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Numerical Computation for the Comparison of Stern Flows around Various Twin Skegs

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Abstract

Numerical analysis of viscous flow around twin-skeg hull forms was conducted according to the variations of distance between skegs and vertical skeg inclinations by using a hydrodynamic analysis system, WAVIS. Six twin-skeg hull forms were derived by combining three distances between skegs (16m, 20m, 24m) and four vertical skeg angles (0°, 10°, 15°, 20°). It is found that the better resistance performance can be obtained with larger vertical skeg angle and smaller skeg distance for the present test cases. It also can be seen that the same trend is true for the nominal wake distributions in the propeller plane. Those tendencies were confirmed by the experimental results of MOERI. It is shown that numerical analysis can be a useful and practical tool for the evaluation and improvement of hydrodynamic performances for the complex stern hull forms with twin skegs.
Keywords: twin-skeg ship, hydrodynamic performance, RANS method, turbulent flow

1 Introduction

Systemic study on the twin-skeg hull form combining high loading capacity and superior resistance and propulsion performance has been carried out by MOERI and several participant Korean shipbuilding companies. Through the aforementioned study, twin-skeg hull form definition, design and modification tool has been developed and both experimental and numerical analysis method was employed to investigate the hydrodynamic performance of designed hull forms. For advancing a good hull form design of the twin-skeg ship, it is important to know the resistance and propulsion characteristics corresponding to the variation of the stern shape. However, compared with mono-hull ships, there are very few data of flow characteristics around a twin-skeg ship having superior hydrodynamic performance. Some related references are as follows; Lee et al. (2002), Lee et al. (2003), Lee et al. (2003), Van and Park (2003), Van et al. (2003).

The main design factors in twin-skeg stern shape variations, which have influences on the hydrodynamic performance, are as follows; 1) Distance between skegs, 2) The longitudinal slope between skegs, 3) Vertical skeg inclination, 4) Longitudinal skeg inclination, 5) Skeg form, 6) Propeller rotational direction.

In the present work, numerical analysis of viscous flows around twin-skeg hull forms was conducted according to the variations of the distance between skegs and the vertical skeg inclination, where bow shapes of those hull forms are kept identical. Numerical results for six hull forms derived by combining four values of the vertical skeg angle and three values of the distance between skegs are compared with each other. Numerical results of nominal wake distribution in propeller plane are compared with experimental results.

The hull form variations were conducted using HCAD (hull form design program developed in MOERI). Three dimensional multi-block grid and viscous flow solutions were obtained from a grid generator and a RANS (Reynolds Averaged Navier-Stokes) solver of WAVIS (Wave and VIScous flow analysis system of MOERI). In the numerical results, streamlines, pressures distributions, nominal wake distributions and viscous drag coefficients for the six twin-skeg hull forms in model scale are compared and the present numerical data are validated with the measured data in MOERI towing tank. Through the present systemic comparison analysis, it is intended to find the special geometrical characteristics of the twin-skeg stern shape that has a good resistance performance and nominal wake distribution in the propeller plane.

2 Hull Form and Numerical Methods

The main dimensions of six twin-skeg hull forms (S1, S2, S3, S4, S5, S6) are as follows; L/B=6.975, B/T=4.107, lcb=-3% of LBP. The bow shape has an extreme V-shape framelines within the range not to be affected seriously from slamming phenomenon. The design speed of full scale ship is 26konts and the corresponding Reynolds number in towing tank model scale is 1.056×10^{7}. The details of the vertical skeg angle and the distance between skegs for each hull form are shown in Table 1, where the longitudinal skeg angle is 0° for all hull forms. The definition of skeg angle and distance, and a body plan of after part can be found in Figure 1 and 2, respectively. Small deformation of skeg shape accompanied these variations.

