

PAPER • OPEN ACCESS

Numerical investigation on fast displacement ship hydrodynamics

To cite this article: S Pacuraru *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **591** 012111

View the [article online](#) for updates and enhancements.

Numerical investigation on fast displacement ship hydrodynamics

S Pacuraru, F Pacuraru and A Presura

”Dunarea de Jos” University of Galati, Faculty of Naval Architecture, Department of Naval Architecture, 47 Domneasca Street, 800008, Galati, Romania

E-mail: florin.pacuraru@ugal.ro

Abstract. In last decade, sustained efforts have been made to improve ship energy efficiency, to reduce fuel consumption and carbon dioxide emissions by means of optimizing the hull forms and propulsion system. The aim of the present paper is to search for solutions to improve the fast-displacement hull forms of passenger ships that navigate on the Danube river and the Black Sea coast, leading to high energy efficiency, reduced emissions and minimised shore-side effects. To investigate the flow around a 31 m fast-displacement monohull passenger ship, a series of 5 numerical simulations for a range of speeds between 4.5 and 12.5 m/s were performed in order to estimate the forces acting on the ship, but also to analyse the hydrodynamic parameters of the flow. Based on the first series of calculation, several solutions to improve the hydrodynamic performance of the hull are considered. The two most effective solutions found have been the trim edge and the interceptor. Different configurations and angles have been systematically investigated in order to find the most efficient geometrical parameters. Finally, the hull with trim wedge leads to a reduction of the power consumption by 2.4 to 5.5% and the interceptor by 2.8 to 8.8%, for speeds higher than 8.4 m/s. For speeds lower than 8.4 m/s the power consumption is higher than bare hull. Moreover, the solutions proposed are easy to implement for new built ships, but also for ships in operation.

1. Introduction

In last decade, sustained efforts have been made to improve ship energy efficiency, to reduce fuel consumption and carbon dioxide emissions by means of optimizing the hull forms and propulsion system. The aim of the present paper is to search for solutions to improve the fast-displacement hull forms of passenger ships that navigate on the Danube river and the Black Sea coast, leading to high energy efficiency, reduced emissions and minimised shore-side effects.

Fast-displacement ships usually combines features of displacement and planning hulls. This kind of ships is supposed to reach higher Froude numbers than displacement ships, which leads to higher trim and sinkage, which directly affects the ship resistance. Several researchers have studied ship powering performance of fast-displacement vessels. The most important studies related to the hydrodynamics of fast-displacement vessels, which establish the behaviour of fast-displacement vessels have been reported by [1 - 4]. Different solutions for improvements of power consumption for this type of ships have been investigated using energy saving devices. The effect of stern wedge on ship powering performance of fast-displacement vessels has been studied by several researchers [5, 6], and recently, the effect the interceptor has been analysed experimentally and numerically by [7 - 9]. More insights on the hydrodynamics of interceptors and juncture flow have been reported by [10 - 12].



To investigate the flow around a 31 m fast-displacement monohull passenger ship, a series of 5 numerical simulations for a range of speeds between 4.5 and 12.5 m/s were performed in order to estimate the forces acting on the ship, but also to analyse the hydrodynamic parameters of the flow. Based on the first series of calculation, several solutions to improve the hydrodynamic performance of the hull are considered. The two most effective solutions found have been the trim edge and the interceptor. Different configurations and angles have been systematically investigated in order to find the most efficient geometrical parameters. Finally, the hull with trim wedge leads to a reduction of the power consumption by 2.4 to 5.5% and the interceptor by 2.8 to 8.8%, for speeds higher than 8.4 m/s. For speeds lower than 8.4 m/s the power consumption higher than bare hull. Moreover, the solutions proposed are easy to implement for new built ships, but also for the ship that are already operating.

2. Numerical a pproach

The NUMECA/FineMarine commercial code has been employed to compute the flow solution around the fast displacement ship. The implicit RANS 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 [13]. The $k-\omega$ SST turbulence model with wall function formulation is used for turbulence closure in this paper. Free-surface capturing strategy is based on multi-phase flow approach using Volume of Fluid method with high-resolution interface schemes. Incompressible and nonmiscible flow phases are modeled using conservation equations for each volume fraction of phase/fluid, [14]. Velocity-pressure coupling is handled with pressure equation formulation (SIMPLE) using a face-based approach. Ship free motion can be simulated with a 6 DOF module. Some degree of freedom can be restrained as well.

