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Evaluation of resistance increase and speed loss of a ship in wind and waves

Shaoze Luo[a,b,c,*], Ning Ma[a,b,c,e], Yoshiaki Hirakawa[d,e]

[a] *School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, China*
[b] *State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, China*
[c] *Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai, China*
[d] *Sea & Air Control System Laboratory, Yokohama National University, Yokohama, Japan*
[e] *Institute of Advanced Sciences, Yokohama, Japan*

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Abstract

Given the indication of the IMO's intent to the application of the EEDI and EEOI, the complete and precise total resistance of a ship and induced speed loss in wind and wave is primarily required. This paper proposed a practicable method to evaluate the total resistance in seaway. Besides the still water resistance, the added resistance due to waves is computed using panel method and the wind resistance is obtained using CFD with the verification of an open wind test and statistical formula. The speed loss is acquired in consideration of the matching of the hull, engine and propeller. A hull optimization method is consequently presented based on the proper resistance evaluation approach. The approach is validated available and the total resistance of a ship could be reduced after hull optimization.

Keywords: Speed loss; Resistance increase; Wind; Wave; Hull form optimization.

1. Introduction

On the background of increasing focus on the reduction of the fuel consumption and demand of energy saving, there is a strong requirement for the complete and accurate evaluation of the resistance increase and speed loss of a ship in seaway instead of the previous simple power estimation in calm water. For this reason, the wind and waves factors contributing to speed loss should be properly considered.

The ship during voyage at actual sea will encounter external weather loads and thus causes the resistance increase, which result in speed reduction if the power never changes, or alternatively, requires an adequate power increasing in order to maintain a certain speed. It is of great importance to give a valid estimation of added resistance considering a given sea condition.

Many studies concerning the added resistance and speed loss have been carried out in these years. Sverre Steen and Zhenju Chuang [14] have provided a method to measure the speed loss from model test and demonstrate the importance of friction correction. Journée [8] has developed a computer program to calculate speed and behavior of ship in seaway. Two factors including the natural speed reduction and voluntary speed reduction are considered. Full comparison between two methods of added resistance evaluation, one developed by Faltinsen, and the other by Salvesen, is performed by Matulja et al. [12, 11]. Pérez Arribas [1] also validated some prediction method against the experimental results of the seakeeping tests and made conclusions about the range of the application of these theories.

This paper defines the total resistance into three parts, still water resistance, added resistance due to waves and wind resistance. Each is evaluated with different methods. What is

* Corresponding author at: School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, China.
E-mail address: 624546581@qq.com (S. Luo).

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more, a critical analysis and comparison for the wind loads has been carried out with statistical, computational and experimental data. Therefore, the resistance increase is predicted and the speed loss is gained in consideration of the interaction of the hull, engine and propeller in seaway. To obtain a better performance of a ship in wind and waves, the speed loss factor and EEOI as objectives are optimized using NSGA-II algorithm.

2. Methods

The added resistance, according to the load components, is divided into two parts, i.e. the wind resistance and the added resistance due to waves. In this paper, the ship is assumed advancing in head waves and the added resistance in waves is calculated with three dimensional panel method while the wind resistance is analyzed in several ways including statistical formulation, full CFD computation and open wind test in towing tank.

2.1. Wave added resistance

The resistance increase in regular waves is calculated with analytical method developed by Chen [2] and Newman [13]. The estimation in irregular waves is based on the linear hypothesis for the ship's response as well as the superposition principle for the components of waves and resistance spectra. Here the added wave resistance is approximated as second order drift force in head wave. The mean added wave resistance $\Delta\overline{R}_{AW}$ would be as follows:

$$\Delta\overline{R}_{AW} = 2\int_0^{\infty} \frac{R_{AW}(\omega_e)}{\varsigma_a^2} S_\varsigma(\omega_e) d\omega_e \tag{1}$$

With $S_\varsigma(\omega_e)$ the wave spectrum, ς_a the significant wave height, ω_e the encountering frequency.

Chen's method includes the first-order and second-order potential theory of wave radiation and diffraction as well as the elimination of irregular frequencies, which is somehow accurate enough for engineering application.

