INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 1)
Available online at: www.ijariit.com

Drag reduction on vessels and study on its viability

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ABSTRACT

The most severe component in the resistance of a ship is the frictional one. As we know the source of this bare hull frictional resistance is the basic wave resistance and viscous resistance or drag. Drag as we know it is directly proportional to the area it acts upon. By reducing the frictional resistance through form optimization, and more viably and hence, more importantly, air lubrication, total resistance and so fuel costs can be decreased. Especially for existing ships, reduction of ship resistance by form optimization is difficult and not cost effective, but the application of air lubrication through injection methods like in the Mitsubishi air film injection study. Reducing the frictional resistance by air injection below the ship in combination with special coatings is an active area of research; anecdotally, performance gains are usually large. The paper gives an overview of some model scale and full-scale measurement results of ships. In this study, the air lubrication method is presented and the effect of air lubrication on resistance. The analyses are performed by a commercial code solving Navier-Stokes equations. The coefficient of frictional resistance of the ship is calculated as an equivalent flat plate of the ship's wetted surface.

Keywords— *Drag reduction, Micro-riblets, Hydrophobic paints*

1. INTRODUCTION

Since the time the optimization of vessels was considered seriously drag reduction has been under investigation to reduce fuel consumption and for low CO2 emissions on the ship. The drag force on a vessel is divided into the form drag and frictional drag.

There are many possibilities to reduce the form drag by means of form optimization procedure and for frictional drag, its reduction depends upon reduction of wetted surface area of the ship and the fluid flow around it. So, in order to trim down the wetted surface area air lubrication is founded to be one of the most promising methods.

Other methods like using hydrophobic paints and micro riblet attachments to ship's hull are also viable options. However, these are mostly considered for high-speed crafts rather than heavy displacement vessels.

Various projects are currently being executed with the objective of studying the effectiveness of these methods theoretically on empirical grounds by prototype testing. Krylova Shipbuilding Research Institute (KSRI) in Russia has studied the effectiveness of air cavity in the ship's hull. National Maritime Research Institute of Japan (NMRIJ) focused on microbubbles injection. There are other ways for drag reduction like using hydrophobic paints and anti-fouling paints. The main reasons for the hull to face drag is peeling away of paint, rusting, bio-fouling, the poor form of the hull, wave making hull forms, poor engine health, poor rudder and steering conditions and of course bad weather. This paper deals with the viability and retrofitting of these options onto operational vessels.

2. BACKGROUND

The frictional resistance is the dominant resistance component for low-Froude-number ships (vessels of heavy displacement e.g. tankers, bulk carriers etc.). Reducing this frictional resistance by air lubrication is attractive. The basic factor for this system to be viable is the fact that the power needed to compress air and inject it under the vessel should be less than the alleged power reduction due to the air lubrication. For heavy displacement ships, any reduction of the local skin friction leads to decreases of the resistance and commensurately fuel savings.

As the Froude number increases and the wave resistance become progressively larger, the effect of air lubrication on the total resistance expectedly decreases. The injection of air requires constant pumping power and if the ship sails too slowly it represents a significant part of the propulsive power. Therefore, air injection is expected to be suited for moderately fast ships with a target speed range of Froude numbers between 0.05 and 0.30.

The air lubrication method which dates back to the 1970s is still a promising research method. In this study, the numerical application of the air lubrication method on a chemical tanker is investigated. The analyses are made for different Froude numbers and air flow velocities for a flat plate in which area is equivalent to the wetted surface area of the ship using towing tank experiments.

3. MICRO-BUBBLE INJECTION

Micro-bubble injection basically involves isolating the contact surface of the vessel with a layer of constantly supplied bubbles.

Laboratory results of micro-bubble injection by Madavan et al. (1983) showed reductions of the frictional drag up to 80%. These micro-bubbles are very difficult to create on a shipping scale, especially since the ship sails in unpredictable sea conditions. As the bubble increases in size, so does its tendency to deform in the shear and turbulent fluctuations of the flow and it is no longer a spherical micro-bubble. Bubbles are on a millimetre scale for current ship applications; the term micro-bubble is no longer applicable.