3. Bare hull calculation

A hard-chine high-speed displacement hull form of 31 m with a twin-screw propulsion arrangement has been selected for the present study. First series of numerical simulations of flow around ships in transition have been carried out to investigate the forces acting on the ship hull, the hull attitude, as well as the flow characteristics obtained from the calculations. In figure 1 the hull form of the passenger ship are presented and table 1 bares main dimensions and the speed range considered in the calculation.

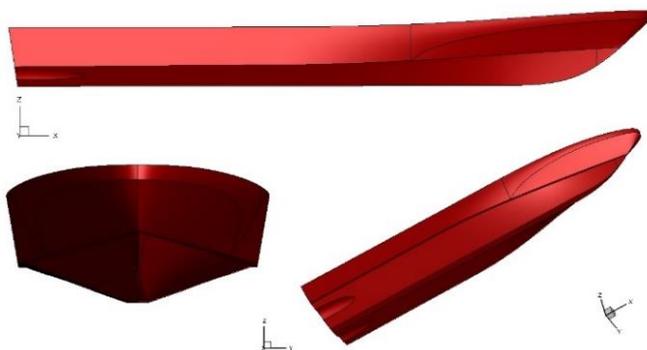


Figure 1. Catamaran wave resistance coefficient.

Table 1. Passenger ship main characteristics.

| No. | Dimensions | Units | Value |
|-----|-----------------------|-------------------|-----------|
| 1 | Length | [m] | 31 |
| 2 | Breadth | [m] | 7 |
| 3 | Depth | [m] | 2.8 |
| 4 | Draft | [m] | 1.35 |
| 5 | Displacement | [m ³] | 118.7 |
| 6 | Speed range | [m/s] | 4.4-13.4 |
| 7 | Fn range | - | 0.25-0.77 |
| 8 | Fn _v range | - | 0.63-1.69 |

To evaluate the ship resistance, the heave and the pitch of bare hull, ten numerical simulations for speeds between 4.4 and 13.4 m/s were performed. For a quantitative assessment, figures 2, 3 and 4 show the variation of total resistance, trim angle and sinkage along with the Froude number (Fn), respectively. Analysing the total resistance variation, figure 3, it can be seen a slope increasing of the

curve for F_n from 0.37 to 0.42. For the same range of the F_n , one can observe that trim has a drop of about one degree, from 0.44 to 1.39, which means that the stern immersion strongly increases. Moreover, when the trim curve reaches the minimum, a slightly change in ship resistance curve can be noticed. Variation of the sinkage with F_n reveals that maximum displacement on vertical direction occur around $F_n=0.45$ and the static z position is again reached at $F_n=0.67$, which means that for higher F_n the vertical hydrodynamic force starts to sustain progressively part of the hull displacement. For the qualitative analysis of hydrodynamic characteristics of the flow around hard-chine high-speed ship, the wave profile, wetted surface and free surface pattern have been investigated, figures 5 to 7. Comparing the longitudinal wave profile along the hull for five Froude numbers (figure 5), two humps appear on the bow wave for the highest four Froude numbers [15, 16].

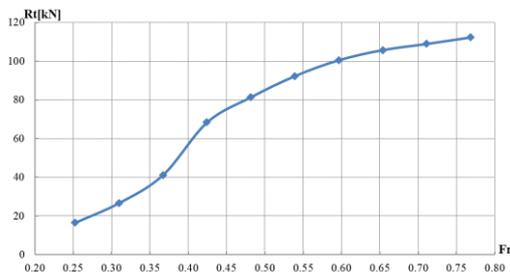


Figure 2. Total ship resistance vs. F_n .

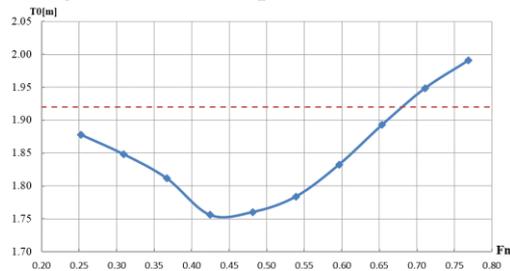


Figure 4. Wave pattern for F_n 0.2-0.8.

