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Optimization of drag reduction effect of air lubrication for a tanker model

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Abstract

The reduction of CO_2 emissions has been a key target in the marine industry since the IMO's MEPC published its findings in 2009. Air lubrication method is one of the mature technologies for commercialization to reduce the frictional resistance and enhance fuel efficiency of ships. Air layer is formed by the coalescence of the injected air bubbles beyond a certain air flow rate. In this study, a model ship ($\lambda = 33.33$) of a 50,000 ton medium range tanker is equipped with an air lubrication system. The experiments were conducted in the 100 m long towing tank facility at the Pusan National University. By selecting optimal air injector configuration and distribution ratio between two injectors, the total resistance of model R_{TM} was able to be reduced down to 18.1% in the model scale. Key issue was found to suppress the sideway leakage of injected air by appropriate injection parameters.

Keywords: Energy efficient ship; Skin frictional drag reduction; Air lubrication; Air layer drag reduction

1. Introduction

The main components of ship resistance consist of resistance due to wave resistance, pressure resistance, and frictional resistance. With the improvement of hull form optimization techniques, the wave and the pressure components could be less than 20 percent of the total drag in most modern ships. Therefore, the advantage from the reduction of the remaining frictional drag would be enormous. The CO_2 emission from international marine bunkers in 2014 was estimated 626.1 million tons (IEA2016). Considering the conversion ratio 3.17 between CO_2 emission and fuel consumption (Corbett et al., 2009), this amounts to 197.5 million tons of fuel consumption, which corresponds to approximately 60 billion US$/year. Thus, 10% reduction of frictional drag would lead to saving of 4.7 billion US$/year.

Air lubrication method is one of the mature technologies for commercialization to reduce the frictional resistance. Drag reduction using air can be categorized by Bubble Drag Reduction (BDR) and Air Layer Drag Reduction (ALDR). In BDR, small bubbles are injected into the boundary layer. The dispersed bubbles act to reduce the bulk density and to modify the turbulent momentum transport, depending on the shape and distribution of air bubbles. Initial report on BDR was by McCormick and Bhattacharyya (1973). It was observed experimentally that drag reduction increases with gas (bubble) flow injection rate (Merkle and Deutsch, 1992).

In ALDR, a seemingly continuous air layer is created between liquid and the hull surface. It reduces the frictional drag on the area covered by the air layer (Sanders et al., 2006; Elbing et al., 2008; Mäkiharju et al., 2012). Elbing et al. (2008) investigated the transition from BDR to ALDR on flat plate test in large circulating water channel. Fig. 1 shows the percentage of drag reduction with the air flux (Mäkiharju et al., 2012). As observed in BDR, for the lower-range of gas injection rates, drag reduction rate is less than 20%. However, above a critical gas injection rate, the ALDR with volumetric air flux being approximately 50 percent greater

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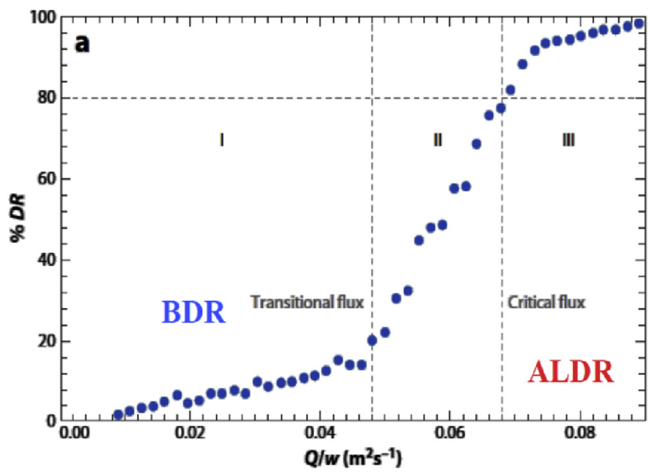

Fig. 1. Change of drag reduction regime with varying air flux (Mäkiharju et al., 2012).

Table 1
Principal particulars of medium range tanker.