Table 1: Skeg angles and distances between skegs for six twin-skeg hull forms

Hull	Vertical Skeg Angle	Skeg distance
S1	0°	20m
S2	10°	16m
S3	10°	20m
S4	10°	24m
S5	15°	20m
S6	20°	20m

It is desirable to use multi-block grid system when viscous flow around a hull form with the complicated twin-skeg stern shape is to be solved. MOERI has developed another viscous solver based on multi-block grid system for WAVIS. Numerical method of new RANS solver is almost same with the previous one. However, this solver contains some more complex algorithm of computation process for multi-block grid treatment. The details of numerical method are explained briefly as follows.

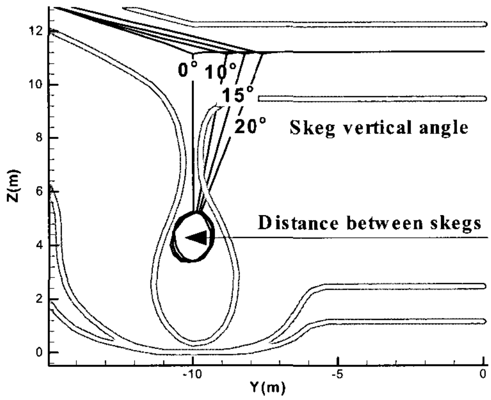

Figure 1: Definition of skeg angle and distance between skegs

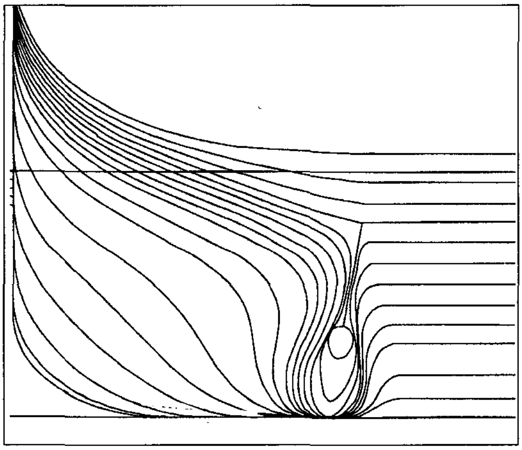

Figure 2: Body plan of after part (skeg angle, 10^{o}, distance 20m)

The governing equations for turbulent flow in the present study are RANS equations for momentum transport and the continuity equation for mass conservation. For turbulence closure, the realizable k-ε model (Shih et al. 1995) is employed. It is advisory to use a near-wall turbulence model to resolve boundary layer up to the wall; however, the number of grid should be almost doubled. For the present study the so-called Launder and Spalding's wall function is utilized to bridge fully turbulent region and wall. The first grid point in the wall function approach is approximately 100 times off the wall compared to that in the near wall turbulence model. It provides the economy and robustness to a viscous flow computation method as a design tool.

WAVIS utilizes a cell-centered finite-volume method to discretize governing equations. Convection terms are discretized using QUICK scheme of the third order. Central difference scheme is utilized for diffusion terms. Linear equations are solved using strongly implicit procedure. If the pressure field is known a prior, momentum equations will give correct velocity field. However, those velocity components will not satisfy the continuity equation. To ensure divergence-free velocity field, the SIMPLEC method is employed. Details of numerical method and turbulence model can be found in Kim et al (2002).

3 Numerical Results

For the strict comparison of the numerical results for each hull form, the grid distribution and the number of grid points (348, 136) were fixed allowing a small deviation in the grid distribution around the stern region. In the numerical results, drag coefficients and nominal wake distribution at the propeller plane are mainly compared with each other. It is explained how the changes of the skeg vertical angle and the distance between skegs influence the hydrodynamic properties by close investigation of flows around the stern. Simultaneously, the qualitative forecasting ability of the present numerical approach was validated by comparing with the measured nominal wake data in MOERI towing tank.

