

TITLE: AIR LUBRICATION SYSTEM FOR A SHIP HULL

FIELD OF THE INVENTION

The present invention relates to a displacement vessel comprising a hull with a design draught that increases from the bow to the stern and with air outlets arranged in a bottom surface of the hull.

BACKGROUND ART

With increasing energy prices and accelerating climate change, there is a growing demand for energy efficient solutions in the maritime sector. Reducing the energy required to power the worlds fleet of displacement ships will be crucial in order to mitigate the use of fossil fuels and introduce greener fuel alternatives.

One initiative is the use of air lubrication systems. These known systems and methods allow for a reduction in the resistance between the ship's hull and water by trapping a layer of air beneath the ship's hull. There are different types of air lubrication technologies, ranging between systems where bubbles are freely released beneath the ship hull, to system where the hull is formed with a cavity in order to trap a pocket of air beneath the hull. For larger displacement ships, the bubble solution is perceived as the most relevant technology.

Typically for air lubrication systems using bubble technology, an air blower or a dedicated system is used to generate air bubbles to pass them continuously beneath the ship's surface. Air bubbles are released at different locations along the bottom of the hull, often symmetrically on both sides of the ship's centre line. The air bubble distribution across the hull surface reduces the drag and resistance working on the ship's hull, creating energy-saving effects. The air lubrication system continuously replenishes the lost air bubbles to ensure that a uniform layer of air bubbles is maintained beneath the ship and the desired effect is produced.

An air lubrication system using bubble technology is expected to achieve up to 5-15% reduction of CO₂ emissions, along with significant savings of fuel.

Even though air lubrication systems using bubble technology are promising, there are some concerns regarding its implementation and performance on ships including:

- Air escaping to the side of hull and aft of the hull, thereby reducing the effect of friction minimisation.

- The compressor energy consumption for continues pumping of air, thereby reducing the saving on fuel.
- Air entering into the propeller and the potential reduction of power, thereby reducing the saving on fuel, and increase in noise and vibration related to the interference of air on the propeller.

Different forms of hull design have been proposed in the prior art to avoid these problems, some by guiding the flow of bubbles such that they remain beneath the hull and others that attempt to avoid the suction of bubbles into the propellers. As will be understood, the trapping of air in a cavity beneath a ship's hull may potentially work counterproductively to avoiding air bubbles entering into the propellers path.

To trap the layer of bubbles beneath the ship's hull is a challenging task. The known solutions using cavities or special hull designs to trap air bubbles beneath the hull create substantial increases in the building cost for a ship. Furthermore, there are concerns related to the handling and stability of ships having such cavities at sea.

The present invention aims to overcome one or more of the aforementioned challenges and deficiencies of the prior art solutions with a new and inventive hull for a displacement ship with an air lubrication system and method for controlling such a system.

SUMMARY OF THE INVENTION

The present invention relates to a displacement vessel, comprising:

- a hull where the design draught of the hull increases from the bow to the stern of the hull,

- air outlets arranged in a bottom surface of the hull,

wherein the air outlets are in fluid communication with one or more compressors and are configured to release air bubbles on the bottom surface of the hull, wherein the vessel further comprises:

- at least two bubble guiding surfaces, arranged symmetrically on opposing sides of a centre line of the hull on the bottom surface of the hull and extending along a

portion of the length of the hull,

wherein the bubble guiding surfaces are protruding away from the bottom surface of the hull,

wherein the bubble guiding surfaces and the air outlets define an air bubble distribution region on the bottom surface of the hull.

The present invention thus solves at least some of the aforementioned problems of the prior art by more effectively trapping air beneath the hull of the vessel and thereby decreasing the friction on the hull. The combined effect of an inclined hull

pressing the released air towards the hull together with the bubble guiding surfaces enclosing the air beneath the hull ensures that air is trapped beneath the hull for longer periods of time in comparison to the prior art.

5 According to the invention, the bubble guiding surfaces may be arranged in such a manner that they are differentiated from bilge keels or other submerged surfaces that may protrude from the hull. Bilge keels are known in the art and provide roll damping. The bubble guiding surfaces may also provide roll damping. However, the bubble guiding surfaces may be arranged such that they entrap air below the bottom surface of the hull, which contrasts to bilge keels that may typically be arranged to
10 the side of the vessel's hull.

The bubble guiding surfaces may typically be arranged on a bottom surface of the hull, extending longitudinally at sides of the hull adjacent a bilge radius. The bilge radius may be defined as the curved plating joining the planar, near vertical sides of the hull to the flat bottom planar surface of the hull. In contrast, bilge keels may
15 typically be arranged on the bilge radius of the hull, such that they do not extend below the lowest draft of the hull or beyond the sideways extension of the side plating. For example, bilge keels may extend 45 degrees in relation to a horizontal plane from the bilge radius.

The bubble guiding surfaces may extend below the lowest draft of the hull.
20 Although in certain embodiments, the bubble guiding surfaces do not extend beyond the lowest draft of the hull. The bubble guiding surfaces may be arranged to extend in a substantially vertical direction orthogonally to the flat bottom surface of the hull. In an aspect of the invention, the bubble guiding surfaces and bottom surface of the hull may be configured such that they form a cavity. Alternatively, a cavity
25 may be arranged in the bottom surface of the hull such that its sidewalls form bubble guiding surfaces.

The skilled person will understand that the design draught may be the draught on which the fundamental design parameters of the ship are based. The design draught may thus be the draught at which the ship is designed to operate and may deviate
30 from the moulded depth of the ship.

In an aspect of the invention, the moulded depth of the hull may increase from the bow to the stern of the hull.

In an aspect of the invention, the beam of the vessel relative to the length of the vessel may be larger than for conventional vessels in order to compensate for the
35 reduction in available draught caused by the extension of the bubble guiding surfaces below the bottom surface of the hull.

In an aspect of the invention, the bubble guiding surfaces may be aligned with the water flow along the bottom surface of the hull.

5 In an aspect of the invention, a bottom surface of the hull may be defined as a planar surface of the hull substantially facing a horizontal direction, arranged below the design waterline of the vessel. In aspects, the bottom surface may be the lowest surface of the hull. Substantially facing a horizontal direction may herein be defined such that the planar of surface lies at an angle of between 0.1 and 10 degrees from a horizontal plane, where said horizontal plane may follow a baseline of the hull. It will be understood that the hull may thus exclude the bubble guiding surfaces,
10 which may typically be arranged as add-ons to the hull.

In an aspect of the invention, at least 50% of the bottom surface of the hull may have a flat or planar surface.

15 In an aspect of the invention, the bubble guiding surfaces may be provided at the flat and/or planar section of the bottom surface of the hull to act as a side wall to prevent the air from escaping from the side of the vessel.

