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A Fundamental Study on the Hull Form Design Method for the Fore-body of Medium-sized Passenger Ship with Gooseneck Bulb

[Jin-Won Yu and Young-Gill Lee]

***Abstract*— The economical and high-performance resistance hull is required due to the increasing oil price and the regulation of CO_2 emissions, one of the methods to improve the resistance performance of medium-sized passenger ship is the hull design adopted with the gooseneck bulb. In order to effectively adopt the gooseneck, the resistance performance estimation and the optimization are demanded in accordance with the bulb parameters. This study performs the numerical series tests on the 5 kinds of bulb parameters to derive the regression equation to be utilized for the hull form design, of which data was analyzed statistically. This regression equation for resistance estimation is to be set as an objective function, and then using the optimization algorithm searches for the combination of the design variables of gooseneck bulb equivalent to the lowest point on the regression equation under several design conditions. Hull form design and its numerical simulation perform on the optimal component of the bulb hull suitable for a particular passenger ship that is among the ferries operating in the sea of the Far East Asia. As a result, the developed design method in this study confirmed the possibility of the hull form design of passenger ship applied gooseneck bulb with a good resistance performance.**

Keywords—Passenger ship, Gooseneck bulb, Resistance performance, Optimization method

I. Introduction

The rise of fuel price and the CO_2 emission regulation draw more attention to the resistance performance of the vessels. In particular, the continued increase of oil price has worsened the financial status of the small-and-medium sized cruise ship companies, which demands to secure the high-performance resistance vessels as a priority option. The study results conducted mainly in Europe represent that the adoption of gooseneck bulb in the passenger ship shows the potentiality of fuel cost savings through its improved resistance performance[1,2,3]. The study for the adoption of gooseneck in the passenger ship is being processed in Korea[4,5,6]. However, the precedent researches only for the design results of the optimized bulb for the specific passenger ship were opened in public, which may be not good enough to be referred to as the references for the development of the hull design adopted with gooseneck bulb.

In order to design the high resistance performance hull with gooseneck bulb, the identification of the relationship between the bulb parameter and their resistance performances should be preceded. Regression analysis of statistical method is used to understand the relationship between the bulb parameter and resistance performance. [7] selected the hull variables affecting the wave-making resistance and form resistance and then derives the regression equation, and proposed the hull improvement method. [8] compared several regression equations in order to estimate the resistance characteristics of the low-speed full ship.

Along with the resistance estimation of the vessel, the hull optimization technique is being utilized in order to improve the resistance performance. [9] performed the optimization of the hull that calculating the flow around the hull as the viscous flow and with the use of SQP(Sequential quadratic programming) as the optimized algorithm. Even though [10] used SQP as the optimized algorithm, but assuming the flow around the hull as the potential flow and performed the research for the development of the optimized hull. [3] designed the bulb hull with the reduced linear wave resistance components, by using FRIENDSHIP module and SHIPFLOW.

In this study, targeting a medium-sized ferry for about 600 on board passenger that is operating in the sea of Far East Asia, the research for the estimation of resistance performance in accordance with the adoption of gooseneck bulb is carried out. The numerical series tests to derive the regression equations for the estimation of resistance are carried out, which can be utilized for hull form design of the passenger ship. The hull form data for about 50 vessels regarding 5 kinds of bulb parameters is created, and their numerical calculation is performed. In order to estimate the resistance characteristics by the gooseneck bulb through the statistical analysis on these data, the regression equation is created. Setting the regression equations as the objective function, a combination of the bulb parameters to design the bulb hull with better resistance performance is derived. SQP method is used as the optimized algorithm, and the hull form design is conducted with the optimized hull bulb parameters, and then by executing the numerical simulation, the changes of resistance performance is verified. In other word, this study is a case of goose neck bulb design for a particular passenger ship, however, by which intends to figure out the estimation of resistance performance and the possibility to use it for the optimal hull form design of passenger ship with gooseneck bulb optimization techniques.

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II. Estimation of the resistance of passenger ship with gooseneck bulb

A. Resistance performance

Centered in Europe, in recent year, the vessels like the cruise and ferries are adopting the gooseneck bulbs. Compared to the high nose bulb which is generally installed in the relatively high speed vessels, gooseneck bulbs are being studied with the better resistance performance ones. However, under the low draft condition, the strong wave breaking phenomena and the increase of resistance caused by the excessively concaved bulb are expected [11]. The gooseneck bulb belongs to the relatively high speed equipment in its designed speed, and can be usefully utilized in improving the resistance performance of the passenger ships without big draft changes as per the operating status, which is regarded as one of the reasons that there were not so many cases the gooseneck bulb has not been adopted with the hull except the gooseneck ship.

