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A sliding grid based method for the roll decay simulation

A Lungu

”Dunarea de Jos” University of Galati, Faculty of Naval Architecture, Department of Naval Architecture, Domneasca Street No. 47, Galati 800008, Romania

E-mail: adrian.lungu@ugal.ro

Abstract. The paper describes a novel technique meant to support the numerical prediction of the roll decay for a ship hull equipped with bilge keels in an attempt of establishing a methodology for accurate prediction of the damping forces which occur during the oscillation. The numerical simulation is achieved by making use of the ISIS-CFD solver, part of the FineTM/Marine package available in the NUMECA suite. The solver is based on finite volume method to build the spatial discretization for the governing equation to solve the incompressible unsteady RANSE in a global approach. Closure to the turbulence is achieved by making use of the detached eddy simulation model which has been found as being enough accurate. All the computations are performed in respect to an earth-fixed Cartesian reference frame with only one degree of freedom i.e. roll motion. The validation of the computed solution is done through the comparisons with the experimental data.

1. Introduction

The increased demand for the higher hydrodynamic performances for ship designs with large bow flare requires detailed studies aimed at finding out how the new hull shapes influence the ship stability and which is the influence that may lead to large roll angle amplitudes, high accelerations and thereby to a high safety risk for human life, ship and cargo. From this particular point of view, the assessment of dynamic stability of a ship hull in the early design phase is needed.

The roll motion of a ship around its longitudinal axis is one of the most important one among the others since when the energy induced by wind, waves or currents is fed into the roll motion system, the roll angle amplitude increases. The energy is usually defined by the roll angle value, angular roll angle velocity and angular acceleration. The properties of the roll motion behaviour are determined by the ship hull shape, the mass distribution and the motion of the surrounding water. The reverse effect of a loss of energy, that decreases the roll angle amplitude, is termed roll decay and is caused by various flow effects such as the wave radiation, viscous friction, eddy separation, lift effects and so on.

Nowadays in the naval architecture the roll motion of a ship is simulated by using computational methods, which are sufficiently accurate for ship design purposes since they account for the viscous roll damping, which can be determined with a satisfactory accuracy in spite of their still high computational costs. Different approaches such as experimental model tests, potential-based methods or empirical prediction methods were developed to cope with this problem. Experimental tests, which are costly, time consuming and suffer from scale effects used to be largely used for became less and less attractive. Empirical methods such as the Ikeda method [1], restricted in their use, as their development was based on a restricted number of slender bodies could not prove the validity for actual ship designs. An alternative approach for computing the roll damping remains the use of



computational fluid dynamic (CFD hereafter) methods that numerically solve the flow problem based either on the Reynolds averaged Navier-Stokes (RANS) equations or on more accurate techniques such as large eddy simulations (LES) or detached eddy simulations (DES). Nevertheless, the high computational cost still prevents its wide use in the design phase.

As the finite-volume-based computational methods have reached the current state, in the past two decades, the number of RANSE-based studies for solving ship roll motion increased continuously. High speed computers set the pace for using higher number of elements and enabled implementation of more flexible grid techniques for simulation of ship roll which included either the overset or sliding grids. Overset grids have found wide application opportunities in numerically simulating ship roll among many researchers working in this field [2-5], whereas the sliding grid technique has been used mainly in the self-propulsion simulations [6-8]. In the Gothenburg 2010 Workshop, simulations of the free decay of the US combatant DTMB 5415 based on four different codes [9] were extensively compared with the experimental data [10] to find out an appropriate method to cope with the given task. The simulations were carried out for the bare hull appended with bilge keels at a forward speed.

The present research work is focused on the free roll decay of the benchmark DTMB 5415 hull fitted only with bilge keels by using a RANSE-based numerical approach. One of its major purposes is to identify the contributions of the wave and eddy damping on the ship roll motion. The flexibility of the ISIS CFD code employed is used and the details of the numerical approach are given and explained in detail in the following sections. Based on the present study, the roll damping can be further assessed by making use of the free roll decay numerical simulation since it has already been stated [11] that the free roll decay shows certain advantages over harmonic excited roll motion technique when the roll damping has to be estimated.

2. Ship geometry, the computational domain and grid generation

The DTMB combatant model 5415 shown in figure 1 was initially studied extensively by using CFD techniques when it was chosen to be one of three test cases in the Gothenburg 2000 Workshop for computational fluid dynamics applied to ship flows. Participants were asked to focus in particular on the total resistance, the wave profile along the hull and at selected locations close to the ship, the overall wave pattern in the near field and the mean flow velocities near the stern, particularly at the propeller plane. Experimental data for this model has been obtained by the DTMB, IIHR, and INSEAN laboratories. A detailed comparison of this data is provided in [9]. The main particulars of the hull model are tabulated in table 1.



Figure 1. Hull geometry.

Table 1. Main particulars of the DTMB 5415 hull.