In an aspect of the invention, the bubble guiding surfaces may be perpendicular to the bottom surface of the hull.

20 In an aspect of the invention, the cross section of the bubble guiding surfaces may be curved or angled in towards the centreline of the hull, to better entrap the air. At least a portion of the cross section of the bubble guiding surfaces may be tilted at an angle deviating from vertical in towards the centreline. At least a portion of the cross section of the bubble guiding surfaces may be horizontally arranged.

25 In an aspect of the invention, the bubble guiding surfaces may extend from air outlets, preferably arranged at the front of the vessel. The front of the bubble guiding surfaces nearest the bow may be arranged at a distance from the air outlets such that air escaping the outlets enters between the bubble guiding surfaces once the vessel moves forward at a predetermined speed. In other aspects, the front of the bubble guiding surface nearest the bow may be arranged in line with the air outlets.

30 In aspects of the invention, the bubble guiding surfaces may extend to the stern of the hull. In certain aspects, the bubble guiding surfaces may be arranged extending to the end of the stern, thus allowing for air to be trapped between the surfaces along the length of the bubble guiding surfaces and providing reduced friction on a longer portion of the hull.

35 In an aspect of the invention, the length of the bubble guiding surfaces may extend at least 80% of the length of the hull. In yet further aspects, the bubble guiding surfaces may extend at least 60 % of the length of the hull. In yet further aspects, the bubble guiding surfaces may extend at least 40 % of the length of the hull. In

yet further aspects, the bubble guiding surfaces may extend at least 30 % of the length of the hull. In yet further aspects, the bubble guiding surfaces may extend at least 20 % of the length of the hull. In yet further aspects, the bubble guiding surfaces may extend at least 10 % of the length of the hull.

- 5 In an aspect of the invention, at least one of the bubble guiding surfaces may be made in one continuous length.

- In an aspect of the invention, the bubble guiding surfaces may be made of several sections. In yet other aspects, the surfaces may be staggered behind each other. The sections of the bubble guiding surfaces may be oriented substantially parallel with the centreline of the hull. Preferably, the bubble guiding surfaces may be configured such that they are aligned with the local waterflow at an area of the hull.
- 10

In an aspect of the invention, the bubble guiding surfaces may also provide roll damping for the ship.

- In an aspect of the invention, the vessel may be a displacement ship that sustains all of its weight at design speed by hydrostatic forces.
- 15

In an aspect of the invention, the vessel may have a deadweight coefficient of more than 0.3. In yet further aspects, the vessel may have more than 0.7, and even more specifically more than 0.8 in deadweight coefficient.

- In an aspect of the invention, at least one bottom surface of the hull may be inclined at a bottom angle from a horizontal plane, wherein the bottom angle may be between 0.2 and 5 degrees. More preferably, the bottom angle may be between 0.25 and 3 degrees. More preferably, the bottom angle may be between 0.5 and 2 degrees. Even more preferably, the angle may be between 1 and 1.5 degrees. The preferable embodiments of the invention may provide an optimal balance between capturing air under the hull whilst mitigating loss of storage space.
- 20
- 25

The bottom angle may be measured between the bottom surface of the hull and a horizontal plane, wherein the horizontal plane is parallel with the surface of the water. The horizontal plane may be parallel with a baseline of the hull.

- In an aspect of the invention, the decrease of the design draught of the hull from the stern to the bow may correspond to the bottom angle.
- 30

In an aspect of the invention, the decrease of the moulded depth of the hull from the stern to the bow may correspond to the bottom angle.

In an aspect of the invention, the ship hull may have a single propeller and a single skeg.

- 35 In an aspect of the invention, the ship hull may have twin propellers and twin skegs.

In an aspect of the invention, the depth of the bubble guiding surfaces may not be constant along the length of the hull.

In an aspect of the invention, the depth of the bubble guiding surfaces may be tapered towards the bow of the hull.

- 5 In an aspect of the invention, the depth of the bubble guiding surfaces may be tapered towards the stern of the hull.

In an aspect of the invention, the depth of the bubble guiding surfaces may be tapered towards the stern of the hull to not increase the draught of the vessel.

- 10 In an aspect of the invention, the depth of the bubble guiding surfaces may be tapered towards the stern and the bow of the hull.

- 15 In an aspect of the invention, the depth of the bubble guiding surface nearest the stern, and/or at the deepest draft of the hull, may be no more than 25% of the depth of the bubble guiding surface at the midships region. Preferably, the depth of the bubble guiding surface nearest the stern, and/or at the deepest draft of the hull, may not extend beyond the deepest draft of the hull. Thus, the depth of the bubble guiding surfaces may be smaller at the deepest-going parts of the hull, thereby minimising the additional draft created by the bubble guiding surfaces.

- 20 In an aspect of the invention, the depth of the bubble guiding surface nearest the bow, and/or adjacent the first air outlets, may be no more than 25% of the depth of the bubble guiding surface at the midships region. Preferably, the depth of the bubble guiding surface nearest the bow, and/or adjacent the first air outlets, may not extend beyond the deepest draft of the hull. Since the air released from the first air outlets may be more likely to stick to the hull of the vessel immediately after release, the depth of the bubble guiding surface in this region may not be required to have the same depth as in the midships region further behind the air outlets where air is more likely to escape from the hull.

In an aspect of the invention, the lower edge of the bubble guiding surfaces may at any point along the length of the hull extend below the bottom surface of the hull.

- 30 In an aspect of the invention, the lower edge of the bubble guiding surfaces may protrude below the bottom surface of the vessel for at least 50% of the length of the bubble guiding surface.

In an aspect of the invention, the bubble guiding surfaces may not comprise enclosed spaces.

- 35 In an aspect of the invention, at least portions of the bubble guiding surfaces may be aligned with the skegs to guide the air from the bottom surface of the hull to the space between the skegs.

In an aspect of the invention, one or more air outlets may be arranged in the bottom surface of the forward part of the hull, preferably within the first 40% of the length of the hull. Even more preferably, the air outlets may be arranged within the first 10% of the length of the bottom surface of the hull, as measured from the forwardmost part of the bottom surface. Yet more preferably, the air outlets may be arranged within the first 5% of the length of the bottom surface of the hull.

The air outlets may typically comprise a plurality of vents arranged symmetrically across the centreline of the hull, evenly spaced out across the breadth of the vessel. Each vent may be individually regulated, thus allowing air flow to be controlled across the bottom surface of the hull. The air outlets may be arranged in a straight line across the hull, or they may be arranged in a V-formation, or in a formation that follows the edge of the forward part of the bottom surface of the hull.

In an aspect of the invention, the end of the bubble guiding surface may be aligned with the air outlets or region of air outlets or may be arranged further away from the bow than the air outlets.

