Recent Advances Towards the Viscous Flow Simulation of Ships Manoeuvering in Waves

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INTRODUCTION

The SWENSE (*Spectral Wave Explicit Navier-Stokes Equations)* approach has been developed since 2003 by the Hydrodynamics & Ocean Engineering (HOE) group of Ecole Centrale de Nantes (ECN). This approach allows the simulation of wave-structure interactions in viscous flow in a very efficient way, by combining the description of undisturbed incident waves by a nonlinear spectral scheme based on potential flow theory and the computation of the nonlinear viscous diffracted flow using the free surface Reynolds Averaged Navier-Stokes (RANS) solver ICARE (using a free-surface tracking method). The coupling between both models is operated in the functional space rather than in the physical space, incident flow parameters being incorporated as forcing terms in modified RANS equations.

The principle of this method is illustrated by figure 1 in which a basic SWENSE calculation is detailed in three steps, in the case of a ship advancing in head waves. From top to bottom: (1) Determination of the undisturbed incident flow, (2) Solution of the SWENS equations giving the non linear viscous flow correction to the incident flow, (3) Solution of the initial problem obtained by summing (1) and (2). Details of this method can be found in Luquet *et al*, (2004).

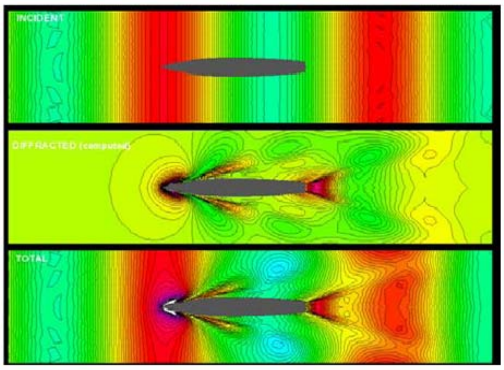


Figure 1: illustration of the SWENSE scheme

This method has been already widely validated for head regular waves acting on a fixed DTMB5415 ship (Luquet *et al*, 2005) or for a TLP platform in regular and irregular waves (Luquet *et al*, 2007), confirming its efficiency in terms of accuracy and CPU time savings.

INCIDENT WAVE MODELS

The application of the SWENSE coupling strategy requires the use of nonlinear incident wave models with a regular continuation of the solution above the incident free surface. Wave models based on spectral expansions naturally satisfy this condition, avoiding the implementation of additional continuation algorithms.

In the case of regular incoming wave, the stream-function theory of Rienecker & Fenton (1981) is used. This method gives the solution for steady periodic nonlinear waves over a horizontal seabed for arbitrary combinations of depth, amplitudes and wavelengths (in the limit of breaking waves). The calculation is based on a spectral expansion of the steady solution in a frame of reference linked to the wave crest. Wave profiles, wave kinematics and associated physical quantities are obtained in a very efficient way, reaching machine accuracy with a very limited number of modes (64 modes for the steepest cases).

In case of irregular waves, either unidirectional or multidirectional, Higher Order Spectral (HOS) schemes are implemented for modeling arbitrary incident wave systems. Both an open sea formulation based on periodicity assumptions, and a closed domain version reproducing waves generated in model basins are available. These developments can be found in Ducrozet *et al* (2005). We would like to emphasize the variety of applications of this technique, beyond its implementation as incident wave model in the present context of SWENSE simulations. Consider for example the study of the mechanisms and statistics of freak wave in open seas (Ducrozet *et al*, 2007), or the numerical modeling of wave tanks, for preparing and documenting wave generation experiments in physical basins (Ducrozet *et al*, 2006).

APPLICATIONS

2 DOF Wigley hull in regular head waves

The method has been applied here to the interaction of a nonlinear regular wave train with a ship with two degrees of freedom (pitch and heave) in deep water. The selected geometry is a Wigley hull, subjected to a constant forward speed motion.
Wave tank tests have been carried out in the Delft University of Technology (Journee, 1992), for four different Wigley hull forms with various wave amplitudes and wavelengths.

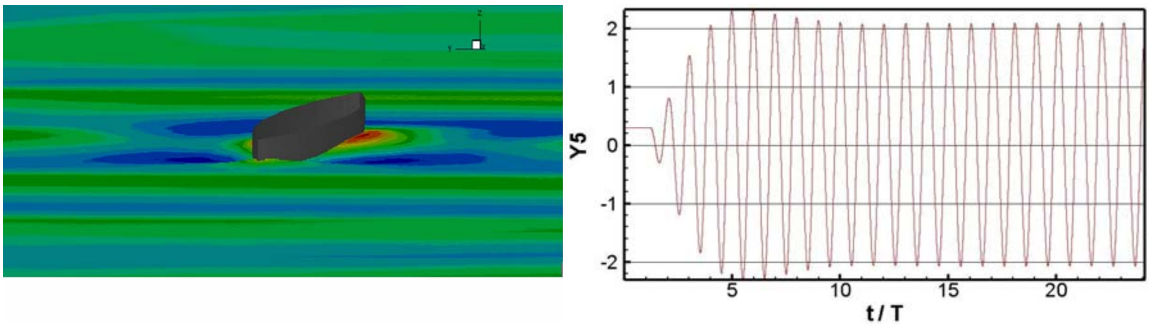


Figure 2. left: Wave pattern of the Wigley hull in regular head waves, free to heave and pitch with forward speed for $\lambda / L_{pp} = 1$. Right : Predicted pitch motion over 24 incoming wave periods.

