View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Hydraulic Engineering Repository

HENRY
Hydraulic Engineering Repository

Ein Service der Bundesanstalt für Wasserbau

Conference Paper, Published Version

Deng, Ganbo; Leroyer, A.; Guilmineau, E.; Queutey, P.; Visonneau, Michel; Wackers, J.

CFD Simulation of PMM Motion in Shallow Water for the DTC Container Ship

Zur Verfügung gestellt in Kooperation mit/Provided in Cooperation with:
Flanders Hydraulics Research, Ghent University, Maritime Technology

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/99855

Vorgeschlagene Zitierweise/Suggested citation:
Deng, Ganbo; Leroyer, A.; Guilmineau, E.; Queutey, P.; Visonneau, Michel; Wackers, J. (2016): CFD Simulation of PMM Motion in Shallow Water for the DTC Container Ship. In: Uliczka, Klemens; Böttner, Carl-Uwe; Kastens, Marko; Eloot, Katrien; Delefortrie, Guillaume; Vantorre, Marc; Candries, Maxim; Lataire, Evert (Hg.): 4th MASHCON - International Conference on Ship Manoeuvring in Shallow and Confined Water with Special Focus on Ship Bottom Interaction. Karlsruhe: Bundesanstalt für Wasserbau. S. 93-98.
https://dx.doi.org/10.18451/978-3-939230-38-0_12.

Standardnutzungsbedingungen/Terms of Use:

Die Dokumente in HENRY stehen unter der Creative Commons Lizenz CC BY 4.0, sofern keine abweichenden Nutzungsbedingungen getroffen wurden. Damit ist sowohl die kommerzielle Nutzung als auch das Teilen, die Weiterbearbeitung und Speicherung erlaubt. Das Verwenden und das Bearbeiten stehen unter der Bedingung der Namensnennung. Im Einzelfall kann eine restriktivere Lizenz gelten; dann gelten abweichend von den obigen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Documents in HENRY are made available under the Creative Commons License CC BY 4.0, if no other license is applicable. Under CC BY 4.0 commercial use and sharing, remixing, transforming, and building upon the material of the work is permitted. In some cases a different, more restrictive license may apply; if applicable the terms of the restrictive license will be binding.

4th MASHCON, Hamburg - Uliczka et al. (eds) - © 2016 Bundesanstalt für Wasserbau ISBN 978-3-939230-38-0 (Online)
DOI: 10.18451/978-3-939230-38-0_12

CFD SIMULATION OF PMM MOTION IN SHALLOW WATER FOR THE DTC CONTAINER SHIP

G Deng, A Leroyer, E Guilmineau, P Queutey, M Visonneau and **J Wackers,** METHRIC, LHEEA/UMR 6598 CNRS, Ecole Centrale de Nantes, France

SUMMARY

This paper is devoted to the validation exercises with the ISIS-CFD code, our in house finite volume RANSE (Reynolds Averaged Navier-Stokes Equation) solver, conducted for the test cases proposed for the 4th MASHCON conference (International Conference on Ship Manoeuvring in Shallow and Confined Water). CFD simulations have been performed for the 4 different pure yaw and pure sway test cases under shallow water condition. Predicted results are compared with the measurement data provided by FHR (Flanders Hydraulic Research).