In an aspect of the invention, further second air outlets may be arranged in the bottom surface of the hull at a point closer to the stern than the first air outlets mentioned above. In a yet more preferable aspect, the further second air outlets may preferably be arranged within 40-80% of the length of the hull from the bow. It will be understood that yet additional air outlets to the first and second air outlets may be arranged along the length of the hull.

In an aspect of the invention, one or more sensors may be arranged on the hull to detect air layer thickness, wherein the sensors may be positioned on the bottom surface of the hull in the air bubble distribution region. In an aspect of the invention, the sensors may be arranged transversely across the hull. In an aspect of the invention, the sensors may be arranged at predetermined intervals along the length of the hull. Preferably, the sensors may be arranged symmetrically around the centreline of the hull. Thus, through the information from sensor measurements of air thickness, a symmetrical distribution of air may be provided or optimised and maintained on the bottom surface of the hull as described below in more detail.

In an aspect of the invention, the sensors for detecting air layer thickness may be arranged towards the stern of the bottom surface of the hull. The sensors may for example be arranged no further forward than 50% of the length of the bottom surface of the hull as measured from the stern, or no further forward than 50% of the length of the bubble guiding surfaces as measured from the stern. Preferably, the sensors may be arranged no further forward than 20% of the length of the bottom surface of the hull as measured from the stern, or no further forward than 20% of the length of the bubble guiding surfaces as measured from the stern.

Typically, it may be advantageous to place sensors at a maximal distance from the air outlets, lengthwise on the bottom surface of the hull, yet within an air bubble distribution region. This is because the loss of bubbles is most likely to increase the farther the distance from the air outlets. Thus, it will be possible to detect the air layer thickness on the bottom surface of the hull, towards the aft, and compensate by providing more air through the air outlets.

In an aspect of the invention the sensors for detecting air layer thickness may be arranged adjacent to the bubble guiding surfaces on an air bubble distribution region. Preferably, the sensors may be arranged closer to the bubble guiding surfaces than the centre line of the hull. The air bubble distribution region may be defined by the space between the bubble guiding surfaces.

Typically, it may be advantageous to place sensors close to the bubble guiding surfaces as these are often arranged towards the perimeter of the bottom surface of the hull. This is because the loss of bubbles is likely to increase along the sides of the hull. Thus, it will be possible to detect the air layer thickness on the bottom surface of the hull towards the side regions where air may often escape, and compensate by regulating which air outlets should provide more air. It may also be possible to recognise an imbalance of air distribution over the centreline of the vessel and compensate by individually regulating the air outlets appropriately.

In an aspect of the invention, the sensor may be a laser, a gas detector, a conductivity detector and more preferably a sonar sensor.

In an aspect of the invention, the vessel may comprise a control system configured to control the one or more compressors and the air outlets and further second air outlets.

In an aspect of the invention, the control system may be configured to regulate separate air outflow for individual air outlets. The present invention also relates to a displacement vessel comprising a hull where the design draught of the hull increases from the bow to the stern of the hull, at least along a portion of the length of the hull, and wherein any of the aforementioned aspects may apply.

In an aspect of the invention, the vessel may comprise a suction sail, wherein air inlets of the suction sail are in fluid communication with the one or more compressors. Thus, the expended energy by the suction sails on compressor power may provide a two-fold function in reducing propulsion power needed on the vessel.

Preferably, the control system may be configured to regulate air flow from the air inlets of the suction sail. Even more preferably, the control system may be configured to regulate air flow from the air inlets of the suction sail, control the compressors and the air outlets on the hull. Thus, optimization of the air suction on

the suction sail and the outlet of air on the bottom of the hull may be achieved leading to a synergy in higher reductions in propulsion power.

5 In an aspect of the invention, the vessel may comprise a plurality of bottom surfaces. A first bottom surface may be arranged in a foremost position towards the bow, where the design draft may steadily increase towards the stern. Additional bottom surfaces may be arranged closer to the stern in relation to the first bottom surface, each additional bottom surface having an angle closer to horizontal than the preceding bottom surface. At least one bottom surface may be horizontal.

10 The present invention also relates to a computer-implemented method for operating an air lubrication system for a displacement vessel, comprising:

- receiving data representing air layer thickness of a hull measured by one or more sensors arranged to detect air layer thickness placed on the bottom surface of the hull in the air bubble distribution region,
- 15 - receiving data representing power consumption of the one or more compressors,
- determining the distribution of air layer thickness in the air bubble distribution region, and
- producing data to control the control system to adjust the air flow of the one or more compressor and release of air bubbles through each of the air outlets to achieve an even distribution of air layer thickness in the air bubble distribution.

20 In an aspect of the invention, the method includes:

- receiving data on power consumption related to vessel propulsion,
- optimising the power consumption of vessel propulsion in relation to power consumption of the one or more compressors.

25 In an aspect of the invention, the velocity of the vessel and/ or the trim angle of the vessel may be adjusted in order to achieve an even distribution of air layer thickness in the air bubble distribution region.

In an aspect of the invention, the trim angle may be different from the bottom angle of the hull.

30 In an aspect of the invention, the trim angle may be measured between the bottom surface of the hull and a horizontal plane, wherein the horizontal plane may be parallel with the surface of the water.

In an aspect of the invention, the trim angle may be changed by reballasting the vessel.

35 In an aspect of the invention, the computer-implemented method, further comprises:

- receiving data representing actual velocity of the vessel and/ or airflow of the one or more compressors and/ or actual trim angle and/ or draft of the vessel,
- determining the water drag on the air bubbles and the forward thrust of the air

bubbles due to inclined bottom surface of the hull on the air bubble distribution region,

- producing data to control the control system to adjust the air flow of the one or more compressor and release of air bubbles through each of the air outlets to achieve an even distribution of air layer thickness in the air bubble distribution region.

The present invention also relates to a machine-learning model for operating an air lubrication system for a displacement vessel, comprising producing data to control the control system to adjust the air flow of the one or more compressor and release of air bubbles through each of the air outlets to achieve an even distribution of air layer thickness in the air bubble distribution region.

In an aspect of the invention, the machine learning model is selected from a group exemplified by but not limited to an artificial neural network, a decision tree, a regression model, a k-nearest neighbour model, a partial least squares model, a support vector machine, a linear regression model, a random forest regressor, or a combination thereof.

The present invention relates to a computer-implemented method of training a machine-learning model for operating an air lubrication system for a displacement vessel, in particular the machine-learning model mentioned above, comprising:

- receiving an input training dataset comprising data from previous voyages of the displacement vessel, and
- receiving data representing air layer thickness of a hull measured by one or more sensors arranged to detect air layer thickness placed on the bottom surface of the hull in the air bubble distribution region,
- receiving data representing power consumption of the one or more compressors,
- determining the distribution of air layer thickness in the air bubble distribution region,
- producing data to control the control system to adjust the air flow of the one or more compressor and release of air bubbles through each of the air outlets to achieve an even distribution of air layer thickness in the air bubble distribution region.