First simulations were run for a non-dimensional incoming wave amplitude $H / L_{pp} = 0.00734$ at a Froude number $Fn = 0.3$. Figure 2 shows the wave pattern around the hull during the computation and the predicted pitch motion for a long simulation. This figure clearly illustrates the convergence of the signal towards a periodic steady state, confirming the efficient treatment of outer boundary conditions.

	Exp	SWENSE ICARE	CFDSHIP	Strip Theory
Y3	1.28	1.14	1.19	1.31
ϕ_{Y3} (deg)	343	335	343	343
Y5	2.21	2.09	2.19	1.5
ϕ_{Y5} (deg)	13	13	14	45

Table 1 : Nondimensional amplitude and phase of the heave and pitch coefficients

First harmonic amplitudes and phases of heave and pitch loads and motions are in good agreement with measurements and other numerical methods: CFDSHIP code solving RANS Equations (Weymouth *et al*, 2005) or strip theory (Journee, 1992), see Table 1.
Note that these computations were run with a coarse grid (120 000 nodes for a half domain) and should improve with finer grids.

Fixed body in irregular sea state

The ability of the SWENSE method to simulate a marine structure interacting with a realistic sea state has been verified by simulating a fixed Series 60 hull, or a fixed TLP in irregular unidirectional waves, see figure 3 extracted from Luquet *et al* (2007).
Extensive validation will soon be undertaken in the case of the S175 containership, selected by the ITTC as a standard test case. A large amount of test data is available for this geometry. For example, Fonseca & Guedes-Soares (2004) gave results for the S175 vessel in irregular head seas using Pierson-Moskowitz spectra of different significant wave heights.

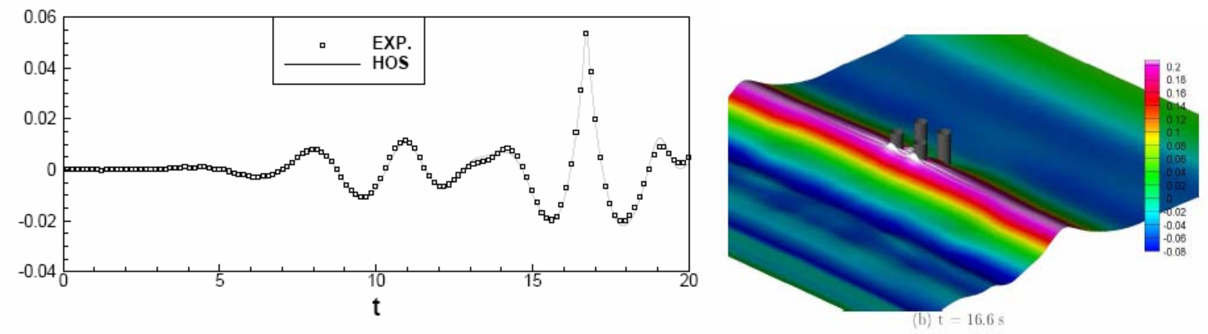


Figure 3: Irregular wave interacting with a fixed TLP model. Left: Incident wave; experiments and HOS simulation compared . Right:Wave pattern at t=16.6s (Luquet et al 2007).

Ship manoeuvering in regular waves with 6 degrees of freedom

This recent simulation is presented in order to demonstrate the capacity of the numerical model to simulate a self-propelled ship manoeuvring in waves. The model is a DTMB5415 in free motion in its six degrees of freedom. The propeller is modelled by a constant forward force, while the rudder action is approximated by a time varying side force applied at the rudder location. The Froude number is Fr=0.25, the wavelength $\lambda/L=1.5$, and the wave steepness $2A/\lambda=0.0133$.
The ship is first accelerated in a rectilinear motion, reaching its nominal speed in head waves. Then, a constant side force is applied towards starboard at the rudder location, and the ship begins a leeward turning manoeuvre over more than one complete circle. Pictures in figure 4 show snapshots of the ship in different heading angles in waves during this turning manoeuvre.