Moriguchi & Kato (2002) used bubbles between 0.5 and 2.5 mm and reported up to a 40% decrease in drag.

Kawamura (2004), using bubbles from 0.3 to 1.3mm scale, found that larger bubbles persisted downstream longer and were more effective at reducing the resistance. As larger bubbles showed less dispersion this may have been an effect of concentration.

Fig. 1: A diagrammatic representation of the Mitsubishi air bubble injection system. The bubbles form a layer trailing behind till the stern increasing in size. Note that the bottom and sides are void of air lubricant here

Mini-bubbles affect the density and viscosity of the flow; viscosity actually increases for small amounts of air, but at high Reynolds number the turbulent stress is larger.

Kitagawa et al. (2005) found that bubbles deformed with a favourable orientation with respect to the flow, reducing turbulent stress as the flow field around the bubble is more isotropic, although other mechanisms have been proposed, such as compression or bubble splitting.

The experiments showed that the bubbles were pushed out of the boundary layer a few meters behind the air injectors, against the direction of buoyancy. A near bubble-free liquid layer was formed near the wall and the effect of air lubrication almost vanished. The experiments indicate that air lubrication will not persist over a long length of time scales.

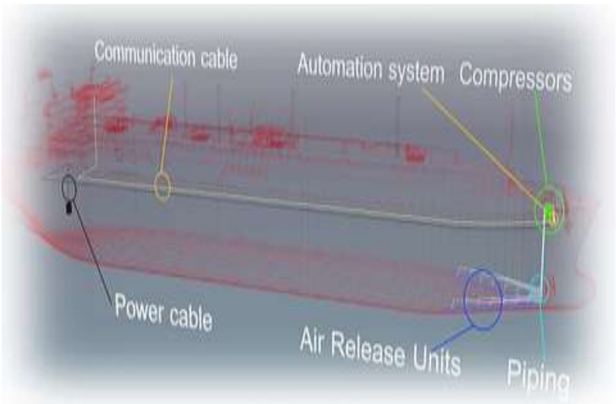

Fig. 2: The control system for air bubble injection from the bridge to the bow. The same system can be repeated at regular intervals with multiple sets of air release units. Note positioning of power cables and compressors

In order to be able to estimate skin friction reduction effect of micro bubbles when it is applied to a full-scale ship, it is necessary to carry out large scale experiments and find out how far in the downstream direction the skin friction reduction effect of micro bubbles persists after injection. It is seen that the skin friction reduction effect persists to the downstream end at both speeds of U=5m/sec and 7m/sec, which is a good sign for its application to a large ship. The skin friction reduction effect is smaller at the higher speed of 7m/sec, whose reason may be that injected bubbles diffuse from the solid wall faster at higher.

Fig. 3: This shows the air release unit on a test system. A mesh strainer attached to the nozzle, preventing marine growth can be operated in back flush, depending on differential pressures

At the same time experiments made in model scale on ships showed that a drag reduction up to 26% is possible on a seagoing vessel of proportional scale. If retrofitting on operational vessels is considered then if bubble lubrication is executed effectively, it requires only a small change to the hull compared to an air-cavity system. It requires injectors of specific bubble sizes to be welded into the underside of the hull plating. Each of them is connected to specific air bottles/tanks.

4. AIR FILM UNDER THE SHIP HULL

Injection of air into the turbulent boundary layer (between the stationary and moving water) can reduce the frictional resistance of the hull. A hull air lubrication system is a technique to reduce the frictional resistance between the ship's hull and the water using a sheet of air. Reducing a ship's resistances causes the required driveline power to be decreased. This reduction on the power cuts down on the fuel consumption of the ship and therefore also decreases the operational costs of the vessel.
In ideal situations, an air film system can achieve up to 15% in the reduction of CO_2 emissions.

Compressors are necessary to inject the air to the bottom of the ship's hull. The amount of air, the ship's geometry and the pressure needed are important factors that play a role in the cost of the hull air lubrication system.