The present invention also relates to a use of the method for at least one of:

- adjusting parameters for an air lubrication system for a displacement vessel,
- optimizing the energy consumption of the air lubrication system for the displacement vessel,
- minimizing the fuel consumption for the displacement vessel by adjusting the parameters of the air lubrication system for the displacement vessel.

The present invention also relates to a data processing apparatus comprising means for carrying out the steps of the computer-implemented method for operating air lubrication of a vessel.

5 In an aspect of the invention, the control system may comprise a data processing apparatus or a computer.

The present invention also relates to a computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the computer-implemented method for operating air lubrication of a vessel.

10 In the following description, numerous specific details are introduced by way of example only to provide a thorough understanding of embodiments of the claimed method, arrangement and system. One skilled in the relevant art, however, will recognize that these embodiments can be practiced without one or more of the specific details, or with other components, arrangements, methods, systems, etc. In other instances, well-known structures or operations are not shown, or are not
15 described in detail, to avoid obscuring aspects of the disclosed embodiments.

BRIEF DESCRIPTION OF THE FIGURES

The following drawings are appended to facilitate the understanding of the invention. The drawings show embodiments of the invention, which will now be described by way of example only, where:

20 Fig. 1A is a side view of a vessel showing the position of the bubble guiding system and air outlets, where the vessel has a bottom surface with a steadily increasing draft extending towards the stern;

Fig. 1B is a side view of a vessel showing the position of the bubble guiding system and air outlets, where the vessel has a bottom surface with a steadily increasing
25 draft extending towards the stern, yet with bubble guiding surfaces tapering in depth towards the stern;

Fig. 2 – is a side view of a vessel, where the vessel has a bottom surface with a steadily increasing draft extending from bow to midships region, and a horizontal bottom surface extending along the midships region to the stern.

30 Fig. 3 – is a view of the bottom surface of the hull, looking from below showing the bubble guiding surfaces, air outlets and sensors;

Fig. 4 – is a cross section view A-A of the hull showing air outlets and bubble guiding surfaces;

Fig. 5 – is a flow chart of the control system and the components.

DETAILED DESCRIPTION OF THE FIGURES

In the following, general embodiments as well as particular exemplary embodiments of the invention will be described. References will be made to the accompanying drawings. It shall be noted, however, that the drawings are exemplary embodiments only, and that other features and embodiments may well be within the scope of the invention as claimed. Further, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality.

Unless otherwise defined, all terms of art, notations and other scientific terms or terminology used herein are intended to have the meanings commonly understood by those of skill in the art to which this invention pertains. Certain terms of art, notations, and other scientific terms or terminology may, however, be defined specifically as indicated below.

The present invention relates to a displacement vessel 1. A displacement vessel 1 is a vessel 1 where the weight of the vessel 1 at design speed is supported by hydrostatic forces.

As shown in Fig. 1A, the hull 11 of the vessel 1 has a design draft D that decreases from the stern 13, along a midships region 14 to the bow 12 of the hull 11. The stern 13 of the hull 11 may be defined as starting from an end point of the midships region 14 where the planar bottom surface 15 of the hull stops and the design draft D and/or moulded depth D_m starts decreasing. Although not visible from the side view in Fig. 1, the skilled person will understand that the bottom surface 15 may refer to a substantially planar surface making up the majority of the hull bottom. This planar surface significantly faces down towards the seabed, and may also be known as a flat bottom. Thus, a midships region 14 may be defined herein as starting at the foremost point of the bottom surface 15 of the hull 11, where the bow 12 ends, and extending to the stern 13.

As the design draught D or the moulded depth D_m of the vessel 1 decreases from the stern 13 to the bow 12 of the hull 11, the bottom surface 15 of the vessel is not horizontal. Horizontal plane in the context of the invention is a parallel alignment with the water line and reflects the state when the vessel floats free in water. The bottom surface 15 of the hull 11 is inclined at a bottom angle α from a horizontal plane, wherein the bottom angle is between 0.5 and 3 degrees, more preferably between 1 and 2 degrees. The bottom angle α is measured between the bottom surface 15 of the hull 11 and a horizontal plane, wherein the horizontal plane is parallel with the surface of the water (Fig. 1A).

The design draft D is illustrated extending from a design waterline vertically down to the lowermost point of the vessel 1. The lowermost point on the vessel in Fig. 1A is formed by the bubble guiding surface 21. The bubble guiding surface 21 is

illustrated along the length of the hull 11 extending from the stern 13 to the bow 12 and protruding from a bottom surface 15 of the hull 11. As will be apparent to the skilled reader, only one of at least two bubble guiding surfaces 21 are visible in the sideview in Fig. 1A.

- 5 Additionally, the exemplary vessel in Fig. 1A is shown having a moulded depth D_m of the vessel 1 decreasing from the stern 13 to the bow 12 of the hull 11. The moulded depth D_m is illustrated extending from the top of the freeboard deck down to the lowermost point of the bubble guiding surface 21 in a vertical direction.

10 As indicated in Fig. 1A, air outlets 31 are arranged towards the bow 12 of the hull 11 parallel to the forwardmost part of the bubble guiding surface 21. The Figure illustrates the air bubbles B being released at the air outlets 31 and travelling down along the hull 11, forming an air film. It will be understood that a second bubble guiding surface 21, not shown in Fig. 1A, will help trap the bubbles 21 on the opposite side along the length of the lowermost point of hull 11. Thus, the bubble
15 guiding surfaces 21 along with the inclination of the hull 11 and the forward moving speed of the vessel 1 keeps the air bubbles B trapped beneath the hull 11 thereby forming an air film and reducing friction on the hull. This area of air distribution A1 is illustrated along the bottom of the hull in Fig. 1A.

20 The bubble guiding surfaces 21 are shown extending from the bow 12 to the stern 13 of the hull 11. The stern 13 starts at the point of maximum design draft D and moulded depth D_m in Fig. 1A. At this point, the air bubbles B pass over to the stern 13 and can be seen travelling up along the hull 11 on the side of the skeg S_k as the draft at the stern 13 decreases in depth. As the bubbles B pass along the stern 13, they will provide a force acting to push the vessel 1 in a forward direction.

