SCHEEPVAART EN TRANSPORT COLLEGE

HOGESCHOOL VOOR DE ZEEVAART ROTTERDAM

Final report Project 2

Air Lubrication

STC - Group
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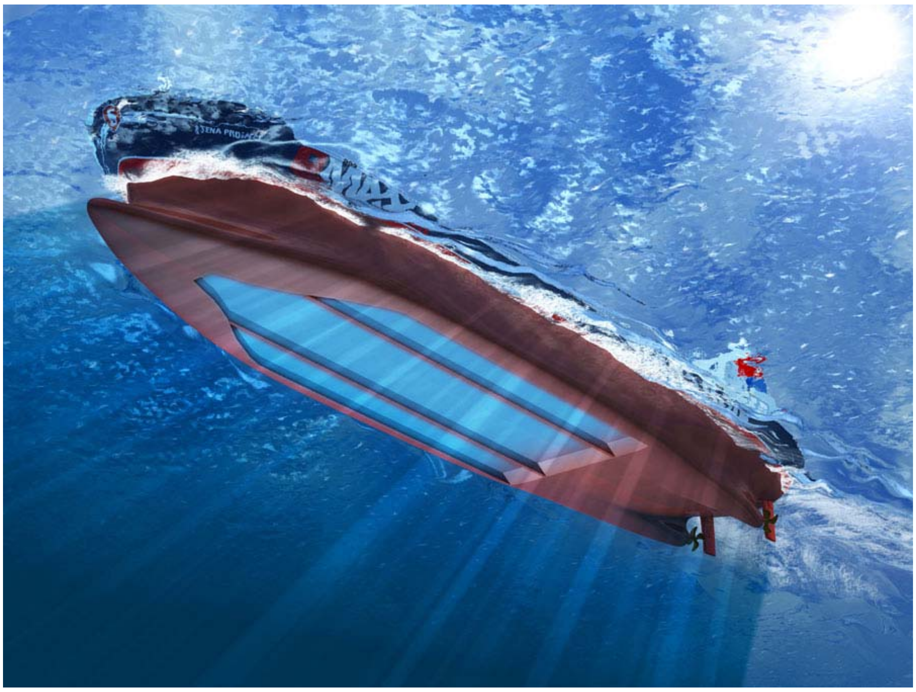

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[1] Preface

Speed is a key factor in shipping. When a ship is designed, one of the things to be looked at is how fast it needs to go in order to transport the cargo or passengers as profitably as possible. For example in container shipping, speed is very important because of the rapid depreciation of the goods after they have been produced.

Also in passenger transport, speed is important. People don't go on a ferry because they want to enjoy the sailing. And in cruising, cruise ships will manoeuvre a lot and sail at slow speeds but occasionally they sprint to get to their next port of call in time.

Achieving speed is not the biggest problem anymore. Nowadays, a bigger issue is the amount of power we use and so the amount of fuel we burn, to achieve this speed. Drag resistance is an important factor when it comes to power needed to propel a ship. Reducing drag resistance means reduction of power necessary and so reduction of fuel consumption, which leads to higher profit margins and a cleaner environment.

One of the solutions that has been thought of is air lubrication. Air lubrication means creating a layer of air around the hull of the ship to reduce the drag resistance. In this project, we will investigate the possibilities of air lubrication in general but particularly for application on seagoing vessels. Put more simply, we will try to find out if air lubrication will work on sea going vessels.

This report contains the explanation and answers to the main question and sub questions regarding air lubrication.

[2] The project

Theme
The general theme of this project is ‘speed’. Every group participating in this project will have a subject that is related to speed. In this case speed refers to sailing speed.

Disciplines
Each group has been assigned a discipline in which the subject of their research has to fit. These disciplines are as follows:
- Propulsion and Auxiliary Systems
- Automation
- Electrical Engineering

This projects discipline is Propulsion and Auxiliary systems.

Problem definition
When shipping goods or passengers, power is needed for propulsion of the ship. When an engine delivers a certain amount of power, the speed of the ship is determined by numerous factors. For example: weight of the ship and her cargo, shape of the hull and wind. One big factor is the drag resistance of the hull of the ship. In the past years, great effort is has been put in to research projects trying to discover what will reduce drag resistance.

A reduced drag resistance will generally lead to more speed, using the same amount of fuel. It needs no explanation that ship-owners will find a reduction in drag resistance interesting. If a ship can sail faster without using more power, it can sail slower using less power, which will lead to using less fuel.

This project will concentrate on Air Lubrication, a method of reducing drag resistance. Very briefly, air lubrication means creating a layer of air or bubbles around the hull or a part of the hull. When sailing, this layer will reduce the drag resistance of the hull.