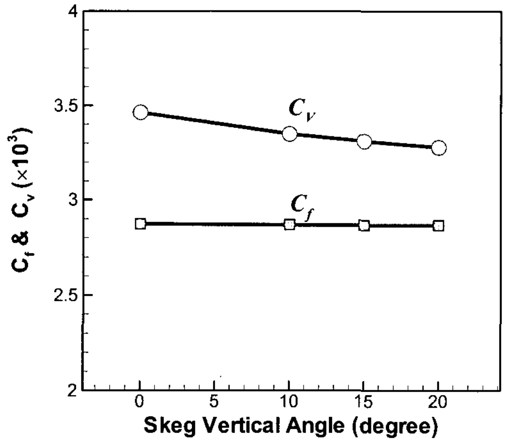

Figure 3: Drag coefficients (vertical angle variation)

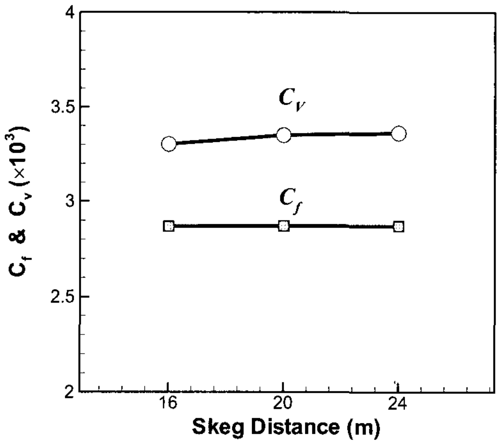

Figure 4: Drag coefficients (distance variation)

Figure 3 shows the influence of the skeg vertical angle change on the viscous drag(C_v), where the distance between skegs is fixed to 20m. The frictional drag(C_f) component remains nearly constant but the viscous drag coefficient decreases as the vertical skeg angle increases. Figure 5 shows the comparison of the pressure distributions around stern part including skegs. As the skeg vertical angle increases, the occupied area of Cp = -0.15 on pressure contours inside of skegs decreases and also the pressure gradients becomes more uniform. When the skeg vertical angle becomes smaller, lower pressure value (Cp<-0.20) appears together with the severe pressure gradients. In other words, alignment of skegs does not coincide with the stern flows as vertical skeg angle decreases and this obstruction will cause a retardation of the flows around skegs. Also severe pressure gradient across the skeg implies the existence of cross flow over the skeg bottom and the formation of stronger vortices and consequently higher viscous pressure drag. This conjecture can be confirmed by wake analysis which will be explained later.

Similar trends for pressure distribution and gradient are found for variation of distance between skegs as shown in Figure 6. Here the skeg vertical angle is kept to 10°. The area of Cp = -0.15 becomes larger and Cp = -0.2 appears as distance increasing. Pressure contours, especially on the skeg surface, becomes smoother as distance decreasing. As a result, viscous pressure drag becomes larger as distance between skegs becomes wider as shown in Figure 4. Though the present computed viscous drag does not contain wave resistance component, it shows the same trend with the MOERI experimental result (Lee et al. 2003).

It seems that more detailed investigation of the skeg distance effect corresponding to ship speed should be carried out in the near future.