25 Furthermore, the stern 13 of the hull 11 exemplified in Fig. 1A is configured to facilitate bubbles B moving adjacent the hull. Thus, issues with bubbles B escaping the hull 11 and coming into the path of the propeller P can be avoided. Additionally, Fig. 1A illustrates some of the forces acting on the vessel 1 from the bubbles B forming an air layer under the hull 11:

- 30 - the buoyancy of the air bubbles B being released F_b , which acts in a vertical direction,
- 35 - the forward thrust F_{ft} of the air bubbles B generated by the buoyancy F_b of the air bubbles on the inclined hull 11 and the effect of the drag of the water on the air film, this force acts in a direction parallel to the bottom surface of the hull
- F_{ab} , the resulting force of the buoyancy of the air bubbles, it acts in a direction orthogonal to the bottom surface of the hull.

Turning to Fig. 1B, this illustrates a vessel 1 essentially similar to that of Fig. 1A. However, the bubble guiding surfaces 21 in the embodiment of Fig. 1B do not project beneath the lowermost point of the bottom surface 15 of the hull 11. Instead, the bubble guiding surfaces 21 taper from a point in the midships region 14 such that they never extend below a baseline of the hull 11. Thus, the embodiment of Fig. 1B does not increase the overall draft of the vessel 1. This has been illustrated in Fig. 1B by displacing the bubbles B travelling across the deepest draft of the vessel 1 in order to clearly show the tapering bubble guiding surfaces 21.

Turning to Fig. 2, another displacement vessel 1 according to the invention is presented. As will be seen, the displacement vessel 1 in Fig. 2 shares many of the same aspects as that of Fig. 1A and reference is made to the description of that figure. However, there are two significant differences:

- The design draft D and moulded depth Dm of the vessel in Fig. 2 increases from the bow 12 towards the stern 13. However, at a point along the midships region 14, the increase in design draft D and/or moulded depth Dm stops and remains the same until the stern 13 of the vessel 1.
- Furthermore, the vessel 1 in Fig. 2 is provided with a rigid sail 50 at the bow 12 of the vessel 1. The rigid sail 50 may be a suction sail, where the air sucked in on the sail 50 may be sent to the air outlets 31,32 beneath the hull 11.

The total bottom surface 15,15' of the hull 11 on the vessel 1 illustrated in Fig. 2 roughly corresponds in length to that in Fig. 1A. Although the entire bottom surface 15,15' of the hull is not arranged in one single plane in Fig. 2, there are two differently angled planes defining the bottom surface 15,15'. A first bottom surface 15 arranged towards the bow 12, where the draft D steadily increases towards the stern 13. And a second bottom surface 15' arranged at a midships region 14 from the first bottom surface 15 and towards the stern 13, along which the draft D does not significantly vary in depth.

In the example in Fig. 2, it is only the first bottom surface 15 that is inclined at an angle α . The second bottom surface 15' is parallel to a horizontal plane. As the skilled person will understand in the context of the invention, there may be several more bottom surfaces 15,15', each planar and with each their own angle α which typically decreases towards the stern 13.

The rigid sail 50, preferably in form of a suction sail as shown in Fig. 2, is a preferred, optional embodiment. Suction sails 50 are known in the art and function by a compressor sucking in air on one side of the sail in order to increase lift on the sail.

The skilled person will understand that sail 50 may also be combined with other hull bottom designs such as the one shown in Fig. 1A or Fig. 1B. There may also be more than one suction sail 50, preferably distributed in the bow part 12 of the vessel 1 in connection to the first and/or second air outlets 31,32. The advantage of the combination of a suction sail 50 with air outlets 31,32 on the bottom of the hull 11 is that the same power consumption by a compressor to produce air bubbles B for release through the air outlets 31 for generation of the air layer under the hull may be used as for powering the suction sail 50. Combined these solutions may reduce the necessary propulsion power with less energy expenditure than each solution used alone.

Now turning to Fig. 3, this illustration shows that on the bottom surface 15 of the hull 11, a series of first air outlets 31 and a series of second air outlets 32 are arranged. These air outlets 31 and 32 release air bubbles B to the bottom surface 15 of the hull 11. The first air outlets 31 and second air outlets 32 are each in fluid communication with one or more compressors 41 (shown in Fig. 4 and Fig. 5).

Although Fig. 3 illustrates a vessel 1 having a series of second air outlets 32, the skilled person will understand that a vessel 1 according to the invention may only be provided with a series of first air outlets 31. In the case of a vessel 1 having a series of first air outlets 31 only, these outlets 31 may typically be arranged towards the frontmost part of the bottom surface 15.

Fig. 3 illustrates an example of the hull 11 with two bubble guiding surfaces 21 that are arranged symmetrically on opposing sides of a centre line C of the hull 11 on a bottom surface 15 of the hull 11. The bubble guiding surfaces 21 protrude away from the hull 11 and extend along at least a portion of the length of the hull 11 and act as a barrier to prevent air bubbles B escaping from the side of the vessel 1.

As shown in Fig. 3, the bubble guiding surfaces 21 and the air outlets 31 define an air bubble distribution region A1 on the bottom surface 15 of the hull 11. The exemplary illustrations of the bubble guiding surfaces 21 in Fig. 3 are of plate-like elements, similar in shape to bilge keels. Although the bubble guiding surfaces 21 may also provide roll damping for the vessel, similar to a bilge keel, the bubble guiding surfaces 21 are primarily configured to guide and trap bubbles B on the bottom surface 15 of the hull 11.

The bottom surface of the hull 15 is represented in Fig. 3 by a dotted line roughly following the outline of the hull 11. This dotted line represents the area of the bottom surface 15, an area that may typically be planar as in the exemplary embodiment of Fig. 1.

The bubble guiding surfaces 21 are attached to the bottom surface 15 of the hull 11 and may therefore increase the design draught D of the vessel 1. If a vessel 1

operates on a route where draught restrictions apply, this may be compensated for by increasing the beam of the vessel 1 and at the same time reducing the design draught D.

5 The deadweight coefficient of the vessel 1, i.e. the ratio of the weight that the vessel 1 carries and the weight of the volume of water that the vessel 1 displaces covers a range starting from 0.3, is typically more than 0.7, and even is more than 0.8 for oil tanker or ore carriers. For many displacement vessels 1, typically more than 50% of the bottom surface of the hull 11 has a flat bottom surface 15. The bubble guiding surfaces 21 are attached to the hull 11 at the flat section of the bottom surface 15 of the hull 11 as shown in Figs. 1-4, and in particular in Fig. 3 where a dotted line is seen encircling the bubble guiding surfaces 21. The dotted line typically represents the area forming a flat, planar bottom surface 15.

Shown in Fig. 3 is a hull configuration with twin propellers P and twin skegs Sk. Also possible are vessel 1 configurations where the hull 11 has one propeller P and one skeg Sk.

