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

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## SUMMARY

This paper is devoted to the validation exercises with the ISIS-CFD code conducted for the test cases proposed for the MASHCON conference. 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.

## 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. Accurate enough predictions 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 motion, more validation works need to be done before we can consider CFD as a reliable tool for those applications. Simulation of PMM motion in shallow water is a challenging task. As flow separates under shallow water condition, especially with PMM motion, physical modelization error due to turbulence modelization could be more important. From numerical point of view, handling ship PMM motion in shallow water with confined side wall is a difficult task. Mesh deformation approach can provide a better numerical accuracy. But it can only be used when ship motion amplitude is small. Overset grid approach is more flexible to handle ship motion in such configuration. However, ensuring a good numerical accuracy while maintaining a good numerical stability with highly stretched grid in such condition is a very difficult task that remains to be solved. Computation for the 4 test cases proposed by the MASHCON conference 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<sup>TM</sup>/Marine in the coming 5.1 release.

## 2 NUMERICAL APPROACH

Computation has been performed with the ISIS-CFD flow solver developed by our team. 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 a 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 flux are computed with a central difference scheme which guarantee 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. Overset approach is implemented recently. 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  $k-\omega$  SST model by Menter [2], for instance are implemented. A more sophisticated turbulence closures are also implemented in the ISIS-CFD solver, an explicit algebraic stress model (EASM) [1]. The EASM model is employed in the present study. Wall function is implemented for two-equation turbulence model.

### 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 sway amplitude 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 except case B 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 sway motion amplitude (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  $0.3L_{pp}$  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.

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 due to discretization error rather than the effect of wall function employed for this computation. Only trim and sinkage results are reported in [3]. The measurement trim angle is about -0.4mm/m for both speeds. CFD prediction agree 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. CFD prediction with single domain agrees well with the data, while an over prediction by 16% is observed with overset approach. The comparison with the measurement data suggests that the single domain computation provides better accuracy compared with overset approach as expected.

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

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 take 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 1 to 8. 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.

Case A (figure 1 and 2) 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 2). 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.

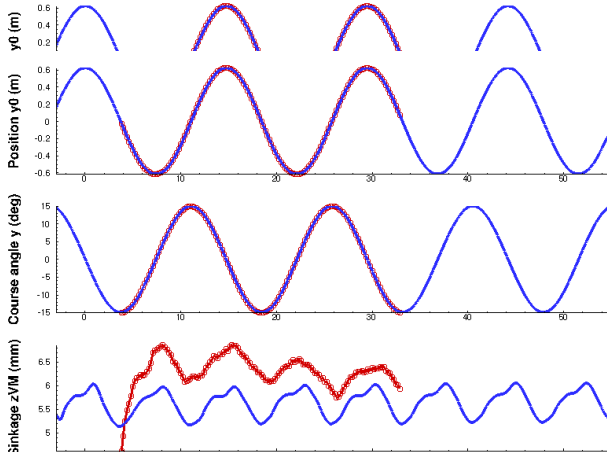


Figure 1. Motions for case A

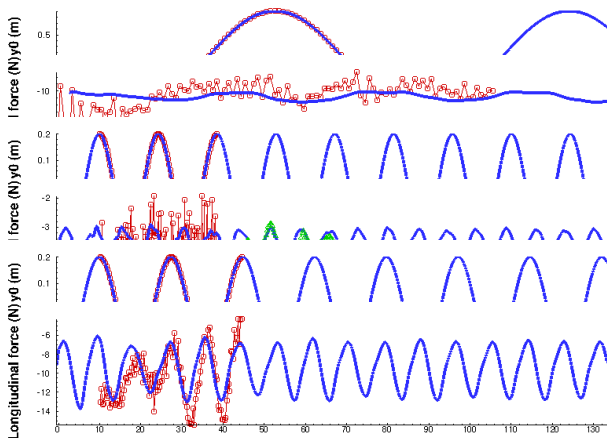


Figure 2. Forces and moments for case A

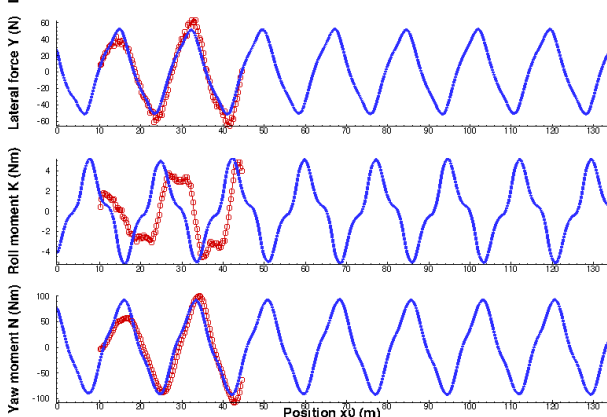


Figure 3. Motions for case B

Figure 4. Forces and moments for case B

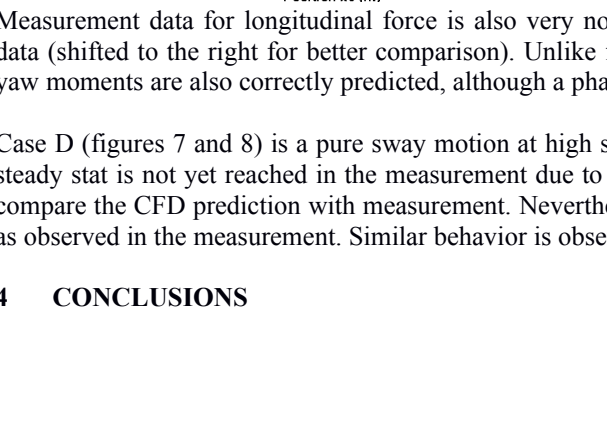


Figure 5. Motions for case C

Figure 6. Forces and moments for case C

Figure 7. Motions for case D

Figure 8. Forces and moments for case D

Case B (figures 3 and 4) is a pure yaw motion with high speed. We fail to obtain plausible result with overset approach for this case. Results shown in figures 3 and 4 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 and agree 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 raw moment.

Case C (figure 5 and 6) 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. 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. Roll and yaw moments are also correctly predicted, although a phase lag is observed for the roll moment.

Case D (figures 7 and 8) is a pure sway motion at high speed. Measurement data for trim and sinkage (figure 7) show that steady stat is not yet reached in the measurement due to limited length of the towing tank. 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 8.

#### 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 become larger, alternatives such as overset approach are needed for such simulation. Such simulations will be investigated in future studies.

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**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.

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