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Experimental investigation of frictional resistance reduction with air layer on the hull bottom of a ship

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ABSTRACT: *In an effort to cope with recent high oil price and global warming, developments of air lubricated ships have been pursued to reduce greenhouse gas emissions and to save fuel costs by reducing the frictional resistance. In this study, reduction in the frictional resistance by air lubrication with air layers generated on the lower surface of a flat plate was investigated experimentally in the large water tunnel of SSMB. The generated air layers were observed, and changes in the local frictional drag were measured at various flow rates of injected air. The results indicated that air lubrication with air layers might be useful in reducing the frictional resistance at specific conditions of air injection. Accordingly, resistance and self-propulsion tests for a 66K DWT bulk carrier were carried out in the towing tank of SSMB to estimate the expected net power savings.*

KEY WORDS: Greenhouse gas emissions; Fuel costs; Frictional resistance; Air lubrication; Air layer; Air injection; Net power savings.

INTRODUCTION

The frictional resistance of a ship is one of major resistance components, approximately 60~70% of the total resistance. Therefore, if significant reduction in the frictional resistance is achieved, it will be useful in reducing greenhouse gas emissions and saving fuel costs consequently.

Air lubrication techniques can reduce the skin friction using air layers or artificial air cavities generated on the wetted hull surface by air injection (Bushnell and Hefner, 1990; Ceccio, 2010a). Some of the basic ideas had been proposed in the 19th century already (Latorre, 1997). However, some technical issues should be resolved for practical applications to large vessels sailing the ocean (Ceccio et al., 2010b): Hull attitude changes during turning or ship motions in waves may hinder resistance reduction with air lubrication by making air-water flows unstable. Moreover, an expensive air supply system should be installed to inject the right amount of air on the hull bottom surface of a large ocean-going vessel and the maintenance of the system should be considered as well. Nevertheless, air lubrication techniques are getting more attention as an effective means to save fuel costs in shipping industries because a recent surge in oil prices might shorten the payback period of an air supply system (Allenström and Leer-Andersen, 2010; Foeth, 2008; Foeth et al., 2010; Hoang et al., 2009; Insel et al., 2010; Thill, 2010).

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Recently, Mitsubishi Heavy Industries developed MALS (Mitsubishi Air Lubrication System), which has been applied to two module carriers of NYK-Hinode Line, a coal carrier built by Oshima Shipbuilding, a ferry of Japan's A-Line Ferry. It was announced that net power savings up to about 13% were obtained from the sea trials of the module carriers (Mizokami et al., 2010; Mizokami et al., 2011; Tanaka, 2011).

In this study, the feasibility of air lubrication technique without any significant changes of the hull form was investigated experimentally. Firstly, the experiments to generate air layers on the lower surface of a flat plate in the large water tunnel of SSMB were conducted The generated air layers were observed, and changes in the local frictional drag were measured. Secondly, resistance and self-propulsion tests for a 66K Supramax bulk carrier were carried out in the towing tank of SSMB. Air layers generated on the hull bottom were observed, and changes in the resistance and propulsion performance were investigated, and the expected net power savings were estimated.

FRICTIONAL DRAG REDUCTION WITH AIR LAYER

When air is injected into the boundary layer of the wetted surface, an air-water mixture flow containing both air bubbles and water can be formed. If the amount of injected air increases, air bubbles begin to coalesce into patches that cover the surface continuously, and a transitional air layer where the patches coexist with air bubbles is formed as shown in Fig. 1(Left). The frictional drag on the surface covered with a continuous air layer can be reduced effectively as if the wetted surface area were reduced because the friction with water may change into that with air (Bushnell and Hefner, 1990). Therefore, on the surface covered with a transitional air layer, it is expected that both air bubbles and patches of continuous air contribute to the frictional drag reduction. Elbing et al. (2008) described that reduction in the local frictional drag can be achieved from about 20% to 80% on the surface covered with a transitional air layer. If the amount of injected air is increased more, coalescence of air bubbles is promoted further and a fully continuous air layer covering the wetted surface on a large scale is developed as shown in Fig. 1(Right) and reduction in the local frictional drag can reach more than 80% (Elbing et al., 2008; Ceccio, 2010a).

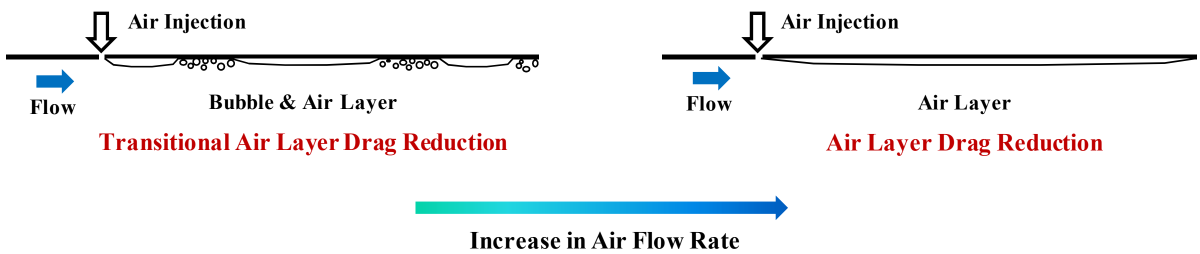

Fig. 1 Schematic figure of drag reduction with air layer, reproduced from Ceccio and Makihärju (2012).

GENERATION OF AIR LAYER UNDER A FLAT PLATE

Experiments with a flat plate were conducted in the large water tunnel. The experimental configuration is shown in the schematic drawing of Fig. 2. Air layers were generated on the lower surface of the flat plate horizontally mounted in the water tunnel to investigate the feasibility of air lubrication for reducing the frictional resistance of ships by injecting air on the bottom of the hull.

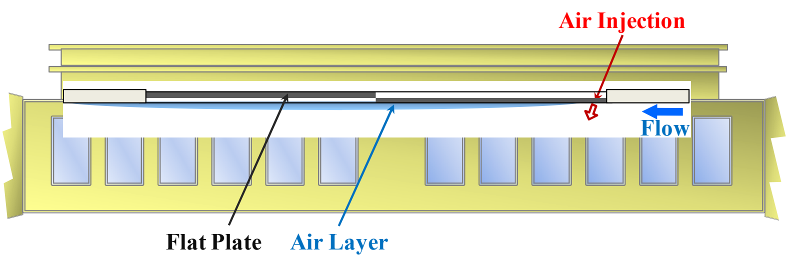

Fig. 2 Experimental configuration for generation of air layer under a flat plate in the water tunnel.