20 The bubble guiding surfaces 21 are fabricated usually from the same material as the hull 11, typically steel. They may also be made from aluminium or composites or combinations thereof. Preferably, the bubble guiding surfaces 21 do not comprise enclosed spaces, thereby avoiding requirements of inspection. The bubble guiding surfaces 21 may be attached by welding to the hull 11. Alternatively, they could be adhesively bonded or form part of the hull's design. A further alternative may be bubble guiding surfaces 21 that are retractable or foldable into the hull 11.

25 The orientation of the bubble guiding surfaces 21 is aligned with the flow of the water around the hull 11. As shown in Fig. 3, the bubble guiding surfaces 21 are aligned such that the air film is substantially guided between the twin skegs Sk.

The bubble guiding surfaces 21 may be arranged perpendicular to the bottom surface 15 of the hull 11 as illustrated in Fig. 3. To enable better entrapment of air bubbles, the cross section of the bubble guiding surfaces 21 may be curved or angled in towards the centreline of the hull, this is not shown in the figures.

30 Different configurations of the air bubble guiding surfaces are conceivable. They may be made in one continuous length, or they be made of several sections. In certain embodiments they may be staggered behind each other and oriented parallel with the centreline C of the hull 11. In one embodiment, the bubble guiding surfaces 21 extend along 60% or more of the length of the hull, or 40 % or more of the length of the hull 11.

The example in Fig. 3 illustrates two main bubble guiding surfaces 21 extending from the first outlets 31 at the front of the bottom surface 15 and towards a stern 13

of the hull 11. As can be seen, the main bubble guiding surfaces 21 end towards the flat bottom surface 15 of the hull 11 indicated by the dotted line showing the periphery of the surface 15. Thus, the main bubble guiding surfaces 21 of Fig. 3 extend over 80% of the bottom surface 15 of the hull 11 and at least over 60% of the entire length of the hull 11. The area formed by the two main bubble guiding surfaces 21 forms an air distribution region A1.

Additionally, two auxiliary bubble guiding surfaces 21' are arranged towards the stern 13 of the hull 11. Each of these auxiliary bubble guiding surfaces 21' extend from a lowermost part of the skegs Sk. The auxiliary bubble guiding surfaces 21' are exemplified as extending from the air distribution region A1 on the bottom surface 15 and towards the propellers P. Thus, these auxiliary bubble guiding surfaces 21' facilitate movement of the bubbles B in between and externally to the skegs Sk, thereby mitigating bubbles B being sucked into contact with the propellers P.

In one embodiment, illustrated in Fig. 2, the depth of the bubble guiding surfaces 21 is not constant along the length of the hull 11. The depth of the bubble guiding surfaces 21 may be tapered towards the bow 12 of the hull 11. Alternatively, the depth of the bubble guiding surfaces 21 may be tapered towards the stern 13 of the hull 11. By tapering the bubble guiding surfaces 21 towards the stern 13 of the hull 11 the design draught D of the vessel is not increased. In yet another embodiment the depth of the bubble guiding surfaces 21 is tapered towards the stern 13 and the bow 12 of the hull 11. The bubble guiding surfaces 21 may be tapered to at least 25% of the depth at a point along the midships region 14.

Furthermore, the extension of the bubble guiding surfaces 21 along the bottom surface 15 of the hull may be adapted to the bottom design i.e. mainly along the bottom surface 15 arranged at an inclined angle. For example, taking the embodiment of Fig. 2, it is conceivable that bubble guiding surfaces 21 are only arranged on the first bottom surface 15, and not on the second bottom surface 15'. Additionally, the bubble guiding surfaces 21 may taper towards the end of the first bottom surface 15, such that they do not extend beyond the lowermost point of the hull 11.

As Fig. 3 illustrates how the bottom surface 15 of the hull 11 tapers towards a narrow point at the bow 12 of the hull 11, thus the first air outlets 31 are arranged in a V-formation along the front edge of the bottom surface 15.

One or more air outlets 31 are arranged in the bottom surface 15 of the forward part of the hull 11, preferably within the first 40% of the length of the hull 11. The front end 21 of the bubble guiding surfaces 21 are aligned with the air outlets 31 where the bubble guiding surfaces 21 overlap with the air outlet 31 as shown in Fig. 2. Alternatively, the end of the bubble guiding surface is moved towards the stern 13

of the hull 11, allowing a gap between the air outlet 31 and the front end 21 of the bubble guiding surface 21.

To ensure an even air bubble distribution within the air bubble distribution region A1, second air outlets 32 may be arranged in the bottom surface 15 of the hull 11, preferably within 40-80% of the length of the hull 11 as seen from the bow 12.

Several sets of sensors 43 are displayed in Fig. 3 arranged on the bottom surface 15 of the hull 11 to detect air layer thickness T_f (Fig. 4). A first pair of sensors 43 is arranged on the air distribution region A1 between the first air outlets 31 and the second air outlets 32, each between the centre line C and the bubble guiding surfaces 21. A further second, third, fourth, fifth and sixth pair of sensors 43 are arranged consecutively behind the second air outlets 32 towards the stern 13 of the hull 11. These sensors 43 are strategically placed to measure the air distribution and thereby enable improved control of the air outlets 31,32.

It will be understood by the skilled person that the number of sensors 43 and their placement in the example of Fig. 3 may be adapted to the specific hull. Typically, the sensors 43 for measuring air layer thickness T_f may at least be arranged towards the stern of the ship 13 and adjacent the bubble guiding surfaces 21. Sternwards areas are often vulnerable to air loss and it may therefore be advantageous to place sensors 43 in these areas to detect air thickness T_f and the need for increase air flow from the outlets 31,32.

It is preferred that the sensors 43 are arranged as pairs or rows to get most accurate measurements along the breadth of the bottom surface 15 of the hull 11. However, the skilled person would be aware that in a more simplified arrangement single sensors 43 may be used instead. These sensors 43 are preferably distributed on the bottom surface 15 area of the hull 11 along the air bubble distribution layer A1 between the air bubble guiding surfaces 21.

Turning to Fig. 4, a cross section A-A of the vessel from Fig. 2 is illustrated. In the cross section view it can be seen that first air outlets 31 are connected to one or more compressors 41 that supply air to the air outlets 31,32. The compressor 41 is exemplified as being connected to the suction wing 50 arranged atop of the deck of the vessel 1. As will be understood by the skilled person, the air may also be drawn into the compressor from a regular inlet, not a suction wing 50. However, in the exemplary embodiment of Fig. 4, there may be an added benefit of having a suction wing 50 where air is sucked in on the low-pressure side of the wing and then taken to the compressor 41 from where it is sent to the air outlets 31,32.

An additional benefit of the embodiment of the invention combining the use of a suction wing 50 with the bubble guiding surfaces 21 is the additional course stability that may be provided by the bubble guiding surfaces 21.

