Threedimensional Unsteady Wave-Body Interactions in a Bounded Domain

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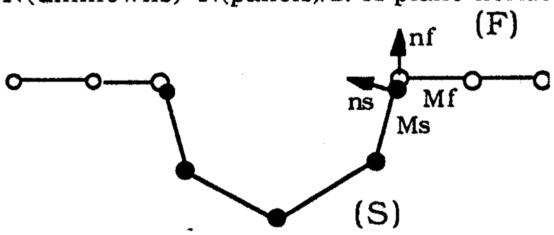
INTRODUCTION

In this paper we report on computations using a linear time-domain formulation for threedimensional free surface flows in a bounded domain. Starting from rest, the generation of gravity waves by moving boundaries, their propagation and interaction with fixed or freely floating bodies are simulated. Various 3D applications are presented, such as: generation of plane waves in a circular basin, free motion of a floating body, interaction of a transient wave with a freely floating body, etc...Typically, these computations give access to wave and body motions, pressures and forces, mass and energy integrals. The computer code may be considered as a "linearized numerical wave basin", and special care has been taken in the formulation and implementation in order to allow the extension to nonlinear wave simulation when sufficient computing facilities will be available.

OUTLINE OF THE FORMULATION

The formulation is based on an integral representation of the solution in a bounded domain using free space (Rankine) Green functions. At a given time T, Laplace's equation is solved, with a Dirichlet condition on the free surface, and a Neumann condition on solid boundaries. From T to T+Dt, linearized differential equations for the velocity potential on the free surface and the wave elevation are integrated using a fourth order Runge-Kutta method. In the case of a freely floating body, a boundary value problem for Φ_t is solved every time step, using the same kernel as for Φ, but with different boundary conditions. Linearized pressures and forces may then be computed, and the equations of motion are integrated from T to T+Dt using the same procedure as for free surface equations, in order to update the body boundary condition. The whole process is then repeated to advance the solution in time.

The integral equations solver is based on a discretization of the boundaries by plane triangular panels, and a piecewise-linear space variation of singularities distributions is assumed. Collocation points are placed at panel vertices, so that continuity of the solution is automatically ensured. This choice also allows a reduction of the number of unknowns for a given number of panels, with typically N(unknowns)≈N(panels)/2. A plane horizontal seabed is accounted for by symmetry.



At the intersection between solid boundaries S and the free surface F, we keep two control points at the same geometrical position: $M_s \in S$, $M_f \in F$. $\Phi(M_f)$ is explicitly given by the Dirichlet condition on the free surface, and $\Phi_n(M_s)$ from the Neumann condition on solid boundaries. $\Phi_n(M_f)$ is then obtained from the solution of integral equations, whereas we simply impose $\Phi(M_s) = \Phi(M_f)$ by space-continuity of the velocity potential.

SOME NUMERICAL RESULTS

We give in this section the results of three significant applications of the numerical model:
- Generation of a transient wave train in a circular basin
- Free motion of a floating body in a circular basin
- Generation of a plane sine wave starting from rest, in the same basin

These computations were performed for two different geometrical configurations:

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-a)- a circular basin of constant depth H=1. and of radius R=2., discretized into 1998 panels, with 1059 unknowns on the half domain (figure 1)
-b)- the same basin, but with a floating hemisphere of radius Rs=0.5 at the center (figure 2). The numbers of panels and unknowns are the same as in case a).

1) Generation of a transient wave train in a circular basin

Starting from rest, a smooth positive velocity alternance is imposed to the part of the circular vertical boundary corresponding to X < -1., the normal velocity being given by $\Phi_n(t)=\tau^4-2\tau^2+1$, with $\tau=(2t/Te)-1$, for $0<t<Te$. The duration of the excitation is Te*sqrt(g/H) = 5. A wave train of finite energy is thus created and propagates in the basin. The simulation has been run over 400 time steps of duration Dt = 0.05. We give in figure 3 a check of mass conservation during the simulation. Variations of volume due to material boundary motion, free surface motion, and their sum (theoretically zero) are respectively plotted. The total variation of volume is about 10^{-3}. Plots of energy integrals during the same simulation are given by figure 4. Kinetic, potential and total energy of the fluid, as well as energy input by the wave making boundary are given. The total fluid energy is clearly kept constant after the end of the wave maker motion.