Main Question
How can air lubrication improve efficiency in sea transport?

Sub questions
To answer the main question, the following sub questions will be answered:
- How can air lubrication reduce drag resistance?
- What complications can be expected with the propeller involving air lubrication?
- How does air lubrication influence maneuverability?
- How does air lubrication influence stability?
- What influence does sea state have on air lubrication?
- How can air lubrication systems be fitted on existing ships?
- What type of air lubrication systems already exist?
- What are the technical demands of an air lubrication system?

[3] The research

Air Lubrication

As explained in the preface, the drag resistance of a ship is an important factor when it comes to determining the efficiency of the ship. The aim of air lubrication is to reduce this friction.

The drag resistance of the hull can be split up into two main parts. One being frictional or viscous drag and the other being pressure drag. A brief explanation of these two sorts of resistance will now follow.

Pressure drag is the drag that is created by a flow field around the hull. In this flow field, water particles show eddying motions, which in this case means that the particles flow around the hull with different velocities. These eddying motions cause resistance and are created by the passage of the hull itself. When a ship has a large block coefficient it will cause a lot of these eddying motions and thus a lot of pressure resistance. (www.seminarprojects.com)

Viscous drag is the resistance that is caused by the creation of a boundary layer. This boundary layer consists of water particles clinging to the hull. These water particles are dragged around by the ship. A part of this resistance can be seen when we look at the stern of the ship. Sometimes it is visible that a bit of water stays with the ship and is only slowly refreshed. It needs no explanation that dragging around water uses extra energy and is therefore extra resistance. When a ship is streamlined or has a low block coefficient, the greater part of the resistance is caused by viscous drag.

Pressure drag is mainly caused by the hull form. Air lubrication aims to reduce the frictional or viscous resistance of the ship. By inserting air in the boundary layer of the flow around the hull, contact between water particles and the hull is being avoided. When there is less or no more contact, the clinging of water particles on to the hull is being avoided. In this way, a lot of resistance is avoided. As mentioned above, the shape of the hull influences the ratio of pressure versus frictional drag, but on average in shipping, the frictional or viscous resistance takes up 80% of the total drag resistance. (Saeed Seif & Taghi Tavako, 2004)

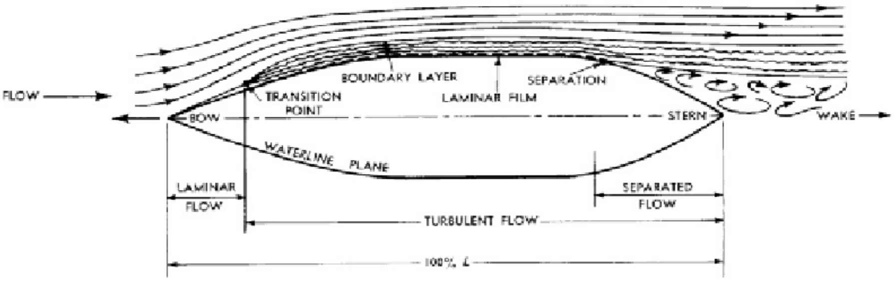

Figure 2 Boundary layer, viscous and pressure drag

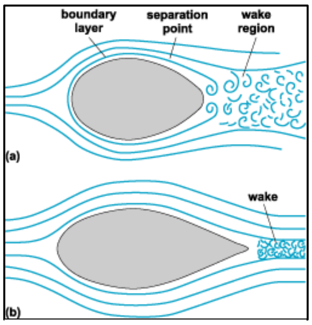

Figure 1 Eddying motions and boundary layer

This air lubrication to reduce the frictional resistance is possible in three methods.

- By creating a layer of small bubbles under the ship.
- By creating one more compartments under the ship which can be filled with air.
- By creating a thin layer of air by water repellent paint.

Method 1: Air bubble layer

Layers of small bubbles are created in the forward section of the ship and have to be directed in such a way that it flows under the ship. This will reduce the drag resistance. Various experiments have been undertaken such as by Moriguchi and Kato (2002). This experiments, which have been done with a model, has shown that reductions of up to 20% can be realized. These experiments had a lot of factors encountered within, such as the effect of the bubble diameter. There have to be some additional auxiliaries and modifications to produce air pressure to create and maintain the layer of air bubbles. The power needed for these, is included in the 20% reduction.

