SIMULATION OF WAVE EFFECT ON SHIP HYDRODYNAMICS BY RANSE

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ABSTRACT

The application of advanced numerical analysis methods based on solution of RANS and VOF equations on ship manoeuvrability hydrodynamics is presented. The test cases selected are container models in oblique motion under the effect of incoming harmonic wave. The computed and measured results are compared. The general agreements between calculations and experiments are satisfying.

Keywords: *RANS, VOF, wave, yaw, sway, heave, pitch*

1. INTRODUCTION

The simulation of wave effect on ship hydrodynamics by using state-of-art CFD is gaining increasing attention in recent years. The advantage of the approach over traditional strip theory or linear/non-linear potential theory is improved accuracy and capability on simulation of ship motion in heavy sea. The disadvantage of demanding computer resources and effort is becoming less bottleneck after high performance parallel computing technology was put into use.

The wave generation using RANS method is a paramount task for the study of maneuvering in wave. Numerical wave generation and diffusion disturb physical wave propagation and affect the quality of numerical maneuvering wave tank (diffraction problem in maneuvering scope). Moreover, dynamic or free motion of the ship sailing in the seaway make numerical simulation more complicated (radiation problem in RASE scope). So far, there is little relevant work available in the literature. There were only a few publications addressing added wave resistance using RANS approach.

One calculation was made by Weynouth etc using CFDSHIP-IOWA0. They studied head sea effects on diffraction problem, forced heaving and pitching motions. Uncertainty study was carried out and systematic calculations of parametric effects were conducted. The comparisons of results from RANS code, strip theory, potential code with experiment show that RANSE code performed much better than other codes.

In this paper, application of computational fluid dynamics on study of ship manoeuvrability hydrodynamics by solving RANS and VOF equations is presented. Firstly, numerical formulations will be described with the focus on numerical wave maker. Secondly, the method will be used to the simulation of a container model running at steady yaw in head wave. Then, the attempt was made for free running model calculations. The accuracy of numerical results will be evaluated by model test data. Finally, future work for improving numerical quality and application to critical ship motion in severe sea will be proposed.

2. NUMERICAL FORMULATION

The Reynolds averaged Navier-Stokes equations with SST K-ω turbulence model for closure were solved. VOF method was adopted to capture free surface interface. The governing equations can be written as follows.

2.1 Continuity equation

The continuity equation is written as:

$$\nabla \bullet \mathbf{u} = 0 \qquad (1)$$

2.2 RANS equation

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \bullet \nabla \mathbf{u} = -\frac{1}{\rho}\nabla p - \mathbf{g} + \nu \nabla^2 \mathbf{u} \qquad (2)$$

2.3 Turbulence model

$$\frac{\partial}{\partial t}(\rho K) + \nabla \cdot (\rho \mathbf{u} K) = P - \rho\varepsilon + \nabla \cdot ((\mu + \frac{\mu_T}{\sigma_K})\nabla K) \qquad (3)$$

$$\frac{\partial}{\partial t}(\rho\omega) + \nabla \cdot (\rho \mathbf{u}\omega) = \nabla \cdot (\Gamma_\omega \nabla \omega) + G_\omega - Y_\omega + D_\omega + S_\omega \qquad (4)$$

2.4 VOF equation

$$\frac{\partial}{\partial t}(r_w) + \nabla \cdot (r_w \mathbf{u}) = 0. \qquad (5)$$

Where:

u	Velocity vector
g	Gravity vector
τ	Stress tensor
ρ	Mixture density
μ	Mixture viscosity
r_w	Volume fraction of water
K	Turbulence energy
ω	Specific dissipation rate
P	Pressure

2.5 Boundary conditions

The inlet is located at one ship length ahead of ship where velocity components and volume fraction were imposed.

The wave was generated from wave maker at inlet using following values:

Wave length $\lambda/L=1.0$
Wave amplitude $\zeta_a/L=0.008$
Wave number $k=2\pi/\lambda$
Wave frequency for deep water $\omega=\sqrt{gk}$
Model speed V=1.89m/s
Wave encounter frequency $\omega_e = \omega + kV$
Period $T=2\pi/\omega_e$
Wave elevation at inlet $\zeta = \zeta_a \sin(\omega_e t)$
X velocity $u = \zeta_a \omega e^{kz} \sin(\omega_e t)$
Z velocity $w = \zeta_a \omega e^{kz} \cos(\omega_e t)$

From above relationship, we can obtain the wave number is 0.98 and corresponding angular frequency of incoming wave is 3.1/s. Wave encounter angular frequency is 4.95/s. The period is 1.27 seconds. Wave amplitude is 0.0512m.

The incoming wave was generated at the start of the calculation. It takes a few periods to eliminate initial disturbance. After about 5 periods, the force record becomes periodic with period 1.27s.