Additionally, the air layer thickness T_f shown in Fig. 4, is measured using one or more sensors 43. The sensor 43 may for example be a laser, a gas detector, a conductivity detector and more preferably a sonar sensor arranged for detecting air bubble distribution.

- 5 Turning now to Fig. 5, an exemplary control system 45 on board the vessel 1 for controlling the flow of air is illustrated.

The vessel 1 preferably comprises a control system 45. The control system 45 is configured to control the one or more compressors 41 and the first air outlets 31 and any other second air outlets 32. The control system 45 comprises a computer and/or
10 a data processing apparatus 46. The control system 45 regulates the air flow for each individual air outlet in the first air outlets 31 and/ or second air outlets 32. Thus, the air film thickness T_f on the air distribution area A1 can be controlled.

Fig. 5 illustrates how the sensors 43 for measuring air film thickness T_f are signally connected to the data processing apparatus 46. Furthermore, data representing
15 actual trim angle β and velocity of the vessel 1 is provided to the data processing apparatus 46. The data processing apparatus 46 is furthermore shown to receive input from the compressor 41, optionally suction wing 50 and the air outlets 31,32. This received input may relate to factors such as power consumption of the air compressor 41, air outlet 31,32 control beneath the hull 11 and inlet control on the
20 suction wing 50. Additionally, the processing apparatus is shown providing output to the air outlets 31,32, compressor 41 and suction wing 50, thereby controlling the flow of air throughout the various equipment.

The air lubrication system of the vessel 1 is controlled by the following computer-implemented method comprising the following steps:

- 25 - receiving data on air layer thickness T_f of a hull measured by one or more sensors 43 placed in the air bubble distribution region A1,
- receiving data representing power consumption P_c of the one or more compressors 41,
- determining the distribution of the air layer thickness T_f in the air bubble
30 distribution region A1 from the received data measured by sensors 43,
- producing data to control the control system 45 to adjust the air flow for one or more compressors 41 and release of air bubbles through each of the first air outlets 31 and second air outlets 32, and thereby achieving an even distribution of air layer thickness T_f in the air bubble distribution region A1.
- 35 Furthermore, the control system can be configured to receive data on the power consumption of vessel propulsion systems. Thus, it may be possible to provide a method and system capable of optimising the use of compressor power with the use of vessel propulsion power in order obtain an effective energy use.

In a further embodiment of the method further parameters are taken into account considering external forces on the air film in the air bubble distribution region A1. This includes:

- the buoyancy F_b of the air bubbles being released,
- 5 - the forward thrust F_{ft} of the air bubbles generated by the buoyancy F_b of the air bubbles on the inclined hull and the effect of the drag of the water on the air film.

The computer-implemented method therefore comprises further:

- receiving data representing actual velocity V of the vessel 1 and/ or airflow of the one or more compressors 41 and/ or actual trim angle β and/ or draft of the vessel 1,
- 10 - determining the water drag on the air bubbles F_d and the forward thrust F_{ft} of the air bubbles due to inclined bottom surface 15 of the hull 11 on the air bubble distribution region A1,
- producing data to control the control system 45 to adjust the air flow of the one or more compressor 41 and release of air bubbles through each of the air outlets 31, 32
- 15 to achieve an even distribution of air layer thickness T_f in the air bubble distribution region A1.

The trim angle β is measured between the bottom surface 15 of the hull 11 and a horizontal plane, wherein the horizontal plane is parallel with the surface of the water. The measured trim angle β may be different from the bottom angle α of the hull. The trim angle β is mainly affected by the load distribution of the cargo in vessel 1. In some cases, the trim angle β may be changed by reballasting the vessel 1.

The air lubrication system for the displacement vessel 1 may also be operated by a machine-learning model. This may comprise producing data to control the control system 45 to adjust the air flow of the one or more compressors 41 and release of air bubbles through each of the air outlets 31, 32 to achieve an even distribution of air layer thickness T_f in the air bubble distribution region A1.

The machine learning model may be selected from a group of methods such as an artificial neural network, a decision tree, a regression model, a k-nearest neighbour model, a partial least squares model, a support vector machine, a linear regression model, a random forest regressor, or a combination thereof.

The machine-learning model may be trained using a training dataset comprising data from previous voyages of the displacement vessel 1, and the following methods steps:

- 35 - receiving data representing air layer thickness T_f of a hull 11 measured by one or more sensors 43 arranged to detect air layer thickness T_f placed on the bottom surface 15 of the hull 11 in the air bubble distribution region A1,
- receiving data representing power consumption of the one or more compressors

41,

- determining the distribution of air layer thickness T_f in the air bubble distribution region A1,

- producing data to control the control system 45 to adjust the air flow of the one or more compressor 41 and release of air bubbles through each of the air outlets 31, 32 to achieve an even distribution of air layer thickness T_f in the air bubble distribution region A1.

The machine learning model may further take into account vessel parameters during sailing, which are typically affecting the power consumption, such as velocity, draft, and trim angle of the vessel.

The method to operate the air lubrication system for the displacement vessel 1 may be used for:

- adjusting parameters for the air lubrication system for a displacement vessel 1,
- optimizing the energy consumption of the air lubrication system for the displacement vessel 1,
- minimizing the fuel consumption for the displacement vessel 1 by adjusting the parameters of the air lubrication system for the displacement vessel 1.

The present invention also relates to a data processing apparatus 46 comprising means for carrying out the steps of the computer-implemented method for operating air lubrication of a vessel.

The present invention also relates to a computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the computer-implemented method for operating air lubrication of a vessel.

The present invention has been the subject of computational fluid dynamic (CFD) modelling. The results of the CFD tests have shown that the vessel 1 with an inclining hull more effectively traps air beneath the hull 11 of the vessel for longer periods of time.

The present invention thus solves at least some of the aforementioned problems of the prior art by more effectively trapping air beneath the hull 11 of the vessel and thereby decreasing the friction on the hull 11.

In the preceding description, various aspects of the vessel and methods according to the invention have been described with reference to the illustrative embodiments. For purposes of explanation, specific numbers, systems and configurations were set forth in order to provide a thorough understanding of the vessel and methods and their workings. However, this description is not intended to be construed in a limiting sense. Various modifications and variations of the illustrative embodiment, as well as other embodiments of the vessel and methods, which are apparent to

persons skilled in the art to which the disclosed subject matter pertains, are deemed to lie within the scope of the present invention.