Designation	Symbol (unit)	Design Load Draft	
		Ship	Model
Scale Ratio	λ	33.33	
Design Speed	V_S (*kts*)	15.10	N.A.
	V_M (*m/s*)	N.A.	1.345
Length Overall	LOA(*m*)	183.0	5.491
Length of Waterline	LWL(*m*)	177.9	5.338
Breadth	B(*m*)	32.2	0.966
Draft			
Forward	TF(*m*)	11.0	0.330
After	TA(*m*)	11.0	0.330
Wetted Surface Area	WSA (m^2)	8018	7.218
Bilge Keel Area	SBK(m^2)	64.4	0.058
Transverse Area above WL	AT (m^2)	672	0.605
Displacement Volume	DISV(m^3)	48,890	1.320

than BDR gives rise to drag reduction rate over 80 percent. The net energy saving rate expected for ALDR in Fig. 1 becomes higher than that for BDR. The net energy saving rate is given by subtracting the energy required to inject the air from the energy saving due to drag reduction. In order to implement air lubrication method in ocean-going vessels, the amount of net energy saving rate becomes significant.

In this study, a model ship based on a 50,000-ton medium range tanker (λ = 33.33) was tested in the towing tank using an air lubrication method. This ship kind had been selected from the viewpoint of the ratio of skin friction out of the entire resistance, the operation profile with shallow draft and the production volume in consideration of future implementation. In order to prevent air leakage, an air fence system was installed at the bottom of the model ship. The model ship was tested in the towing tank to assess the frictional drag reduction and the efficiency of the air lubrication method. It is worthwhile to point out that no attempt is made toward extrapolating measured model resistances in various air injection configuration to full scale resistance performance in this study. This is because no relevant scaling law for the air injection parameters, for instance the equivalent air film thickness t_L, has yet been proposed.

2. Experimental setup

2.1. Ship models

A model ship is manufactured after a 50,000-ton medium range tanker (λ = 33.33). Table 1 provides the principal particulars of the ship used. The bottom of the model was installed acrylic windows to observe dynamics of air lubrication. Fig. 2 shows the photographs of the model ship (Bare Hull). The model tests in this study were conducted based on the Froude's similarity. Although this is a widespread convention in scaled model test for ships, the appropriate scaling for air layer has not been clarified yet.

2.2. Expected effective air lubrication area

The injected air separates the water from the bottom of the hull thus reducing friction. Fig. 3 shows the model ship's flat surface area for air lubrication. Expected effective lubrication area can be divided into air injection device area (denoted "*A*" in Fig. 3), air lubrication control area by fence ("*B*" in Fig. 3) and downstream area ("*C*"). It corresponds to 33% of the total wetted surface area.

A: air injection device area: 2.83%
B: air lubrication control area: 23.84%
C: downstream area: 6.24%

$$A_{LMax} = A + B + C = 2.375\text{m}^2(32.91\%)$$

2.3. Control device and lubrication air flux

In this study, an MFC (Mass Flow Controller) was used to measure and control the air injection flow rate. The capacity of the MFC in this study was 1000ℓ/min and the settling time, which is time taken until the mass flow rate reaches within ±1% of desired value, was approximately 2 s. As depicted in

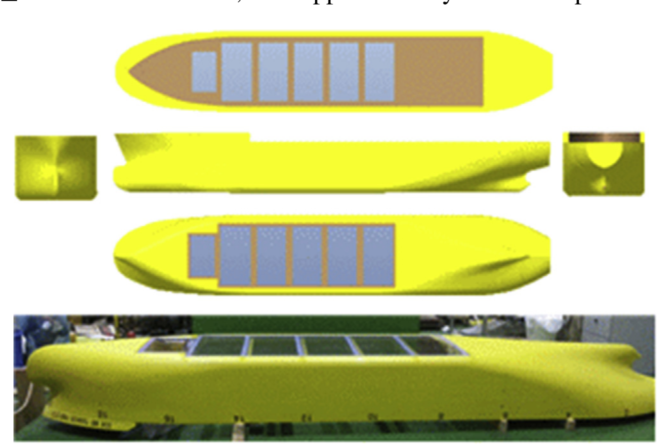

Fig. 2. Photographs of the model ship (Bare Hull).

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