2) Free motion of a floating hemisphere

The same basin geometry is modelized, but now with a floating hemisphere of radius Rs = 0.5 located at the center. The discretized domain is given by figure 2. The floating body is initially given an unit vertical displacement, and then released. The body is thus freely heaving,while the other solid boundaries remain motionless. Vertical displacement, velocity and acceleration of the body during the simulation are given by figure 5. Two alternances of damped oscillatory motion are observed, before the waves radiated by the body and reflected back by the basin boundary reamplify the body motion. The body almost recovers its original displacement about T=18., and then the process of energy exchange between fluid and body is repeated. Mass and energy integrals are plotted in figures 6 and 7. Mass conservation is excellent, and only a small variation ($0(10^{-2})$) of the total energy is observed.

3) Generation of a plane wave

With the same basin geometry and panelization as in case 1), we now simulate the generation and propagation af a plane sine wave of frequency ω*sqrt(H/g) = 2. , starting from initial rest.

The wave is generated by the X<0 half part of the circular vertical wall, acting as a wave generator, the remaining part X>0 acting as a wave absorber. The motion of the boundaries is explicitly deduced from an analytical solution of the transient 2D wave making problem in a semi-infinite domain (Kennard 1949), and corresponds to a plane wave generated by a piston situated at X = -4. The simulation has been run over 400 time steps of duration Dt = 0.10. We give in figure 8 the normal velocity imposed at two particular points of the boundary: the top of the wave maker at X = -2., and the top of the absorber at X = 2. Mass and energy integrals are given by figures 9 and 10. Mass conservation is correct, but a sensible difference between wavemaker power input and fluid energy is observed. The flow that we simulate here apparently requires finer time and space discretizations. After T = 30., a quasi space-periodic wave field is obtained in the wave basin, the time-averaged energy of the fluid being almost constant. The wave elevation at the center of the basin, as a function of time, is given in figure 11. A quasi periodic behaviour is observed between T = 27. and T = 35. At the end of the simulation, the effect of some undesirable reflections on the absorber are observed on free surface plots (not given in this abstract, due to limited space). These reflections are due to the cumulated effect of the discrepancies between the space continuous model from which the Neumann conditions on the vertical wall are deduced, and the behaviour of our 3D numerical model.

CONCLUSION

These applications illustrate the present capabilities of the computing code. Computations were run on a Vax 8700. In the first two cases, very accurate checks of mass and energy conservation are obtained, which globally validates the model. In the last case the need for finer space and time discretizations is clearly demonstrated. Runs on a Cray supercomputer with fine meshes are now planed and results will be available at the workshop. We now concentrate our efforts on two main topics:

a)- reduction of computing time in order to allow the extension to nonlinear flow simulation.

b)- research on robust absorbing conditions for the simulation of flows in unbounded domains .