1 INTRODUCTION

CFD can be considered as a mature tool now for steady state ship hydrodynamic applications such as resistance in calm and deep water. Predictions which are accurate enough can be obtained with reasonable resources even for fully appended hulls, both for model and for full scale in a routine design procedure. However, for applications with unsteady flow such as PMM (Planar Motion Mechanism) motion, more validation works need to be done before we can consider CFD as a reliable tool for those applications. International workshops devoted to ship maneuvering simulation have been organized in 2008 and 2014 (SIMMAN 2008 and SIMMAN 2014, Workshop on Verification and Validation of Ship Maneuvering Simulation Methods). Due to limited submissions with CFD approach, assessment is difficult to make. Simulation of PMM motion in shallow water is a challenging task. As flow separates under shallow water condition, especially with PMM motion, physical modeling error due to turbulence modeling could be more important. From numerical point of view, handling ship PMM motion in shallow water with confined side wall is a difficult task. Overset grid approach is more flexible to handle ship motion in such configuration. However, as conservation property cannot be ensured with overset, ensuring a good numerical accuracy is a very difficult task, especially when the mesh is highly stretched. Mesh deformation approach can provide a better numerical accuracy compared with overset approach. But it can only be used when the ship motion amplitude is small. Computation for the 4 test cases proposed by the MASHCON conference (Eloot, 2016 [3]) will be performed with the latest version of our in house flow solver ISIS-CFD including overset approach, also available in the commercial software FINE^{TM}/Marine in the coming 5.1 release.

2 NUMERICAL APPROACH

The ISIS-CFD flow solver developed by our team is a finite volume code supporting control volume of arbitrary shape. Turbulent flow is simulated by solving the incompressible Reynolds-averaged Navier-Stokes equations (RANS). The flow solver is based on finite volume method to build the spatial discretization of the transport equations. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass conservation constraint, or continuity equation, transformed into a pressure-equation. In the case of turbulent flows, additional transport equations for modeled variables are discretized and solved using the same principles. The gradients are computed with an approach based on Gauss's theorem. Non-orthogonal correction is applied to ensure formal first order accuracy. Second order accurate result can be obtained on a nearly symmetric stencil. Inviscid flux is computed with a piecewise linear reconstruction associated with an upwinding stabilizing procedure which ensures a second order formal accuracy when flux limiter is not applied. Viscous fluxes are computed with a central difference scheme which guarantees a first order formal accuracy. We have to rely on mesh quality to obtain a second order discretization for the viscous term. Free-surface flow is simulated with a multi-phase flow approach. Incompressible and non-miscible flow phases are modeled through the use of conservation equations for each volume fraction of phase/fluid. Implicit scheme is applied for time discretization. Second order three-level time scheme is employed for time-accurate unsteady computation. Velocity-pressure coupling is handled with a SIMPLE like approach. Ship free motion can be simulated with a 6 DOF module. Some degree of freedom can be fixed as well. An analytical weighting mesh deformation approach is employed when free-body motion is simulated. Additionally the overset approach is also implemented recently for the numerical PMM tests. It will be employed in one of the test cases in the present study. Several turbulence models ranging from one-equation model to Reynolds stress transport model are implemented in ISIS-CFD. Most of the classical linear eddy-viscosity based closures like the Spalart-Allmaras one-equation model, the two-equation k-ω SST model by Menter [2], for instance are implemented. More sophisticated turbulence closures like an explicit algebraic stress model (EASM) [1] are also implemented in the ISIS-CFD solver. The EASM model is employed in the present study. Wall function is implemented for two-equation turbulence model.

Overset approach has been implemented recently in the ISIS-CFD code. A distance based cell blanking procedure with high parallel efficiency is implemented. Data exchange between different domains is handled with a second order least squared interpolation procedure. Adaptive grid refinement procedure has been adapted to overset approach in such a way that user can apply an adaptive grid refinement such that mesh size near the overset interface is nearly the same in different overlapping domain.

3 RESULTS AND DISCUSSIONS

The test case simulated in this paper is described in [3]. It concerns the DTC container carrier in model scale with a scale factor of 89.11 and 20% UKC shallow water condition. Water depth is 0.195m. The width of the towing tank (7.0m) is taken into account in the computation. The bare hull configuration (without rudder, propeller and bilge keel) is simulated. There are two test cases with pure yaw motion and two test cases with pure sway motion. Test cases A and B concern a pure yaw motion with a period of 25s and yaw amplitude of 15 degrees. Model speed is 0.599m/s and 0.872m/s respectively. The maximum sway motion is about 0.62m and 0.9m respectively. Test cases C and D concern pure sway motion with a period of 20s and sway amplitude of 0.2m. Model speed is the same as case A and B respectively.