Length, L_{pp} [m]	3.048	Displacement, Δ [m ³]	0.087
Breadth, B [m]	0.405	Wetted surface area, S [m ²]	1.459
Draft, T [m]	0.132	Block coefficient, C_B [-]	0.506

Although not fully appended, i.e. shafts, brackets, rudders and propellers are not taken into consideration, the hull has a special geometry that rises particular difficulties in meshing because of the significant sonar dome existing at the fore extremity as well as to the areas that correspond to the bilge keels extremities. To cope with these problems, an unstructured grid has been chosen in the present study. Even though when dealing with a roll decay problem, usually the mesh deformation is a common choice, herein a sliding-grid-based novel approach is proposed. When computing the fluxes over a sliding interface, establishing connections between cells on the two sides of the interface is necessary. The procedure to connect these cells is performed at each time step in order to account for the rotation of the two sub-domains with respect to each other. This procedure is chosen to remain as close as possible to what it is done for standard cells. Thus, no specific interpolations are used. Instead, for a cell and face on the interface, the cell center in the other sub-domain which best matches the face is searched. No explicit interpolation is used to find the states on the sliding faces; instead, the

coupling algorithm identifies real cells that are used as neighbours for the cells in the other sub-domain. The fluxes are computed across the sliding faces independently of the appertaining sub-domain and therefore without regards to conservation of mass and momentum. The computational grid consisting of 35M cells is shown in figure 2, which depicts a longitudinal cut on the mesh on the top and two cross cuts viewed from the fore (left) and from the aft (right), respectively.

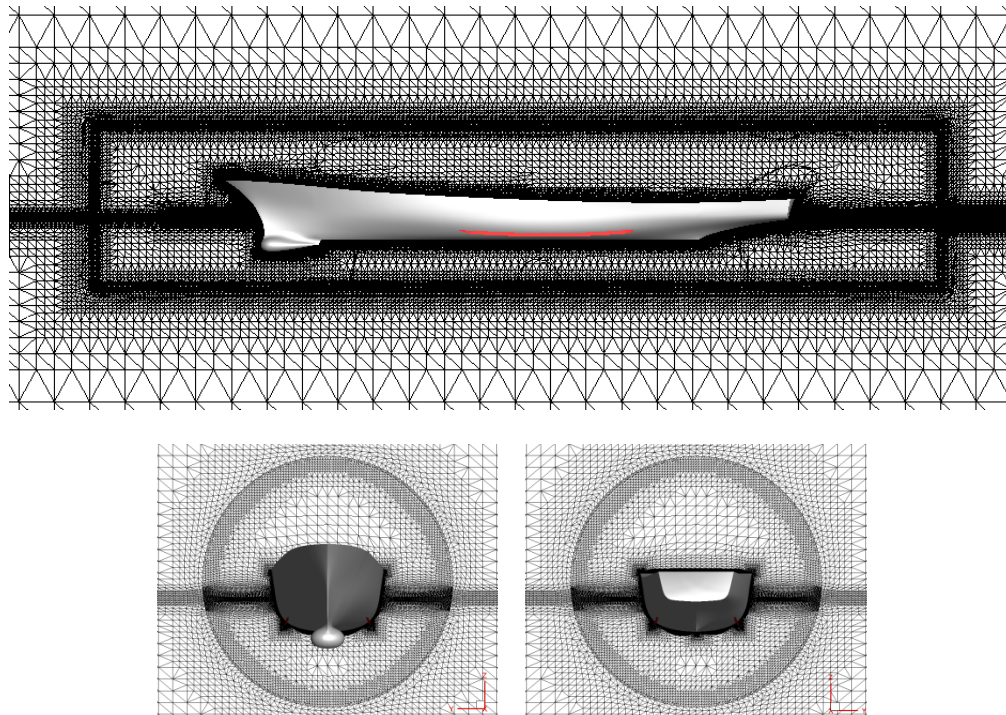


Figure 2. Computational grid.

3. Computational particulars

The numerical solutions reported in the present paper are computed with the ISIS-CFD viscous flow solver, part of the Numeca FineTM/Marine package. Turbulent flow is simulated by solving the unsteady equations of flow. The flow solver is based on finite volume method, which builds up the spatial discretization of the transport equations. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted either from the mass conservation constraint, or from the continuity equation, transformed into a pressure equation. The gradients are computed with an approach based on the Gauss theorem. A second order accuracy level is assured by using a non-orthogonal correction technique. Inviscid fluxes are computed with a piecewise linear reconstruction associated with a stabilizing procedure which ensures a second order formal accuracy when flux limiter is not applied. Viscous fluxes are computed with central difference schemes. Based on the mesh quality, the model assures a second order accuracy discretization for the viscous term. More details on the computational technique are provided in [8], therefore no more details will be provided in here.

Free-surface flow is simulated with a multi-phase volume of fluid approach. Incompressible and non-miscible flow phases are modeled through the use of conservation equations for each volume fraction of phase/fluid. An implicit scheme is applied for the discretization in time whereas a second order three-level time scheme is used for time-accurate unsteady computation. Velocity-pressure coupling is handled with a SIMPLE like approach. The turbulence model is using the Shear Stress Transport (SST) based Detached Eddy Simulation (DES), which provides the accuracy of LES for highly separated flow regions and computational efficiency of RANS in the near-wall region.

Regardless the computational case, the simulation is performed following the same strategy: the flow is accelerated from the rest to the specified velocity for a certain number of time steps enough to reach the stability of the flow around the inclined ship at the given roll angle. During this stage the ship is kept fixed in respect to the longitudinal axis of the Cartesian system and only trims and sinkage moves are allowed. Once the flow is stabilized, the ship is freed and the roll decay is further computed. Depending on the roll angle value, the extension of the acceleration and stability periods vary from 20 to 30 seconds. The time step value was set at $\Delta t = 0.001$ second for all the computations reported in here.