The outlet is at two ship length behind ship. The hydrostatic pressure is specified.

Velocity components and free surface elevation were given on side boundary, which is located at one ship length from centreplane.

Wall function was used on hull boundary to save computer time.

Using these parameters, the simulation of wave effect on steady oblique motion was performed. Yaw angles are 0 and 10 degrees.

2.6 Numerics

Second order upwinding interpolation was used for convection flux. SIMPLE method was applied to obtain pressure. Geometric reconstruction of volume fraction was used to calculate wave elevation.

3. TEST CASEE

A container model (Hamburg Test Case) adopted in EU VIRTUE project was selected for numerical analysis and validation. The body plan and profile of bow and stern are shown in Figure 1. The main particular of the vessel is given in table 1.

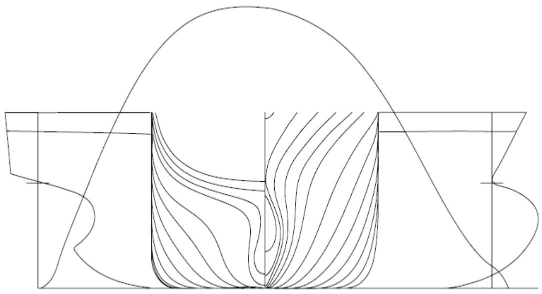


Figure 1. HTC body plan.

Scale 1:24	Ship	Model	Unit
Length between perpendiculars	153.70	6.404	m
Length waterline	153.13	6.380	m
Breadth max., moulded	27.50	1.146	m
Draught fore, moulded	10.30	0.429	m
Draught aft, moulded	10.30	0.429	m
Displacement bare hull, moulded	28332	2.049	m^3
Wetted surface area, bare hull	5577	9.682	m^2
Centre of buoyancy from AP	75.97	3.165	m
Block coefficient	0.651		-
Length – breadth ratio	5.589		-
Breadth – draught ratio	2.670		-

Table 1. Main particulars of HTC.

The calculations were carried out on a 16 processors cluster. The mesh was medium sized with 1.3m cells. The grid sensitivity studies were carried out on the relevant study. The grid effects are in general small for unsteady calculations.

Two test cases were made. One is captive steady yaw motion with incoming wave. The other is free sailing motion with wave effects. The results are given below.

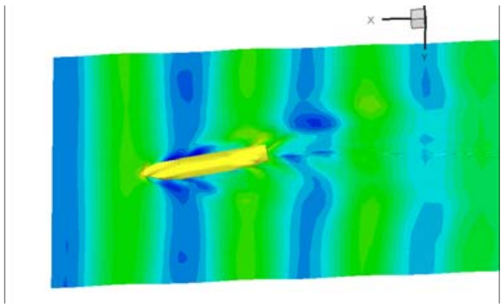
4. CAPTIVE YAW MOTION IN WAVE

Manoeuvring in sea wave was traditionally studied by simplified numerical approach with model test based empirical formula. The accuracy of simulation was case dependent. More reliable numerical tools are in demanding. Recent CFD development provides an advanced alternative to tackle the problem. In EU project VIRTUE, manoeuvring in calm water and wave were studied intensively.

The results of calculations of manoeuvring in calm water covering steady yaw, turning, oscillatory sway and yaw were in good agreement with model test measurement. The part of results of ship manoeuvring in wave will be presented in the paper.

4.1 Captive yaw angle 10 degrees

The first case is captive yaw motion (10 degrees) in wave as shown in snapshot below. The harmonic wave was generated using digital flap maker. The model was in oblique motion at Froude number 0.238 and yaw angle 10



degrees.

The X forces are given in Figure 2, where the results from SSRC (Red), MARIN (Purple) and measurements (Blue and pink) were compared.

The results from MARIN were obtained by a potential solver with viscous correction by PANASSOS. The HSVA experiment results include those with and without wave. As we can clearly see that surge force is constant without wave. The surge force oscillates at the period given above when there was wave. Both computed and measured surge forces in waves oscillate around the value from steady measurement in calm water. However, as can be seen, the amplitudes of oscillations were different. The computed amplitude by FLUENT is close to that from measurement. The predicted amplitude by MARIN is lower than data. It seems that viscous-wave interactions were underestimated by potential solver.

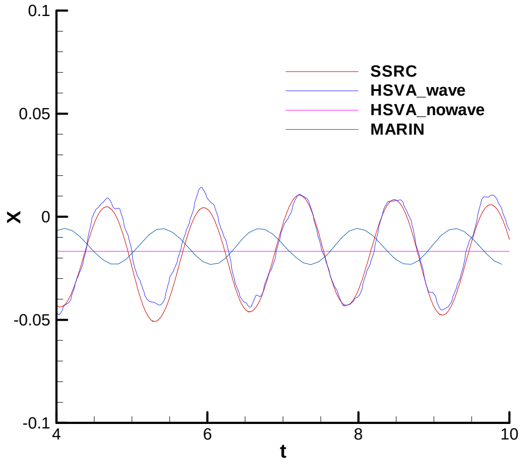


Figure 2. surge force.