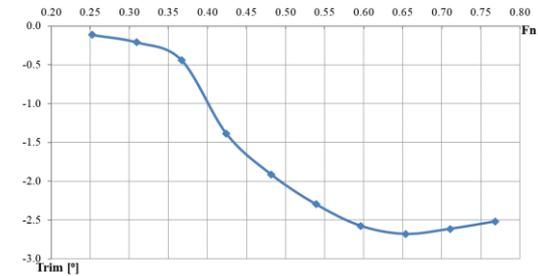


Figure 3. Trim variation with F_n .

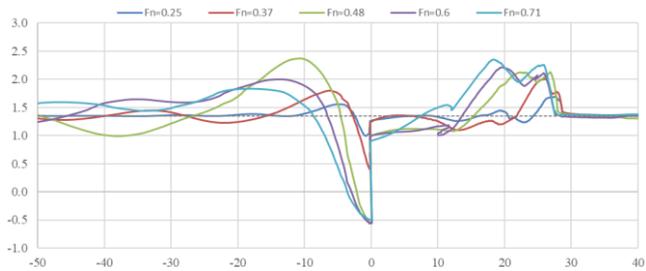


Figure 5. Wave profile along the hull. F_n 0.25-0.71.

In order to clarify the shape of the bow wetted surface have been plotted in figure 6, which reveals that chine spray stops the bow wave developing, breaking the spray sheet. Moreover, investigating the shape of wave profile in the stern region, a higher wave crest downstream the hull stern could be observed for $F_n=0.48$, which is not the highest one. The observation is confirmed by the wave topology plotted in figure 7, which shows the highest rooster tail crest appear for the same F_n . Another aspect that can be highlighted is that the detachment of the bottom flow starts from the $F_n=0.48$. For F_n 0.25 and 0.37 the transom stern is still wetted.

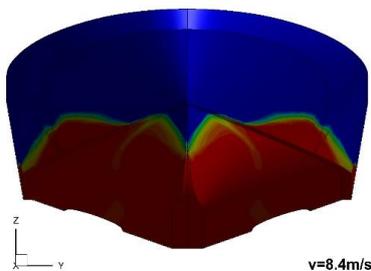


Figure 6. Hull wetted surface. Bow view.

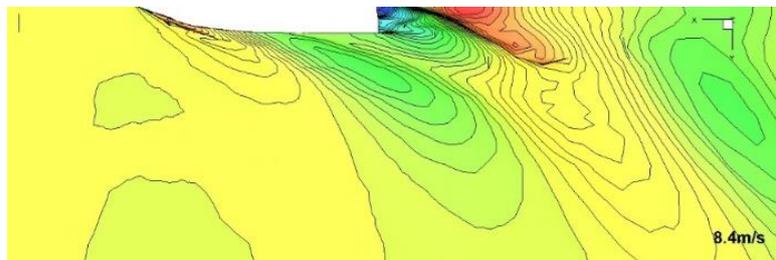
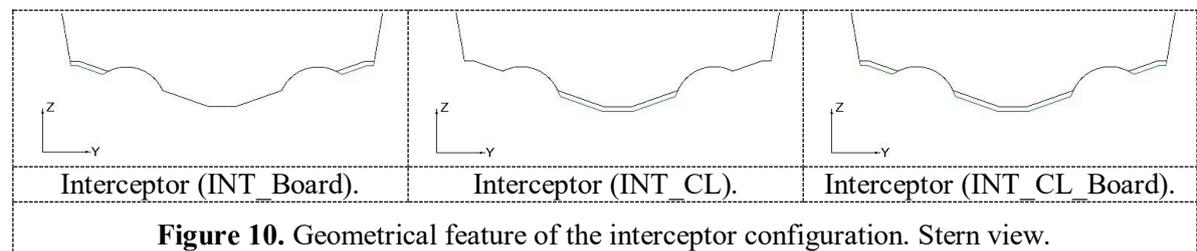
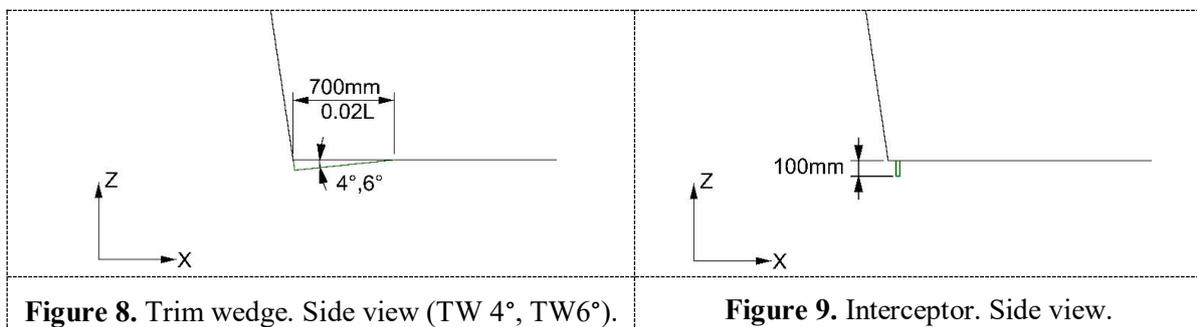