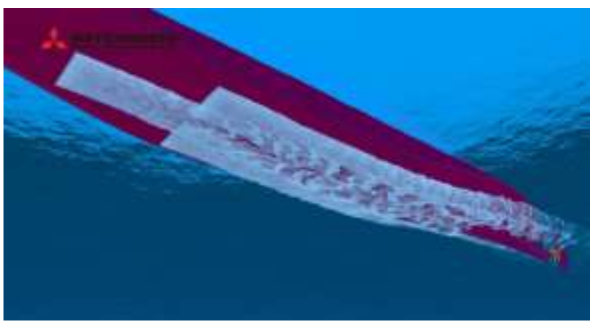

Fig. 4: This depicts the air film lubrication system by Mitsubishi heavy industries LTD. where a film is expelled out in a slit type air release system. Note turbulence induced in the later stages of the film stream

Ships with flat bottoms have an advantage over V-shaped bottoms since the air on a V-shaped bottom will flow away much more easily than a flat bottom. For a V-shaped bottom ship, it would require more air necessary to have the same effect as the flat bottom, increasing the demand for power.

With higher draughts, higher pressure created by the compressor is necessary and therefore requiring more power of the air injection system. To make an air injection system profitable, it is to be considered that the power of the air injection system should be considerably lower than savings in driveline power.

Projects such as Project Energy-saving air-Lubricated Ships (PELS) and the project Sustainable Methods for Optimal design and Operation of ships with air lubricated Hulls (SMOOTH) have researched the effects of air film lubrication. Project PELS researched air lubrication on a model scale and achieved a 3-10% net effective power reduction in calm waters. Project SMOOTH targeted a 15% reduction of the consumed energy by drag reduction by means of air lubrication techniques.

Now coming to retrofitting on operational vessels this would require more hull modifications than the air bubble injection method as powerful compressors are required to be fitted in mild recesses made for the same purpose.

For the majority of current ships sailing, the dominant part of the resistance is due to friction with the surrounding water. Addressing this part of a ship's resistance means to improve the ship's performance on top of what is achievable by "traditional" optimizations, such as shape optimization and minimizing the radiated waves. By reducing the friction improvements of the ship's efficiency of net up to 20% are deemed feasible. There is currently no other technique in naval architecture that can promise such savings. A promising technique to address the frictional resistance of a ship is insulating the ship from the water by actively providing an air-layer between ship and water to drastically reduce the resistance of ships and thereby reduce propulsive power, fuel consumption and CO2 production.

The wave making resistance and form drag can be reduced by optimizing the hull form, but the frictional drag remains proportional to the wetted surface. This is the research topic for the Dutch joint-research project PELS and the EU project SMOOTH, both of which have the goal of not only predicting energy savings using numerical models and model tests but proving it using full-scale demonstrator ships adapted for air film lubrication.

Although decreases in frictional resistance of nearly 20% have been obtained on model-scale ships, experience shows that the implementation of air lubrication can also easily increase the resistance of a ship thus resulting in a possible "breaking" effect.

5. AIR CAVITY SYSTEMS

The air cavity ship or ACS is a vessel with several recesses in its bottom that need to be filled with air. Of course, these cavities can only be fitted to a flat horizontal surface. For the length of the air cavity, no wetted surface is present whatsoever, leading to a local but effective drag reduction.

However, a standing wave is created in the air cavity and the fluid-air interface must re-attach smoothly at the end of the cavity. A simplified model of a two-dimensional cavity is given by Matveev (1999) and MARIN calculated the wave pattern in a barge with many air cavities with RAPID, a fully non-linearized potential flow code. Obtaining correlation with model experiments, however, proved to be less straight forward than expected.

The below method is performed by forming a continuous air layer between the hull and liquid. As the figure indicates drag reduction with the air injection method can be divided into three distinct regions. The first region is BDR (bubble drag reduction) zone, where drag reduction grows linearly with the gas injection rate. Another region is ALDR (air layer drag reduction), where a maximum level of drag reduction is achieved. A transition area is also located between these two regions, where drag reduction increases linearly with a higher trend than the BDR zone.