The sway force in Figure 3 shows similar trend as surge force. The computed sway force from both MARIN and SSRC oscillates periodically after about 5 periods when there was incoming wave. The time record of sway forces from calculations display sinusoidal feature. However, the measured sway force exhibits strong high frequency oscillation. It seems that wave generated in model test suffer from short wave disturbance. The amplitudes of oscillations between calculation and measurement were generally consistent. The averaged sway forces in one period from calculation and measurement are close to that from steady measurement. The agreements between calculations and measurement are acceptable.

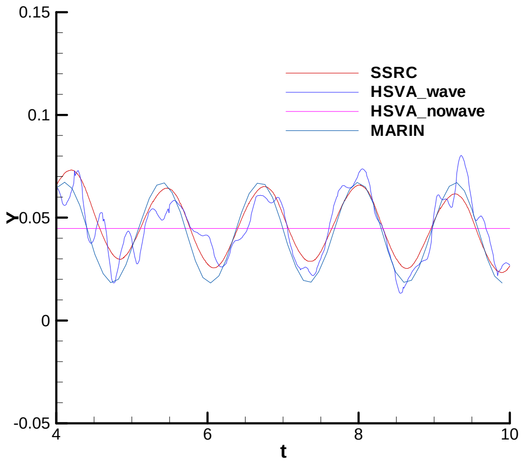


Figure 3. sway force.

The yaw moment was shown in Figure 4. The agreements between calculations and measurement seem pretty satisfying. The computed amplitudes and phase angles are close to measured one. The unsteady time records of forces oscillates around value from steady measurement. Averaged yaw moment by FLUENT is slightly larger than other results. Similar results were obtained in the calculations of steady yaw and turning where predicted yaw moments are slightly larger than measurement. The similar conclusion could be drawn for yaw moment as for surge and sway forces.

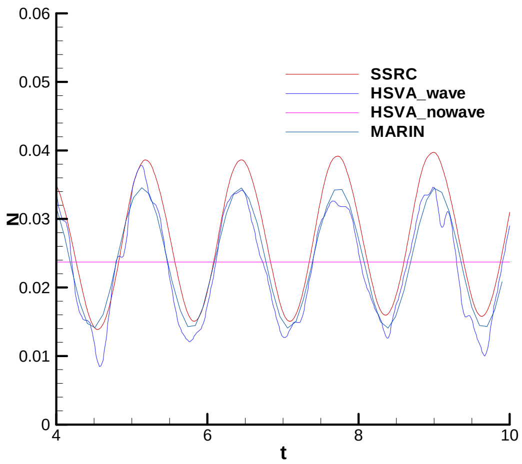


Figure 4. yaw moment.

Additional to calculation of drift angle 10 degrees, the calculation of wave effect at straight forward condition (without yaw) was performed as well.

4.2 Captive straight ahead motion in head wave

As there was no drift angle in the calculation, the sway force, roll moment and yaw moment are all zero. Therefore, only surge force, heave force and pitch moment are presented. Both computed and measured surge forces shown in Figure 5 oscillate around the value from steady measurement. However, as can be seen, the amplitudes of oscillations were depending on the solvers. The computed amplitude by FLUENT is close to the measured one. However, it is much smaller by MARIN's solver. The averaged surge forces from calculations and measurement in one period were close to that from steady measurement without wave. The conclusion for surge force in yaw angle 10 degrees applies to straight ahead condition.

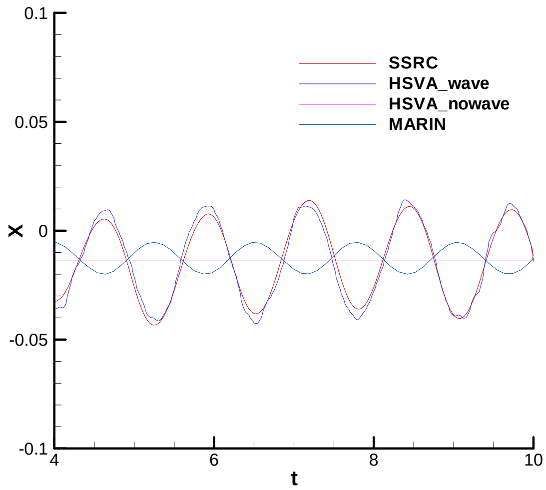


Figure 5. surge force in head wave.