Mesh management is a critical issue for shallow water computation. To ensure a good numerical accuracy, single domain computation with mesh deformation is the best choice. Our mesh deformation approach has been recently adapted for shallow water computation such that mesh deformation in the XY plane near the bottom wall in shallow water configuration is free. With this special implementation, all test cases can be simulated with single domain using mesh deformation. To better handle ship heave and pitch motion with mesh deformation approach, the mesh is generated with the ship model located at a prescribed sinkage position. The prescribed sinkage value for the low and high speed cases are 8mm and 23mm respectively. According to our experiences [4], for shallow water computation, it is preferred to use low Reynolds number model at the hull, and wall function at the bottom wall. This gives a mesh with about 8.2M and 9.2M cells for the low and high speed respectively. For case B, due to high maximum sway motion (about 0.9m over half tank width of 3.5m), mesh deformation is too severe. We also attempt to use the newly developed overset approach for this computation. An overlapping domain containing the hull with outer boundaries located at about 0.3Lpp is generated. It contains about 3.5M cells. The background grid containing about 2M cells is employed to simulate the towing tank. To avoid numerical difficulty related to overset approach as much as possible in this first attempt with overset approach for shallow water application, viscous layer is not inserted at the bottom wall. Moreover, wall function approach is employed at the hull in order to reduce CPU time. Ship heave and pitch motions in the overlapping domain are still handled with mesh deformation, while mesh rigid motion is applied for yaw and sway motions.

Table 1. Results for Resistance Computation

Case	u(m/s)	Rt(N)	Trim(mm/m)	Sink(mm)
A	0.599	3.35	-0.31	5.25
B1	0.872	9.48	-0.41	15.8
B2	0.872	9.60	-0.43	19.1

To initialize the computation with PMM motion, a resistance computation is performed first. Ship resistance, trim and sinkage results for these computations are shown in table 1. Case B1 is performed with single domain, while case B2 is performed with overset approach. Overset approach over predicts ship resistance, trim and sinkage by 1.2%, 4.9% and 21% respectively compared with single domain approach. Based on our experiences with similar configuration [4], ship resistance predicted with wall function is smaller compared with the result obtained with low Reynolds number model. Hence, the over prediction of ship resistance with overset is not due to the use of wall function. Inspection of the numerical result obtained with overset approach reveals that when the ship advance in the numerical tank, water level near the inlet decreases by about 2mm compared with the expected calm water level. This unexpected result must be due to the fact that with overset approach, mass conservation cannot be ensured. As the simulated water level is lower, resistance and sinkage are over predicted. Only trim and sinkage results are reported in [3]. The measurement trim angle is about -0.4mm/m for both speeds. CFD prediction agrees well with the measurement data for this quantity except for the case with low speed. Measurement values for sinkage are 5.1mm and 16.5mm respectively for both speeds. At high speed, the predicted sinkage is only 0.7mm smaller than the measurement value. In relative value, it is only 4.4% smaller. Taken into account measurement uncertainty; we consider that CFD prediction for sinkage with single domain is accurate., Over estimation by 16% observed with overset approach is due to simulated water level in numerical tank as mentioned above. The comparison with the measurement data suggests that the single domain computation provides good prediction for trim and sinkage, while correction should be made based on the simulated water level when using overset approach..

As ship resistance measurement data are not available, to give an indication on numerical uncertainty for hydrodynamic force, comparison of ship resistance for the DTC container ship in deep water is shown in figure 1. The measurement data are provided in [5]. Computations have been performed with the k-ω SST turbulence model with a grid containing about 1M cells on half domain. For all speeds, ship resistance is under predicted by less than 2%. Grid independent study has been performed for the highest speed v=1.668m/s (with Fr=0.218). The later results are also given in table 2. The error shown in this table is the difference between the measurement result (31.83N) and the CFD prediction, while numerical uncertainty is the difference between the CFD result and the extrapolated CFD prediction (30.658N) with observed order of convergence (p=1.95). Such convergence behavior is a typical result obtained with our solver for such verification and validation exercise for a conventional hull form. Predicted resistance becomes smaller than the measurement value when we refine the grid. This is a well-known default of linear turbulence model. CFD prediction can be improved by using a more accurate turbulence model such as the non-linear EASM model. More validations in shallow water on the hydrodynamic forces as well as ship trim and sinkage including the results obtained with our code can be found in [4].