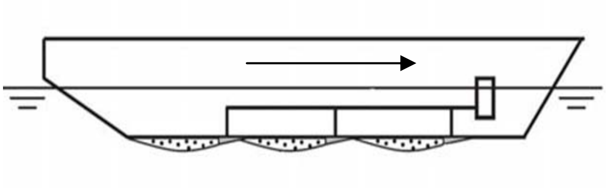

Figure 3 Air lubrication, bubble layer type

Method 2: Air Cavity

The chambers that are created under the ship will be filled with a constant flow of air. This will reduce a certain amount of the body of the ship that will make contact with water, the so called “wetted surface”. What follows is a reduction of drag resistance. This method is called “Air cavity chamber lubrication”. This type of air lubrication is preferably used on ships that have a large flat area as a bottom. This makes it possible to install large air cavities.

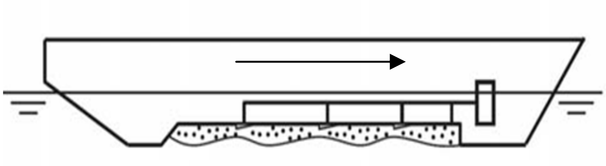

Figure 4 Air lubrication, air cavity type

Method 3: Water repellent paint

The third method is not in fact air lubrication. As described above, the boundary layer is formed by water that is dragged around by the ship. The aim of this method is to prevent the boundary layer from being formed. This could be used as an additional feature for the methods mentioned above.

Figure 5 Section of the Emax-Air vessel of Stena Bulk

Air lubrication and the propeller

The aim of using air lubrication on ships is to reduce the viscous drag resistance of the wetted surface of the ship. To ensure that the efficiency that is gained by using air lubrication is translated in to decreasing fuel consumption or increasing sailing speed, we have to make sure that other aspects of the ships remain unchanged. One of these aspects is the performance of the propeller. The ship uses a propeller to make way through the water. It works by converting the rotation of the engine into horizontal thrust similar to a fan and air. The blades push the water backwards creating acceleration, and therefore a difference in pressure between the forward and rear surface adding to the movement. Years of development have found that the propeller is most efficient when it has a large and uninterrupted flow of water coming to the propeller. For example, conventional propellers are mounted on a shaft. This shaft interrupts the water flow to the propeller. A new development, the azipod makes it possible to mount a propeller in front of the pod, which consists of an outboard electric engine. In this way the propeller has direct access to the water without interruptions. That illustrates the reason for this sub question. It shows that it is important for the propeller to have uninterrupted access to water. An important question therefore is what will happen to this access when air bubbles are injected in the water? Another problem that might occur is cavitation.

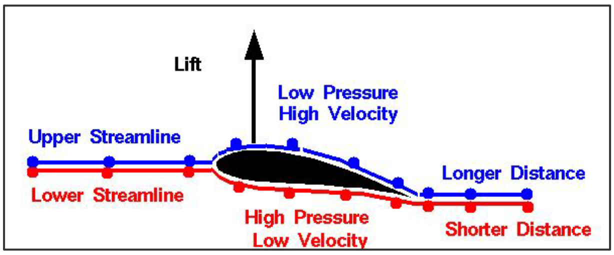

Figure 6 Physics of the propeller blade creating lift

What is cavitation?

Cavitation occurs when in a fluid the hydrostatic pressure becomes very low. In this case it is due to a fast rotating propeller. When speaking of cavitiation, the propeller has two sides, the front which is meant for suction, and the rear where the actual propulsion takes place. On the suction side of the propeller the pressure becomes very low. As a result of the low pressure, the boiling point is reached and vapour bubbles are formed. When later on, these bubbles arrive in the high pressure environment, the bubbles implode. A very powerful shockwave (jet in the picture) is the result. This shockwave is accompanied by high temperature and pressure. This can cause a lot of damage on to the surface of the propeller blade. Although this cavitation occurs when bubbles of vapour are created from the fluid in which the propeller is rotating, it could still be a problem since air is a vapour, or a mixture of vapours.

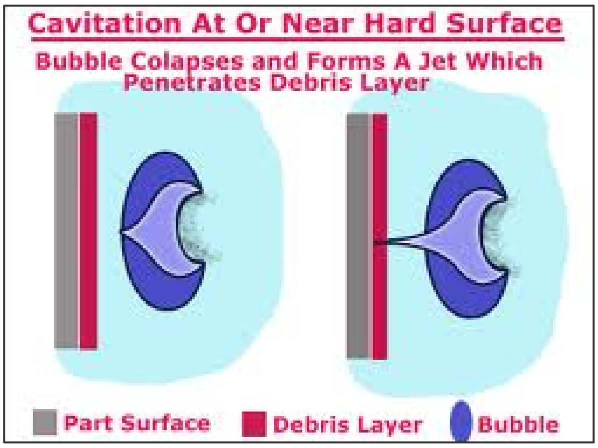

Figure 7 Cavitation

When addressing this problem, the following can be said. It is not to be expected that a layer of air bubbles (or air escaped from the air cavity in the hull of the ship) will follow the curvature on the aft section of the ship. The bubble layer will leave the surface of the hull instead of sticking to it. In this way the air bubbles will not reach the propeller.
This is supported by the following. In their research, Foeth ao. (2009) conclude by saying, amongst other things, that no appreciable effect was found on the propulsion.