4. Results and discussions

A set of six computations for roll angles ranging from 5° to 20° are performed to investigate the ship behaviour when its initial stability is affected. Four small and moderate roll angles from 5° till 12.5° in steps of 2.5° are considered for the decay analysis at first. A thorough series of comparisons with the experimental results reported by Irvine et al. [9, 10, 12] are proposed for verification and validation purposes in figures 3 - 6, which depict the history of the numerical and experimental [9, 10] roll decay drawn against the non-dimensional time. For reasons related to the consistency all the comparisons are performed only up to the non-dimensional time of $T=2.5$. In all the figures the computed solution is drawn with solid line, whereas the experimental data with symbols. The resemblance between the numerical solution and the experimental data is very good not only in terms of the amplitude of the roll angle, but also in terms of the phase, a fact that may confirm the accuracy of the solver.

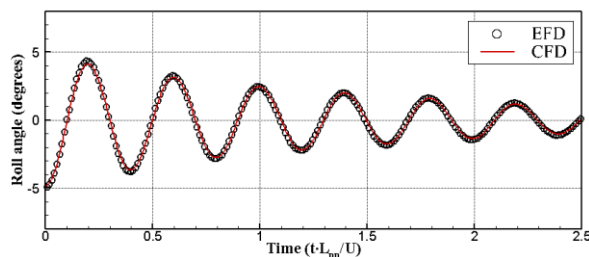


Figure 3. Time history of the numerical and experimental roll decay at 5° .

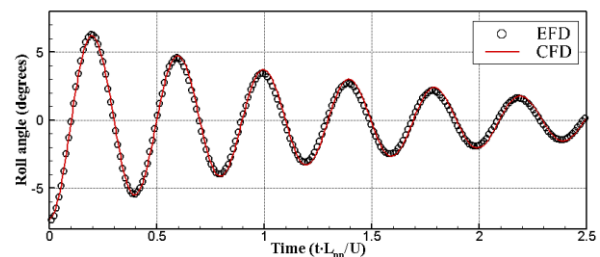


Figure 4. Time history of the numerical and experimental roll decay at 7.5° .

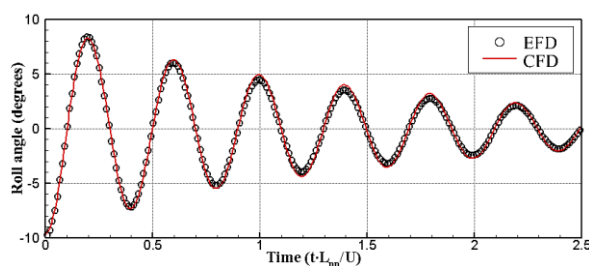


Figure 5. Time history of the numerical and experimental roll decay at 10° .

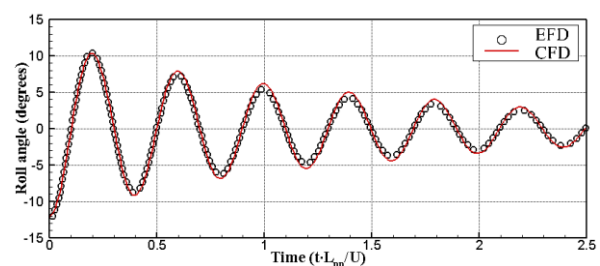


Figure 6. Time history of the numerical and experimental roll decay at 12.5° .

For larger roll angle cases, the roll decay looks slightly different as depicted in figures 7 and 8, which bear out comparisons between the time histories of the computed solutions and the corresponding experimental data [9, 10] for the roll angles of 15° and 20° . Except for the first period when a good agreement between the two is seen, beginning with the second period departures of the numerical solutions from the experimental tests occur. They regard mainly the motion amplitudes and only fairly the associated phases. Unexpectedly, an overestimation for the numerical solution is

revealed for which occurrence a possible reason may be the fact that the turbulence model fails in predicting correctly the flow when violent separations take place.

In the followings an analysis of the flow details is proposed in terms of the wave patterns as well as on the vorticity structure of the flow around the bilge keels since it has been proven that they both are significantly affecting the roll damping phenomenon [9, 11]. For reasons related to the space limitations only the larger roll angles will be considered and further discussed in the present paper, i.e. 10°, 15° and 20°, respectively.

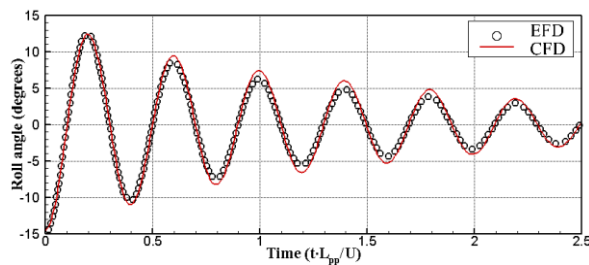


Figure 7. Time history of the numerical and experimental roll decay at 15°.

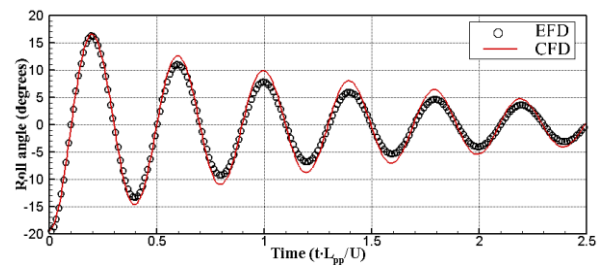


Figure 8. Time history of the numerical and experimental roll decay at 20°.