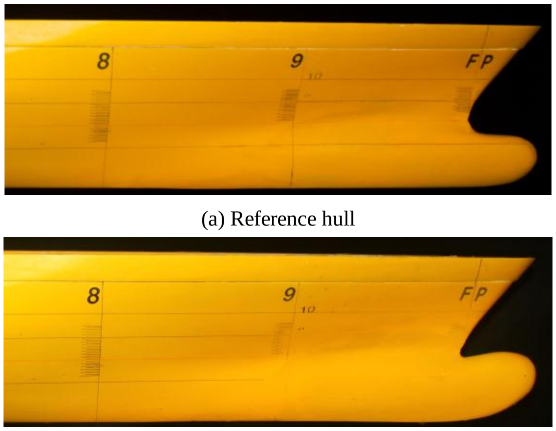
In this study, one of the ships of domestic passenger ship companies providing the transportation services by using the short range international routes, the passenger ship which operates on regular between Incheon(Korea) and Dandong (China) is taken into as the reference hull. And the changes in resistance performance as per the adoption of gooseneck bulb are identified. In order to apply with the gooseneck bulb to the domestic passenger ship, the published hull data were analyzed. By using the wave pattern analysis results on the European passenger ships, [3] was derived from the gooseneck bulb hull with 7% reduction of wave-making resistance, and regarding [4], by changing the width of bulb(the maximum cross-sectional area according to it), that was identified to be expected a better resistance performance with a smaller size than the bulb derived from [3].

Using the result of resistance performance changes in accordance with the side shape of bulb derived by [3] and the width of bulb studied by [4], the designed hull 01 adopted with the gooseneck bulb was designed while maintaining the main body shape of the reference hull [5]. The principal particulars of reference hull are shown in Table 1, and the shape of the reference and designed hull 01 is illustrated by Fig. 1.

TABLE I. PRINCIPAL PARTICULARS OF THE REFERENCE HULL

L_{BP}(m)	156.00	∇(m^3)	10519.74
B(m)	22.00	WSA(m^2)	3600.10
T(m)	6.00	C_B	0.512
Operated speed (kt)	18	Fn	0.235

The resistance performance of the reference hull and the resistance performance change as per the adoption of the gooseneck bulb are identified by performing the model test and numerical simulation. The model test was conducted by the hull towing tank of Inha University, using the model ship produced in the accumulated ratio of 1/75 to the actual size.



(a) Reference hull

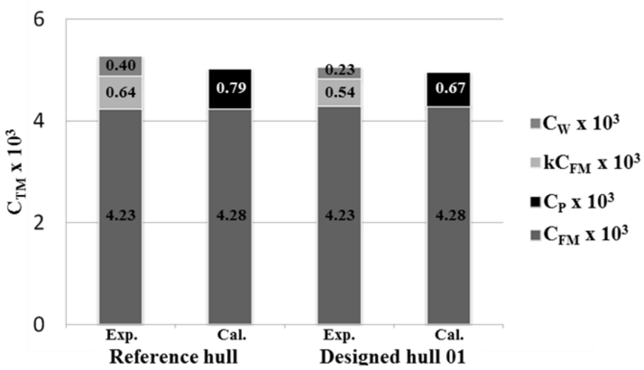
(b) Designed hull 01

Figure 1. Forebody side view of the reference hull and designed hull 01

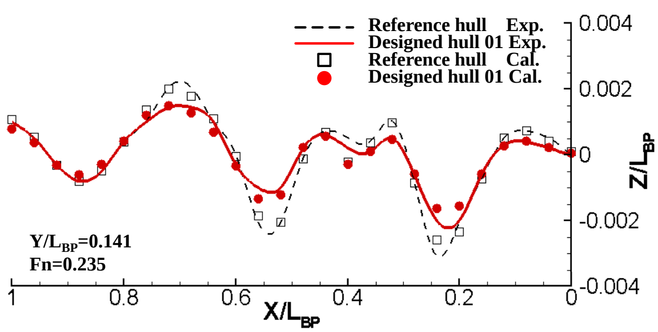
Numerical simulation was conducted by the computer program using Modified Marker-density method that named INHAWAVE-II. The followings are the schematic description of the characteristics of INHAWAVE-II, and its details of calculation method are shown in [12]. INHAWAVE-II may be limited in its use because its flow around the stern of the vessel and the estimation of frictional resistance were somewhat short due to the low degree of turbulent flow around object, however, it can be used for the assessment or reduction of wave-making resistance of the vessel as the program mainly focusing on the numerical simulation of free surface change. As the estimation of wave-making resistance using INHAWAVE-II showed the similar result as the experimental test (Fig.2), which was regarded as appropriate for the estimation of the wave-making resistance in accordance with the gooseneck bulb in this study. In addition, it is one of the other characteristics of INHAWAVE-II, as it is using a rectangular grid system, that the separate operation for the grid generation is not required. This convenience in calculation usefully functions to calculate relatively large numbers of the series of test cases in this study.