Table 2. Grid dependency study for Fr = 0.218.

Nb. cells	Resistance (N)	Error	Uncertainty
400K	32.27	-1.38%	5.3%
1025K	31.53	0.94%	2.8%
2071K	31.21	1.95%	1.8%

Measurement data at Fr = 0.218: resistance = 31.83N

Restarting from the resistance computation, a time accurate unsteady simulation with prescribed PMM motion is performed. For case A with pure yaw motion, a small time step with 2500 time steps per period is necessary to ensure numerical stability. Time step is larger for case C and D with pure sway motion (1000 time steps per period). 20 non-linear iterations per time step are performed. With 64 cores, one time step takes about 100s wall clock time. A typical computation takes about 10 days. The CPU time with overset approach is similar.

Comparison with measurement results for heave and pitch motion as well as longitudinal and lateral forces, roll and yaw moments for different cases are shown in figures 2 to 9. For verification purpose, imposed sway motion, v velocity and yaw motion are also shown in the figures. Forces and moments are given in the horizontal-bound towing carriage coordinate system as described in [3]. Solid lines are CFD predictions, while symbol lines are measurement data. Averaged Reynolds number and Froude number based on ship length are $2.28\text{x}10^6$ and 0.0958 respectively for the case with low speed, and $3.23\text{x}10^6$ and 0.139 respectively for the case with high speed.

Restarting from the resistance computation, a time accurate unsteady simulation with prescribed PMM motion is performed. For case A with pure yaw motion, a small time step with 2500 time steps per period is necessary to ensure numerical stability. Time step is larger for case C and D with pure sway motion (1000 time steps per period). 20 non-linear iterations per time step are performed. With 64 cores, one time step takes about 100s wall clock time. A typical computation takes about 10 days. The CPU time with overset approach is similar.

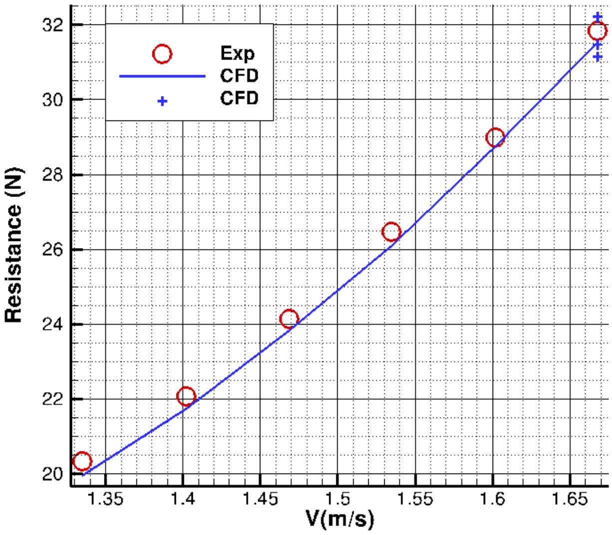

Figure 1. Deep water resistance prediction.

Comparison with measurement results for heave and pitch motion as well as longitudinal and lateral forces, roll and yaw moments for different cases are shown in figures 2 to 9. For verification purpose, imposed sway motion, v velocity and yaw motion are also shown in the figures. Forces and moments are given in the horizontal-bound towing carriage coordinate system as described in [3]. Solid lines are CFD predictions, while symbol lines are measurement data. Averaged Reynolds number and Froude number based on ship length are $2.28\text{x}10^6$ and 0.0958 respectively for the case with low speed, and $3.23\text{x}10^6$ and 0.139 respectively for the case with high speed.