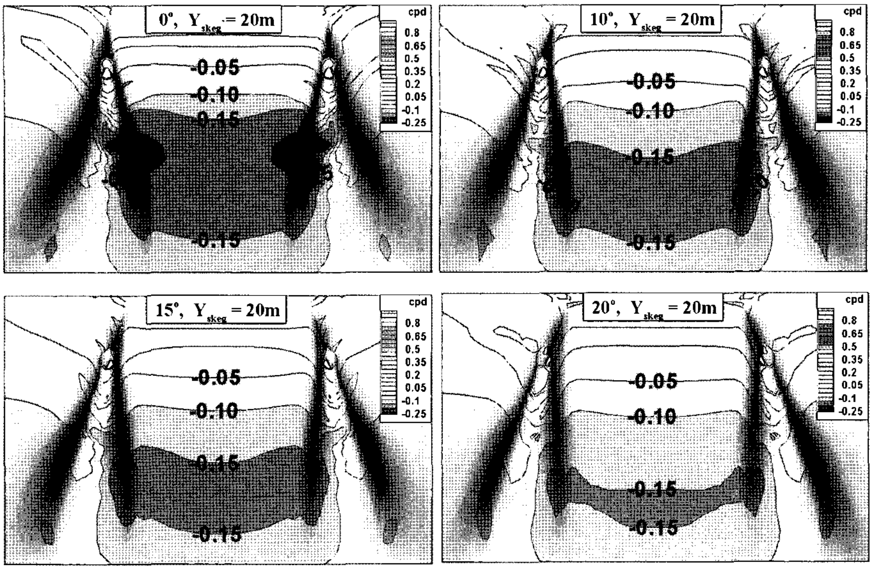

Figure 5: Comparison of pressure distribution (vertical angle: 0°, 10°, 15°, 20°)

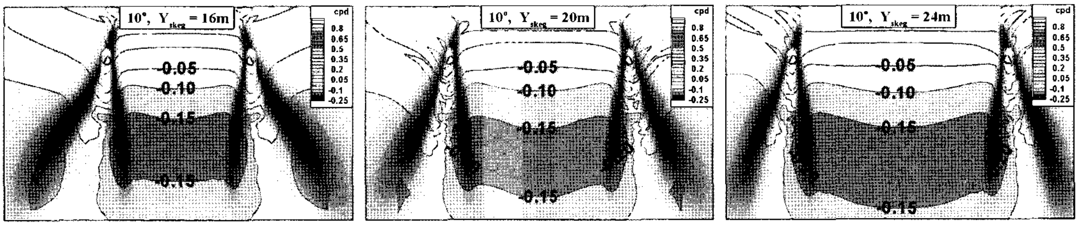

Figure 6: Comparison of pressure distribution (skeg distance: 16m, 20m, 24m)

Nominal wake fractions are compared for vertical skeg angle variation in Figure 7. As the skeg vertical angle decreases, the value of nominal wake fraction is increasing and experimental data show same tendency. The increase of nominal wake with smaller vertical skeg angle is expected because skegs are acting like an obstruction to the stern flows as discussed before. However, it is thought that the maximum variation limit over which the nominal wake fraction does not decrease would exist, because the accompanied skeg body shape for those cases would affect disadvantageously.

The computed wake distributions at the propeller plane according to the skeg vertical angles are compared with the experimental results in Figure 8. For the present computation condition does not include the trim and sinkage change, some deviations can be expected. But, except the lower part of skeg, where the strong longitudinal vortices are generated and flow becomes very complicated, both results show a good agreement. As the skeg vertical angle decreases, the wake distribution inside of skeg becomes thicker because the fluid with low momentum is crossing over the bottom of skeg.