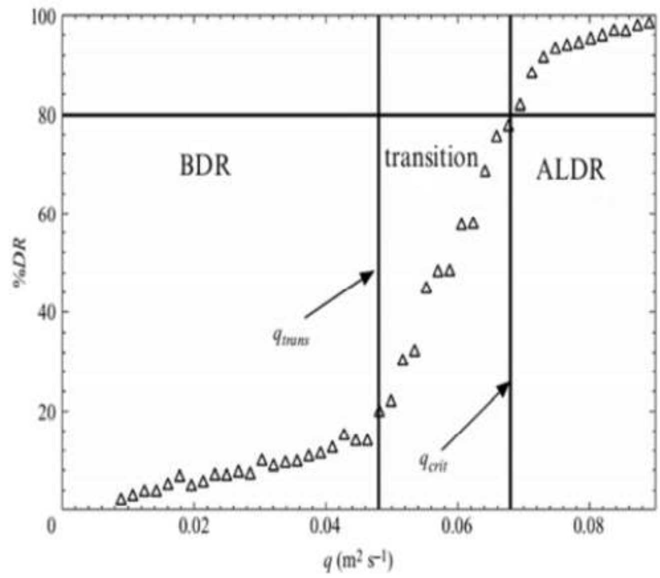

Fig. 5: Percentage of drag reduction(DR) versus volumetric gas injection rate per unit span(q)

Elbing et al. (2008) also found that the critical volumetric air flux to achieve ALDR is approximately proportional to the square of the free-stream speed. For a surface fully roughened, nearly 50% higher volumetric air flux is required to form a stable air layer at free-stream speeds up to 12.5m/s. It was also observed that ALDR is sensitive to inflow conditions.

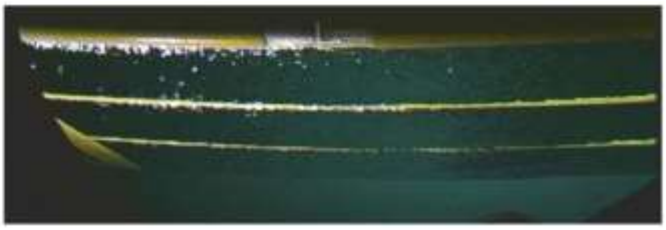

Fig. 6: Side-view of an ACS tested for smooth at SSPA, Sweden, with three large air cavities per section. Flow direction from left to right

The advantage in the aspects of the ACS is that the cavities can be flooded on the intention for increasing the drag on the ship acting as an emergency braking force during plausible collisions or accidents during manoeuvring.

The disadvantage in this system that it is not applicable to operational vessels without large hull form modifications. Also, the application of ACS during bad weather is still an aspect of research and development.

The retrofitting regarding the ACS is also another aspect for consideration as the costs involved during the construction of the vessel. The ACS system is particularly suitable for inland waters as developed by the Chinese river navigation research.

According to experiments with a computer design of bottom profile, on the model of the specific hull form which was enhanced during model tests in towing tank, it became possible to isolate from the water about 50% of the wetted surface. Results of towing tests of both models and their recalculation to full-scale ship with a displacement of 4000t show that within the range of speed 40 to 50 knots the application of artificial cavity should lead to a reduction of towing resistance about 15-24% or, correspondingly, an increase of ship speed about 3-7 knots. Within the range 50 to 60 knots resistance may be reduced on 20-27% or speed increase about 6-9 knots. Power consumption on air supply amounts not more than 2% of propulsion power.

6. MICRO RIBLETS ON SHIP'S HULL

One of the techniques is drag reduction of ships' hulls by imbuing their surfaces with hydrophobic properties This paper presents an alternative method of fabricating micro-riblets using laminate transfer molding to modify painting morphology for micro-riblet replication on ships' hulls.

The implementation of micro-riblets has been used widely in various applications, such as turbine blades, aircraft, and antifouling devices. Besides increasing speeds, drag reduction also reduces fuel consumption in the aviation and shipping industries.

In nature, micro-riblets are available on shark skin, and they make sharks able to move efficiently in the water. Many researchers have sought to replicate shark skin using various techniques. Liu and colleagues in 2012 successfully replicated micro-riblets on shark skin for drag-reducing applications. The pitch distance for shark skin is 100 μm, and the riblets' height is up to 50 μm.