5. FREE RUNNING IN WAVE

Ship sails in seaway in free running condition. Ship attitude is not restrained as in captive condition. The dynamic change of attitude in sea wave was simulated in the calculation. Ship speed is constant at 18 knots. Only surge force can be measured in model test. In the section below, the comparison of calculation with measurement is made.

Only calculation without drift was made to reduce the effort and uncertainty.

The surge force was given in Figure 6.

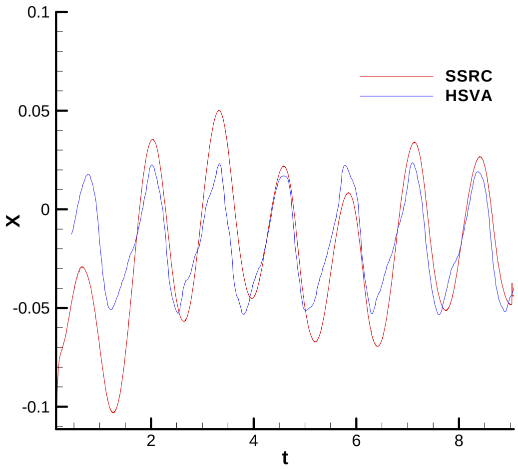


Figure 6. Surge force in free motion.

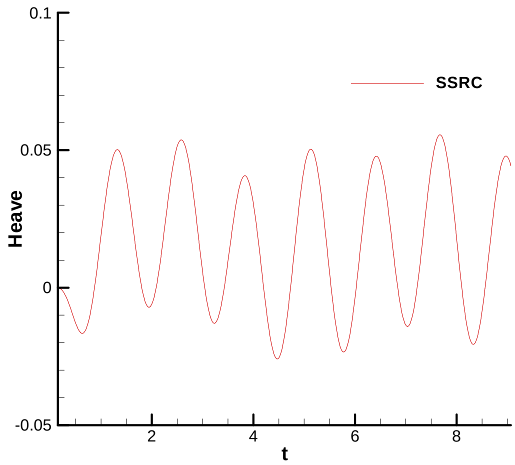


Figure 7. Heave.

The computed and measured surge forces oscillate with same period 1.27s as in captive condition. The computed amplitude of oscillation in free condition was close to that in captive condition while measured amplitude of oscillation in free condition was slightly larger than that in captive condition. The computed surge force shows numerical wave disturbance while measured surge force oscillates periodically. The magnitude of averaged surge forces in one period in calculation and measurement were slightly larger than that in captive condition. The sinkage and trim in free condition tends to increase surge force a few percentage. In general, the agreements between computed and measured surge force were good.

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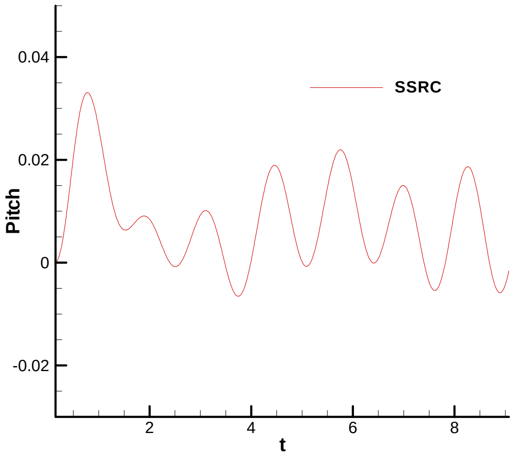

Figure 8. Pitch

Model moves with free pitching of period 1.27s. The oscillation of pitch motion in the calculation was not strictly periodic. There was strong effect from numerical wave. The amplitude of pitch motion is determined by wave induced pitch moment. The averaged pitch in one period is related to steady hydrodynamic pitch moment.

From maneuvering calculations in sea wave and comparison with model tests, the accuracy of CFD tools was generally encouraging. Further implementation of the tool on naval hydrodynamics will be strengthened.

6. FUTURE WORK

CFD tools can be effectively used to study the wave effect on ship hydrodynamics in variety of motion modes. For the purpose of practical application, the following work needs to be established in the future:

- Model test data base with wave and motion signals as well as force components are needed for validation of CFD results
- Although bow wave can be generated reliably, following sea as well as oblique sea need to be generated by RANS approach
- For the calculation of large amplitude ship motion, the quality of deforming mesh needs to be improve

7. CONCLUSION

Based on the computational results, the following conclusions are drawn:

- From the comparisons of computed and measured results it shows that the oscillations of forces in waves depend on the wave amplitude and wave length.
- The effects of wave on time-averaged forces from calculation in captive condition were small. Averaged X, Y, and N were close to those from measurement without wave.
- The forces from measurement in waves suffer from high frequency disturbance. The reason for this whether it is due to wall reflection or wave quality needs to be clarified.
- The computed and measured surge forces in free condition averaged in one period were slightly larger than those in captive condition.

8. REFERENCE

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