LIST OF REFERENCE NUMBERS

- 1 - displacement vessel
- 11 - hull
- 12 - bow
- 5 13 - stern
- 14 - midships region
- 15 - bottom surface
- 21 - bubble guiding surfaces
- 31 - air outlets
- 10 32 - second air outlets
- 41 - compressor
- 43 - sensor to detect air layer thickness (Tf)
- 45 - control system
- 46 - data processing apparatus
- 15 50 - rigid sail e.g. suction wing
- A - cross section
- A1 - air bubble distribution region
- B - air bubbles
- C - centre line
- 20 D - design draught
- Dm - moulded depth
- Fab - apparent buoyancy of air bubbles
- Fb - buoyancy of air bubbles
- Fd - water drag on the air bubbles
- 25 Fft - forward thrust of the air bubbles due to inclined bottom surface of the hull
- P - propeller
- Pc - Power consumption compressor
- Sk - skeg
- Tf - air layer thickness
- 30 α - bottom angle
- β - trim angle (not shown in the figures)

CLAIMS

1. A displacement vessel (1), comprising:
 - a hull (11) where the design draught (D) of the hull increases from the bow (12) to the stern (13) of the hull (11),
 - 5 - first air outlets (31) arranged in a bottom surface (15) of the hull (11), wherein the first air outlets (31) are in fluid communication with one or more compressors (41) and are configured to release air bubbles on the bottom surface (15) of the hull (11),
characterized in that the vessel further comprises:
 - 10 - at least two bubble guiding surfaces (21), arranged symmetrically on opposing sides of a centre line (C) of the hull on the bottom surface (15) of the hull (11) and extending along a portion of the length of the hull (11), wherein the bubble guiding surfaces (21) are protruding away from the bottom surface (15) of the hull (11),
 - 15 wherein the bubble guiding surfaces (21) and the first air outlets (31) define an air bubble distribution region (A1) on the bottom surface (15) of the hull (11).
2. The vessel (1) according to claim 1, wherein the bottom surface (15) of the hull (11) is inclined at a bottom angle (α) from a horizontal plane, wherein the bottom
20 angle (α) is between 0.2 and 5 degrees, preferably between 0.5 and 1 degrees.
3. The vessel (1) according to claim 1, wherein the ship hull has a single propeller (P) and a single skeg (Sk).
- 25 4. The vessel (1) according to claim 1, wherein the ship hull has twin propellers (P) and twin skegs (Sk).
5. The vessel (1) according to claim 1, wherein the depth of the bubble guiding surfaces (21) is not constant along the length of the hull (11).
- 30 6. The vessel (1) according to anyone of claims 1 to 5, wherein the lower edge of the bubble guiding surfaces (21) at any point along the length of the hull (11) extends below the bottom surface (15) of the hull (11).

7. The vessel (1) according to claim 4, wherein at least portions of the bubble guiding surfaces (21) are aligned with the skegs (Sk) to guide the air from the bottom surface (15) of the hull (11) to the space between the skegs (Sk).
- 5 8. The vessel (1) according to claim 1, wherein one or more air outlets (31) are arranged in the bottom surface (15) of the forward part of the hull (11).
9. The vessel (1) according to claim 1, wherein further second air outlets (32) are arranged in the bottom surface (15) of the hull (11) at a point closer to the stern than
10 the air outlets (31).
10. The vessel (1) according to claim 1, wherein one or more sensors (43) are arranged on the hull (11) to detect air layer thickness (Tf), wherein the sensors (43) are positioned on the bottom surface (15) of the hull (11) in the air bubble
15 distribution region (A1).
11. The vessel (1) according to claims 1 and 10, wherein the vessel (1) comprises a control system (45) configured to control the compressor (41) and the first air outlets (31) and/ or further at least second air outlets (32).
20
12. The vessel (1) according to claim 11, wherein the control system (45) is configured to regulate separate air outflow for individual air outlets (31, 32).
13. The vessel (1) according to any of the preceding claims, comprising a suction
25 sail (50), wherein air inlets of the suction sail (50) are in fluid communication with the one or more compressors (41).
14. A computer-implemented method for operating an air lubrication system for a displacement vessel (1) according to claim 1, comprising:
30 - receiving data representing air layer thickness (Tf) of a hull (11) measured by one or more sensors (43) placed on the bottom surface (15) of the hull (11) in the air bubble distribution region (A1) arranged to detect air layer thickness (Tf),
- receiving data representing power consumption of the one or more compressors (41),
- determining the distribution of air layer thickness (Tf) in the air bubble

distribution region (A1),

- producing data to control the control system (45) to adjust the air flow of the one or more compressor (41) and release of air bubbles through each of the air outlets (31, 32) to achieve an even distribution of air layer thickness (Tf) in the air bubble distribution region (A1) .

5

15. The computer-implemented method according to claim 14, further comprising:

- receiving data representing actual velocity (V) of the vessel (1) and/ or airflow of the one or more compressors (41) and/ or actual trim angle (β) and/ or draft of the vessel (1), and

10

adjusting one or more of the vessel parameters being velocity of vessel, trim angle of vessel and draft of vessel or of the airflow of the one or more compressors to optimize the air distribution layer thickness and power consumption used for the vessels voyage and forward thrust.

15

16. The computer implemented method according to claim 14 or 15, further comprising the step of

- determining the water drag on the air bubbles (Fd) and the forward thrust (Fft) of the air bubbles due to inclined bottom surface (15) of the hull (11) on the air bubble distribution region (A1),

20

- producing data to control the control system (45) to adjust the air flow of the one or more compressor (41) and release of air bubbles through each of the air outlets (31, 32) to achieve an even distribution of air layer thickness (Tf) in the air bubble distribution region (A1).

25

17. A machine-learning model for operating an air lubrication system for a displacement vessel (1), in particular for use in the method of any one of claims 14 - 16, comprising producing data to control the control system (45) to adjust the air flow of the one or more compressor (41) and release of air bubbles through each of the air outlets (31, 32) to achieve an even distribution of air layer thickness (Tf) in the air bubble distribution region (A1) and optionally to adjust of one or more of the vessel parameter being velocity of vessel, trim angle of vessel and draft of vessel.

30

18. A computer-implemented method of training a machine-learning model for operating an air lubrication system for a displacement vessel (1), in particular the machine-learning model of claim 17, comprising:

35

- receiving an input training dataset comprising data from previous voyages of the

- displacement vessel (1), and
- producing data to control the control system (45) to adjust the air flow of the one or more compressor (41) and release of air bubbles through each of the air outlets (31, 32) to achieve an even distribution of air layer thickness (Tf) in the air bubble distribution region (A1).
- 5
19. Use of the method according to any of the claims claim 14 to 16 for at least one of:
- adjusting parameters for the air lubrication system for a displacement vessel (1),
 - optimizing the energy consumption of the air lubrication system for the displacement vessel (1),
 - minimizing the fuel consumption for the displacement vessel (1) by adjusting the parameters of the air lubrication system for the displacement vessel (1).
- 10
- 15 19. A data processing apparatus (46) comprising means for carrying out the steps of the method of any one of claims 14-16 and 18.
- 20 20. A computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method of any one of claims 14-16 and 18.