Field research
In our field research ir. Johan de Jong at Marin has been contacted. The reason for this contact was that there were still a few questions after the completion of our desk research. One of those things had to do with our concern about the cavitation that might occur when air bubbles would exist in the water which the propeller rotates in.

The following questions were asked: is there any risk of cavitation occurring on the propeller when air bubbles would appear in the water near that propeller.

The conversation was in Dutch and can be found in the appendix. An interpretation of his answer will now be given.

Figure 8 Cavitation occurring on the propeller under water

Cavitation that results in erosion is definitely relevant, but is mostly seen as a problem that lies outside the boundaries of research to whether air lubrication works or not. In other words, this is a problem to be solved later, first we will focus on the principles and workings of air lubrication. And if cavitation occurs, that will not be directly be caused by the air bubbles since cavitation is the following. Water will boil and transform in to vapor because of local extremely low pressures. When the pressure rises again (when pushed away by the propeller) the vapor bubble collapses (condensates) and causes a shock wave. So cavitation would only indirectly be the result of air bubbles in the water around the propeller. This would occur in the following manner. The propeller rotates in a mixture of air bubbles and water. This mixture has a lower density than water. Now the propeller starts rotating faster because of less power needed to rotate in lower density. Because of this, less water will pass the propeller per rotation. This leads to higher forces and stress in the areas where there is water. Of course, this could lead to cavitation but that depends on how far the propeller operates from the cavitation limits.

Now there is also a positive side on the air bubbles existing in that area. The bubbles will be concentrated in a thin layer that passes just above the propeller. This layer will act as a protective layer against shockwaves. So when cavitation now occurs (for another reason), this layer will reduce the effect of the shockwaves on the hull of the ship.

In conclusion to this part of the conversation, it can be said that if cavitation is a problem, this will be tackled later on, after air lubrication itself has been further developed. So to answer our sub question, it is unsure whether complications may occur. It might be the case that cavitation occurs, but only indirectly and not directly because of the presence of air bubbles around the propeller.

Technical aspects

This chapter will discuss the technical aspects of air lubrication on board sea going vessels. To get to a final report about these technical aspects the following questions will be answered:

- What are the technical demands of an air lubrication system?
- How can air lubrication systems be fitted on existing ships?

When thinking about the technical demands on air lubrication systems one could think about:

- Smoothness of the hull
- Systems to produce and transport air pressure

In the following paragraphs the demands mentioned above will be discussed.

Smoothness of the hull

As discussed earlier, air lubrication is meant to solve a part of the viscous drag. This drag is caused by a boundary layer of water particles dragged around by the ship. The rougher the surface of the ships hull, the more water is dragged around and the bigger the boundary layer becomes. When the boundary layer consists of more water, more air is needed to avoid high frictional drag. This means that vessels with air lubrication should have a smooth hull with no marine growth, this can be achieved by docking more often. But since this is expensive another alternative should be considered, which is called a self polishing coating (SPC). This paint consists of multiple layers. By the speed of the vessel, the paint will polish slowly by wearing of. Because of this mechanism, marine growth has no chance to settle on the hull of the vessel.

Shape of the hull

Air lubrication sometimes demands modifications to be made to the regular shape of the hull. For these demands, see the section on methods of air lubrication.

Power needed to produce air pressure

Power is necessary to produce air pressure for the lubrication of the hull. The amount of power necessary should be deducted from the gains that are made through the air lubrication to get to the total gain in efficiency. According to Wärtsilä, fuel saving on board conventional sea going vessels, by air lubrication, is in the range of 3,5 - 15%, while some studies say even more is possible. (Wärtsilä, 2009)

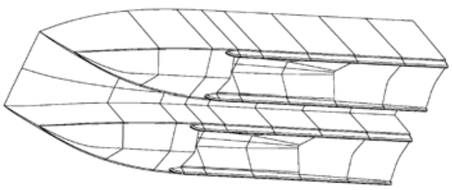

Figure 9 Hull of the air lubrication catamaran model

The flow of air necessary for seagoing vessels is unclear, but a good indication might be the following: A model experiment with a catamaran (2.3 m, scale 1:12) in Langley shows a flow of 1.13 m^3/min. The use of air lubrication on this catamaran shows a drag reduction of 5 - 8%. (Latorre ao. 2003)

The pressure necessary should at least exceed the hydrostatic pressure that is a result of the depth of the air outlets.