2.2. Wind resistance

Fujiwara [5] has developed a new estimation method based on physical component models of the wind loads acting on ships, and this method is later modified for new ship forms such as large containerships. The modified method is more accurate in wind loads estimation of containership compared with Isherwood's [7] empirical formulas analyzed from a wide range of merchant ships. The longitudinal wind drag coefficient C_x then could be calculated from:

$$\begin{aligned} C_x(\Psi_A) = {} & C_{LF}\cos\Psi_A \\ & + C_{XLI}\left(\sin\Psi_A - \frac{1}{2}\sin\Psi_A\cos^2\Psi_A\right)\sin\Psi_A \\ & + C_{ALF}\sin\Psi_A\cos^2\Psi_A \\ & + \frac{A_{RC}}{A_{OD}}\left(C_{D1}\cos^2\Psi_A + C_{D2}\sin\Psi_A\cos\Psi_A\right) \end{aligned} \tag{2}$$

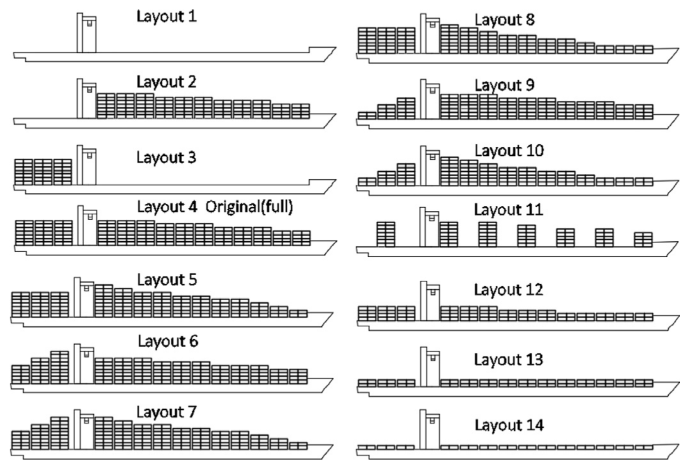

Fig. 1. Container layouts on the deck.

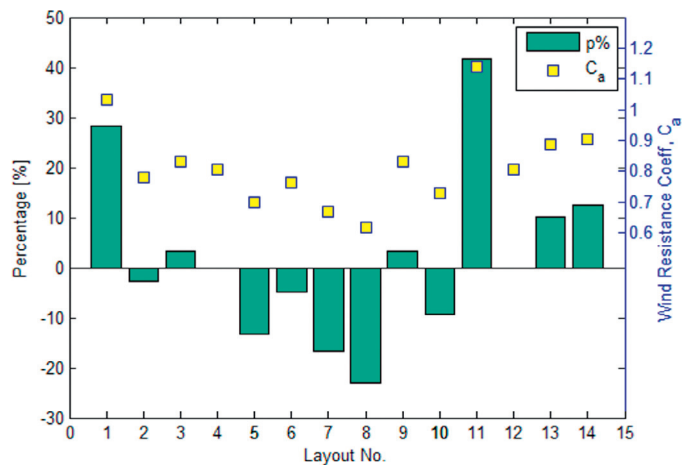

Fig. 2. Coefficient comparison in layouts.

With Ψ_A the angle of attack, C_{LF} the lift force part, C_{XLI} caused by the linear potential theory, and additional force C_{XLI} caused by the 3-dimensional flow effect. A_{RC} corresponds to the lack part area in the lateral projected area on the deck's fully imaged containers A_{OD}. C_{D1} and C_{D2} are the additional coefficients.

For more detailed and precise results, the author has carried out an open wind test in towing tank. The wind profile was studied and compared with other experiment results to validate the feasibility of the open wind test before wind drag of a scale model in different container layouts was measured. The series of the experiment with container layouts in Fig. 1 have been carried out in in Yokohama National University (hereafter simply YNU). The experiment results of the wind resistance coefficients in different layout are displayed in Fig. 2.

Computational calculation is also performed based on the same cases. The Realizable κ-ε turbulence model and standard wall function are adopted and the local refinement is applied to the region near the containers. Second order upwind difference scheme is used for relatively accurate and stable results.

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