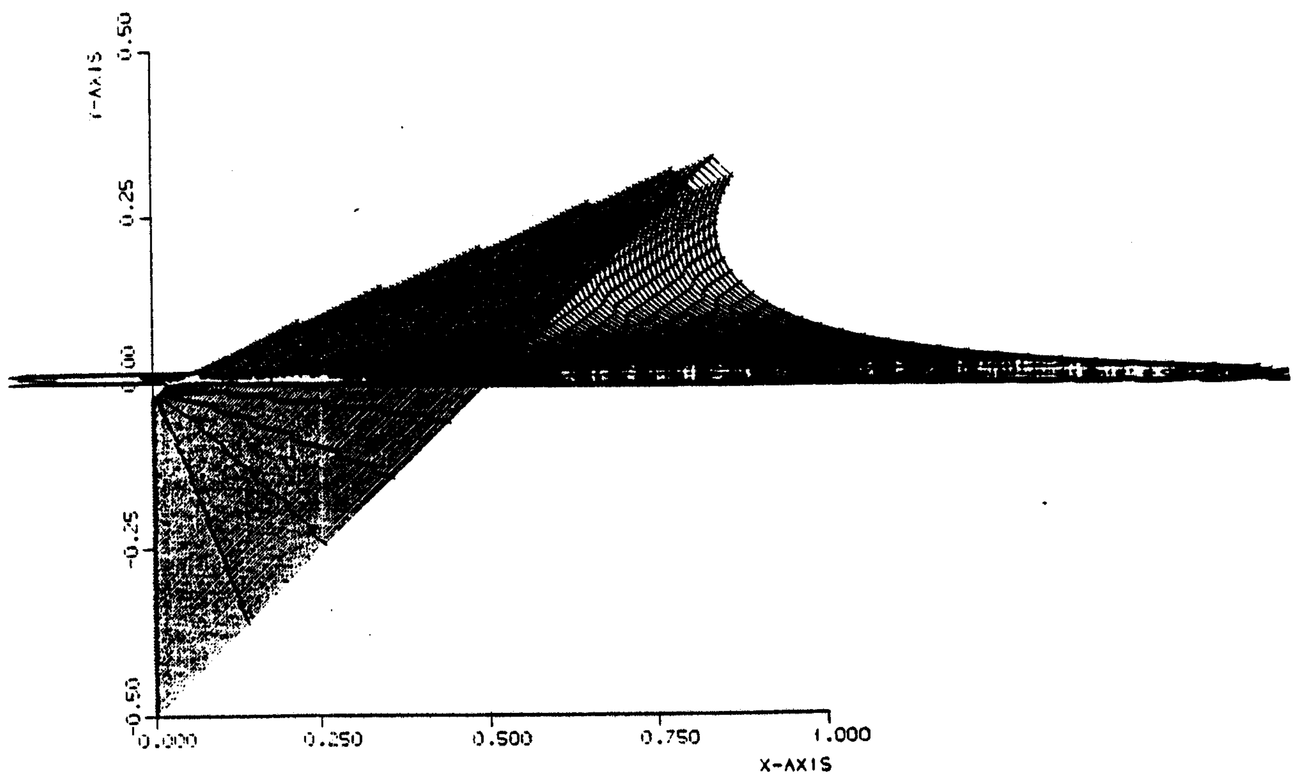

Fig. 2 Numerical simulations of free surface elevations during entry of a wedge with constant vertical velocity 12 m/s. Wedge angle α=45° (see Fig. 1). The figure shows the position of the wedge and the free surface at different time instants.