Another article claims that during a full scale test with the amount of power needed for the air lubrication system was 3% of the propulsion power. (Saeed Seif & Taghi Tavako, 2004)

Figure 10 Air-compressor on board a vessel

Systems to produce and transport air pressure
When air lubrication is wanted on board a ship, a system to produce air pressure and to transport the air should be fitted. Also a way of injecting the air through the ships hull needs a system.

The first system could consist of a compressor and piping to transport the air. The injection of air through the hull of a ship should take place in a safe manner. Think about water coming in to the ship when no air pressure is available, this could occur when the vessel is in the harbor and the system is shut of. Another event that might occur is that, due to poor maintenance, a pipe brakes. For example, a none-return valve could be installed to insure that a flow can go only from one side to another, and not the other way. This is to be seen in the drawing at the end of this section. When using none-return valves, attention must be paid to the maintenance of these valves because of none-return valve corrosion possibly occurring.

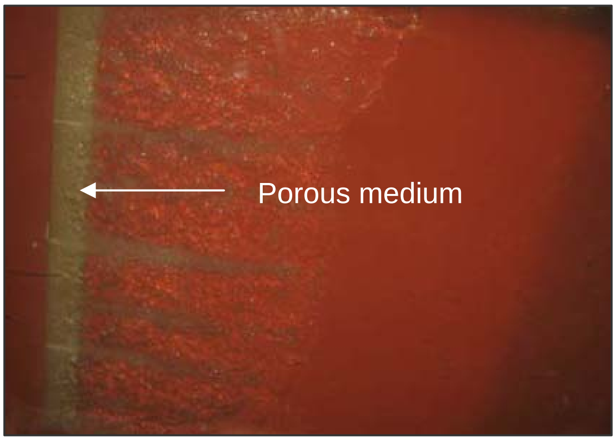

Figure 11 Air bubble layer lubrication

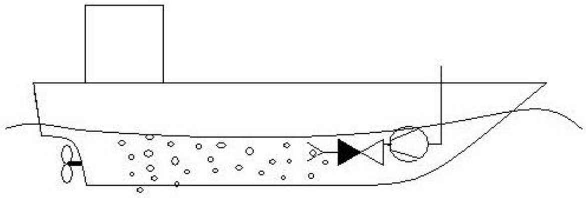
Figure 12 Schematic drawing of an air lubrication system with a compressor and a non return valve

When applying air lubrication by air bubbles, a porous medium is fitted into chambers along the hull of a ship. This porous medium consists of small holes of certain size the size of the holes determines the size of the air bubbles.

Existing ships
In the article that can be found on www.economist.com/node/17647555, it is said that a retrofit system is now on sale. This means that a regular containership can have an air lubrication system of the air cavity type built in during the regular dry-dock period.

So even for existing ships it might be possible to profitably apply air lubrication.

Air lubrication and manoeuvrability

In this section we will investigate whether or not air lubrication will affect the manoeuvrability. This sub question was included because the concern exists that a layer of bubbles would have some kind of influence on the way the ship behaves when manoeuvring.

The two types of air lubrication of which there is a concern about the manoeuvrability, are the air cavity type and the air bubble type.

Seeing the research that has been done already it is to be expected that it will not affect the manoeuvrability as the air cavities will be placed symmetrically around the ship and therefore it will not propel the ship in any direction. There might even be an advantage in manoeuvring for air cavity ships by means of slowing down the ship. When a ship needs to slow down it could shut down the compressors of the air lubrication. This will create a lot of extra drag resistance because of the empty air cavities.

More research has been done on air bubble lubrication. Tests show that bubble lubrication does not affect manoeuvrability. In their research, Foeth and others. (2009) state that: ‘Zig-zag’ tests and combined turning circle/pull-out tests showed small differences in the results. Most of these differences were erratic and fall within the confidence interval of manoeuvring tests’ .This indicates that small influences have been measured but that they are not large enough to speak of a significant change in manoeuvrability. Furthermore Foeth ao.(2009) state: ‘No appreciable effects of air bubble lubrication were found during the resistance and propulsion tests at either model or full scale and no significant effects of air bubble lubrication on manoeuvring and sea keeping model tests could be determined.’