4.1. Influence of the free-surface deformation

First, a comparative analysis of the computed free-surface profiles is proposed in figure 9, which depicts the wave system developed around the moving hull free to roll. $T=0$ denotes the moment when the inclined hull is freed to roll, $T=1/4$ and $T=3/4$ correspond to the moment when the hull is horizontal, whereas $T=3/4$ corresponds to the moment the ship is inclined on the opposite direction. The periodic move in respect to the free surface determines a significant change of the wave configuration in terms of lengths, amplitudes and periodicity, a fact that leads to an increase of the wave component of the resistance. This change amplifies with the increase of the initial roll angle as it will be shown in the following sections. Obviously, since the resistance augmentation is proportional to the squared ship speed, during the navigation such motions should be avoided as much as possible.

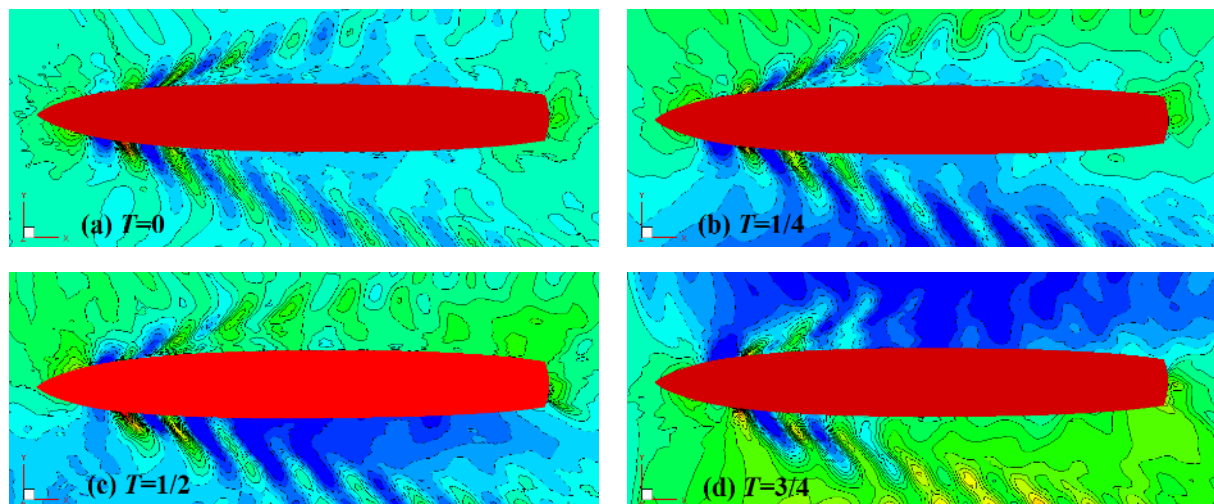


Figure 9. Free-surface topology computed over a full period of roll decay at 10°.

Similar conclusions may be withdrawn when analysing the roll motion for the 15° computational case depicted in figure 10 and for the 20° computational case shown in figures 10 and 11 in which waves are represented at half of their absolute values for the sake of the clarity of their representation. The free-surface shape shows larger values for wave crests and troughs, as expected. The energy

radiated by the moving hull disturbs the periodicity of the wave system, a fact that determines the increase of the ship resistance. Moreover, the waves developed by the hull roll motion determine an unexpected propagation at the upstream of the bow which suggests that the radiation becomes larger than usual. However, the fore waves are efficiently damped by the grid roughness which has been placed there, so the upstream boundary condition was not violated at all.

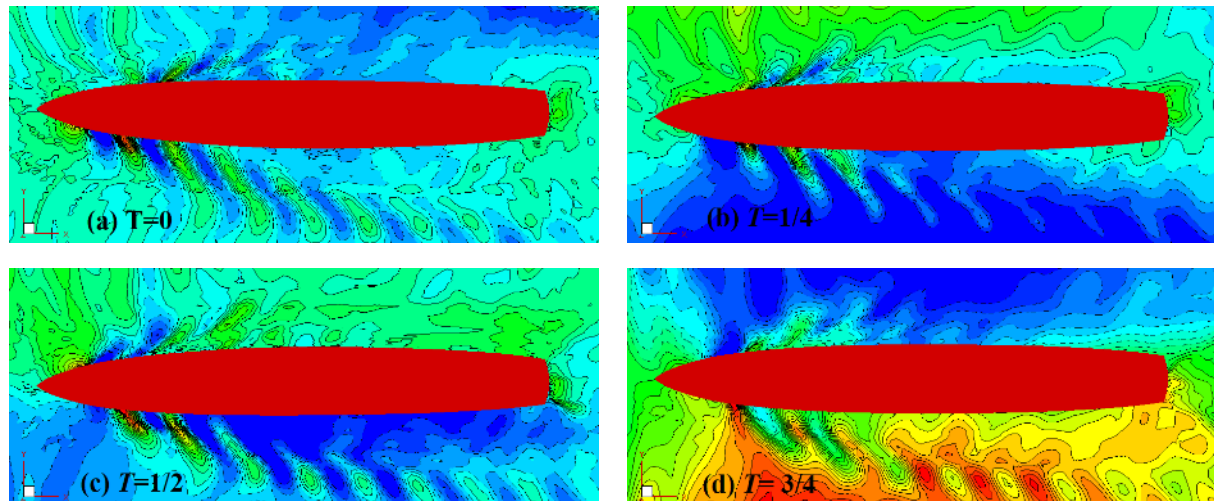


Figure 10. Free-surface topology computed over a full period of roll decay at 15° .