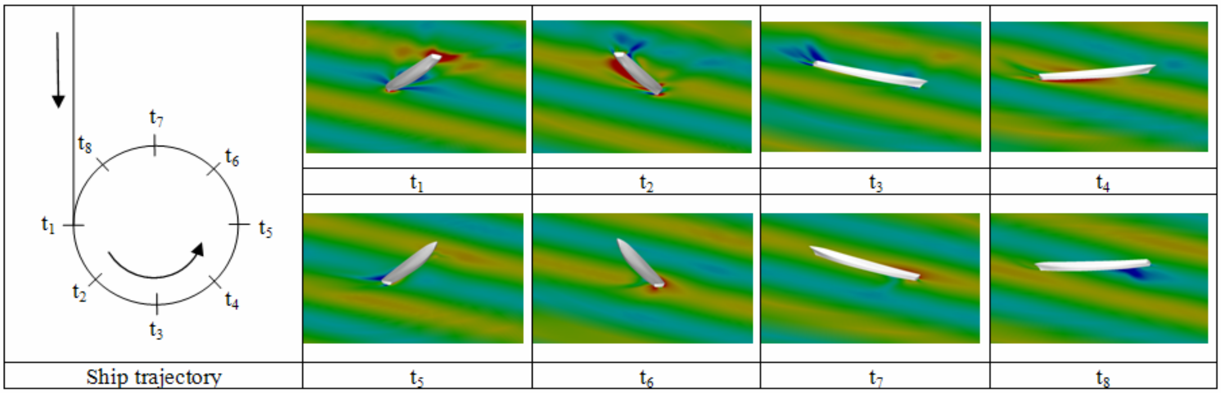
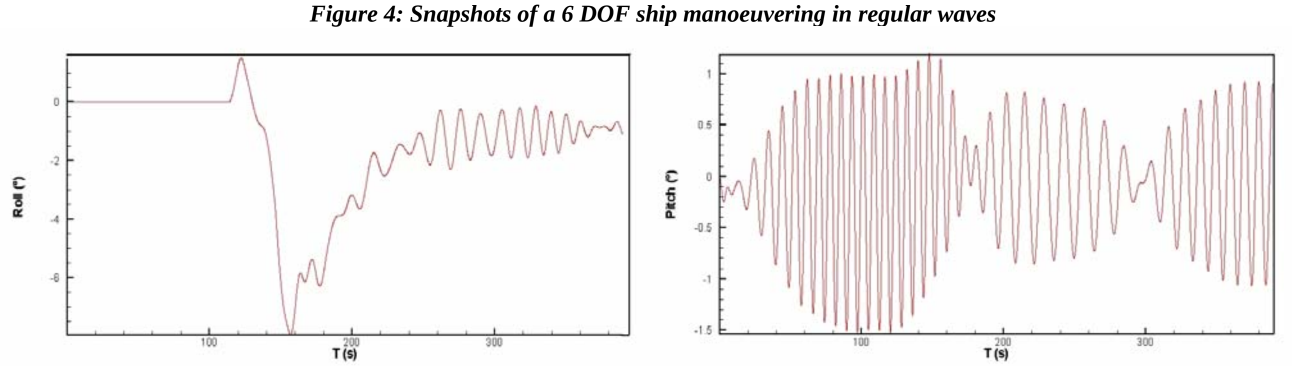


Figure 4: Snapshots of a 6 DOF ship manoeuvering in regular waves



***Figures** 5 & 6: Time traces of roll (left) and pitch(right) angles*

Figures 5 and 6 give time traces of roll and pitch motions over the full duration of the simulation.

CONCLUSION AND FUTURE APPLICATIONS

The SWENSE approach has been carefully validated versus experiments in the case of a captive naval combatant in regular head waves (see e.g. Luquet *et al*, 2005). The implementation of a HOS solver instead the stream function theory model now allows arbitrary incident wave systems to be taken into account in the simulations. The exceptional numerical efficiency of this scheme has to be emphasized. The typical ratio of reduction of CPU time compared to a direct approach is about 50 for a simulation in regular waves, for equivalent accuracy and this ratio will be even more favorable in more complex sea conditions.

In addition, the principle of the SWENSE coupling retains all the capacities of the free surface Navier-Stokes solver ICARE in which it is implemented. Especially, ICARE is able to cope with either stationary structures or ships with forward speed, manoeuvering vessels, with possibly 6DOF fluid-body motion coupling for self propelled vessels.

All these new capabilities open the way to the simulation of seakeeping and maneuvering problems for self propelled ships in real fluid in a unified manner, while accounting for arbitrary incoming wave systems. Figure 7, reproduced from Ducrozet *et al* (2007), gives an example of the nonlinear simulation of a directional wave system, over a large domain (approximately 105km^2).

Each new step towards this objective has now to be carefully validated.

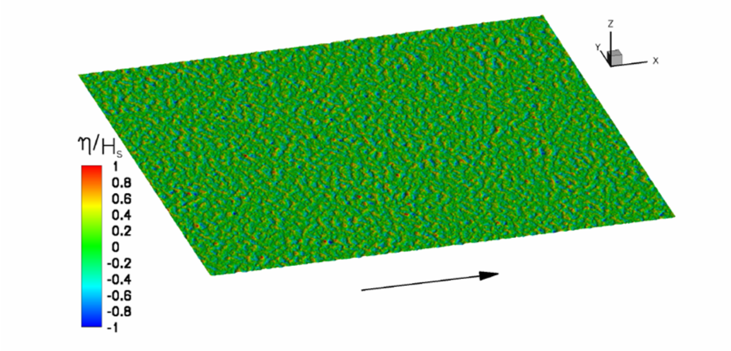


***Figure 7** HOS simulation of a directional wave system.*
Tp=12.5s, Hs=10.9m, λ_p=244m. Domain size 10250m x 10250m (105 km^2).

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