Another project, that of the Istanbul technical university comes up with the following conclusion about manoeuvrability :
‘’When drag becomes subject of active and locally adjustable air supply, this could be exploited in terms of improved manoeuvrability and, in this way, safety.’’ (Istanbul technical university, 2010) Put in a different way. The air lubrication can be used in improving the manoeuvring characteristics of a ship. Therefore it is necessary to be able to control the air lubrication in different sections of the ship individually. In this way it becomes possible to adjust the drag resistance of different sections of the ship and with that adjust the manoeuvring characteristics of the ship. It must be said that this probably needs a lot of extra research and a comprehensive system to control and monitor the air lubrication system.

The conclusion that can be made is that air lubrication will not affect the manoeuvrability in a negative way.

Sea state and air lubrication

In terms of behaviour in sea state one has to think of stability as well. During the "Project Energiebesparende Luchtgesmeerde Schepen (PELS)" (Goldan 2005) a team of investigators (The project was carried out by a consortium consisting of shipbuilding enterprises) studied on the influence of waves when using air lubrication. Some different situations have been tested by using a 6m model.

This summarizes their conclusion:
Air lubrication, when using the air chamber-type, has a positive influence on course stability.
Air lubrication, in general, has a small influence on ships motion and behaviour in waves. The PELS team (Thill ao. 2005) found that the air bubble lubrication does not have a significant effect on the rolling and heaving behavior of the ship. But when speaking of air cavity ships that encounter beam waves (waves that hit the ship in a ninety degree angle on the fore and aft-line) they measured more roll. So when designing an air cavity ship, this should be taken into account.

The stream formed by the bubbles appears to be stable, even when in heavy swell.
Air chambers appear to be more sensitive in waves and ship movements. Under specific circumstances (speed and course), the air has a good chance to escape. A solution can be found by an additional amount of air into the chambers.
Nevertheless it appears that reduction of power (or in other words reduction of friction) is still achievable. At lower speeds the reduction of friction is negligible.

Figure 13 Model in the Marin air lubrication project

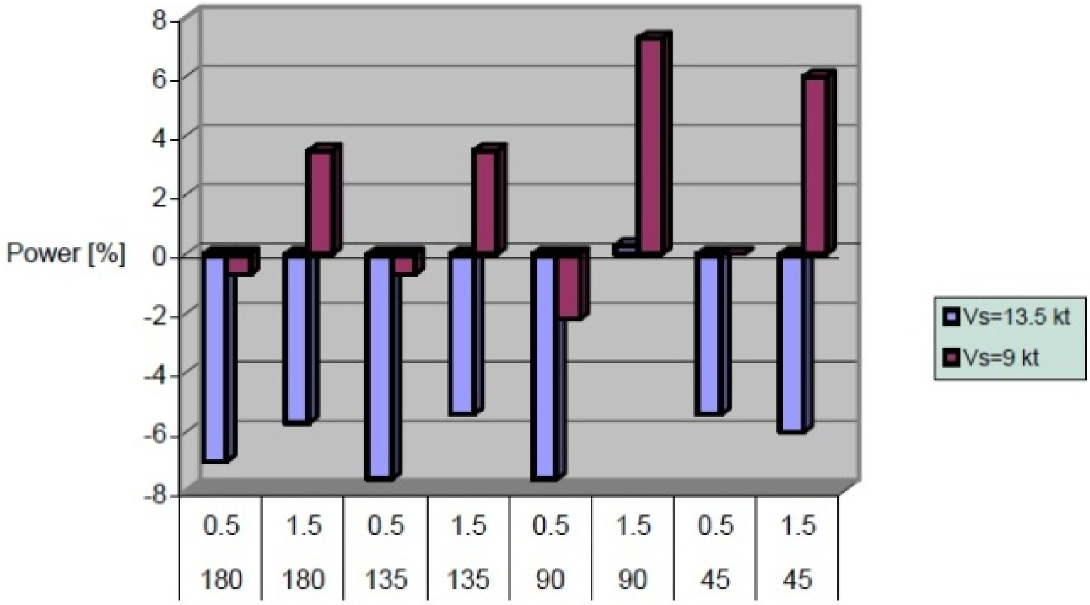

Figure 14 Wave height and direction

This figure shows results of effective power reduction (%) in waves. Interesting are the results of the speed of 9 knots compared to the speed of 13,5 knots. See also the result when waves approach in a 90 degree angle.

In terms of stability, the next figure shows the ships heaving motions. The test shows negligible results. Heaving motions are quite the same with or without using the bubbles of air.