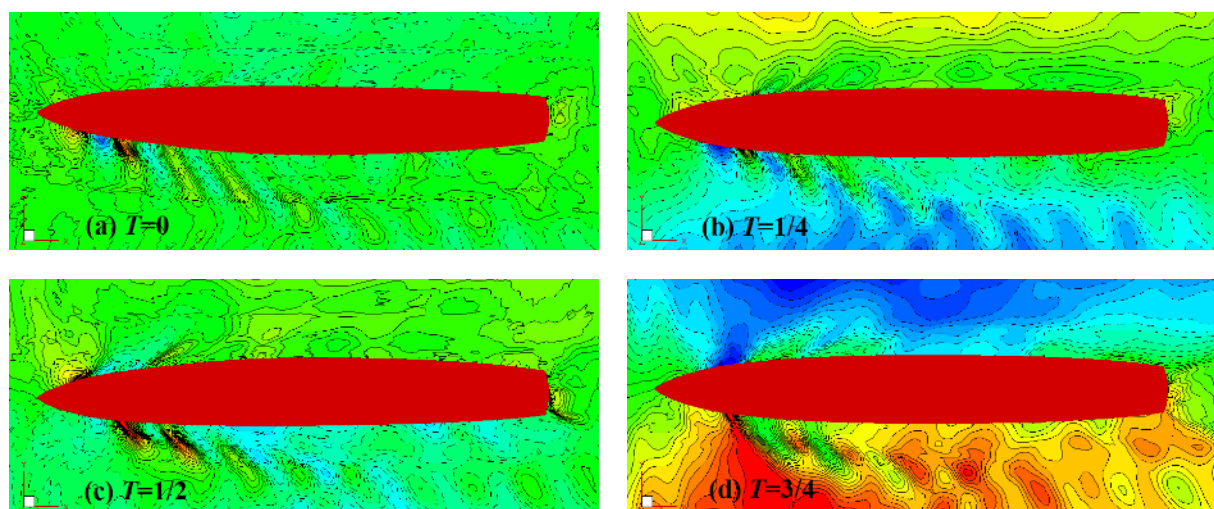


Figure 11. Free-surface topology computed over a full period of roll decay at 20° .

4.2. Influence of eddies detachment

Another important issue of the roll decay is related to the detachment of eddies generated by the bilge keel. A sequence of four snapshots of the axial velocity is shown in figures 12 to 14 for the cross section at the midship (around the bilge keel on the port side). The strong interactions between the wake of bilge keel and the flow around it are obvious. At the first time instant $T=0$ the hull is rotating counterclockwise (10° roll angle and maximum roll velocity). A large clockwise rotating flow is initiated at the tip of the bilge keel; this vortex convects high momentum fluid towards the boundary layer on the hull surface on the left of the bilge keel, and vice-versa low momentum fluid from the boundary layer at the right side. As a consequence, the boundary layer on the hull surface is thinner on the left than on the right. At the same time, the wake of the keel is on the outer face of the bilge keel and the clockwise rotating vortex shed from the tip of the keel is seen. The stream wise velocity field

shows a significant defect beneath the hull in each side of the centerline, within which the boundary layer gets thicker. At $T=1/4$ when the ship position is midway between the oscillation peaks. The keel vortices get stronger and rotates clockwise. At the next time instant, the ship is approaching the maximum roll angle in the opposite direction; the clockwise rotating flow around the tip of the bilge keel weakens on the right bilge keel, while the wake of the left bilge keel and the tip vortex shed from it becomes stronger. At this time instant a clockwise flow around the keel starts to appear and, at the sequent snapshot, this vortex is well developed. At the time instant $T=1/2$ the tip vortex of the left keel reaches its maximum strength. Worth mentioning that when the hull reaches again the horizontal position at $T=3/4$, the vortices change their position, remaining again behind the keel, dissipating their energy before they are eventually shed away. The larger the roll angle is, the more obvious the mechanism described above is, [13].