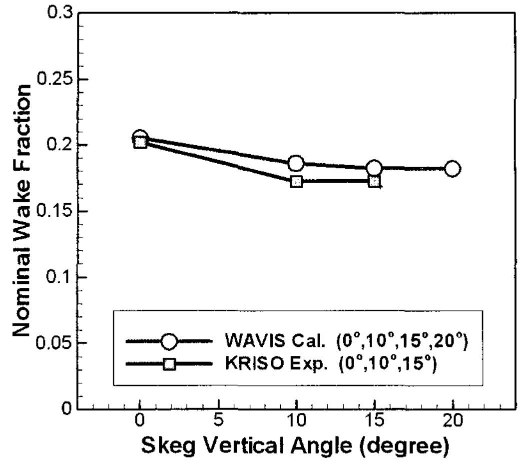

Figure 7: Nominal wake fraction versus skeg vertical angle

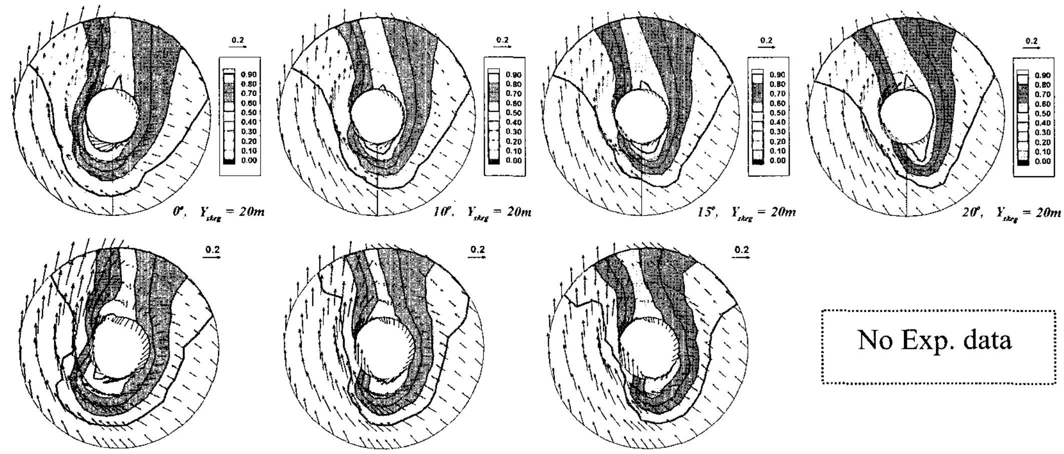

Figure 8: Comparison of wake distribution (vertical angle: 0°, 10 °, 15 °, 20 °; upper: computation, lower: experiment)

The circumferential distributions of axial velocity at 0.7Rp (Radius of propeller) in propeller plane are compared for variation of skeg vertical angles in Figure 9. Top of propeller plane is defined as 0^{o} and position angle is increasing in counterclockwise direction viewed from behind. The value of lowest velocity on top of propeller plane (0^{o}) due to the existence of the hull in front is almost same for different vertical angles; however, the position is shifted to counterclockwise direction because vertical inclination of skeg is also rotated in this direction. This feature also can be found in Figure 8. The lower axial velocity contour on top is inclined to counterclockwise direction as vertical skeg angle changes from 0^{o} to 20^{o}. Another trough in velocity distribution is found around the bottom of skeg (180^{o}) where the low momentum flow inside of boundary layer converges into. The width and depth of this trough becomes smaller as the vertical skeg angle increasing and more uniform and favorable axial flow is expected. Circumferential mean of tangential component are compared along the radial direction in Figure 10. The tangential component increases greatly as skeg vertical angle decreasing because of the high pressure gradient between outside and inside of skeg bottom as shown in Figure 5.

The larger tangential velocity component means that the stronger longitudinal vortices are generated and this will cause the increase of resistance as shown in Figure 3.

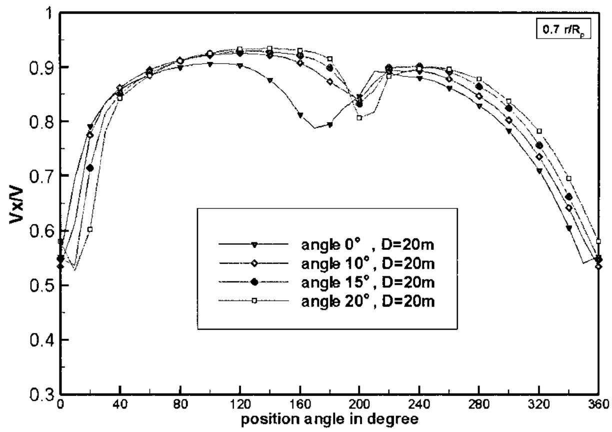

Figure 9: Circumferential distribution of axial velocity (0.7Rp, propeller plane)