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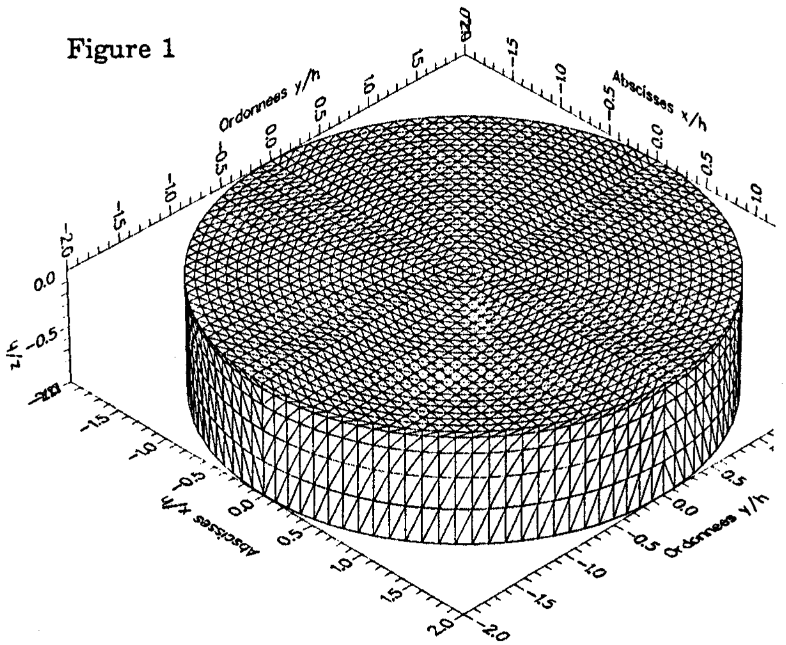
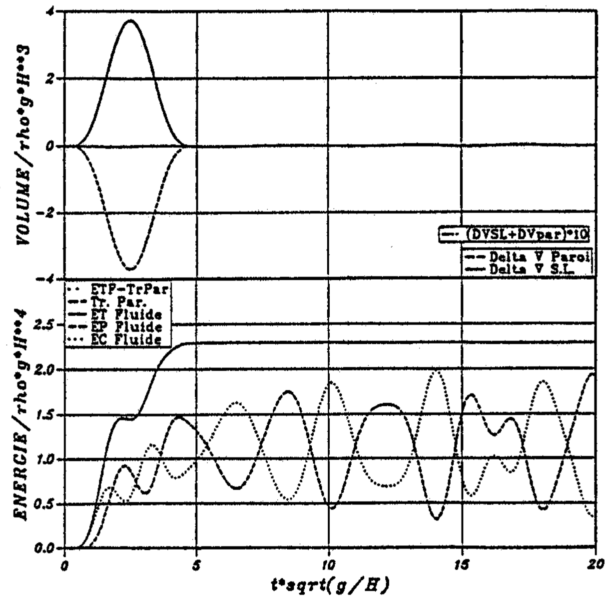
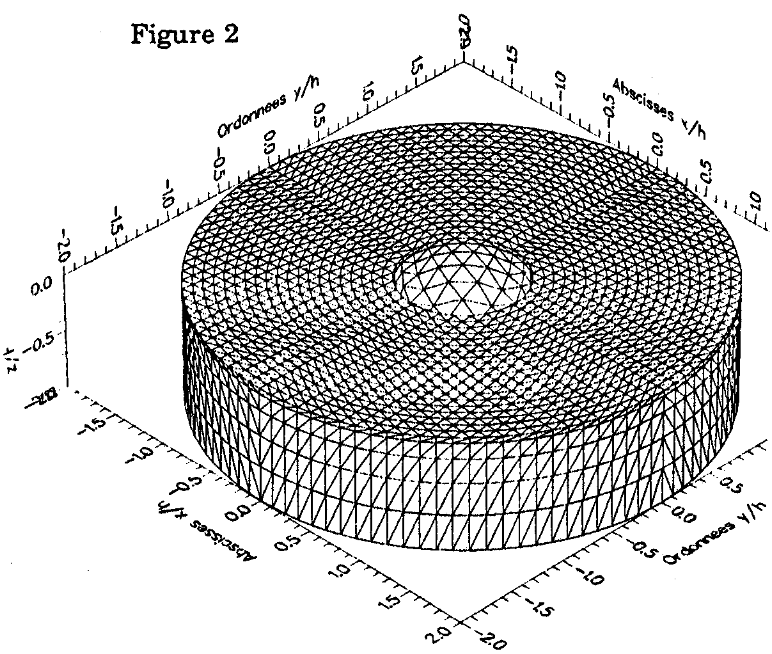
Figure 1