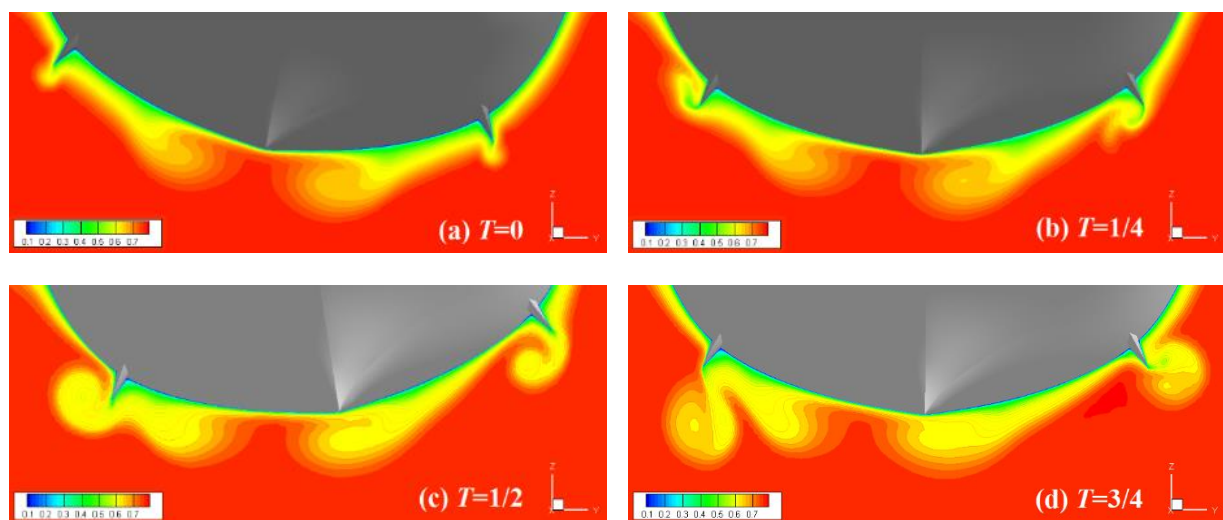


Figure 12. Streamwise velocity distribution computed over a full period of roll decay at 10°

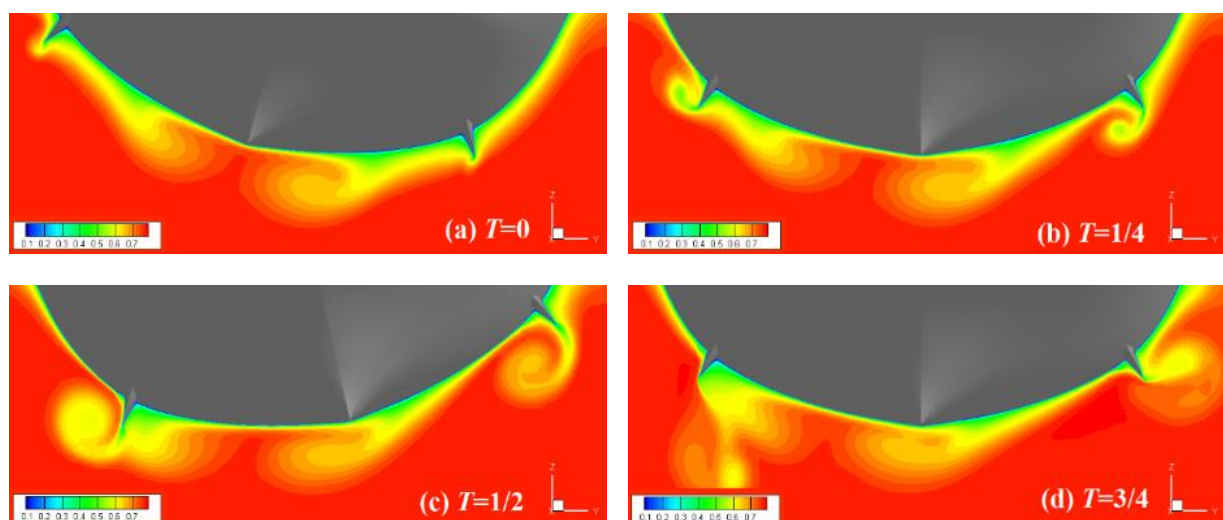


Figure 13. Streamwise velocity distribution computed over a full period of roll decay at 15° .

A better representation of the vortex shedding process is based on the vorticity contours drawn in the same cross section as for the streamwise velocity as shown in figures 15 and 16. Figure 15 depicts the vorticity computed over a full period of roll decay at 15° , whereas figure 16 over the full period of 20° . The vorticity maps emphasize not only the location of the core of the vortices, but also provide

information concerning their intensities. Since the figures describe the same flow conditions, the remarks made when the solutions drawn in figures 12-14 remain valid here as well. The only supplemental information regards the mechanism that takes place right before the vortex shedding. When the hull changes the roll direction, the vortices became weaker, therefore the energy loss creates the condition for shedding. It is interesting to mention that the shedding process is preceded by a split of the core, a fact that can be seen in figures 15(d) and 16(d).

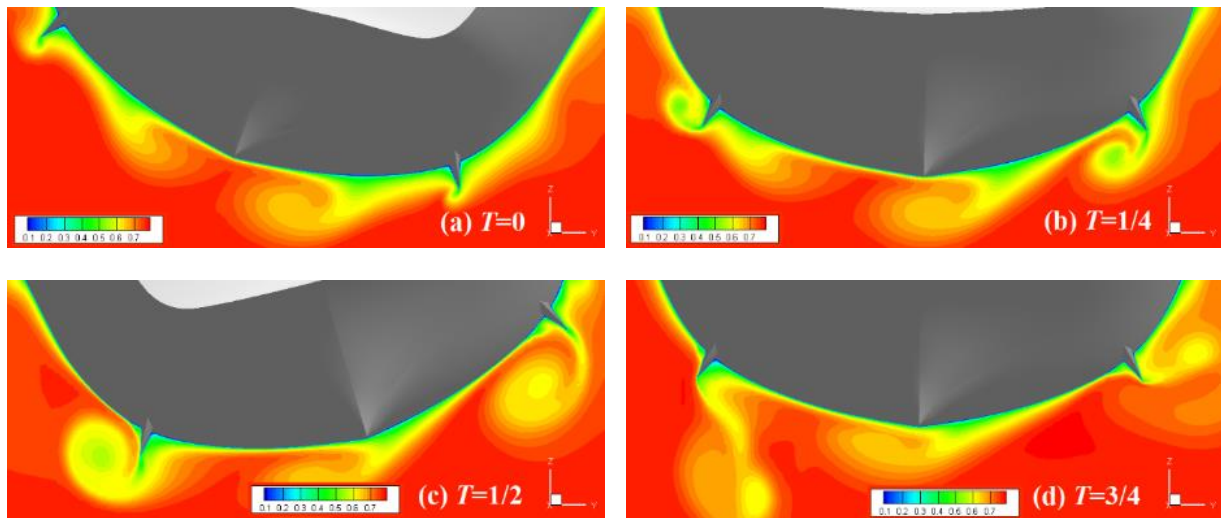


Figure 14. Streamwise velocity distribution computed over a full period of roll decay at 20° .

