# NUMERICAL TOWING TANK FOR SHIP MOTION

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## ABSTRACT

It is desirable to simulate the towing tank experiment for wave generation and ship's motion by a numerical model, so that in the absence of a tank, numerical experiments can be performed, and the ship's geometry can be changed for parametric studies systematically. At the same time, this offers a numerical method to study the importance of non-linear terms in the free surface boundary condition and large angles in ship motion within the assumptions used, such as inviscid fluid.

In the formulation of the problem, fluid flow is assumed to be incompressible and irrotational. The governing equation and the boundary conditions are the conventional ones. Boundary Integral Method with a direct method formulation is used to solve the numerical problem.

On the free surface, the boundary condition is expressed in terms of the material derivative rather than the partial derivatives with respect to time. These material derivative terms are then represented in finite difference forms. Results from previous time steps are used to construct a time stepping solution

scheme. Non-linear terms are approximated by their previous computed values to avoid iteration. These finite difference representations of the material derivatives can be formulated either explicitly or implicitly.

For the numerical method, the boundary is divided into small segments known as boundary elements. Zeroth order elements are studied here and higher order elements will be considered for further applications. The numerical model works very well without applying any smoothing technique to the free surface. Velocity as well as displacement of each element is determined precisely by a second order interpolation; while at the neighbourhood of the solid boundary where wave-structure interactions take place, an extrapolation of the wave profile is required to determine the wave elevation on the structure's surface.

Solution starts from an undisturbed fluid, and a periodic motion is assigned to the wave maker for wave generation. The time stepping proceeds more than 60 sec (real time) at a time step of 0.05 sec without any apparent numerical instability. Comparison between linear and non-linear results have also been made. For finite depth water wave of small amplitude, the linear and non-linear solutions are almost identical. For short wave-length, the non-linear solution is currently under investigation.

Limitations of the computer program have been studied. We believe that the solution is mainly affected by two parameters.

a) The size of the element on the free surface is thought to be critical for the following reasons:

   i. There must be a sufficient number of elements to represent the wave profile, so that, a smooth surface is ensured to avoid the necessity of a smoothing procedure. A number of more than twenty four elements per wave-length is considered to be necessary.

ii. Size of the element must be small enough for extrapolation of the wave elevation onto the solid boundary without introducing excessive error. A linear extrapolation of the wave slope or a second order extrapolation of the wave elevation does not show any significant difference on the solution.

iii. On the other hand, the element size cannot be too small, otherwise, information will travel through elements and results in a leakage problem in the model. A guideline to follow is that the element size must be at least twice the product of the wave speed and the time step.

b) The second parameter thought to be important is the size of the time step. In most of the time stepping solution problems, time step is believed to be associated with the stability of the computer program. In other words, the time step must be small enough to ensure the approximation made previously for the non-linear terms at the free surface to be valid. Moreover, when proceeding from one time step to the next time step, the calculation of the new wave profile is done explicitly. A smaller time step can lower the accumulated error to within an acceptable limit.

With the above limitations, the solution is yet very expensive and time consuming in the non-specialized computer such as VAX 750 currently used.

Further work will be on the computation of large amplitude waves, breaking waves, as well as non-linear ship motions. With a specialized computer, an extension of this solution method to three dimensional problems seem very promising.

## REFERENCES


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## Discussion

**Yue:** I have two comments regarding your investigation of the Courant number.

1) For linear problems, the Courant number can be determined analytically from a linear stability analysis.

2) Are the curves mislabeled in your results? The method should become more stable as $\Delta t$ decreases. Your plots indicate the opposite trend.

**Chan:** Referring to Dr. Yue's comment 1, this was considered and free surface boundary condition was used for the relationships. I will appreciate if he can identify a reference or a work for this problem. For comment number 2, I would say the stability of a problem does not seem to have anything to do with the precision and smoothness of the result. I have done a linear and non-linear comparison on the wave profile and it seems to me that the linear wave elevation calculated at the right end has lost its precision. Moreover, since a different scheme is used to integrate the potential value, a more precise solution is expected in the non-linear waves. This is done by a fifth order Gaussian integration technique.

Finally, it seems that whether the boundary condition is satisfied at the exact boundary plays an important role on the smoothness of the result.

**Newman:** You have done nice work on a tough problem. We have devoted much effort to the same problem here at MIT. Some of this will be described in the next talk. One specific question. Have you had any special problems in determining the intersection points of the free surface with the wavemaker or the body?

**Chan:** In answering the question, this problem does not exist for linear cases. However, for the non-linear solution, there is a problem in the determination of the intersection point of the free surface and the solid boundary. What we find is the potential value of the element next to the solid boundary is unrealistic. In order to overcome the problem, a quadratic extrapolation method is used to determine the intersection point. This extrapolation technique seems to work well for low frequency waves, but there is no test case to guarantee it will function for high frequencies.

**X.J. Wu:** Do you have any experiments with which to compare your results?

**Chan:** We hope to do model tests at British Columbia Research, but we will have to wait for the results.

X.J. Wu: It seems to me that this is a new concept. As we know, there exist errors in both the model tests and theoretical models. Therefore, we usually need a comparative study on both the experimental data and numerical computations to confirm the predictions for a new type of marine structure, Sometimes, due to the discrepancy we further discovered some new physical phenomena and thus advance our technology. However, when the numerical towing tank is used, both the theoretical calculation and the numerical tank are based on the same idealized theories, good agreement may always be achieved. Hence, we may lose the possibility to check our results, to find new phenomenon and to improve existing techniques. Furthermore, the physical reality is much more complicated. In many cases, we can obtain reasonable predictions by idealized theories owing to mutual error cancellation rather than the "correct" description of a real physical model. But there is no such a cancellation in a numerical tank. Finally, it may be difficult for a numerical tank technique to simulate the realistic fluid-structure interaction which, in addition to those considered in the potential theory, involves more complicated factors, such as wake, vortex, etc. Nevertheless, this work is very interesting and I would like to see the authors' further development.

X.J. Wu: Is the tank of finite or infinite length?

Chan: It is of finite length, but I hope to be able to add a radiation type of condition.

X.J. Wu: I think that one of the possible advantages of the numerical tank is that it can simulate open sea conditions to avoid the side wall effect in model tank testing.