Separating the resistance components from the operating speed, the result of the model test is shown in the Fig. 2 (a). In case of the reference hull, the portion of residuary resistance occupying in total resistance of the model ship is about 20%. When dividing the residuary resistance into form resistance and wave-making resistance, the portion of wave-making resistance occupying in the residuary resistance is about 38%, whereas the form resistance is about 62%, which means through the adoption of gooseneck bulb the form resistance was reduced by about 15% and the wave-making resistance by about 44% compared to those of reference hull. Thus, the reduced wave-making resistance was well illustrated in the result of wave height in the Fig. 2(b) as well. The location of wave height measurement is positioned as far as the width of main body from the center of hull(Y/L_{BP}=0.141), and as the wave shapes of designed hull 01 becomes a gradual reduction compared to that of the reference hull, and the maximum wave height is also low, the wave-making resistance is expected to be reduced. Not only the wave-making resistance but also the form resistance is decreased. It is considered that the lower free surface flow would have changed by the changed the bulb shape.

Comparing the model test and the results of numerical calculation, they show the close results with each other, which can be verification of the numerical calculation. In case of the model test, the dividing the resistance of the ship components into frictional resistance and residuary resistance is being used. However, in case of numerical simulation, the ship resistance is composed of the frictional resistance obtained by integrating tangential stress and the pressure resistance obtained by integrating normal stress. The pressure resistance is obtained by integrating the pressure in the direction components of the ship and can be regarded as the lump sum of the viscous pressure resistance and wave-making resistance. Accordingly, this study will compare and evaluate the resistance performance as per the bulb form not by the residuary resistance coefficient but by the pressure resistance coefficient, on the implementation of the series tests and the optimized bulb forms.



(a) Resistance components



(b) Wave profile

Figure 2. Model test and numercal simulation results

From the result of numerical simulation, the pressure resistance portion out of total resistance that the object hull is receiving in the operating speed occupies about 20%, and it is identified that the adoption of bulb can reduce the pressure resistance by 15%.

B. *Estimation of pressure resistance*

Referring to the result of changes in the bulb parameters and the pressure resistance performed in the recent research[6], the bulb parameters(the ratio of bulb to hull and the characteristics of the gooseneck bulb) which were used for the regression analysis for the estimation of resistance performance of the passenger ship, and their ranges are set as follows;

1) $C_{ABT} = A_{BT} / A_{MS}$. $0.070 \le C_{ABT} \le 0.100$
2) $C_{LPR} = L_B / L_{BP}$. $0.030 \le C_{LPR} \le 0.046$
3) $C_{ZB} = Z_B / T_{FP}$. $0.690 \le C_{ZB} \le 0.820$
4) $C_\nabla = \nabla_B / \nabla_S$. $0.030 \le C_\nabla \le 0.068$
5) $C_{RB} = r_Z / r_L$. $0.140 \le C_{RB} \le 0.480$

where C_{ABT} is the cross sectional area ratio, C_{LPR} is the ratio of the length of bulb, C_{ZB} is the central position ratio of bulb, C_∇ is the bulb volume ratio, C_{RB} is rise of the bulb, A_{BT} is the cross sectional area of bulb, A_{MS} is the cross sectional area at midship, L_{PR} is the length of bulb, L_{BP} is the length of ship, Z_B is the central height of bulb, T_{FP} is the draft at FP, ∇_B is the volume of bulb, ∇_S is the volume of ship under waterline, r_Z is the length form FP to bulb top and r_L is the height of bulb top, respectively.