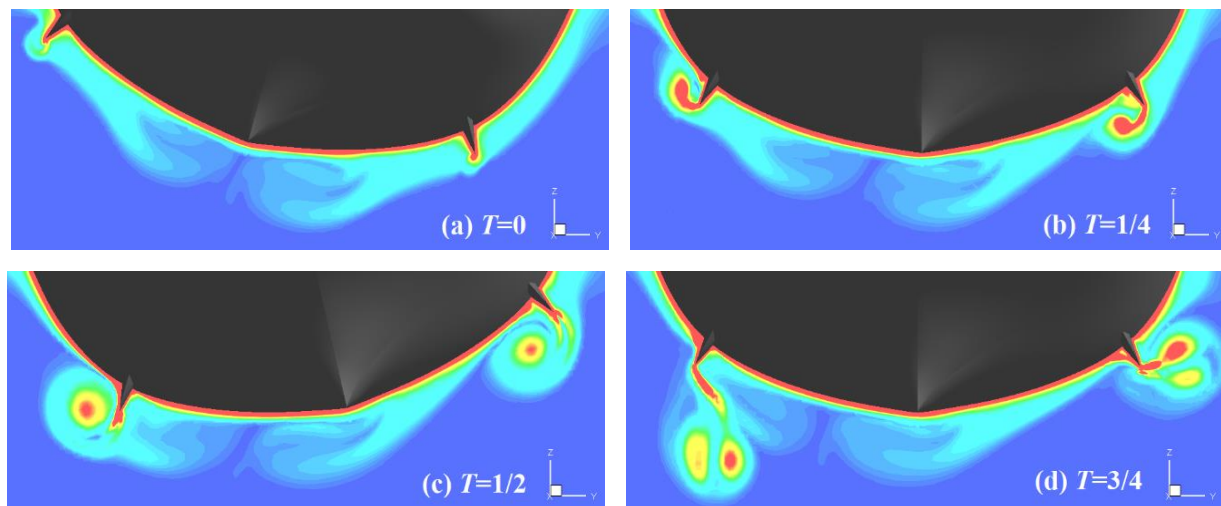
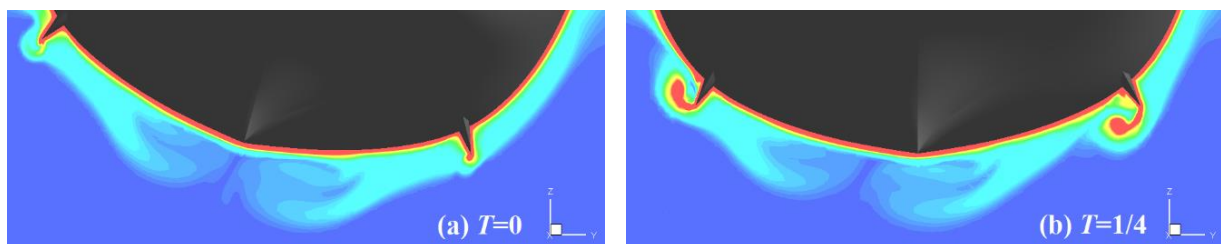


Figure 15. Vorticity distribution computed over a full period of roll decay at 15° .



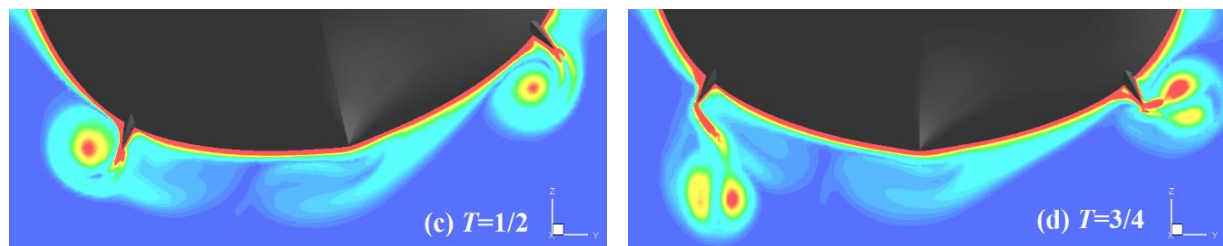


Figure 16. Vorticity distribution computed over a full period of roll decay at 20° .

The above process is cyclic and lasts till the hull stops rolling because of the decay. The energy spent for creating, sustaining then shedding the vortices by the bilge keel contributes to the augmentation of the ship resistance. Although apparently this may lead to higher costs with the fuel for the ship owner, the benefits that result in terms of the ship stability are more significant, therefore the keels are in certain cases recommended.