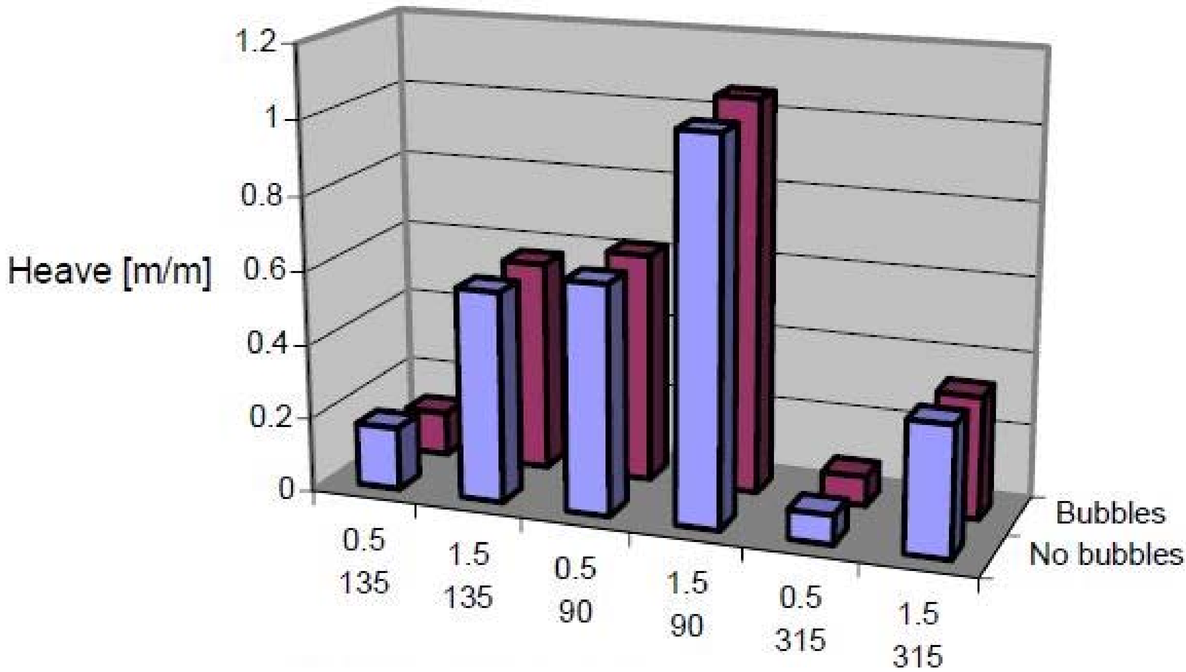

Figure 15 Heave reaction due to wave height and heading

[4] Conclusion & Recommendations

The aim of this conclusion is to answer our main question: how can air lubrication improve efficiency in sea transport?

Several reports indicate that air lubrication does indeed reduce drag resistance of surfaces that move through water. This is the result of a smaller boundary layer because of an air layer existing around the hull. So by introducing a layer of air, whether this is by air bubbles or air cavities, the resistance of the surface is reduced.

The question remains whether this can be used to improve the efficiency in sea transport. There are a few different problems that can arise when putting the air lubrication principle in to practice on sea-going ships. Research has been done into the following problems: influence of sea state on the air layer, changes in stability, changes in maneuvering characteristics, propeller efficiency and the technical demands of the system.

Most of the sources indicate that there is no significant change in stability and maneuvering characteristics. In case of air cavity ships, it might even be possible to influence the maneuvering characteristics to the operator's demands.

Also the influence of the sea state on the air layer seems not to be a big problem. The technical demands aren't very complicated except for the fact that this applies to new-build ships. Even for existing ships it might be possible to apply air lubrication. The DK Group of Rotterdam has announced that they have released an option to retro-fit air cavity type lubrication. (www.economist.com)

There are still a few doubts about the influence of the air lubrication system on the propeller efficiency. The air will probably not follow the curvature of the ship aft and therefore will not end up on the suction side of the propeller where it would affect the propeller efficiency.

Over the past years, a lot of research projects were undertaken and after overcoming the first problems, it seems much clearer now that air lubrication does indeed show positive efficiency gains. An overview of some of the promising results is given in this article: www.economist.com/node/17647555

In the conversation we had by e-mail with ir. J.H. de Jong of Marin, we asked him about the gains that could be made on efficiency. He replied that efficiency is a complicated concept that needs further defining before use. But he also said that the reduction of engine power when sailing on the same speed would be up to 12-15%. This includes the power that is needed for the extra auxiliaries that would be needed to maintain the air lubrication. These results where measured on inland barges in full scale tests.

To conclude, it can be said that air lubrication is a promising technique. However, the technique has not been developed to full perfection.