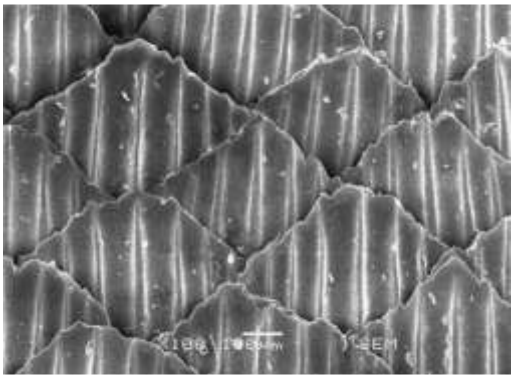

Fig. 7: A microscopic view of shark enlarged to a 100-micrometre scale. This texture is aiming to be replicated in a ship hull.

Currently, riblets are fabricated by using a rolling technique (Stille et al., 2014), and direct replication is done using photolithography. The technique was applied to shark skin and ahs model ship model, only on a specimen.

In the experiments, the riblet shapes on the models were fabricated by molds made of nylon wire and filled with silicon rubber and hardener was poured on top of the nylon pattern, and the silicon rubber was allowed to cure before being released from the pattern. A painting process was applied to the cavity of the micro-riblets structure on the silicon rubber. Then, a painted area was attached to the ship's hull. Commercial painting materials were used. After the paint material had cured, silicon rubber was released, resulting in a micro-riblets structure on the ship's hull. The micro-riblets structure covered 50 % of the ship's hull area, on the front side, as shown in figure below.

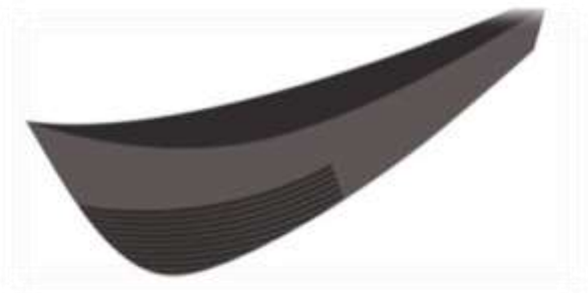

Fig. 8: Ship's hull area, on the front side

The speed test of the modified ship's hull painting was conducted by pulling under various powers. Further replications in a test using a painting technique showed low accuracy, especially with bigger riblet sizes. This may lead to the increasing aspect ratio of the wall structure of the silicon mold. Several gas traps were also produced during the replication since the process was not conducted under vacuum conditions.

Under similar propulsion force, the boat model with mico-riblets performed faster than the model without riblets. This effect increases with increasing propulsion power, as shown in figure. As shown in the figure, the use of micro-riblets increases the speed of the model by up to 40%. This value might be increased by decreasing riblet sizes closer to shark skin dimensions.

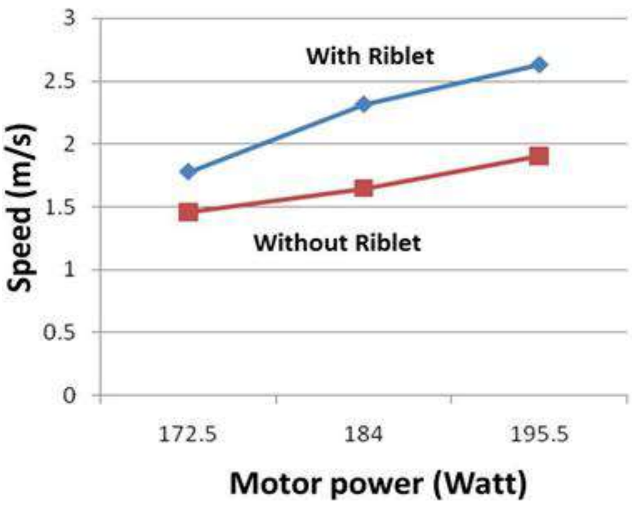

Fig. 9: Speed test

Speed tests show that a ship with micro riblets like the LTM-μR is up to 40% faster than one with a conventional surface paint texture. The effect of LTM-μR is more significant with higher propulsion power, as indicated by applying more power to the motor. The tests also verified that micro-riblets are suitable for high-speed ships or boats.