Regarding the general bulb parameters, number of the bulb parameters to be considers were reduced in number by grasping the correlation among the bulb parameters in order to create the data necessary to derive the regression equations effectively. As an example of the research result on [6], over 0.10 of the bulb cross-sectional area ratio, the pressure resistance was increased compared to the reference hull, and over 0.08~0.1 of that the pressure resistance was heavily decreased, and at 0.07~0.08 the variation of pressure resistance was small decreased. Based on these, the range of the bulb cross-sectional ratios to be considered from the aspect of the resistance performance was set as 0.07~0.10. Also other bulb parameters are selected by a process similar to this.

Changing the bulb parameter, 50 kinds of gooseneck bulb hulls were deduced, and conducting the numerical simulation pressure resistance of hulls is calculated respectively. As the series test hulls are identical in their hulls before 9 stations, in order to save time required for the calculation and number of grid, it was calculated excluding the stern flow part of main body in the calculation area. From the middle part of main body to the stern, the cross-sectional shape is treated as the identical shape and the force component to the X-direction was not considered in the calculation.

In order to grasp the changes of resistance performance and the functions correlation of the bulb parameters, the calculation results of the numerical series test hulls are analyzed in statistical methods and the regression equations are derived. Setting pressure resistance coefficients as the dependent variable, and bulb parameter as independent variables, the regression analysis is performed, and the variables are selected as be which was one of the variable selection methods commonly used in the regression analysis. The regression equations combined with the selected variables is shown in the equation(1), and the determination coefficient and the regression coefficients derived from it are shown on Table 2.

$$f(x)= \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5 +\beta_6X_1^2+ \beta_7X_2^2+ \beta_8X_3^2+ \beta_9X_5^2 +\beta_{10}X_1X_2+\beta_{11}X_1X_4+\beta_2X_1X_5+\beta_{13}X_2X_5+\beta_4X_4X_5 \quad (1)$$

$X_1=C_{ABT}$, $X_2=C_{LPR}$, $X_3=C_{ZB}$, $X_4=C_{\nabla}$, $X_5=C_{RB}$

TABLE II. COEFFICIENTS OF THE REGRESSION EQUATION AND DETERMINATION

β_0	7.569	β_1	-9.137	β_2	5.776
β_3	-23.816	β_4	41.616	β_5	9.501
β_6	40.320	β_7	-5.780	β_8	15.969
β_9	-9.740	β_{10}	-53.496	β_{11}	56.163
β_{12}	19.065	β_{13}	-11.790	β_{14}	-14.978
r_a^2	0.959				

III. Optimization of gooseneck bulb

SQP method is used as an optimization techniques. That is utilized in many fields as the direct searching method, verified of its usefulness. In this study, objective function is the least under the conditions that the estimation value of the pressure resistance coefficients in the regression equation of the present research. The design variables are the independent variables of the regression equations, they are C_{ABT}, C_{LPR}, C_{ZB}, C_{∇}, C_{RB}. Constraints are set as the conversion range of the bulb parameters. The optimal bulb parameter derived through the optimization are shown in Table 3, and the shape of the designed hull 01 and 02 is illustrated by Fig. 3.

TABLE III. RESULTS OF THE GOOSENECK BULB OPTIMIZATION

	Design hull 01	Design hull 02	Changes (%)
C_{ABT}	0.095	0.070	-26.3
C_{LPR}	0.423	0.460	8.6
C_{ZB}	0.730	0.737	1.0
C_{∇}	0.058	0.047	-19.2
C_{RB}	0.205	0.189	-7.9
C_P (estimation)	0.643	0.488	-24.1

Comparing the wave height contours between reference hull and bulb hull (Designed hull 01, 02) as Fig. 4, the divergent wave heavily occurring in the part of forward shoulder of reference hull tended to be decreasing by the gooseneck bulb. Comparing the pressure distribution of the hull surface and the wave profile in Fig.5, the bulb hull changed the phase of wave, and the distribution of occurring in the main body around FP of the reference hull is significantly decreased. It is judged that the adoption of bulb may enlarge the energy loss in creating the wave around the bulb, however, improve the resistance performance of the bulb hull by reducing the pressure resistance of the fore body.