Case A (figure 2 and 3) is a pure yaw motion at low speed. Sinkage is under predicted by about 0.5mm. Trim angle is also slightly under predicted. Taking into account measurement and numerical uncertainty, it can be considered that ship motion is correctly predicted. Measurement data for longitudinal force is very noisy (figure 3). To allow a better comparison, smoothed measurement data is also plotted. It can be seen that the predicted longitudinal force agree well with the smoothed measurement data. The predicted lateral force is quite different from the measurement data. First order amplitude is almost 3 times smaller than the measurement value. Such huge discrepancy is not consistent with the good agreement observed for the yaw moment. Moreover, lateral forces are correctly predicted for the cases with pure sway motion. We believe that there might be a measurement data processing problem for the lateral force for this test case.

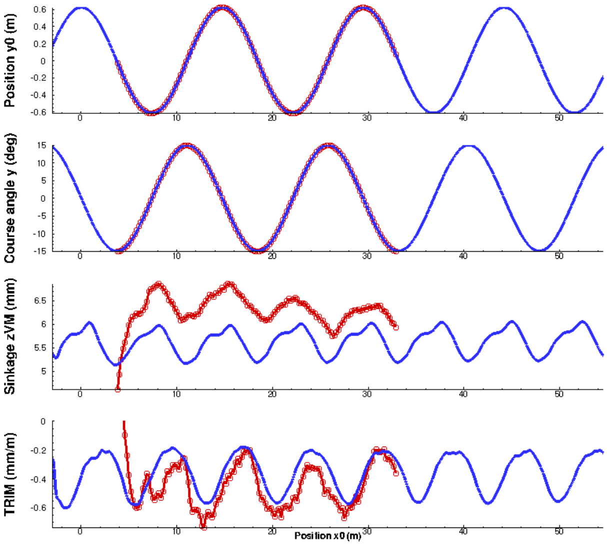

Figure 2. Motions for case A

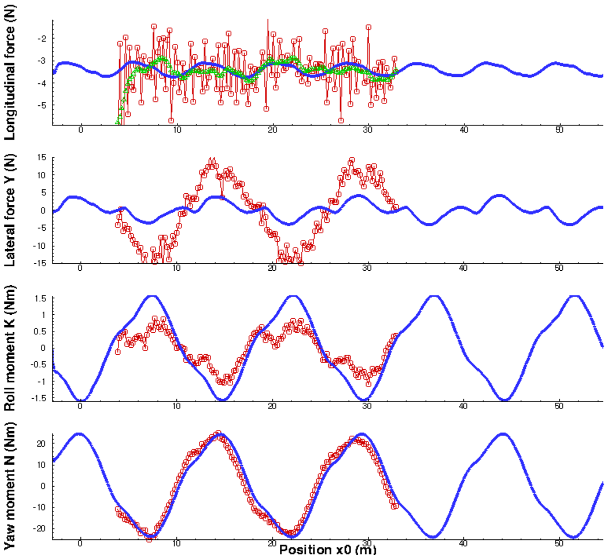

Figure 3. Forces and moments for case A

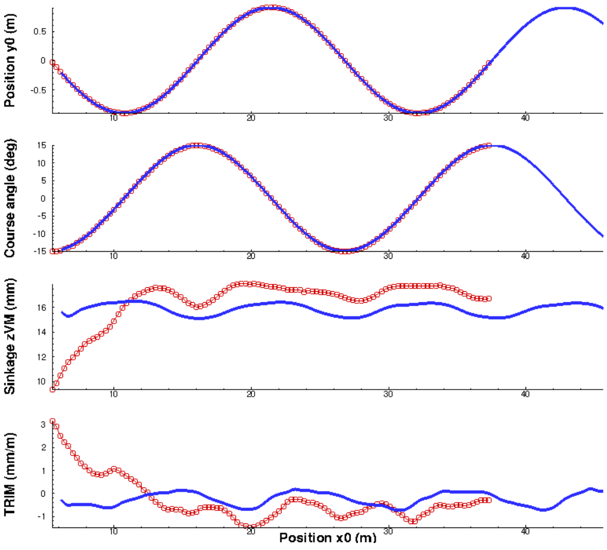

Figure 4. Motions for case B

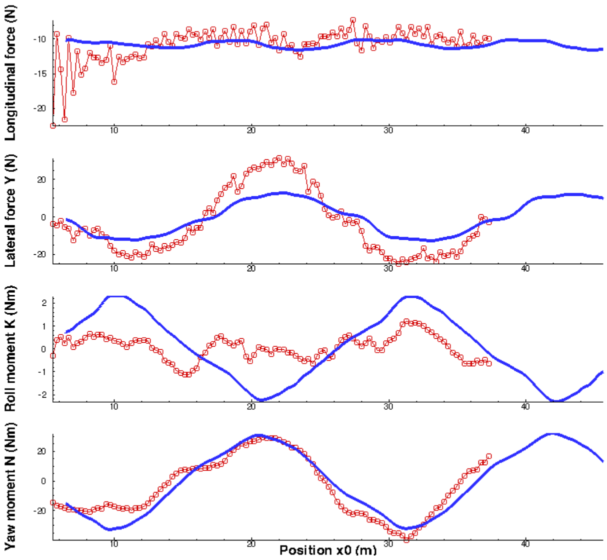

Figure 5. Forces and moments for case B

Case B (figures 4 and 5) is a pure yaw motion with high speed. We fail to obtain plausible result with overset approach for this case. Results shown in figures 4 and 5 are also obtained with single domain approach with mesh deformation. Predicted heave motion is about 1mm smaller compared with the measurement data with very small fluctuation. Pitch angle is very small. Longitudinal force is almost constant. It agrees well with the measurement data. As for case A, amplitude of the lateral force is under predicted by about 50%. However, yaw moment is in much better agreement. As for case A, roll moment amplitude is also higher in the CFD computation. But it remains very small compared with the yaw moment.