Figures 3 & 4: Mass and energy integrals
Smooth excitation

Figure 2



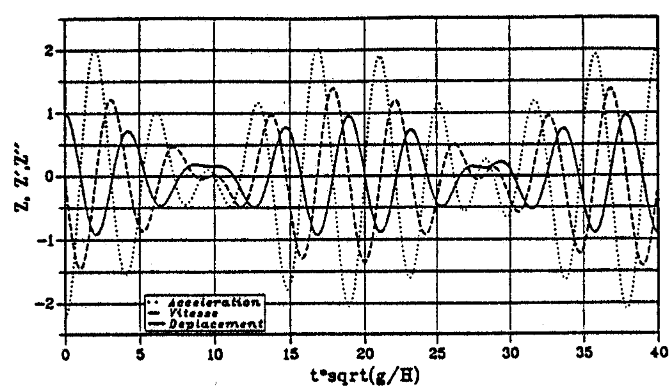
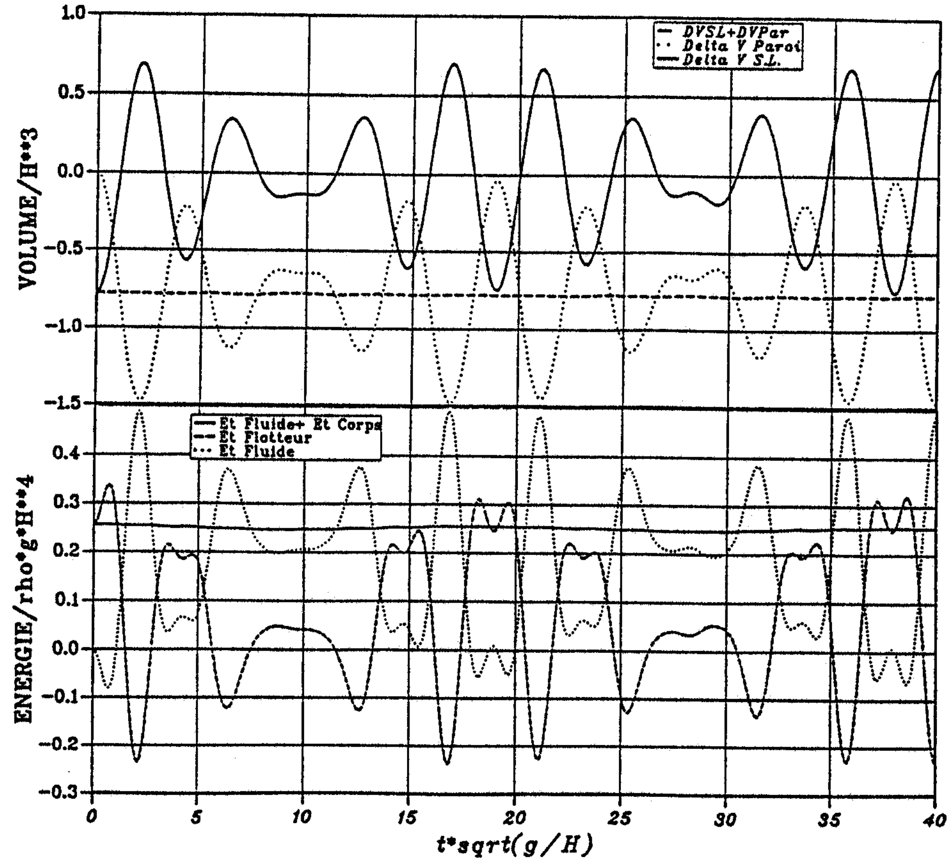


Figure 5: Freely floating hemisphere:
displacement, velocity, acceleration

Figures 6 & 7: Freely floating hemisphere:
Mass and energy integrals



Generation of a plane wave in a circular basin, omega=2.0

Figure 8: Wavemaker motion, upstream (x=-2)
and downstream (x=2)

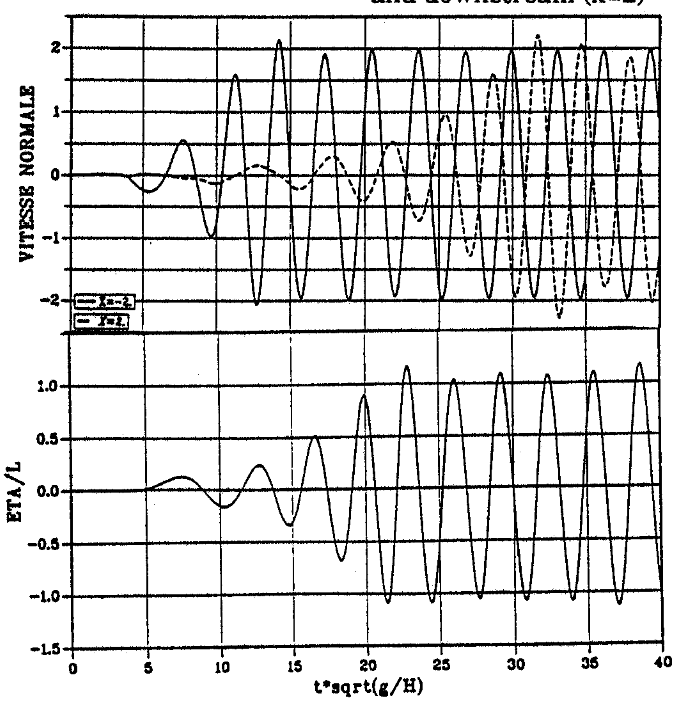


Figure 11: Wave elevation at the center of the basin

Figures 9 & 10: Mass and energy integrals