5. Conclusions

The present paper represents a continuation of the scientific effort made in the past couple of years by the members of the numerical ship hydrodynamics research group the author belongs to, [14-17]. The large variety of the problems related to the ship stability determined not only tremendous scientific output in the scientific community, but also a series of numerical innovations meant to increase the efficiency of the numerical simulation for a given level of accuracy. In this sense, the present paper describes a novel approach based on the sliding-grid technique.

The decay motion as well as the harmonic excited roll motion is established techniques to estimate roll damping for ships. Both methods have advantages and disadvantages that may affect their applicability. In the present research the roll damping decay is investigated for the DTMB combatant ship model in various conditions. For this purpose, the roll decay is simulated by means of the numerical solution of the unsteady three dimensional Reynolds-averaged Navier–Stokes equations in which closure to the turbulence is achieved through the shear stress transport based DES, which provides the accuracy of LES for highly separated flow regions and computational efficiency of RANS in the near-wall region. The topic is worthy of investigation since the viscous roll damping is an important parameter which can be used for simulations of the parametric roll, capsizing, operability etc. A sliding-grid-based novel approach is proposed for dealing with the periodic oscillation of the hull in respect to the water surface. The numerical solutions are validated through a series of comparisons with the available experimental data [12]. With this turnaround at hand, the following conclusions may be put forward:

- The sliding-grid approach proved to be proper for the roll decay study;
- Comparisons with the experimental data of the ISIS-CFD numerical solutions proved not only the accuracy of the solver, but also its robustness;
- The rolling motion determines a significant change in the free-surface profile, therefore an associated increase of the ship resistance is expected to produce;
- Since the viscous roll decay induced by the periodic eddy separation have proven to be a key issue of the roll motion, more studies are required for establishing an appropriate methodology for the correct estimation of their contribution in the total energetic budget of the roll damping process.

6. References

- [1] Ikeda Y, Himeno Y and Tanaka N 1978 A prediction method for ship roll damping *Report of the Department of Naval Architecture University of Osaka Prefecture* Rep. no. 00405
- [2] Chen HC and Liu T 2002 Time-domain simulation of large amplitude ship roll motions by a Chimera RANS method *Int. J. Offshore Polar Eng.* **12**(3) 206–212

- [3] Araki M, Ohashi K and Hirata N 2014 An analysis of bilge keel effects using RANS with overset grids method *Proc. 14th ISSW Kuala Lumpur* 216–228
- [4] Sadat-Hosseini H, Kim DH, Carrica P and Stern F 2016 URANS simulations for a flooded ship in calm water and regular beam waves *Ocean Engineering* **120** 318–330
- [5] Begovic E, Mancini S, Day AH and Incecik A 2017 Applicability of CFD methods for roll damping determination of intact and damaged ship: results and scientific applications derived from the Italian PON ReCaS Project *High Performance Scientific Computing Using Distributed Infrastructures* 343–359
- [6] Visonneau M, Queutey P, Wackers J and Deng J 2012 Sliding grids and adaptive grid refinement applied to ship hydrodynamics *Proc. 29th ONR Symp. Naval Hydrodynamics Gothenburg, Sweden*
- [7] Wackers J, Deng J, Guilimeau E, Leroyer A, Queutey P and Visonneau M 2013 Combined refinement criteria for anisotropic grid refinement in free-surface flow simulation *Computers and Fluids* **92** 1-26
- [8] Lungu A 2018 Numerical simulation of the resistance and self-propulsion model tests *Proc. of the ASME 37th Int. Conf. on Ocean, Offshore and Arctic Engineering OMAE2018* Madrid Spain Paper OMAE2018-77767
- [9] Larsson L, Stern F and Visonneau M 2010 *CFD in ship hydrodynamics. Results of the Gothenburg 2010 Workshop* Gothenburg Sweden
- [10] Irvine M, Longo J and Stern F 2004 Towing-tank tests for surface combatant for free roll decay and coupled pitch and heave motions *Proc. 25th Symp. Naval Hydrodynamics*, St. John's, Newfoundland and Labrador Canada
- [11] Wasserman S, Feder DF and Abdel-Maksoud M 2016 Estimation of ship roll damping – a comparison of the decay and the harmonic excited roll motion technique for a post Panamax container ship *Ocean Engineering* **120** 371–382
- [12] Irvine M, Longo J and Stern F 2013 Forward speed calm water roll decay for surface combatant 5415: global and local flow measurements *J. Ship Research* **57**(4) 202–219
- [13] Lungu A and Ungureanu C 2008 Numerical study of a 3-D juncture flow. *AIP Conf. Proc.* **1048**(1) pp 839-842
- [14] Pacuraru F and Domnisoru L 2017 Numerical investigation of shallow water effect on a barge ship resistance *ModTech 5th Int. Conf., IOP Conf. Series: Materials Science and Engineering* **227**
- [15] Pacuraru S, Domnisoru L and Pacuraru F 2018 Numerical study on motions of a containership on head waves *ModTech 6th Int. Conf., IOP Conf. Series: Mat. Sci. and Eng.* **400**(8)
- [16] Bekhit A S 2018 Unsteady RANSE simulation for ship resistance, heave and pitch in regular head waves *ModTech 6th Int. Conf., IOP Conf. Series: Mat. Sci. and Eng.* **400**(8)
- [17] Bekhit A S 2018 Numerical simulation of the ship self-propulsion prediction using body force method and fully discretized propeller model *ModTech 6th Int. Conf., IOP Conf. Series: Mat. Sci. and Eng.* **400**