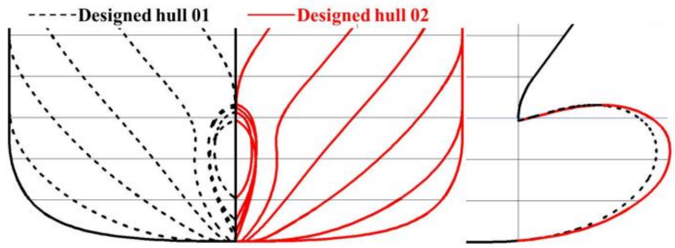


Figure 3. Ship lines of the designed hull 01 and 02

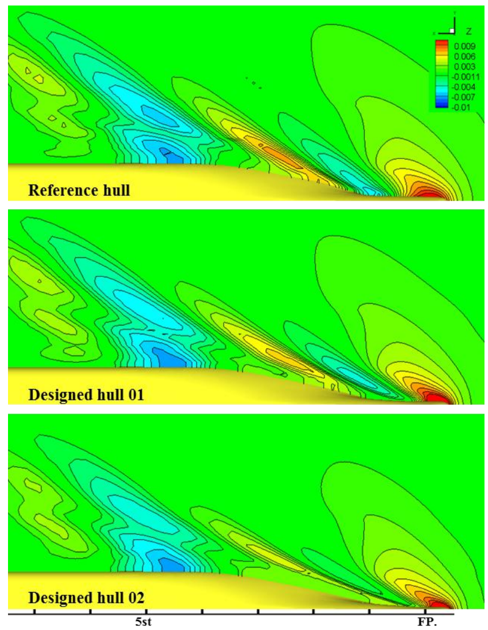


Figure 4. Wave height contours around the reference hull and designed hulls

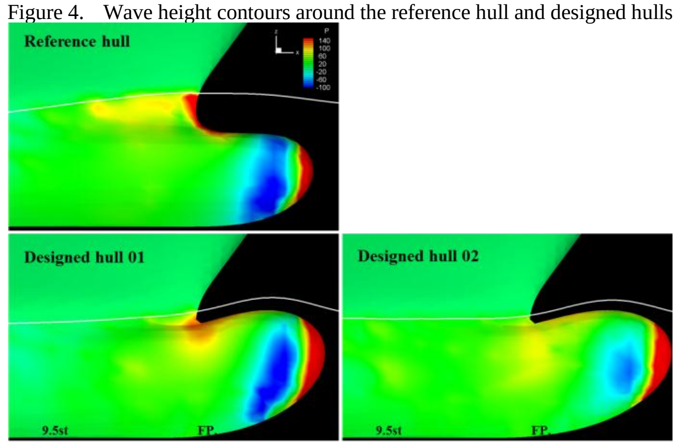


Figure 5. Pressure distribution of the reference hull and designed hulls

Fig. 6 shows the longitudinal direction by integrating the pressure resistance value occurred in the grid with the same X position. Of the vertical axis '+' means an increase in resistance and '-' means the contribution of the resistance decrease. Sum up the histogram values to the longitudinal direction, total pressure resistance taking on the whole main body can be obtained. The pressure resistance value taking on the bulb of the reference hull 67% of total pressure resistance of the reference hull. The pressure resistance value taking on the blub of the designed hull 01 shows a bit increased as 69% of total pressures resistance of the reference hull however, those of the design hull 02 was shown significantly decreased to 45%. It is considered that a reduction in the size of bulb is the cause. On FP(9.9st.~10.1st.), the reference hull is taken 13% of total pressure resistance. Whereas in the designed hulls, a decrease in resistance occurs that are 5% in the designed hull 01 and 1% in the designed hull 02. It is considered that resulted from the changes of the wave pattern form due to the gooseneck bulb.

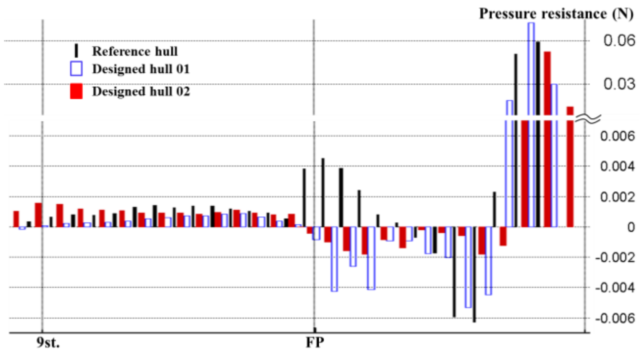


Figure 6. Comparison of the pressure resistance on the longitudinal region divided along to hull surfaec

The adoption of bulb reduce the pressure resistance of the forward part of the hull, which came up with the results that the designed hull 01 showed 15% reduction of total pressure resistance compared to the reference hull, and the designed hull 02 32% reduction. It was verified that the designed hull 02 also reduced the resistance taking on the bulb itself through the optimization of the bulb, so resistance performance more improve.