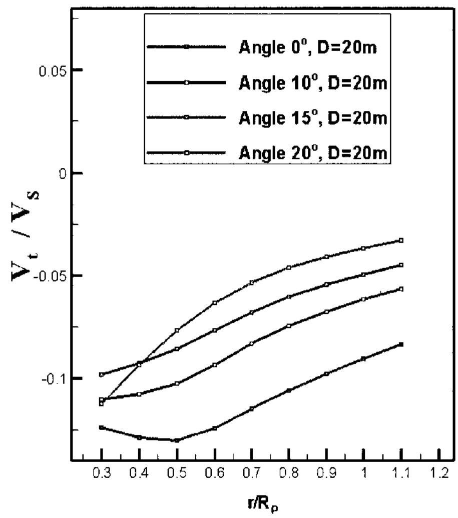

Figure 10: Circumferential mean of tangential velocity (skeg angle variation)

The computed nominal wake fractions for distance variation between skegs are compared with experiments in Figure 11. As the distance between skegs increases, the nominal wake fraction is decreasing because skegs are located farther from the centerline and the incoming flows are freer from the bottom boundary layer and have higher axial velocity.

Figure 12 shows the comparison of the wake distributions for the hull forms with the distance between skegs of 16m and 24m, where the nominal wake fraction for each hull form is the lowest and the highest, respectively. For 16m distance case, upward velocity component is dominant in incoming flow and skeg is aligned relatively well with the flow direction. But 24m distance case, flow from outside to inside (from right to left in Figure 12) becomes more significant. Skeg becomes an obstruction to this flow as in case of vertical skeg angle 0^{o}, so stronger longitudinal vortex formation and consequent higher viscous drag is expected. Circumferential mean of tangential velocity component for 24m distance case is much bigger than that for 16m distance case as shown in Figure 13.

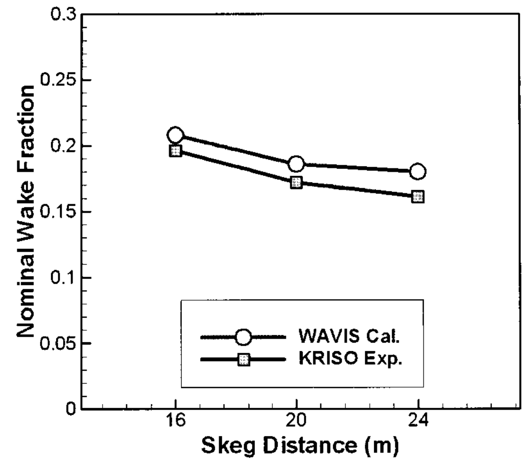

Figure 11: Nominal wake fraction versus distance between skegs

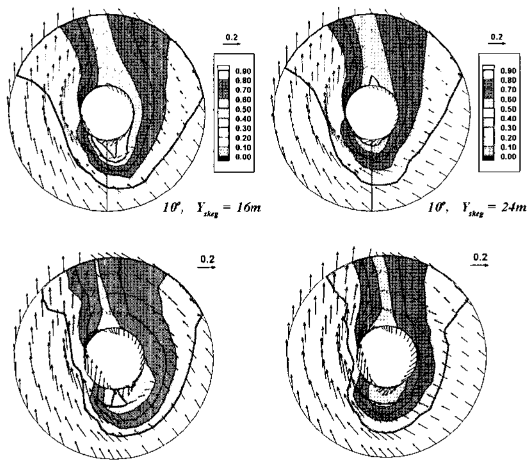

Figure 12: Comparison of wake distribution (skeg distance: 16, 24m; upper: computation, lower: experiment)

It can be explained why this flow feature occurs by examining the skeg body shape and the flow pattern around it in Figure 10 and 11. Because the skeg vertical angles are same, the internal flows between skegs for the two hull forms show nearly same pattern and Figure 9 shows this results. However, the effect of the skeg body shape more strongly disturbs the flow outside the skeg tunnel and the phenomenon that the streamlines flow from the skeg outside to the skeg tunnel is more considerable for the hull form with the skeg distance of 16m.