Figure 7. Wave pattern for different speeds.

4. Trim wedges and interceptors

Based on the findings discussed above, few solutions for improvement of fast displacement hard chine passenger ship have been investigated. Trim wedge and interceptors have been considered to explore the efficiency in trim reduction with positive impact on power consumption. A stern wedge can be recognized as a discontinuity in the hull buttocks near the transom (usually located within 3% LWL of the transom) [17]. Trim wedge is expected to be more efficient over a Froude number range from 0.4 to 0.5. Another option to control the dynamic trim is the interceptor. An interceptor is a thin plate or blade, protruded from the hull normal to the flow direction causing a stagnating flow region near the blade, see figure 9. The resultant pressure acts on the hull bottom creating the effects such as the trim moment, which adds lift and finally controls the attitude of the craft [18]. Two different angles for the trim wedge (figure 8) and three interceptor configurations (figure 10) have been considered in the present study.



The present study considers a systematically full-scale ship resistance calculation in calm water for a high-speed displacement hull. Five different sets of simulations were performed for five speeds corresponding to a range of Froude numbers between 0.25 and 0.71 to compute the flow around two trim wedge and three interceptor configurations. To analyse the effect hull modification on the trim, its absolute value determined based on RANS computations for each case mentioned above, the absolute reductions of the trim are tabulated in table 2.

Table 2. The effect of trim wedge and interceptor on ship trim.

| No. | v (m/s) | Fn - | Interceptor | | | Trim wedge | |
|-----|------------|---------|-----------------------|--------------------|--------------------------|-------------------|-------------------|
| | | | INT_Board (degree) | INT_CL (degree) | INT_CL_Board (degree) | TW 4° (degree) | TW 6° (degree) |
| 1 | 4.4 | 0.25 | 0.05 | 0.11 | 0.16 | 0.03 | 0.04 |
| 2 | 6.4 | 0.37 | 0.16 | 0.32 | 0.46 | 0.08 | 0.14 |
| 3 | 8.4 | 0.48 | 0.48 | 0.87 | 1.27 | 0.25 | 0.38 |
| 4 | 10.4 | 0.60 | 0.63 | 1.11 | 1.64 | 0.32 | 0.49 |
| 5 | 12.4 | 0.71 | 0.88 | 1.56 | 2.28 | 0.47 | 0.68 |

As expected, the trim is progressively reduced over the Fn range for each investigated case, since it is significantly influenced by the hydrodynamic forces. Comparing the effect of trim edge and interceptor, it can be clearly seen that, at least for the configuration tested, the interceptor is much effective than trim wedge. The investigation of dynamic pressure distribution on the bottom of the hull for a different configuration, prove the same idea stated before, figure 12. This may suggest that higher angle of trim wedge should be further considered for next studies. Trim variation versus Fn are depicted in figure 11 for trim wedge and figure 12 for interceptor configuration.

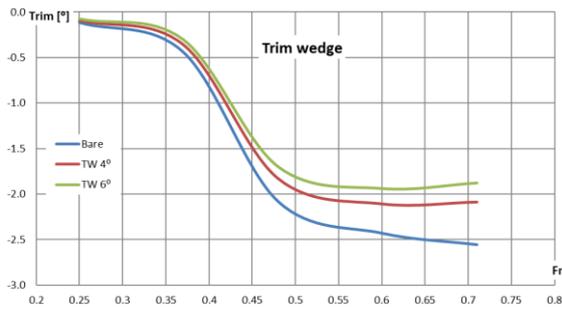


Figure 11. Variation of trim for different angles of the transom wedge.