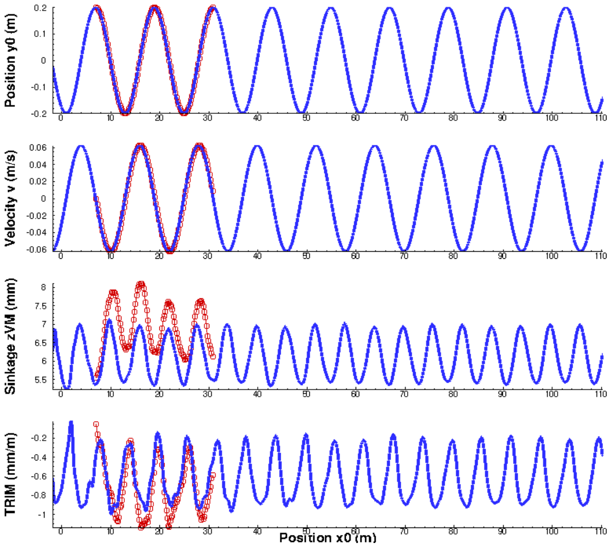

Figure 6. Motions for case C

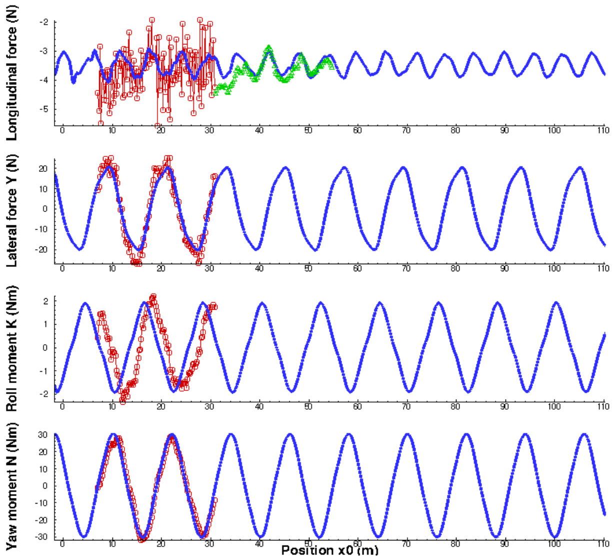

Figure 7. Forces and moments for case C

Case C (figure 6 and 7) is a pure sway motion at low speed. Predictions for trim and sinkage are similar for case A. Measurement data for longitudinal force is also very noisy. It varies from -6N to -2N, while CFD prediction varies from -4N to -3N only. As for case A, smoothed measurement data is also plotted to allow a better comparison. CFD prediction agrees well with the smoothed measurement data (shifted to the right for better comparison). Unlike for case A, good agreement is observed for lateral force. Force amplitude is under predicted only by about 15% rather than by 3 times. Roll and yaw moments are also correctly predicted, although a phase lag is observed for the roll moment.

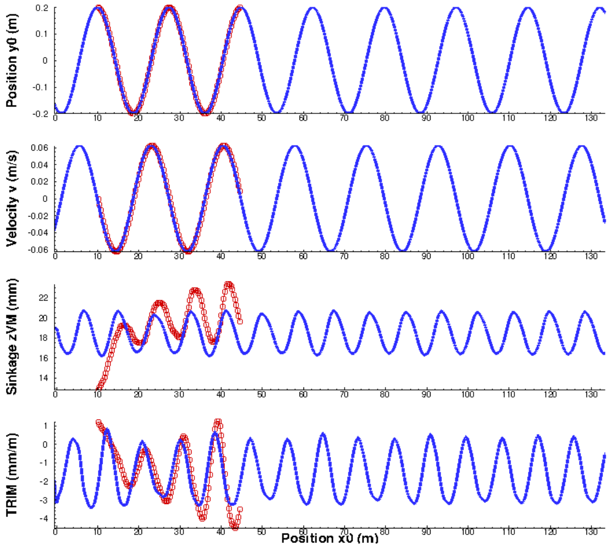

Figure 8. Motions for case D

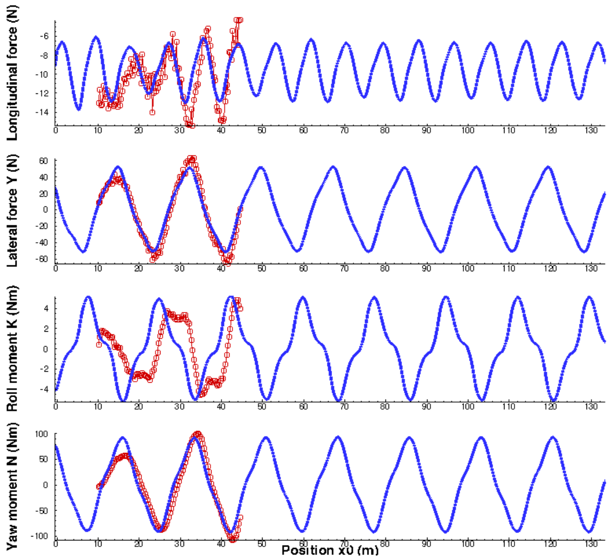

Figure 9. Forces and moments for case D

Case D (figures 8 and 9) is a pure sway motion at high speed. CFD computation aims at predicting fully established stat with quasi periodic result. Measurement data were recorded only for the first 2 periods after the acceleration due to limited length of the towing tank. Figure 8 shows that due to the transitional effect during the acceleration period, ship trim and sinkage are far from the expected quasi periodic behavior. For this reason, it is difficult to compare the CFD prediction with measurement. Nevertheless, the predicted trim and sinkage are about the same magnitude as observed in the measurement. Similar behavior is observed for force and moments shown in figure 9..To better validate CFD computation, a transitional flow simulation with exactly the same motion laws applied during the acceleration period as in the measurement could be more useful. Unfortunately, those motions laws are not specified in [3]. Another interesting alternative is to perform CFD simulation corresponding to arm rotating basin.