Otherwise, for the hull form with the skeg distance of 20m, the streamlines are uniform and its wake distribution shows a good pattern.

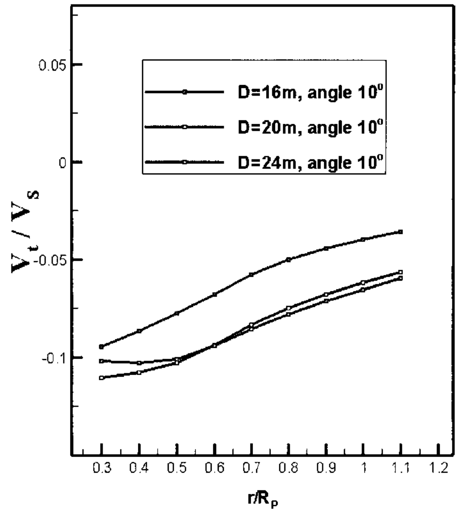

Figure 13: Circumferential mean of tangential velocity (distance variation)

4 Conclusions

A numerical study on the hydrodynamic performance of a twin-skeg ship according to the variations of the skeg vertical angle and the distance between skegs was carried out by systemically investigating turbulent flows characteristics for six twin-skeg hull forms. The present computed results show a good agreement with the MOERI experimental results. It is found that the increase of the skeg vertical angle raises the resistance performance of twin-skeg ship and the distance between skegs should be narrow appropriately to improve this performance when the skeg vertical angle is determined. In view point of nominal wake, it is found that the increase of the skeg vertical angle and decrease of the distance between skegs give more favorable velocity distribution in propeller plane.

In present study, it is clearly shown that the carefully validated CFD code can be a useful tool to understand the flow phenomena and to enhance the hydrodynamic performance of a twin-skeg ship in the preliminary design stage.

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References

Kim, W. J., D. H. Kim and S. H. Van. 2002. Computational study on turbulent flows around modern tanker hull forms. International Journal for Numerical Methods in Fluids, **38, 4,** 377-406.

Lee, C. J., Y. Y. Lee, S. H. Van, I. R. Park, Y. S. Hwang, J. S. Park, S. P. Kim and N. J. Park. 2002. Development of Twin-skeg Hull Forms for Mega Containership and Powering Performances Evaluation. Proceedings of the Annual Autumn Meeting, SNAK, 157-161.

Lee, Y. Y., C. J. Lee, S. H. Van, Y. S. Hwang, J. S. Park, S. P. Kim and N. J. Park. 2003. A Development of Basic Hull Forms and a Survey on the Performance for Twin-skeg Mega Containership. Proceedings of the Annual Spring Meeting, SNAK, 24-28.

Lee, Y. Y., C. J. Lee, S.H. Van, J. S. Park, Y. S. Kim and N. J. Park. 2003. Investigation of Powering Performance with Parametric Variation of Distance and Vertical Angle of Twin-skegs. Proceedings of the Annual Autumn Meeting, SNAK, 229-233.

Shih, T. -H., W. W. Liou, A. Shabir and J. Zhu. 1995. A New k-ε Eddy Viscosity Model for High Reynolds Number Turbulent Flows-Model Development and Validation. Computers & Fluids, **2, 3,** 227-238.

Van, S. H. and I. R. Park. 2003. Comparison of Hydrodynamic Characteristics of Twin-skeg ships corresponding to the Hull Variation. Proceedings of the Annual Spring Meeting, SNAK, 324-329.

Van, S. H., I. R. Park, J. Kim and C. J. Lee. 2003. Hydrodynamic Performance Analysis for the Twin-skeg Ship with the Variation of Stern Hull Shape. Proceedings of the Annual Autumn Meeting, SNAK, 240-244.