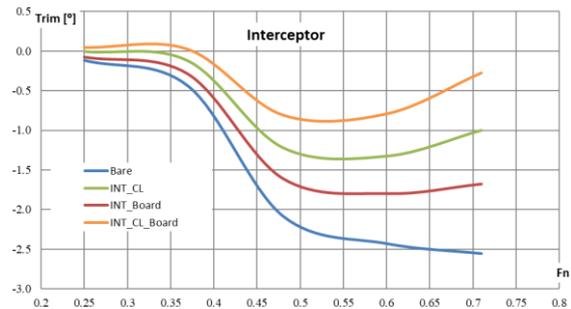


Figure 12. Variation of trim for different configuration of interceptor.

The higher reduction of trim experienced by the hull have been found for interceptor extended in the centre line and board region (INT_CL_Board, figure 10, right side picture) and it was of 2.2 degree, at Fn=0.7. This trim reduction brings a decreasing in ship resistance of 7.66% as one can see in the table 3, where the relative values have been computed considering as reference the results of calculation for bare hull.

Table 3. The effect of trim wedge and interceptor on ship resistance.

| No. | v (m/s) | Fn | Interceptor | | | Trim wedge | |
|-----|------------|------|------------------|---------------|---------------------|--------------|--------------|
| | | | INT_Board (%) | INT_CL (%) | INT_CL_Board (%) | TW 4° (%) | TW 6° (%) |
| 1 | 4.4 | 0.25 | 11.04 | 18.70 | 26.50 | 5.32 | 8.35 |
| 2 | 6.4 | 0.37 | 3.96 | 5.58 | 8.58 | 1.33 | 1.29 |
| 3 | 8.4 | 0.48 | -3.64 | -6.17 | -8.77 | -2.43 | -3.82 |
| 4 | 10.4 | 0.60 | -2.76 | -4.82 | -6.48 | -2.96 | -3.87 |
| 5 | 12.4 | 0.71 | -3.30 | -7.06 | -7.66 | -4.91 | -5.44 |

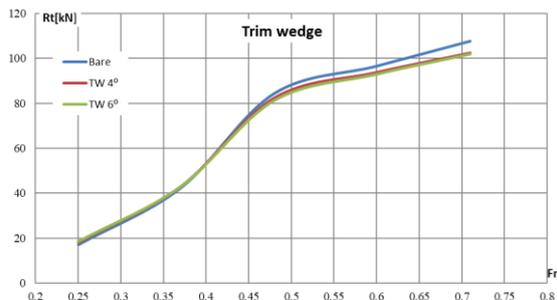


Figure 13. Variation of total ship resistance for different angles of the transom wedge.

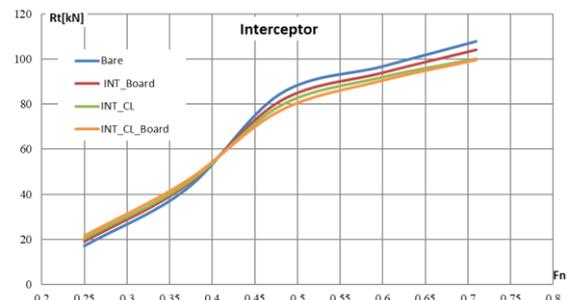


Figure 14. Variation of total ship resistance for different configuration of interceptor.

On the other hand, the maximum reduction of the ship resistance, of 8.8% have been found for the same configuration but for lower trim reduction of 1.27 degree. This might be explained by the high amplitude of stern wave occurring at $F_n=0.48$ for the bare hull, see figure 5. By reducing its amplitude, the ship resistance could be significantly reduce too. Total resistance curves computed for each solution, chosen for the trim reduction, have been plotted in figure 13 for trim wedge and figure 14 for interceptor. Both solutions proved to be effective reducing the total ship resistance for F_n higher than 0.4.

5. Conclusions

The main conclusions drawn up from this study are the following:

Free-surface flow around the fast displacement monohull was successfully computed for Froude numbers between 0.25 and 0.77. The ship resistance, sinkage and trim were estimated by RANS-VOF simulation.