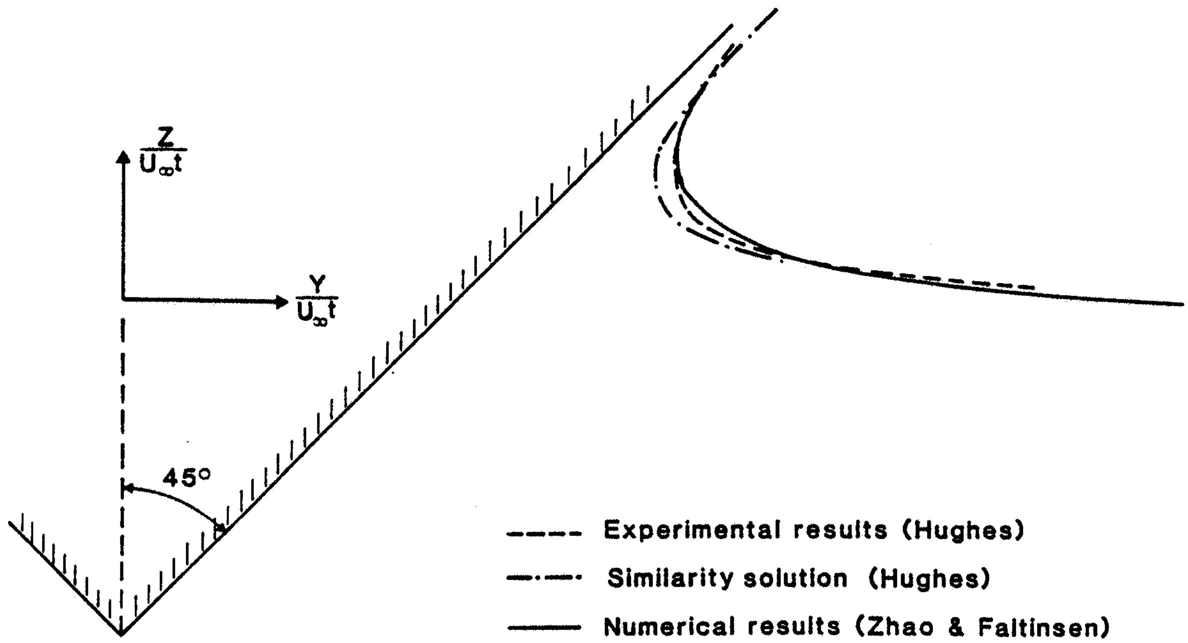

Fig. 3 Predictions of free surface elevations during entry of a wedge (α = 45° (see Fig. 1)) with constant vertical velocity U_∞, t = time variable.

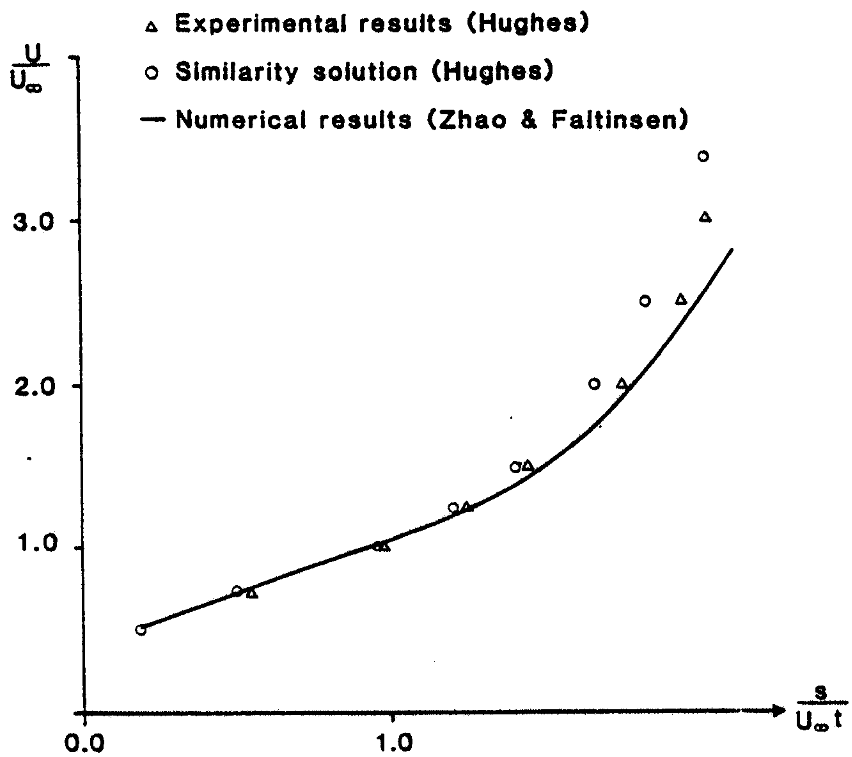

Fig. 4 Prediction of fluid velocities during entry of a wedge (α=45° (see Fig. 1)) with constant vertical velocity U_∞, t = time variable.

Clement: Could you explain how you calculate the pressure? My question is motivated by the discrepancy between your results and Greenhow's result for the pressure distribution. It seems to me that your methods are quite similar.

Zhao: In our numerical calculation the direct pressure integration method was used. The discrepancy between our results and Greenhow's is due to the fact that Greenhow's numerical simulation broke down before he got a steady state solution.

Tuck: I would like to add two entries to the reference list. First a very recent paper by Howison and Ockendon in JFM, Jan 1991 issue, where the similarity solution is further discussed for small deadrise angles, at $g = 0$. Secondly, a paper of my own in J. Hydro. in 1974, entitled "Low-aspect-ratio flat-ship theory." This is relevant because the longitudinal coordinate is time-like; hence the theory is just Wagner's plus gravity. Some similarity solutions are exhibited, even with $g \neq 0$.

Zhao: Thank you for your comments. Specifically, the second paper you mentioned seems to be quite interesting for us.