Projects going on involving air lubrication are:
Stena Bulk, they have a 15 meter model in the Emax-air project and they have a design for LNG-tanker which incorporates kite technology, optimized hull shape and air lubrication to save about 7 metric tones of fuel per day.
Damen Shipyards is involved in the PELS project which is actively engaged in air lubrication research

The Till Deymann has stopped using their air lubrication system. The ship is still active but not using air lubrication anymore. In a conversation with ship-owner Deymann it became clear that the system did not work. There was no satisfactory answer to the question why it does not work. It is possible that this system was not developed to complete perfection because it is a relatively early design compared to the projects that are now active.

Recommendations

After this conclusion, we recommend that more research has to be done on the following aspects of this technique:
Positioning of the system and cavities.
Shape of the hull.

Also, thought should be spent on the most efficient way to distribute the air layer.
But most of all, air lubrication should not be thrown in the bin but should be considered as a good addition to the techniques that will help bring down fuel consumption and emissions.

Figure 16 A picture of the Till Deymann, a semi-twinhull bow type ship with air lubrication

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[6] Appendix

Conversation by e-mail with ir. J.H. de Jong at Marin

2011/2/4 Jong, Johan H. de <J.H.de.Jong@marin.nl>
Beste Witzier,

Wij willen jullie interesse in deze materie aanmoedigen maar adviseren jullie eerst kennis te nemen van de bestaande literatuur en deze zorgvuldig te bestuderen. Indien daarna gerichte vragen bestaan willen we die pogen te beantwoorden. Helaas ontbreekt ons de tijd om jullie in deze fase te helpen.

met groeten

Johan H. de Jong

2011/2/14 Rieks Witzier <riekswitzier@gmail.com>
Geachte heer De Jong,
Na bestudering van de bestaande literatuur blijven nog een aantal vragen bestaan. Wij hopen dat u ons daar antwoord op kunt en wilt geven.

Allereerst valt het ons op dat in de literatuur, voorzover voor ons beschikbaar, nergens stil wordt gestaan bij het verschijnsel van cavitatie waardoor de schroef sterk beschadigd raakt. Kunt u ons vertellen of er geen gevaar bestaat dat door de aanwezigheid van lucht in het aangevoerde water naar de schroef cavitatie ontstaat?

Een tweede vraag strekt zich tot het rendement van air lubrication. In de literatuur worden zeer uiteenlopende uitspraken gedaan over het te behalen rendement. In welke orde van grootte moeten we denken als het gaat om de besparingen dan wel rendementen die te behalen zijn met air lubrication.

Vriendelijke groeten,

Rieks Witzier (e.a.)

2011-2-14 Jong, Johan H. de <J.H.de.Jong@marin.nl>
Beste Rieks,

Goede vragen!

1. Cavitatie die inderdaad mogelijk erosie kan veroorzaken op de schroef is zeker relevant, maar wordt terecht vaak gezien als een randvoorwaarde probleem (lossen we later op!) Echter cavitatie is in eerste instantie een koken van het water door een sterke lokale verlaging van de druk bv tgv een (te) grote belasting op de schroef (je wilt het water te snel vooruit duwen/accelereren). Er ontstaat dan een waterdamp bel (geen lucht dus). Pas als deze bel weer condenseert/collapsed kan er schade ontstaan. Ofwel zelfs als er lucht door de schroef heen zou gaan zou het effect indirect zijn en wel als volgt:
·De schroef ‘voelt’ luchtbellen en gaat daardoor harder draaien omdat de water massa die door de schroefschijf heengaat kleiner wordt, lokaal kan dat op de plaatsen waar nog wel water is tot een grotere belasting aanleiding geven (tenslotte wordt het water sneller weggeduwd om dat de schroef harder draait), die dan mogelijk tot cavitatie leidt. Of dat gebeurd hangt af van hoever je van de cavitatiegrens afzit.

·Echter het goede nieuws is dat de meeste lucht in een dunne laag boven de schroef langs gaat en daar zelfs voor een dempende laag zorgt die als er cavitatie is (om een andere reden) deze laag het effect daarvan op de huid (drukfluctuaties) dempt.

2. De besparingen op het motorvermogen (bij dezelfde vaarsnelheid) lijkt voor binnenvaartschepen op ongeveer 12-15% uit te komen, indien men kiest voor de luchtkamers oplossing. De andere oplossingen lijken veel minder op te leveren. Deze getallen zijn op ware grootte gemeten. De verwachting is dat dit nog iets beter kan worden indien het ontwerp van de luchtkamer configuratie verder is verbeterd.
Indien je hier wilt spreken over rendement dan moet je dat eerst goed definiëren. In bovenstaande 12-15% is inbegrepen het vermogen dat je kwijt bent aan het luchtpompen.

Succes met het werk.

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