Two practical solutions for trim reduction have been employed. The effects of the trim wedge and the interceptors on the trim and total ship resistance have been investigated along a range of Froude numbers between 0.25 and 0.71. The calculation revealed that the trim can be reduced with up to about 2 degree by using interceptor.

The positive effect on ship resistance for both solutions starts for F_n higher than 0.4 as can clearly seen in figure 13 and figure 14, leading to reductions of total resistance between 2.4 and 8.8% (table 3). For lower F_n , their effect is negative, with lower increased values for trim wedge, which may recommend trim wedge for the ship which operates often at speeds corresponding to F_n less than 0.4.

The most significant total resistance improvement have been found for INT_CL_Board at $F_n=0.48$ of about 8.5% and INT_CL_Board and INT_CL at $F_n=0.71$ of about 7 %.

Further studies will be developed to investigate the optimum dimension of interceptors and other energy saving devices.

6. References

- [1] Muller-Graf B 1991 The Effect on an Advanced Spray Rail System on Resistance and Development of Spray of Semi-Displacement Round Bilge Hulls *Proc. Fast Sea Transportation* Trondheim, Norway **1** 125-142
- [2] Bojovic P and Sahoo P 2000 Effect of Stern Wedges and Advanced Spray Rail System on Calm Water Resistance of High-Speed Displacement Hull Forms *Proc. of Sea Australia 2000* (Sydney, Australia)
- [3] Savitsky D 2003 On the Subject of High-speed Monohulls *Greek Section of the Society of Naval Architects and Marine Engineers* (Athens, Greece)
- [4] Savitsky D 2014 Semi-displacement hulls - a misnomer? *SNAME's 4th Chesapeake power boat Symposium* (Annapolis, USA)
- [5] Karafiath G and Fisher SC 1987 The Effect of Stern Wedges on Ship Powering Performance *Nav. Eng. J.* **99** 27-38
- [6] Bojovic P, Sahoo PK and Salas M 2004 Effect of Stern Wedges and Advanced Spray Rail System on Calm Water Resistance of High-speed Displacement Hull Form *Proc. of Pacific 2004 International Maritime Conference* (Sydney, Australia: L Prandolini Publishing House)
- [7] Brizzolara S 2003 Hydrodynamic Analysis of Interceptors with CFD Methods, *Proc. of the 7th International Conference on Fast Sea Transportation* (Ischia, Italy) 49-56
- [8] Ghassemi H, Mansouri M and Zaferanlouei S 2011 Interceptor hydrodynamic analysis for handling trim control problems in the high-speed crafts *Proc. IMechE.* **225C** 2597
- [9] Avci AG and Barlas B 2018 An experimental investigation of interceptors for a high-speed hull *Int. J. Nav. Arch. Oc. Eng.* 1-18
- [10] Brizzolara S and Molini A 2005 Hydrodynamics of interceptors: a fundamental study *Proc. ICMRT 2005 International Conference on Maritime Research and Transportation* (Ischia, Italy)

- [11] Lungu A and Ungureanu C 2008 Numerical Study of a 3-D Juncture Flow *AIP Conference Proceedings* **1048**(1) 839-842
- [12] Lungu A and Ungureanu C 2009 Numerical simulation of the turbulent flow around a strut mounted on a plate *AIP Conference Proceedings* **1168**(1) 647-650
- [13] Duvigneau R, Visonneau M and Deng GB 2003 On the role played by turbulence closures in hull shape optimization at model and full-scale *J. Mar. Sci. Tech.* **8**(1) 1–25
- [14] Queutey P and Visonneau M 2007 An interface capturing method for free-surface hydrodynamic flows *Comp & Fluids* **36**(9) 1481–1510
- [15] Lungu A, Raad PE and Mori KH 1998 Turbulent Early-stage Breaking Wave Simulation *ASME FED Summer Meeting* (Vancouver, Canada) paper FEDSM97-3404
- [16] Lungu A and Mori K 1994 Applications of composite grid method for free-surface flow computations by finite difference method *J. Soc. Nav. Arc. Jap* **175** 1-10
- [17] Maki KJ 2005 *Transom Stern Hydrodynamics* PhD thesis University of Michigan
- [18] Karimi A, Seif MH and Abbaspoor MS 2013 An experimental study of interceptor's effectiveness on hydrodynamic performance of high-speed planning crafts *Pol. Mar. Res.* **20**(2) 21-29