4 CONCLUSIONS

The 4 test cases proposed for the MASHCON conference with PMM pure yaw and pure sway motion for the DTC carrier in shallow water have been computed with the ISIS-CFD flow solver. Good agreement is observed for ship motions, forces and moments in general except for lateral force for pure yaw motion. All computations have been performed with single domain approach using mesh deformation. When ship motion amplitude becomes larger, alternatives such as overset approach are needed for such simulation. Such simulations will be investigated in future studies.

5 ACKNOWLEDGEMENTS

This work was granted access to the HPC resources under the allocation 2015-2a1308 made by GENCI (Grand Equipement National de Calcul Intensif). The authors are in debt to K. Eloot et al. for providing the experimental data.

6 REFERENCES

1. Deng, G.; Queutey, P.; Visonneau, M. (2005). Three-Dimensional Flow Computation with Reynolds Stress and Algebraic Stress Models. Engineering *Turbulence Modelling and Experiments 6*, W. Rodi and M. Mulas eds. Elsevier, pp. 389-398..

2. Menter, F.R. (1993). Zonal two-equations k-ω turbulence models for aerodynamic flows. *AIAA Paper* 93-2906.

3. Eloot, K.; Vantorre, M.; Delefortrie, G.; Lataire, E. (2016). Running Sinkage and Trim of the DTC Container Carrier in Harmonic Sway and Yaw Motion: Open Model Test Data for Validation Purposes. *Fourth International Conference on Ship Manoeuvring in Shallow and Confined Water (MASHCON): Ship - Bottom Interaction*, 23-25 May 2016, Hamburg, Germany.

4. Mucha, P.; Deng, G.; Gourlay, T. ; Moctar O. el (2016). Validation Studies on Numerical Prediction of Ship Squat and Resistance in Shallow Water. *Fourth International Conference on Ship Manoeuvring in Shallow and Confined Water (MASHCON): Ship - Bottom Interaction*, 23-25 May 2016, Hamburg, Germany.

5. Moctar, O. el; Shigunov, V.; Zorn, T. (2012). Duisburg Test Cases: Post-Panamax Container Ship for Benchmarking. *Ship Technology Research, Schiffstechnik* Vol. 59, No. 3.

7 AUTHORS' BIOGRAPHIES

Ganbo Deng holds a research position in the METHRIC group of LHEEA at Ecole Centrale de Nantes, France. His main activities concern CFD code development and application for hydrodynamic. His recent activities concern overset development.

Alban Leroyer holds an associate professor position in the METHRIC group of LHEEA at Ecole Centrale de Nantes, France. His main activities concern FSI simulation.

Emmanuel Guilmineau holds the current position of Researcher at CNRS (French National Center for Scientific Research). He is responsible for the study of turbulence models.

Patrick Queutey holds the current position of Researcher at CNRS (French National Center for Scientific Research). He is at the head of the METHRIC team (Turbulent Modelling of Incompressible Flows at High Reynolds Number).

Michel Visonneau , born in France in 1957. He obtained the Engineer's diploma in 1980 from Ecole Nationale Supérieure de Mécanique (now Centrale Nantes) and the diploma of Advanced Naval Architecture from ENSM in 1981. In 1985, he got the PhD of Fluid Dynamics and Heat Transfer of University of Nantes and entered the "Centre National de la Recherche Scientifique (CNRS)" as Research Scientist. He was the head of the CFD department of the Fluid Mechanics Laboratory (ECN) from 1995 to 2011. In 2001, he got the Research Habilitation Diploma. He holds the position of Research Director within CNRS from 2006. His main research topics are Computational Fluid Dynamics (CFD), Ship Hydrodynamics and Turbulence Modeling for high Re flows. In 1991, he got the 2nd Cray Prize for CFD and was awarded 30th Georg Weinblum Memorial Lecturer (2007-2008) in 2007.

Jeroen Wackers holds a research position in the METHRIC group of LHEEAat Ecole Centrale de Nantes, France. He is responsible for the study of adaptive grid refinement.