IV. Conclusion

To hull form design for passenger ship with good resistance performance, the correlation between the bulb parameters and their resistance performances are formulated through the regression analysis, and by using the regression equations and the optimization algorithm, the optimal bulb hull is derived.

The adoption of gooseneck bulb change the phase of the wave and reduce the pressure resistance at the forward part of hull, which resulted in the improvement of the resistance performance for passenger ship. To design the optimal bow hull form with gooseneck bulb, the regression equations for estimating the pressure resistance and the optimal bulb parameters are researched.

Through the optimization, the hull allows to reduce the pressure resistance occurring on the bulb itself as well, which can reduce the pressure resistance by 20% more than the precedent studied gooseneck bulb hull and by 32% compared to the reference hull. Through these, it is confirmed that the optimization of the gooseneck bulb for a particular vessel be possible.

At present study, the derivation of the regression equation and the optimization of the bulb for a particular vessel have been carried out. Hereafter research, by correcting the regression equations so as for principal particulars, especially C_B, to be applicable for the resistance estimation to other types of vessel to some extent, the research to enhance the versatility of the gooseneck bulb-use optimization method will be continuously performed.

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References

[1] Heimann, J. & Harries, S., "Optimization of the Wave- Making Characteristics of Fast Ferries," 7th Int. Conference on Fast Sea Transportation FAST"03, Ischia (Gulf of Naples), Italy, 2003.

[2] Maisonneuve, J.J. Harries, S. Marzi, J. Raven, H.C. Viviani, U. & Piippo, H., "Towards Optimal Design of Ship Hull Shapes," 8th Int. Marine Design Conf. IMDC'03, Athens, Greece, 3-5 June, 2003.

[3] Heimann, J., "CFD Based Optimization of the Wave-Making Characteristics of Ship Hulls," Technischen Universität Berlin, Germany, 2005.

[4] Yu, J.W. Lee, Y.G. & Jeong, K.L., "A Study on the Resistance Performance of the Goose Neck Bulbous Bow by Numerical Simulation Method," Journal of the Society of Naval Architects of Korea, Vol. 47, No.5, pp.689-696, 2010. in Korean.

[5] Yu, J.W. Lee, Y.G. & Park, Y.H., "A Fundamental Study on Bulbous Bow Design for the Resistance Reduction of Domestic Passenger Ships," Proceedings of the Annual Spring Meeting of the Society of Naval Architects of Korea, pp.1150-1155, 2013. in Korean.

[6] Yu, J.W. Lee, Y.G. & Park, Y.H., "A Study on Determination of Gooseneck Bulb Parameter for Domestic Passenger Ships," Proceedings of the Annual Autumn Meeting of the Society of Naval Architects of Korea, pp.491-498, 2013. in Korean.

[7] Hong, S.W., Cho, K.J., Yun, D.S., Kim, E.C. and Jung, W.C., "Estimation of Ship Resistance by Statistical Analysis and its Application to Hull Form Modification," Journal of the Society of Naval Architects of Korea, Vol. 25, No. 4, pp.28-38, 1988. in Korean.

[8] Min, K.S., "A Study on the Regression Analysis for the Prediction of Resistance and Propulsion Characteristics of Full Slow-Speed Ships," Journal of the Society of Naval Architects of Korea, Vol. 27, No. 1, pp.84-98, 1990.

[9] Tahara, Y., Himeno, Y. and Tsukahara, T, "An Application of Computational Fluid Dynamic to Tanker Hull Form Optimization Problem," Proceedings 3rd Osaka Colloquium on Advanced CFD Applications to Ship Flow And Hull Form Design, Osaka, Japan, pp.515-531, 1998.

[10] Choi, H.J., Lee, G.W. and Yun, S.D., "Study for the Development of an Optimum Hull Form using SQP," Journal of Korean Navigation and Port Research, Vol. 30, No. 10, pp. 869-875, 2006. in Korean.

[11] Kim, H.C., "Resistance and propulsion of the ship," The ship fluid dynamics research group, the Society of Naval Architects of Korea, 2009. in Korean.

[12] Jeong, K.L. Lee, Y.G. & Kim, N.C., "A Fundamental Study for the Numerical Simulation Method of Green Water Occurrence on Box Deck," Journal of the Society of Naval Architects of Korea, Vol. 47, No. 2, pp.188-195, 2010. In Kroean.