Retrofitting on operational vessels stands to be one of the deterrent factors of its adoption to shipbuilders and ship-owners. The fact that extensive use of molds is involved and silicon rubber components may be practically applicable in heavy weather conditions stands as a facet for more research. Nano-fibers shaped to form micro-riblets printed 3 dimensionally is a viable option if a mode of attachment to hull plating is found.

7. HYDROPHOBIC PAINTS

Superhydrophobic coatings have important applications in the maritime industry. They can yield heavy reduction in skin friction drag for ships' hulls, thus increasing fuel efficiency. Such a coating would allow ships to increase their speed and range while reducing fuel costs.

They can also reduce corrosion and prevent marine organisms from growing on a ship's hull thus also solving the problem of fouling. Japanese research has stressed on anti-fouling paints to be the key to reduction in the skin friction but this was seen to have a negative impact on the marine and aquatic life.

The coatings also make removal of salt deposits possible without using fresh water. Furthermore, super hydrophobic coatings have the ability to harvest other minerals from seawater brine with ease.

Super hydrophobic coatings rely on a delicate micro or nanostructure for their repellence—this structure is easily damaged by abrasion or cleaning; therefore, the coatings are most used on things such as electronic components, which are not prone to wear. Objects subject to constant friction like boat hulls would require constant re-application of such a coating to maintain a high degree of performance.

A super hydrophobic coating is a nanoscopic surface layer that repels water. Droplets hitting this kind of coating can fully rebound in the shape of column or pancake. Super hydrophobic coatings can be made from many different materials.

Fig. 10: The angle of contact of water on the surface is what determined the wetting of a surface. If a paint can increase the angle of contact to greater than 90° it can drastically reduce the wetted surface area of the hull.

The following are known possible bases for the coating:

- Manganese oxide polystyrene (MnO2/PS)
- Zinc oxide polystyrene (ZnO/PS) nano-composite
- Precipitated calcium carbonate
- Carbon nanotube structures

The molecular layer creates strong surface tension forces on the exterior of your exterior of the hull. Water and grime droplets will bead up and eventually roll off as the ship moves. This makes the hull have lesser wetted surface area.

The sol-gel materials that are used in hydrophobic coating form a mono-layer surface structure, which is slick thus allowing water and even ice to be effortlessly removed. The super-hydrophobic effect created by the coat will last even with continuous exposure to water and chemical cleaning agents. What's more, hydrophobic coatings can be applied to multiple locations.

The results of experiments were as expected with the hydrophobic coating providing a 20 less drag force on the model. This will surely increase the speed of the model and better economic rates. Thus, hydrophobic paints are a must for the upcoming future but with better ecological development.

8. CONCLUSION

We have seen extensively that the means of frictional resistance of a ship can be reduced in many ways, some more than the rest but each needs their own individual research and development. The intent of this presentation was to convey the viability of coupling the mentioned methods with each other. For example, microbubble injection is applicable to three-fourths of the ship excluding the forward bow part. If microbubble injection could be coupled with micro-riblets the forward half of the ship (i.e.) the bow part could also be resistance free even more if it could be a wave breaking hull form. The sides of the vessel that's immersed under the waterline could be coated with super hydrophobic paints.

Perhaps with increased awareness and more developed options of retrofitting drag reduction means could be brought into consideration. An optimist-realist thought process can show that as much as 65% of drag reduction can be achieved with just 2-5% of engine power consumption. This causes increased profits, lower carbon footprints and of course lesser SO_x, NO_x, DPM emissions as Jan 1st 2020 isn't very far away.

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9. ACKNOWLEDGEMENT

I would like to thank Ms M. S. Shruthi, B.E (CSE), from Indian Institute of Information Technology Sricity, Chittoor, Andhra Pradesh, India, for her advice and technical support on all technological aspects of the paper and its publishing.

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